

K11 Sub-Family Reference Manual

Supports: MK11DX128AVMC5, MK11DX256AVMC5,
MK11DN512AVMC5



Document Number: K11P121M50SF4V2RM
Rev. 6, April 2014

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Chapter 1

About This Document

1.1 Overview

1.1.1 Purpose

This document describes the features, architecture, and programming model of the Freescale K11 microcontroller.

1.1.2 Audience

This document is intended for system architects and software application developers who are using (or considering using) the microcontroller in a system.

1.2 Conventions

1.2.1 Numbering systems

The following suffixes identify different numbering systems:

| This suffix | Identifies a |
|-------------|--|
| b | Binary number. For example, the binary equivalent of the number 5 is written 101b. In some cases, binary numbers are shown with the prefix 0b. |
| d | Decimal number. Decimal numbers are followed by this suffix only when the possibility of confusion exists. In general, decimal numbers are shown without a suffix. |
| h | Hexadecimal number. For example, the hexadecimal equivalent of the number 60 is written 3Ch. In some cases, hexadecimal numbers are shown with the prefix 0x. |

1.2.2 Typographic notation

The following typographic notation is used throughout this document:

| Example | Description |
|-----------------------|--|
| <i>placeholder, x</i> | Items in italics are placeholders for information that you provide. Italicized text is also used for the titles of publications and for emphasis. Plain lowercase letters are also used as placeholders for single letters and numbers. |
| code | Fixed-width type indicates text that must be typed exactly as shown. It is used for instruction mnemonics, directives, symbols, subcommands, parameters, and operators. Fixed-width type is also used for example code. Instruction mnemonics and directives in text and tables are shown in all caps; for example, BSR. |
| SR[SCM] | A mnemonic in brackets represents a named field in a register. This example refers to the Scaling Mode (SCM) field in the Status Register (SR). |
| REVNO[6:4], XAD[7:0] | Numbers in brackets and separated by a colon represent either: <ul style="list-style-type: none"> • A subset of a register's named field For example, REVNO[6:4] refers to bits 6–4 that are part of the COREREV field that occupies bits 6–0 of the REVNO register. • A continuous range of individual signals of a bus For example, XAD[7:0] refers to signals 7–0 of the XAD bus. |

1.2.3 Special terms

The following terms have special meanings:

| Term | Meaning |
|------------|--|
| asserted | Refers to the state of a signal as follows: <ul style="list-style-type: none"> • An active-high signal is asserted when high (1). • An active-low signal is asserted when low (0). |
| deasserted | Refers to the state of a signal as follows: <ul style="list-style-type: none"> • An active-high signal is deasserted when low (0). • An active-low signal is deasserted when high (1). <p>In some cases, deasserted signals are described as <i>negated</i>.</p> |
| reserved | Refers to a memory space, register, or field that is either reserved for future use or for which, when written to, the module or chip behavior is unpredictable. |
| w1c | Write 1 to clear: Refers to a register bitfield that must be written as 1 to be "cleared." |

Chapter 2

Introduction

2.1 Overview

This chapter provides high-level descriptions of the modules available on the devices covered by this document.

2.2 Module Functional Categories

The modules on this device are grouped into functional categories. The following sections describe the modules assigned to each category in more detail.

Table 2-1. Module functional categories

| Module category | Description |
|----------------------------|---|
| ARM® Cortex®-M4 based core | <ul style="list-style-type: none"> 32-bit MCU core from ARM's Cortex-M class adding DSP instructions based on ARMv7 architecture |
| System | <ul style="list-style-type: none"> System integration module Power management and mode controllers <ul style="list-style-type: none"> Multiple power modes available based on run, wait, stop, and power-down modes Low-leakage wakeup unit Miscellaneous control module Crossbar switch Peripheral bridge Direct memory access (DMA) controller with multiplexer to increase available DMA requests. External watchdog monitor Watchdog |
| Memories | <ul style="list-style-type: none"> Internal memories include: <ul style="list-style-type: none"> Program flash memory On devices with FlexMemory: FlexMemory <ul style="list-style-type: none"> FlexNVM FlexRAM On devices with program flash only: Programming acceleration RAM SRAM Serial programming interface: EzPort |

Table continues on the next page...

Table 2-1. Module functional categories (continued)

| Module category | Description |
|--|---|
| Clocks | <ul style="list-style-type: none"> Multiple clock generation options available from internally- and externally-generated clocks System oscillator to provide clock source for the MCU RTC oscillator to provide clock source for the RTC |
| Security | <ul style="list-style-type: none"> Cyclic Redundancy Check module for error detection Hardware encryption, along with a random number generator Tamper detect and secure storage |
| Analog | <ul style="list-style-type: none"> High speed analog-to-digital converter Comparator Digital-to-analog converter Internal voltage reference Bandgap voltage reference |
| Timers | <ul style="list-style-type: none"> Programmable delay block FlexTimers Periodic interrupt timer Low power timer Carrier modulator transmitter Independent real time clock |
| Communications | <ul style="list-style-type: none"> Serial peripheral interface Inter-integrated circuit (I²C) UART Integrated interchip sound (I²S) |
| Human-Machine Interfaces (HMI) | <ul style="list-style-type: none"> General purpose input/output controller |

2.2.1 ARM® Cortex®-M4 based core modules

The following core modules are available on this device.

Table 2-2. Core modules

| Module | Description |
|-------------------------------|--|
| ARM Cortex-M4 | <p>The ARM Cortex-M4 is the newest member of the Cortex M Series of processors targeting microcontroller cores focused on very cost sensitive, deterministic, interrupt driven environments. The Cortex M4 processor is based on the ARMv7 Architecture and Thumb®-2 ISA and is upward compatible with the Cortex M3, Cortex M1, and Cortex M0 architectures. Cortex M4 improvements include an ARMv7 Thumb-2 DSP (ported from the ARMv7-A/R profile architectures) providing 32-bit instructions with SIMD (single instruction multiple data) DSP style multiply-accumulates and saturating arithmetic.</p> |
| NVIC | <p>The ARMv7-M exception model and nested-vector interrupt controller (NVIC) implement a relocatable vector table supporting many external interrupts, a single non-maskable interrupt (NMI), and priority levels.</p> <p>The NVIC replaces shadow registers with equivalent system and simplified programmability. The NVIC contains the address of the function to execute for a particular handler. The address is fetched via the instruction port allowing parallel register stacking and look-up. The first sixteen entries are allocated to ARM internal sources with the others mapping to MCU-defined interrupts.</p> |

Table continues on the next page...

Table 2-2. Core modules (continued)

| Module | Description |
|----------------------------------|--|
| AWIC | The primary function of the Asynchronous Wake-up Interrupt Controller (AWIC) is to detect asynchronous wake-up events in stop modes and signal to clock control logic to resume system clocking. After clock restart, the NVIC observes the pending interrupt and performs the normal interrupt or event processing. |
| Debug interfaces | Most of this device's debug is based on the ARM CoreSight™ architecture. Four debug interfaces are supported: <ul style="list-style-type: none"> • IEEE 1149.1 JTAG • IEEE 1149.7 JTAG (cJTAG) • Serial Wire Debug (SWD) • ARM Real-Time Trace Interface |

2.2.2 System Modules

The following system modules are available on this device.

Table 2-3. System modules

| Module | Description |
|---|--|
| System integration module (SIM) | The SIM includes integration logic and several module configuration settings. |
| System mode controller (SMC) | The SMC provides control and protection on entry and exit to each power mode, control for the Power management controller (PMC), and reset entry and exit for the complete MCU. |
| Power management controller (PMC) | The PMC provides the user with multiple power options. Ten different modes are supported that allow the user to optimize power consumption for the level of functionality needed. Includes power-on-reset (POR) and integrated low voltage detect (LVD) with reset (brownout) capability and selectable LVD trip points. |
| Low-leakage wakeup unit (LLWU) | The LLWU module allows the device to wake from low leakage power modes (LLS and VLLS) through various internal peripheral and external pin sources. |
| Miscellaneous control module (MCM) | The MCM includes integration logic |
| Crossbar switch (XBS) | The XBS connects bus masters and bus slaves, allowing all bus masters to access different bus slaves simultaneously and providing arbitration among the bus masters when they access the same slave. |
| Peripheral bridges | The peripheral bridge converts the crossbar switch interface to an interface to access a majority of peripherals on the device. |
| DMA multiplexer (DMAMUX) | The DMA multiplexer selects from many DMA requests down to a smaller number for the DMA controller. |
| Direct memory access (DMA) controller | The DMA controller provides programmable channels with transfer control descriptors for data movement via dual-address transfers for 8-, 16-, 32- and 128-bit data values. |
| External watchdog monitor (EWM) | The EWM is a redundant mechanism to the software watchdog module that monitors both internal and external system operation for fail conditions. |
| Software watchdog (WDOG) | The WDOG monitors internal system operation and forces a reset in case of failure. It can run from an independent 1 KHz low power oscillator with a programmable refresh window to detect deviations in program flow or system frequency. |

2.2.3 Memories and Memory Interfaces

The following memories and memory interfaces are available on this device.

Table 2-4. Memories and memory interfaces

| Module | Description |
|---------------------------------------|--|
| Flash memory | <ul style="list-style-type: none"> Program flash memory — non-volatile flash memory that can execute program code FlexMemory — encompasses the following memory types: <ul style="list-style-type: none"> For devices with FlexNVM: FlexNVM — Non-volatile flash memory that can execute program code, store data, or backup EEPROM data For devices with FlexNVM: FlexRAM — RAM memory that can be used as traditional RAM or as high-endurance EEPROM storage, and also accelerates flash programming For devices with only program flash memory: Programming acceleration RAM — RAM memory that accelerates flash programming |
| Flash memory controller | Manages the interface between the device and the on-chip flash memory. |
| SRAM | Internal system RAM. Partial SRAM kept powered in VLLS2 low leakage mode. |
| SRAM controller | Manages simultaneous accesses to system RAM by multiple master peripherals and core. |
| System register file | 32-byte register file that is accessible during all power modes and is powered by VDD. |
| VBAT register file | 32-byte register file that is accessible during all power modes and is powered by VBAT. |
| Serial programming interface (EzPort) | Same serial interface as, and subset of, the command set used by industry-standard SPI flash memories. Provides the ability to read, erase, and program flash memory and reset command to boot the system after flash programming. |

2.2.4 Clocks

The following clock modules are available on this device.

Table 2-5. Clock modules

| Module | Description |
|-----------------------------|---|
| Multi-clock generator (MCG) | <p>The MCG provides several clock sources for the MCU that include:</p> <ul style="list-style-type: none"> Phase-locked loop (PLL) — Voltage-controlled oscillator (VCO) Frequency-locked loop (FLL) — Digitally-controlled oscillator (DCO) Internal reference clocks — Can be used as a clock source for other on-chip peripherals |
| System oscillator | The system oscillator, in conjunction with an external crystal or resonator, generates a reference clock for the MCU. |
| Real-time clock oscillator | The RTC oscillator has an independent power supply and supports a 32 kHz crystal oscillator to feed the RTC clock. Optionally, the RTC oscillator can replace the system oscillator as the main oscillator source. |

2.2.5 Security and Integrity modules

The following security and integrity modules are available on this device:

Table 2-6. Security and integrity modules

| Module | Description |
|--|---|
| Cryptographic acceleration unit (CAU) | Supports DES, 3DES, AES, MD5, SHA-1, and SHA-256 algorithms via simple C calls to optimized security functions provided by Freescale. |
| Random number generator (RNG) | Supports the key generation algorithm defined in the Digital Signature Standard. |
| Cyclic Redundancy Check (CRC) | Hardware CRC generator circuit using 16/32-bit shift register. Error detection for all single, double, odd, and most multi-bit errors, programmable initial seed value, and optional feature to transpose input data and CRC result via transpose register. |
| DryIce (tamper detection and secure storage) | The DryIce module includes a 32-byte secure memory that is asynchronously erased on any tamper detect. In addition, it can optionally force a System Reset and/or invalidate the Real Time Clock. |

2.2.6 Analog modules

The following analog modules are available on this device:

Table 2-7. Analog modules

| Module | Description |
|---|---|
| 16-bit analog-to-digital converters (ADC) | 16-bit successive-approximation ADC |
| Analog comparators (CMP) | Compares two analog input voltages across the full range of the supply voltage. |
| 6-bit digital-to-analog converters (DAC) | 64-tap resistor ladder network which provides a selectable voltage reference for applications where voltage reference is needed. |
| 12-bit digital-to-analog converters (DAC) | Low-power general-purpose DAC, whose output can be placed on an external pin or set as one of the inputs to the analog comparator or ADC. |
| Voltage reference (VREF) | Supplies an accurate voltage output that is trimmable in 0.5 mV steps. The VREF can be used in medical applications, such as glucose meters, to provide a reference voltage to biosensors or as a reference to analog peripherals, such as the ADC, DAC or CMP. |

2.2.7 Timer modules

The following timer modules are available on this device:

Table 2-8. Timer modules

| Module | Description |
|---------------------------------|---|
| Programmable delay block (PDB) | <ul style="list-style-type: none"> • 16-bit resolution • 3-bit prescaler • Positive transition of trigger event signal initiates the counter • Supports two triggered delay output signals, each with an independently-controlled delay from the trigger event • Outputs can be OR'd together to schedule two conversions from one input trigger event and can schedule precise edge placement for a pulsed output. This feature is used to generate the control signal for the CMP windowing feature and output to a package pin if needed for applications, such as critical conductive mode power factor correction. • Continuous-pulse output or single-shot mode supported, each output is independently enabled, with possible trigger events • Supports bypass mode • Supports DMA |
| Flexible timer modules (FTM) | <ul style="list-style-type: none"> • Selectable FTM source clock, programmable prescaler • 16-bit counter supporting free-running or initial/final value, and counting is up or up-down • Input capture, output compare, and edge-aligned and center-aligned PWM modes • Operation of FTM channels as pairs with equal outputs, pairs with complimentary outputs, or independent channels with independent outputs • Deadtime insertion is available for each complementary pair • Generation of hardware triggers • Software control of PWM outputs • Up to 4 fault inputs for global fault control • Configurable channel polarity • Programmable interrupt on input capture, reference compare, overflowed counter, or detected fault condition • Quadrature decoder with input filters, relative position counting, and interrupt on position count or capture of position count on external event • DMA support for FTM events |
| Periodic interrupt timers (PIT) | <ul style="list-style-type: none"> • Four general purpose interrupt timers • Interrupt timers for triggering ADC conversions • 32-bit counter resolution • DMA support |
| Low-power timer (LPTimer) | <ul style="list-style-type: none"> • Selectable clock for prescaler/glitch filter of 1 kHz (internal LPO), 32.768 kHz (external crystal), or internal reference clock • Configurable Glitch Filter or Prescaler with 16-bit counter • 16-bit time or pulse counter with compare • Interrupt generated on Timer Compare • Hardware trigger generated on Timer Compare |
| Carrier modulator timer (CMT) | <ul style="list-style-type: none"> • Four CMT modes of operation: <ul style="list-style-type: none"> • Time with independent control of high and low times • Baseband • Frequency shift key (FSK) • Direct software control of CMT_IRO pin • Extended space operation in time, baseband, and FSK modes • Selectable input clock divider • Interrupt on end of cycle with the ability to disable CMT_IRO pin and use as timer interrupt • DMA support |

Table continues on the next page...

Table 2-8. Timer modules (continued)

| Module | Description |
|-----------------------|--|
| Real-time clock (RTC) | <ul style="list-style-type: none"> Independent power supply, POR, and 32 kHz Crystal Oscillator 32-bit seconds counter with 32-bit Alarm 16-bit Prescaler with compensation that can correct errors between 0.12 ppm and 3906 ppm |

2.2.8 Communication interfaces

The following communication interfaces are available on this device:

Table 2-9. Communication modules

| Module | Description |
|---|---|
| Serial peripheral interface (SPI) | Synchronous serial bus for communication to an external device |
| Inter-integrated circuit (I2C) | Allows communication between a number of devices. Also supports the System Management Bus (SMBus) Specification, version 2. |
| Universal asynchronous receiver/transmitters (UART) | Asynchronous serial bus communication interface with programmable 8- or 9-bit data format and support of ISO 7816 smart card interface |
| I2S | The I ² S is a full-duplex, serial port that allows the chip to communicate with a variety of serial devices, such as standard codecs, digital signal processors (DSPs), microprocessors, peripherals, and audio codecs that implement the inter-IC sound bus (I ² S) and the Intel® AC97 standards |

2.2.9 Human-machine interfaces

The following human-machine interfaces (HMI) are available on this device:

Table 2-10. HMI modules

| Module | Description |
|-------------------------------------|--|
| General purpose input/output (GPIO) | <p>All general purpose input or output (GPIO) pins are capable of interrupt and DMA request generation.</p> <p>All GPIO pins have 3.3 V tolerance.</p> |

2.3 Orderable part numbers

The following table summarizes the part numbers of the devices covered by this document.

Table 2-11. Orderable part numbers summary

| Freescall part number | CPU frequenc y | Pin count | Package | Total flash memory | Program flash | EEPROM | SRAM | GPIO |
|-----------------------|----------------------|--------------|---------|--------------------------|------------------|--------|-------|------|
| MK11DX128AVMC5 | 50 MHz | 121 | MAPBGA | 192 KB | 128 KB | 4 KB | 32 KB | 64 |
| MK11DX256AVMC5 | 50 MHz | 121 | MAPBGA | 320 KB | 256 KB | 4 KB | 32 KB | 64 |
| MK11DN512AVMC5 | 50 MHz | 121 | MAPBGA | 512 KB | 512 KB | — | 64 KB | 64 |

Chapter 3 Chip Configuration

3.1 Introduction

This chapter provides details on the individual modules of the microcontroller. It includes:

- module block diagrams showing immediate connections within the device,
- specific module-to-module interactions not necessarily discussed in the individual module chapters, and
- links for more information.

3.2 Core modules

3.2.1 ARM Cortex-M4 Core Configuration

This section summarizes how the module has been configured in the chip. Full documentation for this module is provided by ARM and can be found at arm.com.

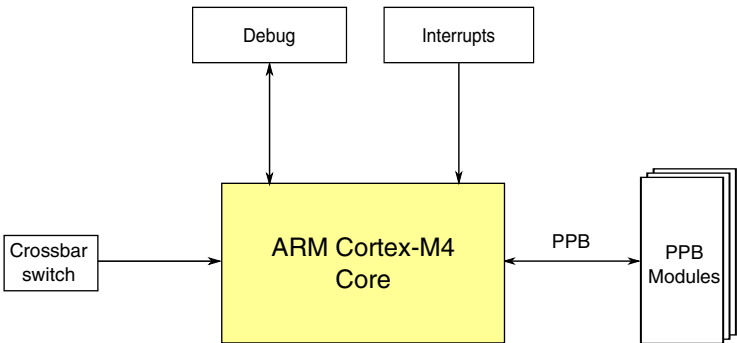


Figure 3-1. Core configuration

Table 3-1. Reference links to related information

| Topic | Related module | Reference |
|-------------------------------------|--|--|
| Full description | ARM Cortex-M4 core | ARM Cortex-M4 Technical Reference Manual |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| System/instruction/data bus module | Crossbar switch | Crossbar switch |
| Debug | IEEE 1149.1 JTAG Serial Wire Debug (SWD) ARM Real-Time Trace Interface | Debug |
| Interrupts | Nested Vectored Interrupt Controller (NVIC) | NVIC |
| Private Peripheral Bus (PPB) module | Miscellaneous Control Module (MCM) | MCM |
| Private Peripheral Bus (PPB) module | Memory-Mapped Cryptographic Acceleration Unit (MMCAU) | MMCAU |

3.2.1.1 Buses, interconnects, and interfaces

The ARM Cortex-M4 core has four buses as described in the following table.

Table 3-2. Buses of ARM Cortex-M4 core and their description

| Bus name | Description |
|------------------------------|--|
| Instruction code (ICODE) bus | The ICODE and DCODE buses are muxed. This muxed bus is called the CODE bus and is connected to the crossbar switch via a single master port. |
| Data code (DCODE) bus | |

Table continues on the next page...

Table 3-2. Buses of ARM Cortex-M4 core and their description (continued)

| Bus name | Description |
|------------------------------|--|
| System bus | The system bus is connected to a separate master port on the crossbar. |
| Private peripheral (PPB) bus | The PPB provides access to these modules: <ul style="list-style-type: none"> ARM modules such as the NVIC, ETM, ITM, DWT, FBP, and ROM table Freescale Miscellaneous Control Module (MCM) Memory-Mapped Cryptographic Acceleration Unit (MMCAU) |

3.2.1.2 System Tick Timer

The System Tick Timer's clock source is always the core clock, FCLK. This results in the following:

- The CLKSOURCE bit in SysTick Control and Status register is always set to select the core clock.
- Because the timing reference (FCLK) is a variable frequency, the TENMS bit in the SysTick Calibration Value Register is always zero.
- The NOREF bit in SysTick Calibration Value Register is always set, implying that FCLK is the only available source of reference timing.

3.2.1.3 Debug facilities

This device has extensive debug capabilities including run control and tracing capabilities. The standard ARM debug port that supports JTAG and SWD interfaces. Also the cJTAG interface is supported on this device.

3.2.1.4 Core privilege levels

The ARM documentation uses different terms than this document to distinguish between privilege levels.

| If you see this term... | it also means this term... |
|-------------------------|----------------------------|
| Privileged | Supervisor |
| Unprivileged or user | User |

3.2.2 Nested Vectored Interrupt Controller (NVIC) Configuration

This section summarizes how the module has been configured in the chip. Full documentation for this module is provided by ARM and can be found at arm.com.

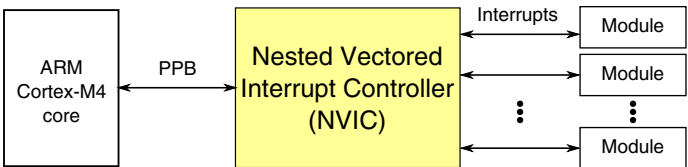


Figure 3-2. NVIC configuration

Table 3-3. Reference links to related information

| Topic | Related module | Reference |
|------------------------------|---|--|
| Full description | Nested Vectored Interrupt Controller (NVIC) | ARM Cortex-M4 Technical Reference Manual |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Private Peripheral Bus (PPB) | ARM Cortex-M4 core | ARM Cortex-M4 core |

3.2.2.1 Interrupt priority levels

This device supports 16 priority levels for interrupts. Therefore, in the NVIC each source in the IPR registers contains 4 bits. For example, IPR0 is shown below:

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|------|----|----|----|----|----|----|----|------|----|----|----|----|----|----|----|------|----|----|----|----|----|---|---|------|---|---|---|---|---|---|---|
| | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | IRQ3 | | | | 0 | 0 | 0 | 0 | IRQ2 | | | | 0 | 0 | 0 | 0 | IRQ1 | | | | 0 | 0 | 0 | 0 | IRQ0 | | | | 0 | 0 | 0 | 0 |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

3.2.2.2 Non-maskable interrupt

The non-maskable interrupt request to the NVIC is controlled by the external \overline{NMI} signal. The pin the \overline{NMI} signal is multiplexed on, must be configured for the \overline{NMI} function to generate the non-maskable interrupt request.

3.2.2.3 Interrupt channel assignments

The interrupt source assignments are defined in the following table.

- Vector number — the value stored on the stack when an interrupt is serviced.
- IRQ number — non-core interrupt source count, which is the vector number minus 16.

The IRQ number is used within ARM's NVIC documentation.

Table 3-5. Interrupt vector assignments

| Address | Vector | IRQ ¹ | NVIC non-IPR register number ² | NVIC IPR register number ³ | Source module | Source description |
|--|--------|------------------|---|---|---------------|--|
| ARM Core System Handler Vectors | | | | | | |
| 0x0000_0000 | 0 | — | — | — | ARM core | Initial Stack Pointer |
| 0x0000_0004 | 1 | — | — | — | ARM core | Initial Program Counter |
| 0x0000_0008 | 2 | — | — | — | ARM core | Non-maskable Interrupt (NMI) |
| 0x0000_000C | 3 | — | — | — | ARM core | Hard Fault |
| 0x0000_0010 | 4 | — | — | — | ARM core | MemManage Fault |
| 0x0000_0014 | 5 | — | — | — | ARM core | Bus Fault |
| 0x0000_0018 | 6 | — | — | — | ARM core | Usage Fault |
| 0x0000_001C | 7 | — | — | — | — | — |
| 0x0000_0020 | 8 | — | — | — | — | — |
| 0x0000_0024 | 9 | — | — | — | — | — |
| 0x0000_0028 | 10 | — | — | — | — | — |
| 0x0000_002C | 11 | — | — | — | ARM core | Supervisor call (SVCall) |
| 0x0000_0030 | 12 | — | — | — | ARM core | Debug Monitor |
| 0x0000_0034 | 13 | — | — | — | — | — |
| 0x0000_0038 | 14 | — | — | — | ARM core | Pendable request for system service (PendableSrvReq) |
| 0x0000_003C | 15 | — | — | — | ARM core | System tick timer (SysTick) |
| Non-Core Vectors | | | | | | |
| 0x0000_0040 | 16 | 0 | 0 | 0 | DMA | DMA channel 0 transfer complete |
| 0x0000_0044 | 17 | 1 | 0 | 0 | DMA | DMA channel 1 transfer complete |
| 0x0000_0048 | 18 | 2 | 0 | 0 | DMA | DMA channel 2 transfer complete |
| 0x0000_004C | 19 | 3 | 0 | 0 | DMA | DMA channel 3 transfer complete |
| 0x0000_0050 | 20 | 4 | 0 | 1 | DMA | DMA channel 4 transfer complete |
| 0x0000_0054 | 21 | 5 | 0 | 1 | DMA | DMA channel 5 transfer complete |
| 0x0000_0058 | 22 | 6 | 0 | 1 | DMA | DMA channel 6 transfer complete |
| 0x0000_005C | 23 | 7 | 0 | 1 | DMA | DMA channel 7 transfer complete |
| 0x0000_0060 | 24 | 8 | 0 | 2 | DMA | DMA channel 8 transfer complete |

Table continues on the next page...

Table 3-5. Interrupt vector assignments (continued)

| Address | Vector | IRQ ¹ | NVIC non-IPR register number ² | NVIC IPR register number ³ | Source module | Source description |
|-------------|--------|------------------|---|---|-------------------|---|
| 0x0000_0064 | 25 | 9 | 0 | 2 | DMA | DMA channel 9 transfer complete |
| 0x0000_0068 | 26 | 10 | 0 | 2 | DMA | DMA channel 10 transfer complete |
| 0x0000_006C | 27 | 11 | 0 | 2 | DMA | DMA channel 11 transfer complete |
| 0x0000_0070 | 28 | 12 | 0 | 3 | DMA | DMA channel 12 transfer complete |
| 0x0000_0074 | 29 | 13 | 0 | 3 | DMA | DMA channel 13 transfer complete |
| 0x0000_0078 | 30 | 14 | 0 | 3 | DMA | DMA channel 14 transfer complete |
| 0x0000_007C | 31 | 15 | 0 | 3 | DMA | DMA channel 15 transfer complete |
| 0x0000_0080 | 32 | 16 | 0 | 4 | DMA | DMA error interrupt channels 0-15 |
| 0x0000_0084 | 33 | 17 | 0 | 4 | MCM | — |
| 0x0000_0088 | 34 | 18 | 0 | 4 | Flash memory | Command complete |
| 0x0000_008C | 35 | 19 | 0 | 4 | Flash memory | Read collision |
| 0x0000_0090 | 36 | 20 | 0 | 5 | Mode Controller | Low-voltage detect, low-voltage warning |
| 0x0000_0094 | 37 | 21 | 0 | 5 | LLWU | Low Leakage Wakeup NOTE: The LLWU interrupt must not be masked by the interrupt controller to avoid a scenario where the system does not fully exit stop mode on an LLS recovery. |
| 0x0000_0098 | 38 | 22 | 0 | 5 | WDOG or EWM | Both watchdog modules share this interrupt |
| 0x0000_009C | 39 | 23 | 0 | 5 | RNG | Random Number Generator |
| 0x0000_00A0 | 40 | 24 | 0 | 6 | I ² C0 | — |
| 0x0000_00A4 | 41 | 25 | 0 | 6 | I ² C1 | — |
| 0x0000_00A8 | 42 | 26 | 0 | 6 | SPI0 | Single interrupt vector for all sources |
| 0x0000_00AC | 43 | 27 | 0 | 6 | SPI1 | Single interrupt vector for all sources |
| 0x0000_00B0 | 44 | 28 | 0 | 7 | I ² S0 | Transmit |
| 0x0000_00B4 | 45 | 29 | 0 | 7 | I ² S0 | Receive |
| 0x0000_00B8 | 46 | 30 | 0 | 7 | — | — |
| 0x0000_00BC | 47 | 31 | 0 | 7 | UART0 | Single interrupt vector for UART status sources |
| 0x0000_00C0 | 48 | 32 | 1 | 8 | UART0 | Single interrupt vector for UART error sources |
| 0x0000_00C4 | 49 | 33 | 1 | 8 | UART1 | Single interrupt vector for UART status sources |
| 0x0000_00C8 | 50 | 34 | 1 | 8 | UART1 | Single interrupt vector for UART error sources |
| 0x0000_00CC | 51 | 35 | 1 | 8 | UART2 | Single interrupt vector for UART status sources |

Table continues on the next page...

Table 3-5. Interrupt vector assignments (continued)

| Address | Vector | IRQ ¹ | NVIC non-IPR register number ² | NVIC IPR register number ³ | Source module | Source description |
|-------------|--------|------------------|---|---------------------------------------|---------------------|---|
| 0x0000_00D0 | 52 | 36 | 1 | 9 | UART2 | Single interrupt vector for UART error sources |
| 0x0000_00D4 | 53 | 37 | 1 | 9 | UART3 | Single interrupt vector for UART status sources |
| 0x0000_00D8 | 54 | 38 | 1 | 9 | UART3 | Single interrupt vector for UART error sources |
| 0x0000_00DC | 55 | 39 | 1 | 9 | ADC0 | — |
| 0x0000_00E0 | 56 | 40 | 1 | 10 | CMP0 | — |
| 0x0000_00E4 | 57 | 41 | 1 | 10 | CMP1 | — |
| 0x0000_00E8 | 58 | 42 | 1 | 10 | FTM0 | Single interrupt vector for all sources |
| 0x0000_00EC | 59 | 43 | 1 | 10 | FTM1 | Single interrupt vector for all sources |
| 0x0000_00F0 | 60 | 44 | 1 | 11 | FTM2 | Single interrupt vector for all sources |
| 0x0000_00F4 | 61 | 45 | 1 | 11 | CMT | — |
| 0x0000_00F8 | 62 | 46 | 1 | 11 | RTC | Alarm interrupt |
| 0x0000_00FC | 63 | 47 | 1 | 11 | RTC | Seconds interrupt |
| 0x0000_0100 | 64 | 48 | 1 | 12 | PIT | Channel 0 |
| 0x0000_0104 | 65 | 49 | 1 | 12 | PIT | Channel 1 |
| 0x0000_0108 | 66 | 50 | 1 | 12 | PIT | Channel 2 |
| 0x0000_010C | 67 | 51 | 1 | 12 | PIT | Channel 3 |
| 0x0000_0110 | 68 | 52 | 1 | 13 | PDB | — |
| 0x0000_0114 | 69 | 53 | 1 | 13 | — | — |
| 0x0000_0118 | 70 | 54 | 1 | 13 | — | — |
| 0x0000_011C | 71 | 55 | 1 | 13 | — | — |
| 0x0000_0120 | 72 | 56 | 1 | 14 | DAC0 | — |
| 0x0000_0124 | 73 | 57 | 1 | 14 | MCG | — |
| 0x0000_0128 | 74 | 58 | 1 | 14 | Low Power Timer | — |
| 0x0000_012C | 75 | 59 | 1 | 14 | Port control module | Pin detect (Port A) |
| 0x0000_0130 | 76 | 60 | 1 | 15 | Port control module | Pin detect (Port B) |
| 0x0000_0134 | 77 | 61 | 1 | 15 | Port control module | Pin detect (Port C) |
| 0x0000_0138 | 78 | 62 | 1 | 15 | Port control module | Pin detect (Port D) |
| 0x0000_013C | 79 | 63 | 1 | 15 | Port control module | Pin detect (Port E) |
| 0x0000_0140 | 80 | 64 | 2 | 16 | Software | Software interrupt ⁴ |

1. Indicates the NVIC's interrupt source number.

2. Indicates the NVIC's ISER, ICER, ISPR, ICPR, and IABR register number used for this IRQ. The equation to calculate this value is: $IRQ \div 32$

3. Indicates the NVIC's IPR register number used for this IRQ. The equation to calculate this value is: $IRQ \div 4$

4. This interrupt can only be pended or cleared via the NVIC registers.

3.2.2.3.1 Determining the bitfield and register location for configuring a particular interrupt

Suppose you need to configure the low-power timer (LPTMR) interrupt. The following table is an excerpt of the LPTMR row from [Interrupt channel assignments](#).

Table 3-6. LPTMR interrupt vector assignment

| Address | Vector | IRQ ¹ | NVIC non-IPR register number ² | NVIC IPR register number ³ | Source module | Source description |
|-------------|--------|------------------|---|---------------------------------------|-----------------|--------------------|
| 0x0000_0128 | 74 | 58 | 1 | 14 | Low Power Timer | — |

1. Indicates the NVIC's interrupt source number.
2. Indicates the NVIC's ISER, ICER, ISPR, ICPR, and IABR register number used for this IRQ. The equation to calculate this value is: $IRQ \div 32$
3. Indicates the NVIC's IPR register number used for this IRQ. The equation to calculate this value is: $IRQ \div 4$

- The NVIC registers you would use to configure the interrupt are:
 - NVICISER1
 - NVICICER1
 - NVICISPR1
 - NVICICPR1
 - NVICIABR1
 - NVICIPR14
- To determine the particular IRQ's bitfield location within these particular registers:
 - NVICISER1, NVICICER1, NVICISPR1, NVICICPR1, NVICIABR1 bit location = $IRQ \bmod 32 = 26$
 - NVICIPR14 bitfield starting location = $8 * (IRQ \bmod 4) + 4 = 20$

Since the NVICIPR bitfields are 4-bit wide ([16 priority levels](#)), the NVICIPR14 bitfield range is 20-23

Therefore, the following bitfield locations are used to configure the LPTMR interrupts:

- NVICISER1[26]
- NVICICER1[26]
- NVICISPR1[26]
- NVICICPR1[26]
- NVICIABR1[26]
- NVICIPR14[23:20]

3.2.3 Asynchronous Wake-up Interrupt Controller (AWIC) Configuration

This section summarizes how the module has been configured in the chip. Full documentation for this module is provided by ARM and can be found at arm.com.

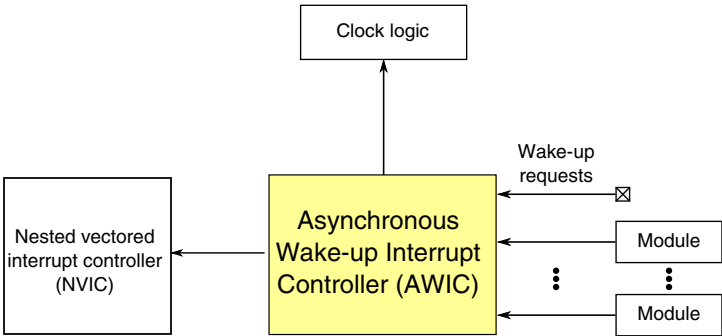


Figure 3-3. Asynchronous Wake-up Interrupt Controller configuration

Table 3-7. Reference links to related information

| Topic | Related module | Reference |
|-------------------|---|--------------------------------------|
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| | Nested Vectored Interrupt Controller (NVIC) | NVIC |
| Wake-up requests | | AWIC wake-up sources |

3.2.3.1 Wake-up sources

The device uses the following internal and external inputs to the AWIC module.

Table 3-8. AWIC Stop and VLPS Wake-up Sources

| Wake-up source | Description |
|-------------------------|---|
| Available system resets | RESET pin and WDOG when LPO is its clock source, and JTAG |
| Low-voltage detect | Mode Controller |
| Low-voltage warning | Mode Controller |
| Pin interrupts | Port Control Module - Any enabled pin interrupt is capable of waking the system |
| ADCx | The ADC is functional when using internal clock source |
| CMPx | Since no system clocks are available, functionality is limited |
| I ² C | Address match wakeup |
| UART | Active edge on RXD |

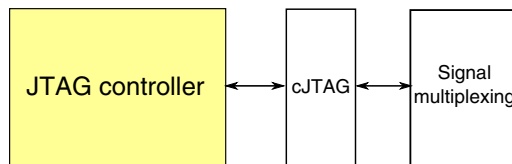
Table continues on the next page...

Table 3-8. AWIC Stop and VLPS Wake-up Sources (continued)

| Wake-up source | Description |
|----------------|---|
| LPTMR | Functional when using clock source which is active in Stop and VLPS modes |
| RTC | Functional in Stop/VLPS modes |
| I2S (SAI) | Functional when using an external bit clock or external master clock |
| Tamper detect | Interrupt or a reset |
| NMI | Non-maskable interrupt |

3.2.4 JTAG Controller Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.


Figure 3-4. JTAGC Controller configuration
Table 3-9. Reference links to related information

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Full description | JTAGC | JTAGC |
| Signal multiplexing | Port control | Signal multiplexing |

3.3 System modules

3.3.1 SIM Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

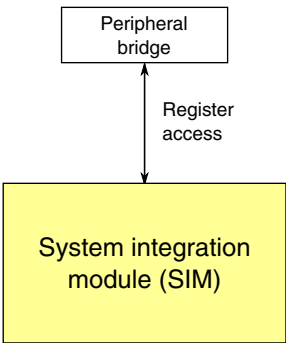


Figure 3-5. SIM configuration

Table 3-10. Reference links to related information

| Topic | Related module | Reference |
|-------------------|----------------|------------------------------------|
| Full description | SIM | SIM |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |

3.3.2 System Mode Controller (SMC) Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

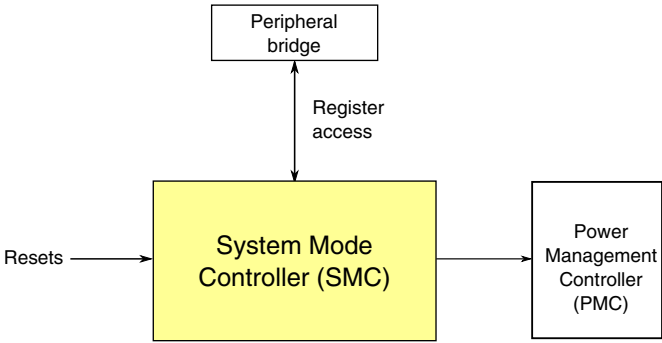


Figure 3-6. System Mode Controller configuration

Table 3-11. Reference links to related information

| Topic | Related module | Reference |
|-------------------|------------------------------|-----------------------------------|
| Full description | System Mode Controller (SMC) | SMC |
| System memory map | | System memory map |
| Power management | | Power management |

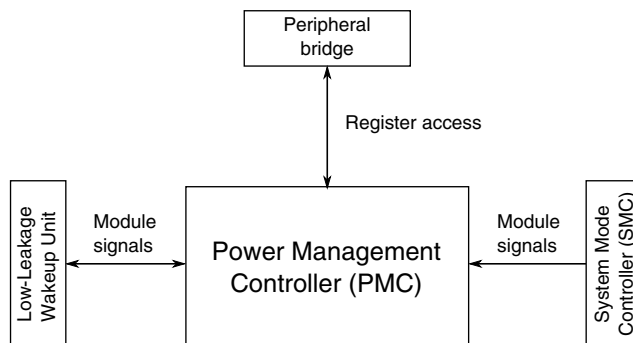
Table continues on the next page...

Table 3-11. Reference links to related information (continued)

| Topic | Related module | Reference |
|-------|-----------------------------------|-----------------------|
| | Power management controller (PMC) | PMC |
| | Low-Leakage Wakeup Unit (LLWU) | LLWU |
| | Reset Control Module (RCM) | Reset |

3.3.3 PMC Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.


Figure 3-7. PMC configuration
Table 3-12. Reference links to related information

| Topic | Related module | Reference |
|-------------------|--------------------------------|--|
| Full description | PMC | PMC |
| System memory map | | System memory map |
| Power management | | Power management |
| Full description | System Mode Controller (SMC) | System Mode Controller |
| | Low-Leakage Wakeup Unit (LLWU) | LLWU |
| | Reset Control Module (RCM) | Reset |

3.3.4 Low-Leakage Wake-up Unit (LLWU) Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

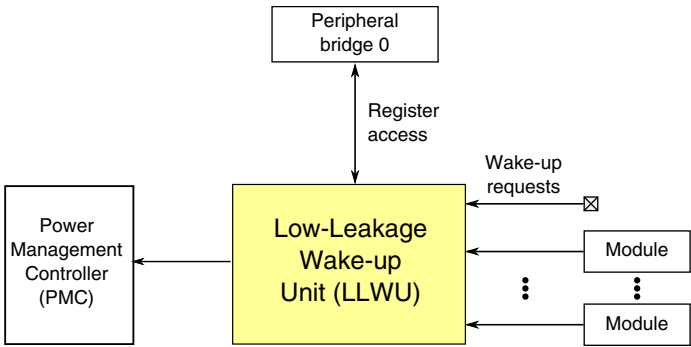


Figure 3-8. Low-Leakage Wake-up Unit configuration

Table 3-13. Reference links to related information

| Topic | Related module | Reference |
|-------------------|-----------------------------------|---|
| Full description | LLWU | LLWU |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management chapter |
| | Power Management Controller (PMC) | Power Management Controller (PMC) |
| | Mode Controller | Mode Controller |
| Wake-up requests | | LLWU wake-up sources |

3.3.4.1 Wake-up Sources

This chip uses the following internal peripheral and external pin inputs as wakeup sources to the LLWU module:

- LLWU_P0-15 are external pin inputs. Any digital function multiplexed on the pin can be selected as the wakeup source. See the chip's signal multiplexing table for the digital signal options.
- LLWU_M0IF-M7IF are connections to the internal peripheral interrupt flags.

NOTE

$\overline{\text{RESET}}$ is also a wakeup source, depending on the bit setting in the LLWU_RST register. On devices where $\overline{\text{RESET}}$ is not a dedicated pin, it must also be enabled in the explicit port mux control.

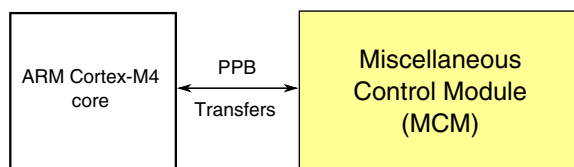
Table 3-14. Wakeup sources for LLWU inputs

| Input | Wakeup source | Input | Wakeup source |
|----------|-------------------------------|-----------|--------------------------|
| LLWU_P0 | PTE1/LLWU_P0 pin | LLWU_P12 | PTD0/LLWU_P12 pin |
| LLWU_P1 | PTE2/LLWU_P1 pin | LLWU_P13 | PTD2/LLWU_P13 pin |
| LLWU_P2 | PTE4/LLWU_P2 pin | LLWU_P14 | PTD4/LLWU_P14 pin |
| LLWU_P3 | PTA4/LLWU_P3 pin ¹ | LLWU_P15 | PTD6/LLWU_P15 pin |
| LLWU_P4 | PTA13/LLWU_P4 pin | LLWU_M0IF | LPTMR ² |
| LLWU_P5 | PTB0/LLWU_P5 pin | LLWU_M1IF | CMP0 ² |
| LLWU_P6 | PTC1/LLWU_P6 pin | LLWU_M2IF | CMP1 ² |
| LLWU_P7 | PTC3/LLWU_P7 pin | LLWU_M3IF | Reserved |
| LLWU_P8 | PTC4/LLWU_P8 pin | LLWU_M4IF | Reserved |
| LLWU_P9 | PTC5/LLWU_P9 pin | LLWU_M5IF | RTC Alarm ² |
| LLWU_P10 | PTC6/LLWU_P10 pin | LLWU_M6IF | Reserved |
| LLWU_P11 | PTC11/LLWU_P11 pin | LLWU_M7IF | RTC Seconds ² |

1. The `EZP_CS` signal is checked only on *Chip Reset not VLLS*, so a VLLS wakeup via a non-reset source does not cause EzPort mode entry. If NMI was enabled on entry to LLS/VLLS, asserting the NMI pin generates an NMI interrupt on exit from the low power mode.
2. Requires the peripheral and the peripheral interrupt to be enabled. The LLWU's WUME bit enables the internal module flag as a wakeup input. After wakeup, the flags are cleared based on the peripheral clearing mechanism.

3.3.5 MCM Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.


Figure 3-9. MCM configuration
Table 3-15. Reference links to related information

| Topic | Related module | Reference |
|------------------------------|------------------------------------|------------------------------------|
| Full description | Miscellaneous control module (MCM) | MCM |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Transfers | ARM Cortex-M4 core | ARM Cortex-M4 core |
| Private Peripheral Bus (PPB) | | |

3.3.6 Crossbar-Light Switch Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

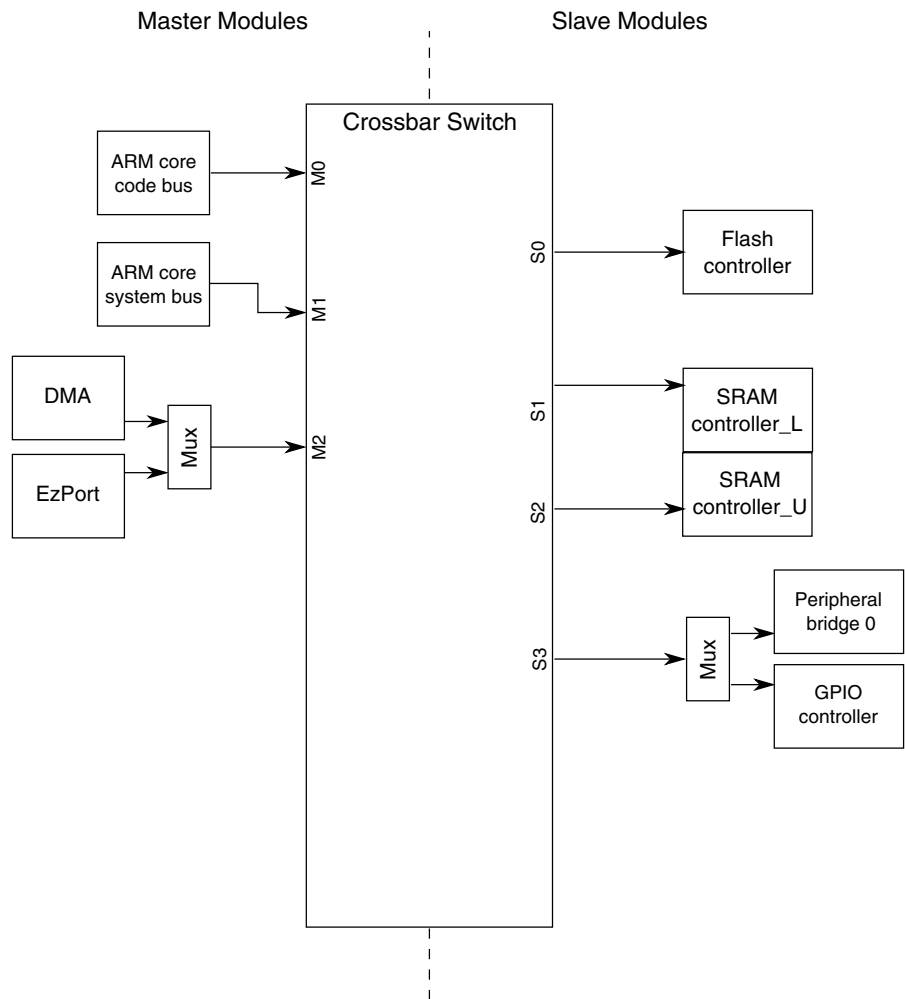


Figure 3-10. Crossbar-Light switch integration

Table 3-16. Reference links to related information

| Topic | Related module | Reference |
|------------------------|--------------------|------------------------------------|
| Full description | Crossbar switch | Crossbar Switch |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Crossbar switch master | ARM Cortex-M4 core | ARM Cortex-M4 core |
| Crossbar switch master | DMA controller | DMA controller |
| Crossbar switch master | EzPort | EzPort |

Table continues on the next page...

Table 3-16. Reference links to related information (continued)

| Topic | Related module | Reference |
|------------------------|--------------------|------------------------------------|
| Crossbar switch slave | Flash | Flash |
| Crossbar switch slaves | SRAM controllers | SRAM configuration |
| Crossbar switch slave | Peripheral bridges | Peripheral bridge |
| Crossbar switch slave | GPIO controller | GPIO controller |

3.3.6.1 Crossbar-Light Switch Master Assignments

The masters connected to the crossbar switch are assigned as follows:

| Master module | Master port number |
|---------------------|--------------------|
| ARM core code bus | 0 |
| ARM core system bus | 1 |
| DMA/EzPort | 2 |

NOTE

The DMA and EzPort share a master port. Since these modules never operate at the same time, no configuration or arbitration explanations are necessary.

The crossbar switch comes out of reset with a fixed priority. The priority from highest to lowest is masters M0 -> M1 -> M2 -> M3. M4-M7 are unused.

3.3.6.2 Crossbar-Light Switch Slave Assignments

The slaves connected to the crossbar switch are assigned as follows:

| Slave module | Slave port number |
|---------------------------------------|-------------------|
| Flash memory controller | 0 |
| SRAM controllers | 1,2 |
| Peripheral bridge 0/GPIO ¹ | 3 |

1. See [System memory map](#) for access restrictions.

3.3.7 Peripheral Bridge Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

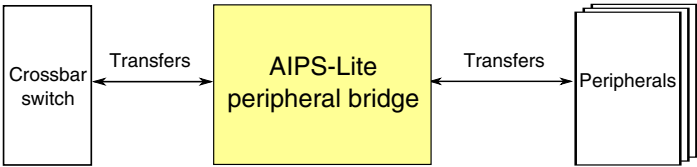


Figure 3-11. Peripheral bridge configuration

Table 3-17. Reference links to related information

| Topic | Related module | Reference |
|-------------------|-------------------------------|---|
| Full description | Peripheral bridge (AIPS-Lite) | Peripheral bridge (AIPS-Lite) |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Crossbar switch | Crossbar switch | Crossbar switch |

3.3.7.1 Number of peripheral bridges

This device contains one peripheral bridge.

3.3.7.2 Memory maps

The peripheral bridges are used to access the registers of most of the modules on this device. See [AIPS0 Memory Map](#) for the memory slot assignment for each module.

3.3.8 DMA request multiplexer configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

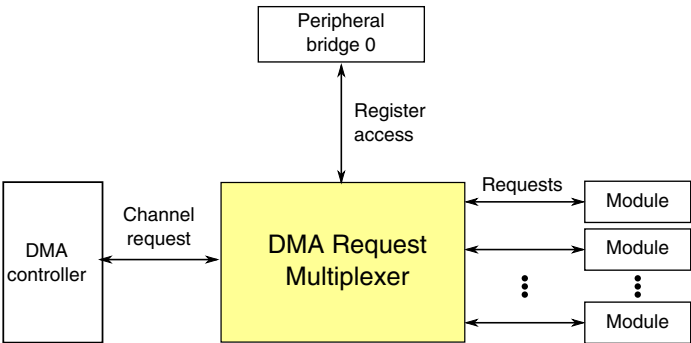


Figure 3-12. DMA request multiplexer configuration

Table 3-18. Reference links to related information

| Topic | Related module | Reference |
|-------------------|-------------------------|-------------------------------------|
| Full description | DMA request multiplexer | DMA Mux |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Channel request | DMA controller | DMA Controller |
| Requests | | DMA request sources |

3.3.8.1 DMA MUX request sources

Table 3-19. DMA request sources - MUX 0

| Source number | Source module | Source description |
|---------------|---------------|-------------------------------|
| 0 | — | Channel disabled ¹ |
| 1 | Reserved | Not used |
| 2 | UART0 | Receive |
| 3 | UART0 | Transmit |
| 4 | UART1 | Receive |
| 5 | UART1 | Transmit |
| 6 | UART2 | Receive |
| 7 | UART2 | Transmit |
| 8 | UART3 | Receive |
| 9 | UART3 | Transmit |
| 10 | Reserved | Receive |
| 11 | Reserved | Transmit |
| 12 | Reserved | Receive |
| 13 | Reserved | Transmit |

Table continues on the next page...

Table 3-19. DMA request sources - MUX 0 (continued)

| Source number | Source module | Source description |
|---------------|---------------------|--------------------|
| 14 | I ² S0 | Receive |
| 15 | I ² S0 | Transmit |
| 16 | SPI0 | Receive |
| 17 | SPI0 | Transmit |
| 18 | SPI1 | Receive |
| 19 | SPI1 | Transmit |
| 20 | — | — |
| 21 | — | — |
| 22 | I ² C0 | — |
| 23 | I ² C1 | — |
| 24 | FTM0 | Channel 0 |
| 25 | FTM0 | Channel 1 |
| 26 | FTM0 | Channel 2 |
| 27 | FTM0 | Channel 3 |
| 28 | FTM0 | Channel 4 |
| 29 | FTM0 | Channel 5 |
| 30 | FTM0 | Channel 6 |
| 31 | FTM0 | Channel 7 |
| 32 | FTM1 | Channel 0 |
| 33 | FTM1 | Channel 1 |
| 34 | FTM2 | Channel 0 |
| 35 | FTM2 | Channel 1 |
| 36 | Reserved | — |
| 37 | Reserved | — |
| 38 | Reserved | — |
| 39 | Reserved | — |
| 40 | ADC0 | — |
| 41 | Reserved | — |
| 42 | CMP0 | — |
| 43 | CMP1 | — |
| 44 | Reserved | — |
| 45 | DAC0 | — |
| 46 | Reserved | — |
| 47 | CMT | — |
| 48 | PDB | — |
| 49 | Port control module | Port A |
| 50 | Port control module | Port B |
| 51 | Port control module | Port C |
| 52 | Port control module | Port D |

Table continues on the next page...

Table 3-19. DMA request sources - MUX 0 (continued)

| Source number | Source module | Source description |
|---------------|---------------------|--------------------|
| 53 | Port control module | Port E |
| 54 | DMA MUX | Always enabled |
| 55 | DMA MUX | Always enabled |
| 56 | DMA MUX | Always enabled |
| 57 | DMA MUX | Always enabled |
| 58 | DMA MUX | Always enabled |
| 59 | DMA MUX | Always enabled |
| 60 | DMA MUX | Always enabled |
| 61 | DMA MUX | Always enabled |
| 62 | DMA MUX | Always enabled |
| 63 | DMA MUX | Always enabled |

1. Configuring a DMA channel to select source 0 or any of the reserved sources disables that DMA channel.

3.3.8.2 DMA transfers via PIT trigger

The PIT module can trigger a DMA transfer on the first four DMA channels. The assignments are detailed at [PIT/DMA Periodic Trigger Assignments](#) .

3.3.9 DMA Controller Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

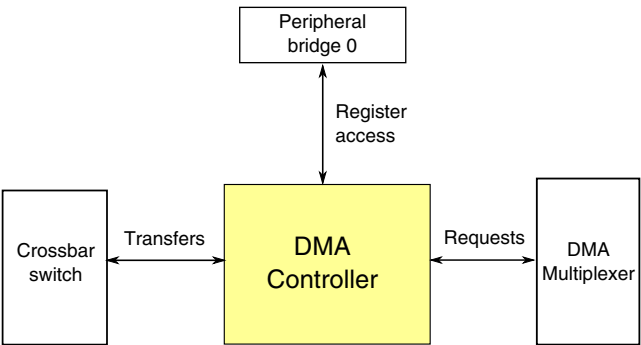


Figure 3-13. DMA Controller configuration

Table 3-20. Reference links to related information

| Topic | Related module | Reference |
|-------------------|---------------------------------|------------------------------------|
| Full description | DMA Controller | DMA Controller |
| System memory map | | System memory map |
| Register access | Peripheral bridge (AIPS-Lite 0) | AIPS-Lite 0 |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Transfers | Crossbar switch | Crossbar switch |

3.3.10 External Watchdog Monitor (EWM) Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

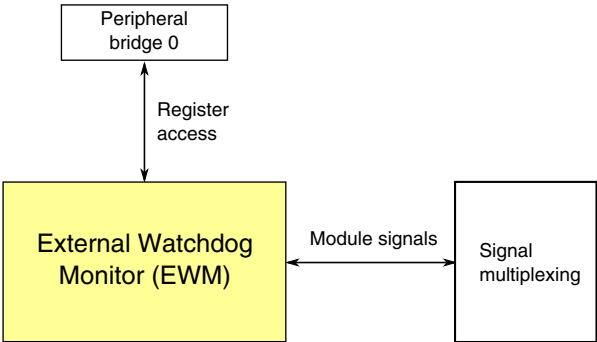


Figure 3-14. External Watchdog Monitor configuration

Table 3-21. Reference links to related information

| Topic | Related module | Reference |
|---------------------|---------------------------------|-------------------------------------|
| Full description | External Watchdog Monitor (EWM) | EWM |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Signal multiplexing | Port Control Module | Signal multiplexing |

3.3.10.1 EWM clocks

This table shows the EWM clocks and the corresponding chip clocks.

Table 3-22. EWM clock connections

| Module clock | Chip clock |
|-----------------|-----------------|
| Low Power Clock | 1 kHz LPO Clock |

3.3.10.2 EWM low-power modes

This table shows the EWM low-power modes and the corresponding chip low-power modes.

Table 3-23. EWM low-power modes

| Module mode | Chip mode |
|-------------|-----------------|
| Wait | Wait, VLPW |
| Stop | Stop, VLPS, LLS |

3.3.10.3 $\overline{\text{EWM_OUT}}$ pin state in low power modes

During Wait, Stop, and Power Down modes the $\overline{\text{EWM_OUT}}$ pin preserve its state before entering Wait or Stop mode. When the CPU enters a Run mode from Wait or Stop recovery, the pin resumes its previous state before entering Wait or Stop mode. When the CPU enters Run mode from Power Down, the pin returns to its reset state.

3.3.11 Watchdog Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

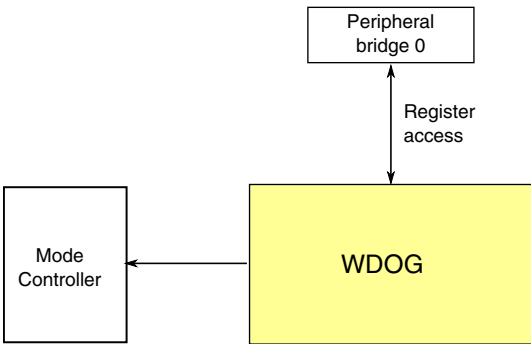


Figure 3-15. Watchdog configuration

Table 3-24. Reference links to related information

| Topic | Related module | Reference |
|-------------------|----------------------|--|
| Full description | Watchdog | Watchdog |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| | Mode Controller (MC) | System Mode Controller |

3.3.11.1 WDOG clocks

This table shows the WDOG module clocks and the corresponding chip clocks.

Table 3-25. WDOG clock connections

| Module clock | Chip clock |
|------------------|-----------------|
| LPO Oscillator | 1 kHz LPO Clock |
| Alt Clock | Bus Clock |
| Fast Test Clock | Bus Clock |
| System Bus Clock | Bus Clock |

3.3.11.2 WDOG low-power modes

This table shows the WDOG low-power modes and the corresponding chip low-power modes.

Table 3-26. WDOG low-power modes

| Module mode | Chip mode |
|-------------|--|
| Wait | Wait, VLPW |
| Stop | Stop, VLPS |
| Power Down | LLS(static retained), VLLSx(Power Off) |

3.4 Clock modules

3.4.1 MCG Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

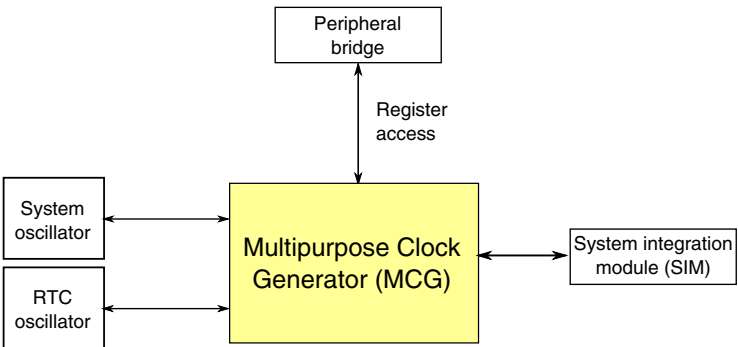


Figure 3-16. MCG configuration

Table 3-27. Reference links to related information

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Full description | MCG | MCG |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Signal multiplexing | Port control | Signal multiplexing |

3.4.2 OSC Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

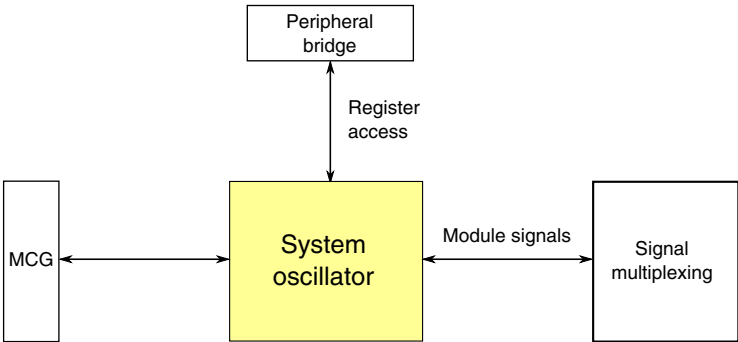


Figure 3-17. OSC configuration

Table 3-28. Reference links to related information

| Topic | Related module | Reference |
|-------------------|----------------|------------------------------------|
| Full description | OSC | OSC |
| System memory map | | System memory map |
| Clocking | | Clock distribution |

Table continues on the next page...

Table 3-28. Reference links to related information (continued)

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Power management | | Power management |
| Signal multiplexing | Port control | Signal multiplexing |
| Full description | MCG | MCG |

3.4.2.1 OSC modes of operation with MCG

The MCG's C2 register bits configure the oscillator frequency range. See the OSC and MCG chapters for more details.

3.4.3 RTC OSC configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

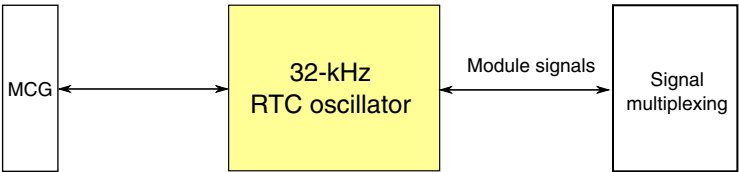


Figure 3-18. RTC OSC configuration

Table 3-29. Reference links to related information

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Full description | RTC OSC | RTC OSC |
| Signal multiplexing | Port control | Signal multiplexing |
| Full description | MCG | MCG |

3.5 Memories and memory interfaces

3.5.1 Flash Memory Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

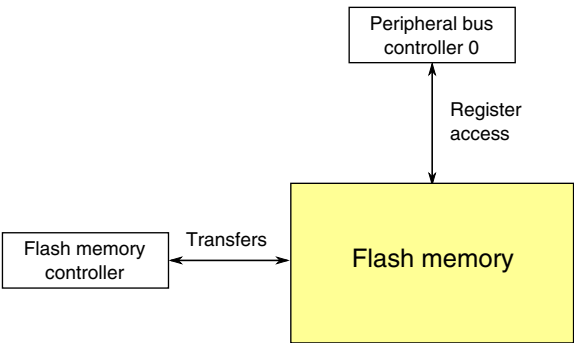


Figure 3-19. Flash memory configuration

Table 3-30. Reference links to related information

| Topic | Related module | Reference |
|-------------------|-------------------------|---|
| Full description | Flash memory | Flash memory |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Transfers | Flash memory controller | Flash memory controller |
| Register access | Peripheral bridge | Peripheral bridge |

3.5.1.1 Flash memory types

This device contains the following types of flash memory:

- Program flash memory — non-volatile flash memory that can execute program code
- FlexMemory — encompasses the following memory types:
 - For devices with FlexNVM: FlexNVM — Non-volatile flash memory that can execute program code, store data, or backup EEPROM data
 - For devices with FlexNVM: FlexRAM — RAM memory that can be used as traditional RAM or as high-endurance EEPROM storage, and also accelerates flash programming
 - For devices with only program flash memory: Programming acceleration RAM — RAM memory that accelerates flash programming

3.5.1.2 Flash Memory Sizes

The devices covered in this document contain:

- For devices with program flash only: 2 blocks of program flash consisting of 2 KB sectors

- For devices that contain FlexNVM: 1 block of program flash consisting of 2 KB sectors
- For devices that contain FlexNVM: 1 block of FlexNVM consisting of 2 KB sectors
- For devices that contain FlexNVM: 1 block of FlexRAM

The amounts of flash memory for the devices covered in this document are:

| Device | Program flash (KB) | Block 0 (P-Flash) address range ¹ | FlexNVM (KB) | Block 1 (FlexNVM/ P-Flash) address range ¹ | FlexRAM/ Programming Acceleration RAM (KB) | FlexRAM/ Programming Acceleration RAM address range |
|----------------|--------------------|--|--------------|---|--|---|
| MK11DX128VM C5 | 128 | 0x0000_0000–0x0001_FFFF | 64 | 0x1000_0000–0x1000_FFFF | 4 | 0x1400_0000–0x1400_0FFF |
| MK11DX256VM C5 | 256 | 0x0000_0000–0x0003_FFFF | 64 | 0x1000_0000–0x1000_FFFF | 4 | 0x1400_0000–0x1400_0FFF |
| MK11DN512VM C5 | 512 | 0x0000_0000–0x0003_FFFF | — | 0x0004_0000–0x0007_FFFF | 4 | 0x1400_0000–0x1400_0FFF |

1. For program flash only devices: The addresses shown assume program flash swap is disabled (default configuration).

3.5.1.3 Flash Memory Size Considerations

Since this document covers devices that contain program flash only and devices that contain program flash and FlexNVM, there are some items to consider when reading the flash memory chapter.

- The flash memory chapter shows a mixture of information depending on the device you are using.
- For the program flash only devices:
 - The programming acceleration RAM is used for the Program Section command.
- For the devices containing program flash and FlexNVM:
 - Since there is only one program flash block, the program flash swap feature is not available.

3.5.1.4 Flash Memory Map

The various flash memories and the flash registers are located at different base addresses as shown in the following figure. The base address for each is specified in [System memory map](#).

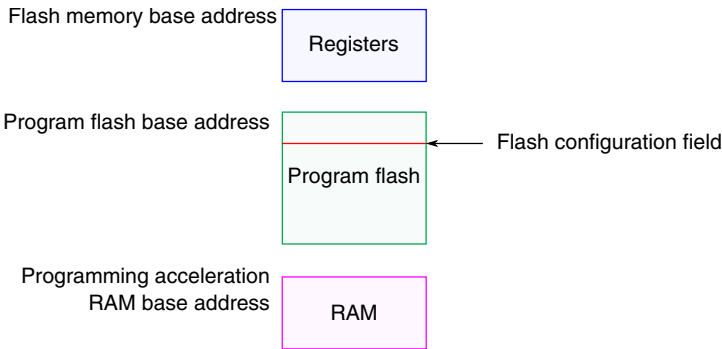


Figure 3-20. Flash memory map for devices containing only program flash

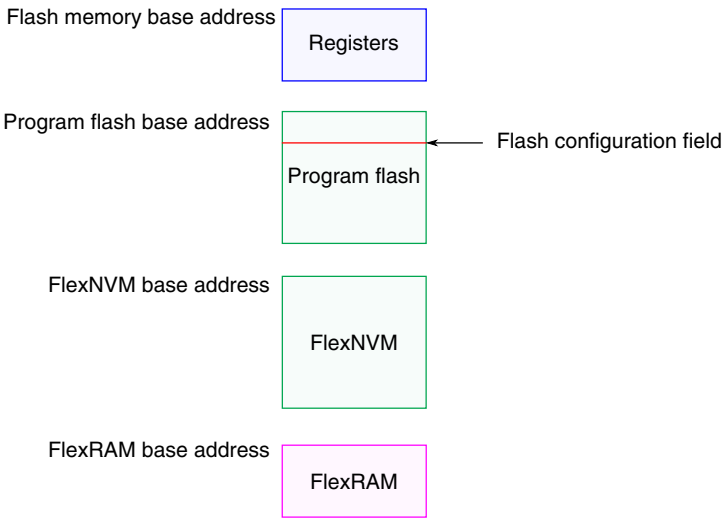


Figure 3-21. Flash memory map for devices containing FlexNVM

3.5.1.5 Flash Security

How flash security is implemented on this device is described in [Chip Security](#).

3.5.1.6 Flash Modes

The flash memory operates in NVM normal and NVM special modes. The flash memory enters NVM special mode when the EzPort is enabled ($\overline{\text{EZP_CS}}$ asserted during reset). Otherwise, flash memory operates in NVM normal mode.

3.5.1.7 Erase All Flash Contents

An Erase All Flash Blocks operation can be launched by software through a series of peripheral bus writes to flash registers. In addition the entire flash memory may be erased external to the flash memory from the SWJ-DP debug port by setting DAP_CONTROL[0]. DAP_STATUS[0] is set to indicate the mass erase command has been accepted. DAP_STATUS[0] is cleared when the mass erase completes.

The EzPort can also initiate an erase of flash contents by issuing a bulk erase (BE) command. See the EzPort chapter for more details.

3.5.1.8 FTF_FOPT Register

The flash memory's FTF_FOPT register allows the user to customize the operation of the MCU at boot time. See [FOPT boot options](#) for details of its definition.

3.5.2 Flash Memory Controller Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

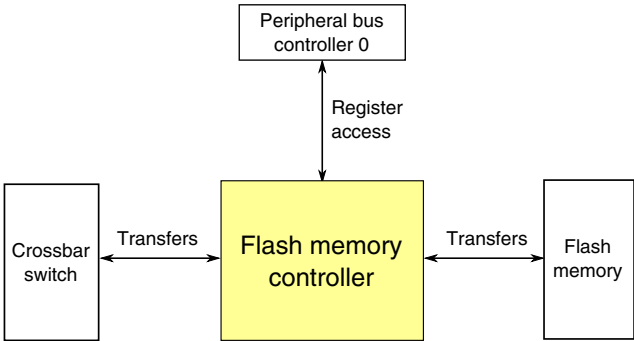


Figure 3-22. Flash memory controller configuration

Table 3-31. Reference links to related information

| Topic | Related module | Reference |
|-------------------|-------------------------|---|
| Full description | Flash memory controller | Flash memory controller |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Transfers | Flash memory | Flash memory |
| Transfers | Crossbar switch | Crossbar Switch |
| Register access | Peripheral bridge | Peripheral bridge |

3.5.2.1 Number of masters

The Flash Memory Controller supports up to eight crossbar switch masters. However, this device has a different number of crossbar switch masters. See [Crossbar-Light Switch Configuration](#) for details on the master port assignments.

3.5.2.2 Program Flash Swap

On devices that contain program flash memory only, the program flash memory blocks may swap their base addresses.

While not using swap:

- FMC_PFB0CR controls the lower code addresses (block 0)
- FMC_PFB1CR controls the upper code addresses (block 1)

If swap is used, the opposite is true:

- FMC_PFB0CR controls the upper code addresses (now in block 0)
- FMC_PFB1CR controls the lower code addresses (now in block 1)

3.5.3 SRAM Configuration

This section summarizes how the module has been configured in the chip.

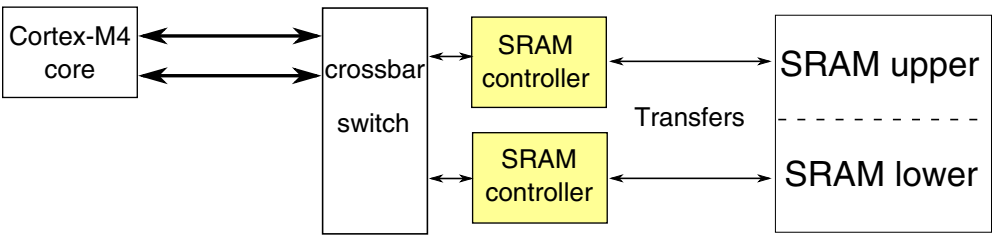


Figure 3-23. SRAM configuration

Table 3-32. Reference links to related information

| Topic | Related module | Reference |
|-------------------|--------------------|------------------------------------|
| Full description | SRAM | SRAM |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Transfers | SRAM controller | SRAM controller |
| | ARM Cortex-M4 core | ARM Cortex-M4 core |

3.5.3.1 SRAM sizes

This device contains SRAM accessed by bus masters through the cross-bar switch. The amount of SRAM for the devices covered in this document is shown in the following table.

| Device | SRAM (KB) |
|---------------|-----------|
| MK11DX128VMC5 | 32 |
| MK11DX256VMC5 | 32 |
| MK11DN512VMC5 | 64 |

3.5.3.2 SRAM Arrays

The on-chip SRAM is split into two equally-sized logical arrays, SRAM_L and SRAM_U.

The on-chip RAM is implemented such that the SRAM_L and SRAM_U ranges form a contiguous block in the memory map. As such:

- SRAM_L is anchored to 0x1FFF_FFFF and occupies the space before this ending address.
- SRAM_U is anchored to 0x2000_0000 and occupies the space after this beginning address.

Valid address ranges for SRAM_L and SRAM_U are then defined as:

- SRAM_L = [0x2000_0000–(SRAM_size/2)] to 0x1FFF_FFFF
- SRAM_U = 0x2000_0000 to [0x2000_0000+(SRAM_size/2)-1]

This is illustrated in the following figure.

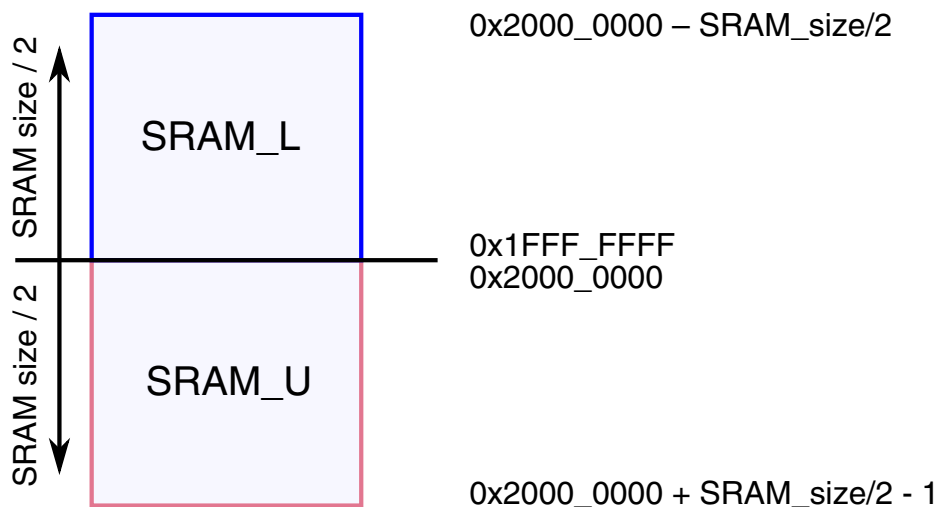


Figure 3-24. SRAM blocks memory map

For example, for a device containing 64 KB of SRAM the ranges are:

- SRAM_L: 0x1FFF_8000 – 0x1FFF_FFFF
- SRAM_U: 0x2000_0000 – 0x2000_7FFF

3.5.3.3 SRAM retention in low power modes

The SRAM is retained down to VLLS3 mode.

In VLLS2 the 4 or 16 KB (user option) region of SRAM_U from 0x2000_0000 is powered. These different regions (or partitions) of SRAM are labeled as follows:

- RAM1: the 4 KB region always powered in VLLS2
- RAM2: the additional 12 KB region optionally powered in VLLS2
- RAM3: the rest of system RAM

In VLLS1 and VLLS0 no SRAM is retained; however, the [32-byte register file](#) is available.

3.5.4 System Register File Configuration

This section summarizes how the module has been configured in the chip.

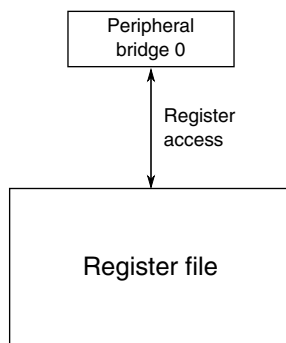


Figure 3-25. System Register file configuration

Table 3-33. Reference links to related information

| Topic | Related module | Reference |
|-------------------|----------------|------------------------------------|
| Full description | Register file | Register file |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |

3.5.4.1 System Register file

This device includes a 32-byte register file that is powered in all power modes.

Also, it retains contents during low-voltage detect (LVD) events and is only reset during a power-on reset.

3.5.5 VBAT Register File Configuration

This section summarizes how the module has been configured in the chip.

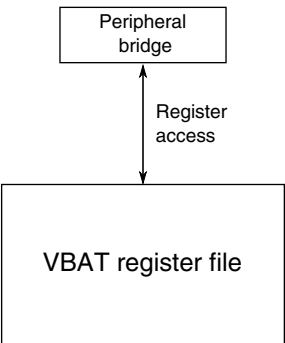


Figure 3-26. VBAT Register file configuration

Table 3-34. Reference links to related information

| Topic | Related module | Reference |
|-------------------|--------------------|------------------------------------|
| Full description | VBAT register file | VBAT register file |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |

3.5.5.1 VBAT register file

This device includes a 32-byte register file that is powered in all power modes and is powered by VBAT.

It is only reset during VBAT power-on reset.

3.5.6 EzPort Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

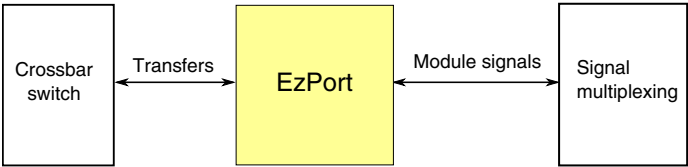


Figure 3-27. EzPort configuration

Table 3-35. Reference links to related information

| Topic | Related module | Reference |
|------------------|----------------|------------------------|
| Full description | EzPort | EzPort |

Table continues on the next page...

Table 3-35. Reference links to related information (continued)

| Topic | Related module | Reference |
|---------------------|-----------------|-------------------------------------|
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Transfers | Crossbar switch | Crossbar switch |
| Signal Multiplexing | Port control | Signal Multiplexing |

3.5.6.1 JTAG instruction

The system JTAG controller implements an EZPORT instruction. When executing this instruction, the JTAG controller resets the core logic and asserts the EzPort chip select signal to force the processor into EzPort mode.

3.5.6.2 Flash Option Register (FOPT)

The FOPT[EZPORT_DIS] bit can be used to prevent entry into EzPort mode during reset. If the FOPT[EZPORT_DIS] bit is cleared, then the state of the chip select signal ($\overline{\text{EZP_CS}}$) is ignored and the MCU always boots in normal mode.

This option is useful for systems that use the $\overline{\text{EZP_CS}}$ /NMI signal configured for its NMI function. Disabling EzPort mode prevents possible unwanted entry into EzPort mode if the external circuit that drives the NMI signal asserts it during reset.

The FOPT register is loaded from the flash option byte. If the flash option byte is modified the new value takes effect for any subsequent resets, until the value is changed again.

3.6 Security

3.6.1 CRC Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

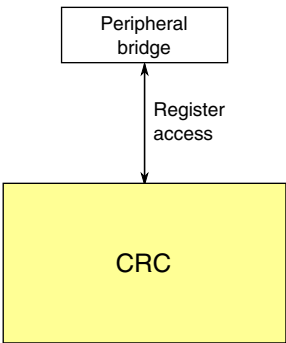


Figure 3-28. CRC configuration

Table 3-36. Reference links to related information

| Topic | Related module | Reference |
|-------------------|----------------|-----------------------------------|
| Full description | CRC | CRC |
| System memory map | | System memory map |
| Power management | | Power management |

3.6.2 MMCAU Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

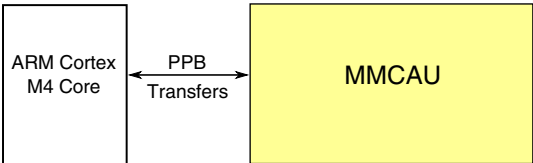


Figure 3-29. MMCAU configuration

Table 3-37. Reference links to related information

| Topic | Related module | Reference |
|---|--------------------|--|
| Full description | MMCAU | MMCAU |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Power Management | | Power Management |
| Transfers Private Peripheral Bus (PPB) | ARM Cortex M4 Core | ARM Cortex-M4 Technical Reference Manual |

3.6.3 RNG Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

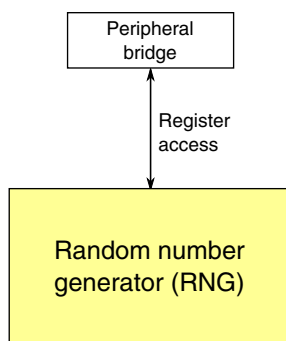


Figure 3-30. RNG configuration

Table 3-38. Reference links to related information

| Topic | Related module | Reference |
|-------------------|----------------|------------------------------------|
| Full description | RNG | RNG |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |

3.6.4 Drylce (tamper detect and secure storage) configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

NOTE

The information on this module is available only under NDA.
Please contact your local sales office for details.

3.7 Analog

3.7.1 16-bit SAR ADC Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

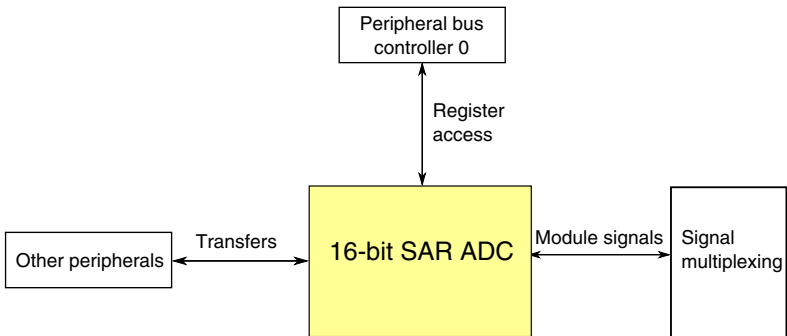


Figure 3-31. 16-bit SAR ADC configuration

Table 3-39. Reference links to related information

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Full description | 16-bit SAR ADC | 16-bit SAR ADC |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Signal multiplexing | Port control | Signal multiplexing |

3.7.1.1 ADC instantiation information

This device contains one ADC.

3.7.1.1.1 Number of ADC channels

The number of ADC channels present on the device is determined by the pinout of the specific device package. For details regarding the number of ADC channel available on a particular package, refer to the signal multiplexing chapter of this MCU.

3.7.1.2 DMA Support on ADC

Applications may require continuous sampling of the ADC (4K samples/sec) that may have considerable load on the CPU. Though using PDB to trigger ADC may reduce some CPU load, the ADC supports DMA request functionality for higher performance when the ADC is sampled at a very high rate or cases where PDB is bypassed. The ADC can trigger the DMA (via DMA req) on conversion completion.

3.7.1.3 Connections/channel assignment

3.7.1.3.1 ADC0 Connections/Channel Assignment

NOTE

As indicated by the following sections, each ADCx_DP_x input and certain ADCx_DM_x inputs may operate as single-ended ADC channels in single-ended mode.

3.7.1.3.1.1 ADC0 Channel Assignment for 121-Pin Packages

| ADC Channel (SC1n[ADCH]) | Channel | Input signal (SC1n[DIFF]= 1) | Input signal (SC1n[DIFF]= 0) |
|-----------------------------|---------|---------------------------------|---------------------------------|
| 00000 | DAD0 | ADC0_DP0 and ADC0_DM0 | ADC0_DP0 |
| 00001 | DAD1 | ADC0_DP1 and ADC0_DM1 | ADC0_DP1 |
| 00010 | DAD2 | Reserved | Reserved |
| 00011 | DAD3 | ADC0_DP3 and ADC0_DM3 | ADC0_DP3 |
| 00100 ¹ | AD4a | Reserved | ADC0_SE4a |
| 00101 ¹ | AD5a | Reserved | ADC0_SE5a |
| 00110 ¹ | AD6a | Reserved | ADC0_SE6a |
| 00111 ¹ | AD7a | Reserved | ADC0_SE7a |
| 00100 ¹ | AD4b | Reserved | ADC0_SE4b |
| 00101 ¹ | AD5b | Reserved | ADC0_SE5b |
| 00110 ¹ | AD6b | Reserved | ADC0_SE6b |
| 00111 ¹ | AD7b | Reserved | ADC0_SE7b |
| 01000 | AD8 | Reserved | ADC0_SE8 |
| 01001 | AD9 | Reserved | ADC0_SE9 |
| 01010 | AD10 | Reserved | ADC0_SE10 |
| 01011 | AD11 | Reserved | ADC0_SE11 |
| 01100 | AD12 | Reserved | ADC0_SE12 |
| 01101 | AD13 | Reserved | ADC0_SE13 |
| 01110 | AD14 | Reserved | ADC0_SE14 |
| 01111 | AD15 | Reserved | ADC0_SE15 |

Table continues on the next page...

| ADC Channel (SC1n[ADCH]) | Channel | Input signal (SC1n[DIFF]= 1) | Input signal (SC1n[DIFF]= 0) |
|-----------------------------|---------|---------------------------------|----------------------------------|
| 10000 | AD16 | Reserved | Reserved |
| 10001 | AD17 | Reserved | Reserved |
| 10010 | AD18 | Reserved | Reserved |
| 10011 | AD19 | Reserved | ADC0_DM0 |
| 10100 | AD20 | Reserved | ADC0_DM1 |
| 10101 | AD21 | Reserved | ADC0_SE21 |
| 10110 | AD22 | Reserved | ADC0_SE22 |
| 10111 | AD23 | Reserved | 12-bit DAC0 Output/ ADC0_SE23 |
| 11000 | AD24 | Reserved | Reserved |
| 11001 | AD25 | Reserved | Reserved |
| 11010 | AD26 | Temperature Sensor (Diff) | Temperature Sensor (S.E) |
| 11011 | AD27 | Bandgap (Diff) ² | Bandgap (S.E) ² |
| 11100 | AD28 | Reserved | Reserved |
| 11101 | AD29 | VREFH (Diff) | VREFH (S.E) |
| 11110 | AD30 | Reserved | VREFL |
| 11111 | AD31 | Module Disabled | Module Disabled |

1. ADCx_CFG2[MUXSEL] bit selects between ADCx_SEn channels a and b. Refer to MUXSEL description in ADC chapter for details.
2. This is the PMC bandgap 1V reference voltage not the VREF module 1.2 V reference voltage. Prior to reading from this ADC channel, ensure that you enable the bandgap buffer by setting the PMC_REGSC[BGBE] bit. Refer to the device data sheet for the bandgap voltage (V_{BG}) specification.

3.7.1.4 ADC Channels MUX Selection

The following figure shows the assignment of ADCx_SEn channels a and b through a MUX selection to ADC. To select between alternate set of channels, refer to ADCx_CFG2[MUXSEL] bit settings for more details.

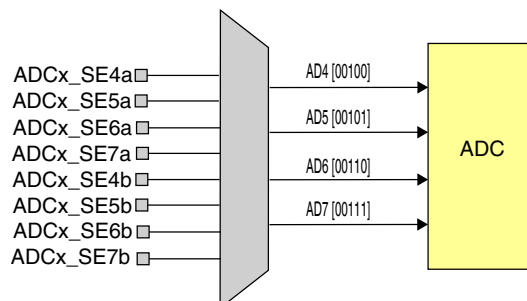


Figure 3-32. ADCx_SEn channels a and b selection

3.7.1.5 ADC Reference Options

The ADC supports the following references:

- VREFH/VREFL - connected as the primary reference option
- 1.2 V VREF_OUT - connected as the V_{ALT} reference option

ADCx_SC2[REFSEL] bit selects the voltage reference sources for ADC. Refer to REFSEL description in ADC chapter for more details.

3.7.1.6 ADC triggers

The ADC supports both software and hardware triggers. The primary hardware mechanism for triggering the ADC is the PDB. The PDB itself can be triggered by other peripherals. For example: RTC (Alarm, Seconds) signal is connected to the PDB. The PDB input trigger can receive the RTC (alarm/seconds) trigger forcing ADC conversions in run mode (where PDB is enabled). On the other hand, the ADC can conduct conversions in low power modes, not triggered by PDB. This allows the ADC to do conversions in low power mode and store the output in the result register. The ADC generates interrupt when the data is ready in the result register that wakes the system from low power mode. The PDB can also be bypassed by using the ADCxTRGSEL bits in the SIM_SOPT7 register.

For operation of triggers in different modes, refer to Power Management chapter.

3.7.1.7 Alternate clock

For this device, the alternate clock is connected to OSCERCLK.

NOTE

This clock option is only usable when OSCERCLK is in the MHz range. A system with OSCERCLK in the kHz range has the optional clock source below minimum ADC clock operating frequency.

3.7.1.8 ADC low-power modes

This table shows the ADC low-power modes and the corresponding chip low-power modes.

Table 3-40. ADC low-power modes

| Module mode | Chip mode |
|----------------|---------------------------------|
| Wait | Wait, VLPW |
| Normal Stop | Stop, VLPS |
| Low Power Stop | LLS, VLLS3, VLLS2, VLLS1, VLLS0 |

3.7.2 CMP Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

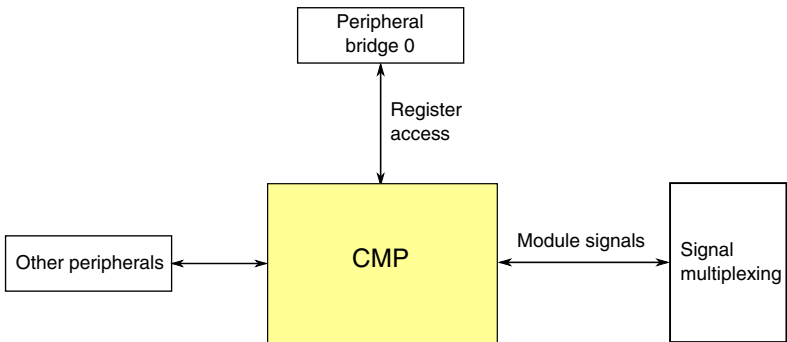


Figure 3-33. CMP configuration

Table 3-41. Reference links to related information

| Topic | Related module | Reference |
|---------------------|------------------|-------------------------------------|
| Full description | Comparator (CMP) | Comparator |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Signal multiplexing | Port control | Signal multiplexing |

3.7.2.1 CMP input connections

The following table shows the fixed internal connections to the CMP.

Table 3-42. CMP input connections

| CMP Inputs | CMP0 | CMP1 |
|------------|----------|----------|
| IN0 | CMP0_IN0 | CMP1_IN0 |
| IN1 | CMP0_IN1 | CMP1_IN1 |

Table continues on the next page...

Table 3-42. CMP input connections (continued)

| CMP Inputs | CMP0 | CMP1 |
|------------|----------------------|--------------------------|
| IN2 | CMP0_IN2 | — |
| IN3 | CMP0_IN3 | 12-bit DAC0_OUT/CMP1_IN3 |
| IN4 | — | — |
| IN5 | VREF Output/CMP0_IN5 | VREF Output/CMP1_IN5 |
| IN6 | Bandgap | Bandgap |
| IN7 | 6b DAC0 Reference | 6b DAC1 Reference |

3.7.2.2 CMP external references

The 6-bit DAC sub-block supports selection of two references. For this device, the references are connected as follows:

- VREF_OUT - V_{in1} input
- VDD - V_{in2} input

3.7.2.3 External window/sample input

Individual PDB pulse-out signals control each CMP Sample/Window timing.

3.7.3 12-bit DAC Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

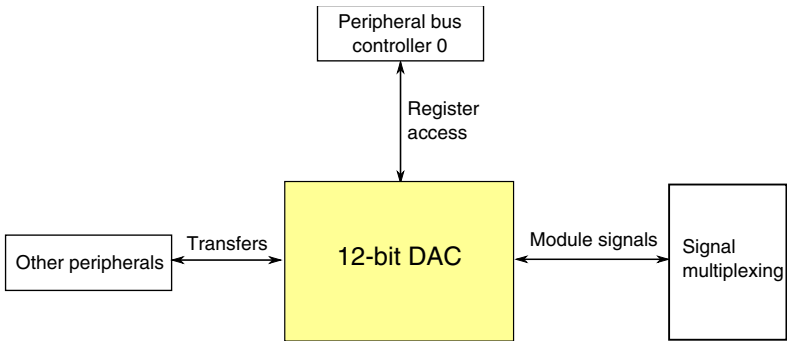


Figure 3-34. 12-bit DAC configuration

Table 3-43. Reference links to related information

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Full description | 12-bit DAC | 12-bit DAC |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Signal multiplexing | Port control | Signal multiplexing |

3.7.3.1 12-bit DAC Overview

This device contains one 12-bit digital-to-analog converter (DAC) with programmable reference generator output. The DAC includes a FIFO for DMA support.

3.7.3.2 12-bit DAC Output

The output of the DAC can be placed on an external pin or set as one of the inputs to the analog comparator or ADC.

3.7.3.3 12-bit DAC Reference

For this device VREF_OUT and VDDA are selectable as the DAC reference. VREF_OUT is connected to the DACREF_1 input and VDDA is connected to the DACREF_2 input. Use DACx_C0[DACRFS] control bit to select between these two options.

Be aware that if the DAC and ADC use the VREF_OUT reference simultaneously, some degradation of ADC accuracy is to be expected due to DAC switching.

3.7.4 VREF Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

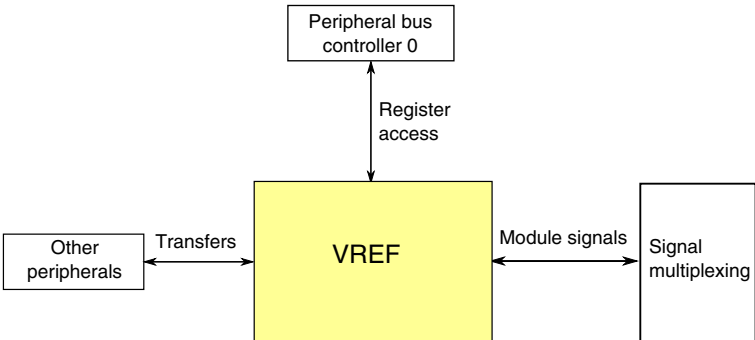


Figure 3-35. VREF configuration

Table 3-44. Reference links to related information

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Full description | VREF | VREF |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Signal multiplexing | Port control | Signal multiplexing |

3.7.4.1 VREF Overview

This device includes a voltage reference (VREF) to supply an accurate 1.2 V voltage output.

The voltage reference can provide a reference voltage to external peripherals or a reference to analog peripherals, such as the ADC, DAC, or CMP.

NOTE

PMC_REGSC[BGEN] bit must be set if the VREF regulator is required to remain operating in VLPx modes.

NOTE

For either an internal or external reference if the VREF_OUT functionality is being used, VREF_OUT signal must be

connected to an output load capacitor. Refer the device data sheet for more details.

3.8 Timers

3.8.1 PDB Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

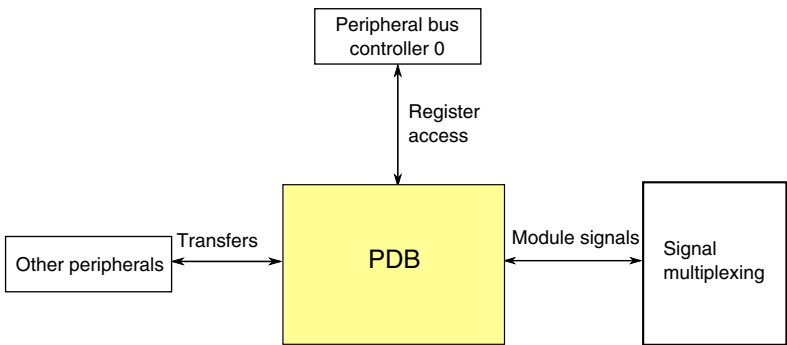


Figure 3-36. PDB configuration

Table 3-45. Reference links to related information

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Full description | PDB | PDB |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Signal multiplexing | Port control | Signal multiplexing |

3.8.1.1 PDB Instantiation

3.8.1.1.1 PDB Output Triggers

Table 3-46. PDB output triggers

| | |
|---|----------------|
| Number of PDB channels for ADC trigger | 1 |
| Number of PDB channels to inter-connect with FTM0 | 1 ¹ |

Table continues on the next page...

Table 3-46. PDB output triggers (continued)

| | |
|--|---|
| Number of pre-triggers per PDB channel | 2 |
| Number of DAC triggers | 1 |
| Number of PulseOut | 2 |

1. The PDB output trigger to FTM0 will occur only once. To have a reoccurring FTM0 trigger, disable and enable PDB_CH1C1[EN] or PDB_SC[PDBEN], after a trigger is sent to FTM0.

3.8.1.1.2 PDB Input Trigger Connections

Table 3-47. PDB Input Trigger Options

| PDB Trigger | PDB Input |
|-------------|--|
| 0000 | External Trigger |
| 0001 | CMP 0 |
| 0010 | CMP 1 |
| 0011 | Reserved |
| 0100 | PIT Ch 0 Output |
| 0101 | PIT Ch 1 Output |
| 0110 | PIT Ch 2 Output |
| 0111 | PIT Ch 3 Output |
| 1000 | FTM0 initialization trigger and channel triggers, as programmed in the FTM external trigger register (EXTTRIG) |
| 1001 | FTM1 initialization trigger and channel triggers, as programmed in the FTM external trigger register (EXTTRIG) |
| 1010 | FTM2 initialization trigger and channel triggers, as programmed in the FTM external trigger register (EXTTRIG) |
| 1011 | Reserved |
| 1100 | RTC Alarm |
| 1101 | RTC Seconds |
| 1110 | LPTMR Output |
| 1111 | Software Trigger |

3.8.1.2 PDB Module Interconnections

| PDB trigger outputs | Connection |
|---------------------|--|
| Channel 0 triggers | ADC0 trigger |
| Channel 1 triggers | synchronous input 1 of FTM0 |
| DAC triggers | DAC0 trigger |
| Pulse-out | Pulse-out connected to each CMP module's sample/window input to control sample operation |

3.8.1.3 Back-to-back acknowledgement connections

The application code can set the PDBx_CHnC1[BB] bits to configure the PDB pre-triggers as a single chain or several chains.

3.8.1.4 PDB Interval Trigger Connections to DAC

In this MCU, PDB interval trigger connections to DAC are implemented as follows.

- PDB interval trigger 0 connects to DAC0 hardware trigger input.

3.8.1.5 DAC External Trigger Input Connections

In this MCU, the following DAC external trigger inputs are implemented.

3.8.1.6 Pulse-Out Connection

3.8.1.7 Pulse-Out Enable Register Implementation

The following table shows the comparison of pulse-out enable register at the module and chip level.

Table 3-48. PDB pulse-out enable register

| Register | Module implementation | Chip implementation |
|----------|-------------------------------|---|
| POnEN | 7:0 - POEN 31:8 - Reserved | 0 - POEN[0] for CMP0 1 - POEN[1] for CMP1 31:2 - Reserved |

3.8.2 FlexTimer Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

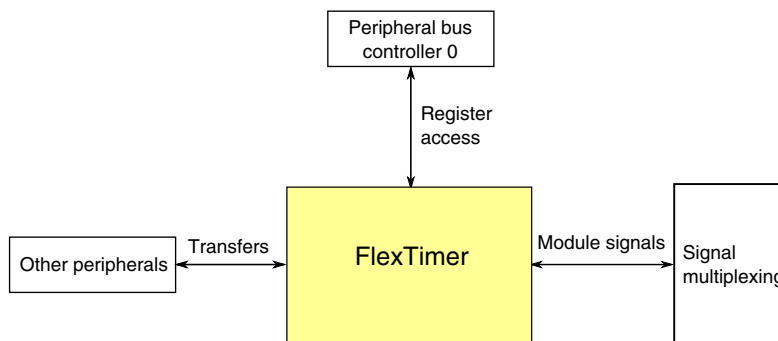


Figure 3-37. FlexTimer configuration

Table 3-49. Reference links to related information

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Full description | FlexTimer | FlexTimer |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Signal multiplexing | Port control | Signal multiplexing |

3.8.2.1 Instantiation Information

This device contains three FlexTimer modules.

The following table shows how these modules are configured.

Table 3-50. FTM Instantiations

| FTM instance | Number of channels | Features/usage |
|--------------|--------------------|--|
| FTM0 | 8 | 3-phase motor + 2 general purpose or stepper motor |
| FTM1 | 2 ¹ | Quadrature decoder or general purpose |
| FTM2 | 2 ¹ | General purpose |

1. Only channels 0 and 1 are available.

3.8.2.2 External Clock Options

By default each FTM is clocked by the internal bus clock (the FTM refers to it as system clock). Each module contains a register setting that allows the module to be clocked from an external clock instead. There are two external FTM_CLKINx pins that can be selected by any FTM module via the SIM_SOPT4 register.

3.8.2.3 Fixed frequency clock

The fixed frequency clock for each FTM is MCGFFCLK.

3.8.2.4 FTM Interrupts

The FlexTimer has multiple sources of interrupt. However, these sources are OR'd together to generate a single interrupt request to the interrupt controller. When an FTM interrupt occurs, read the FTM status registers (FMS, SC, and STATUS) to determine the exact interrupt source.

3.8.2.5 FTM Fault Detection Inputs

The following fault detection input options for the FTM modules are selected via the SIM_SOPT4 register. The external pin option is selected by default.

- FTM0 FAULT0 = FTM0_FLT0 pin or CMP0 output
- FTM0 FAULT1 = FTM0_FLT1 pin or CMP1 output
- FTM0 FAULT2 = FTM0_FLT2 pin
- FTM0 FAULT3 = FTM0_FLT3 pin
- FTM1 FAULT0 = FTM1_FLT0 pin or CMP0 output
- FTM1 FAULT1 = CMP1 output
- FTM2 FAULT0 = FTM2_FLT0 pin or CMP0 output
- FTM2 FAULT1 = CMP1 output

3.8.2.6 FTM Hardware Triggers

The FTM synchronization hardware triggers are connected in the chip as follows:

- FTM0 hardware trigger 0 = CMP0 Output or FTM1 Match (when enabled in the FTM1 External Trigger (EXTTRIG) register)
- FTM0 hardware trigger 1 = PDB channel 1 Trigger Output or FTM2 Match (when enabled in the FTM2 External Trigger (EXTTRIG) register)
- FTM0 hardware trigger 2 = FTM0_FLT0 pin
- FTM1 hardware trigger 0 = CMP0 Output
- FTM1 hardware trigger 1 = CMP1 Output
- FTM1 hardware trigger 2 = FTM1_FLT0 pin

- FTM2 hardware trigger 0 = CMP0 Output
- FTM2 hardware trigger 2 = FTM2_FLT0 pin

For the triggers with more than one option, SIM_SOPT4 controls the selection.

3.8.2.7 Input capture options for FTM module instances

The following channel 0 input capture source options are selected via SIM_SOPT4. The external pin option is selected by default.

- FTM1 channel 0 input capture = FTM1_CH0 pin or CMP0 output or CMP1 output
- FTM2 channel 0 input capture = FTM2_CH0 pin or CMP0 output or CMP1 output

3.8.2.8 FTM output triggers for other modules

FTM output triggers can be selected as input triggers for the PDB and ADC modules. See [PDB Instantiation](#) and [ADC triggers](#).

3.8.2.9 FTM Global Time Base

This chip provides the optional FTM global time base feature (see [Global time base \(GTB\)](#)).

FTM0 provides the only source for the FTM global time base. The other FTM modules can share the time base as shown in the following figure:

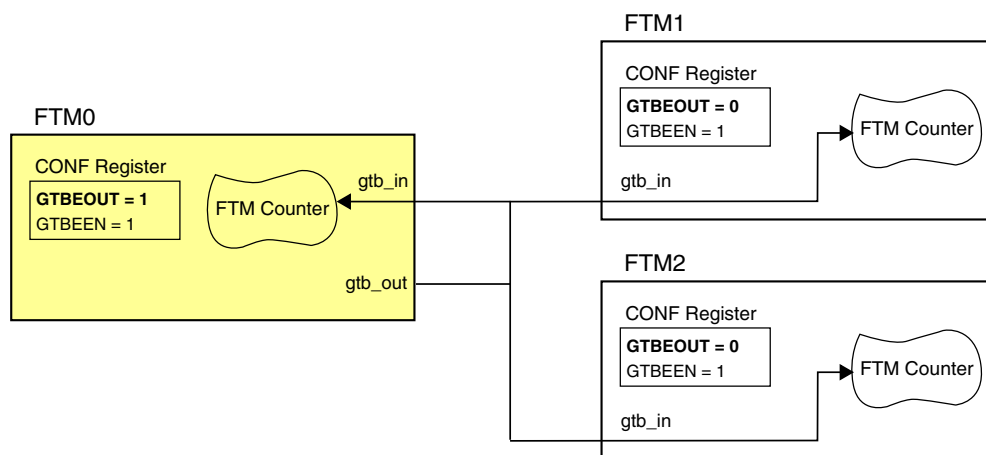


Figure 3-38. FTM Global Time Base Configuration

3.8.2.10 FTM BDM and debug halt mode

In the FTM chapter, references to the chip being in "BDM" are the same as the chip being in "debug halt mode".

3.8.3 PIT Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

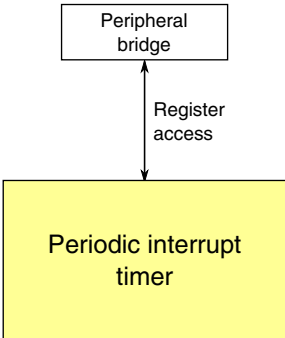


Figure 3-39. PIT configuration

Table 3-51. Reference links to related information

| Topic | Related module | Reference |
|-------------------|----------------|------------------------------------|
| Full description | PIT | PIT |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Power management | | Power management |

3.8.3.1 PIT/DMA Periodic Trigger Assignments

The PIT generates periodic trigger events to the DMA Mux as shown in the table below.

Table 3-52. PIT channel assignments for periodic DMA triggering

| DMA Channel Number | PIT Channel |
|--------------------|---------------|
| DMA Channel 0 | PIT Channel 0 |
| DMA Channel 1 | PIT Channel 1 |
| DMA Channel 2 | PIT Channel 2 |
| DMA Channel 3 | PIT Channel 3 |

3.8.3.2 PIT/ADC Triggers

PIT triggers are selected as ADCx trigger sources using the SIM_SOPT7[ADCxTRGSEL] fields. For more details, refer to SIM chapter.

3.8.4 Low-power timer configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

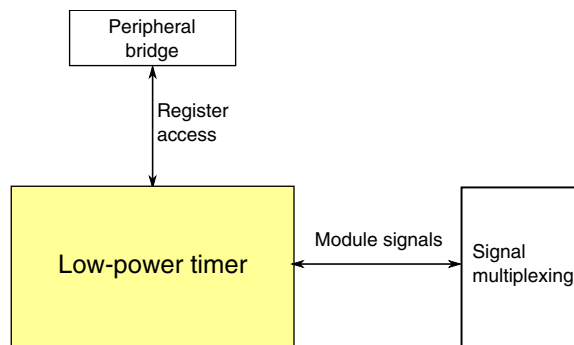


Figure 3-40. LPTMR configuration

Table 3-53. Reference links to related information

| Topic | Related module | Reference |
|---------------------|-----------------|-------------------------------------|
| Full description | Low-power timer | Low-power timer |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Power management | | Power management |
| Signal Multiplexing | Port control | Signal Multiplexing |

3.8.4.1 LPTMR prescaler/glitch filter clocking options

The prescaler and glitch filter of the LPTMR module can be clocked from one of four sources determined by the LPTMR0_PSR[PCS] bitfield. The following table shows the chip-specific clock assignments for this bitfield.

NOTE

The chosen clock must remain enabled if the LPTMR is to continue operating in all required low-power modes.

| LPTMR0_PSR[PCS] | Prescaler/glitch filter clock number | Chip clock |
|-----------------|--------------------------------------|--|
| 00 | 0 | MCGIRCLK — internal reference clock (not available in VLPS/LLS/VLLS modes) |
| 01 | 1 | LPO — 1 kHz clock (not available in VLLS0 mode) |
| 10 | 2 | ERCLK32K — secondary external reference clock |
| 11 | 3 | OSCERCLK — external reference clock (not available in VLLS0 mode) |

See [Clock Distribution](#) for more details on these clocks.

3.8.4.2 LPTMR pulse counter input options

The LPTMR_CSR[TPS] bitfield configures the input source used in pulse counter mode. The following table shows the chip-specific input assignments for this bitfield.

| LPTMR_CSR[TPS] | Pulse counter input number | Chip input |
|----------------|----------------------------|----------------|
| 00 | 0 | CMP0 output |
| 01 | 1 | LPTMR_ALT1 pin |
| 10 | 2 | LPTMR_ALT2 pin |
| 11 | 3 | LPTMR_ALT3 pin |

3.8.5 CMT Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

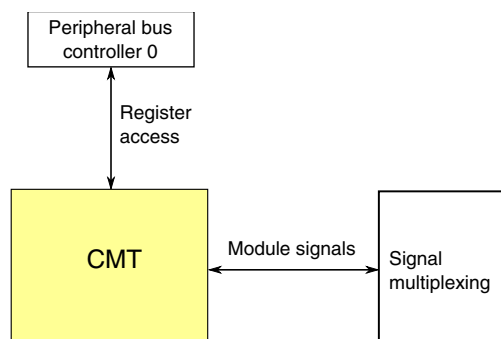


Figure 3-41. CMT configuration

Table 3-54. Reference links to related information

| Topic | Related module | Reference |
|---------------------|-------------------------------------|-------------------------------------|
| Full description | Carrier modulator transmitter (CMT) | CMT |
| System memory map | | System memory map |
| Clocking | | Clock distribution |
| Power management | | Power management |
| Signal multiplexing | Port control | Signal multiplexing |

3.8.5.1 Instantiation Information

This device contains one CMT module.

3.8.5.2 IRO Drive Strength

The IRO pad requires higher current drive than can be obtained from a single pad. For this device, the pin associated with the CMT_IRO signal is doubled bonded to two pads.

SIM_SOPT2[PTD7PAD] can be used to configure the pin associated with the CMT_IRO signal as a higher current output port pin.

3.8.6 RTC configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

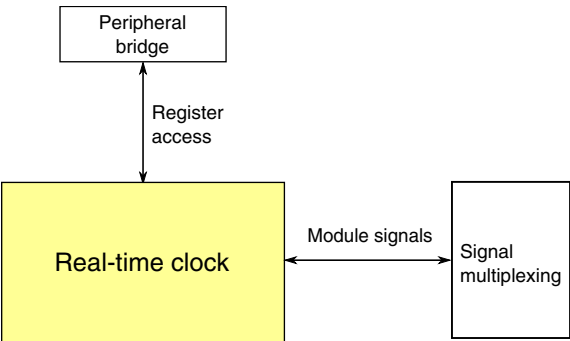


Figure 3-42. RTC configuration

Table 3-55. Reference links to related information

| Topic | Related module | Reference |
|-------------------|----------------|------------------------------------|
| Full description | RTC | RTC |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Power management | | Power management |

3.8.6.1 RTC_CLKOUT signal

When the RTC is enabled and the port control module selects the RTC_CLKOUT function, the RTC_CLKOUT signal outputs a 1 Hz or 32 kHz output derived from RTC oscillator as shown below.

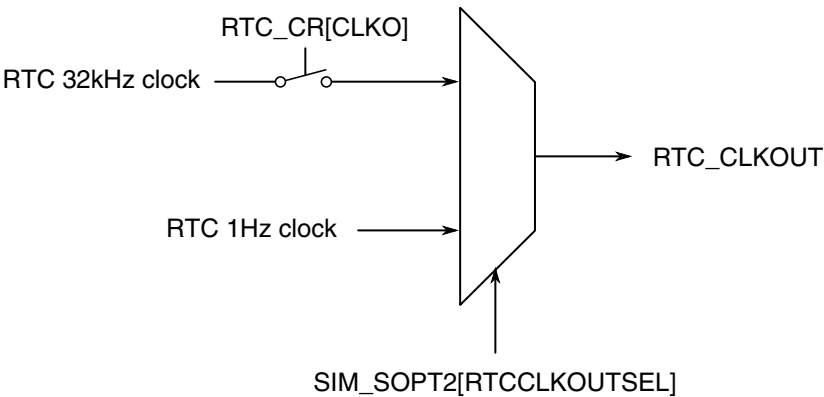


Figure 3-43. RTC_CLKOUT generation

3.9 Communication interfaces

3.9.1 SPI configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

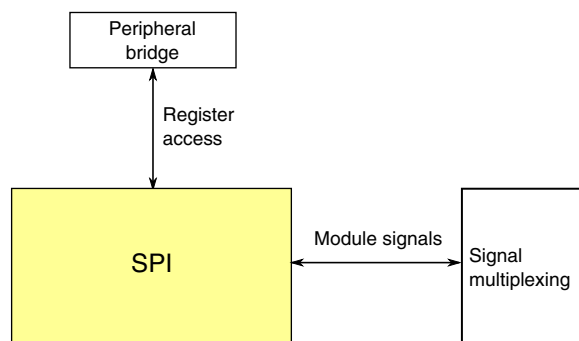


Figure 3-44. SPI configuration

Table 3-56. Reference links to related information

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Full description | SPI | SPI |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Signal Multiplexing | Port control | Signal Multiplexing |

3.9.1.1 SPI Modules Configuration

This device contains two SPI modules .

3.9.1.2 SPI clocking

The SPI module is clocked by the internal bus clock (the DSPI refers to it as system clock). The module has an internal divider, with a minimum divide is two. So, the SPI can run at a maximum frequency of bus clock/2.

3.9.1.3 Number of CTARs

SPI CTAR registers define different transfer attribute configurations. The SPI module supports up to eight CTAR registers. This device supports two CTARs on all instances of the SPI.

In master mode, the CTAR registers define combinations of transfer attributes, such as frame size, clock phase, clock polarity, data bit ordering, baud rate, and various delays. In slave mode only CTAR0 is used, and a subset of its bitfields sets the slave transfer attributes.

3.9.1.4 TX FIFO size

Table 3-57. SPI transmit FIFO size

| SPI Module | Transmit FIFO size |
|------------|--------------------|
| SPI0 | 4 |
| SPI1 | 4 |

3.9.1.5 RX FIFO Size

SPI supports up to 16-bit frame size during reception.

Table 3-58. SPI receive FIFO size

| SPI Module | Receive FIFO size |
|------------|-------------------|
| SPI0 | 4 |
| SPI1 | 4 |

3.9.1.6 Number of PCS signals

The following table shows the number of peripheral chip select signals available per SPI module.

Table 3-59. SPI PCS signals

| SPI Module | PCS Signals |
|------------|--------------|
| SPI0 | SPI_PCS[4:0] |
| SPI1 | SPI_PCS[2:0] |

3.9.1.7 SPI Operation in Low Power Modes

In VLPR and VLPW modes the SPI is functional; however, the reduced system frequency also reduces the max frequency of operation for the SPI. In VLPR and VLPW modes the max SPI_CLK frequency is 2MHz.

In stop and VLPS modes, the clocks to the SPI module are disabled. The module is not functional, but it is powered so that it retains state.

There is one way to wake from stop mode via the SPI, which is explained in the following section.

3.9.1.7.1 Using GPIO Interrupt to Wake from stop mode

Here are the steps to use a GPIO to create a wakeup upon reception of SPI data in slave mode:

1. Point the GPIO interrupt vector to the desired interrupt handler.
2. Enable the GPIO input to generate an interrupt on either the rising or falling edge (depending on the polarity of the chip select signal).
3. Enter Stop or VLPS mode and Wait for the GPIO interrupt.

NOTE

It is likely that in using this approach the first word of data from the SPI host might not be received correctly. This is dependent on the transfer rate used for the SPI, the delay between chip select assertion and presentation of data, and the system interrupt latency.

3.9.1.8 SPI Doze Mode

The Doze mode for the SPI module is the same as the Wait and VLPW modes for the chip.

3.9.1.9 SPI Interrupts

The SPI has multiple sources of interrupt requests. However, these sources are OR'd together to generate a single interrupt request per SPI module to the interrupt controller. When an SPI interrupt occurs, read the SPI_SR to determine the exact interrupt source.

3.9.1.10 Writing SPI Transmit FIFO

In Master mode, only 32-bit write accesses are supported for the PUSH register, the top TX FIFO entry. In Slave mode, 8-bit, 16-bit and 32-bit write accesses are supported for the PUSH register, although each write increments the write pointer.

3.9.2 I2C Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

NOTE

The Open Drain mode on SDA, SCL pins has to be enabled by setting PORTx_PCRn[ODE] bits.

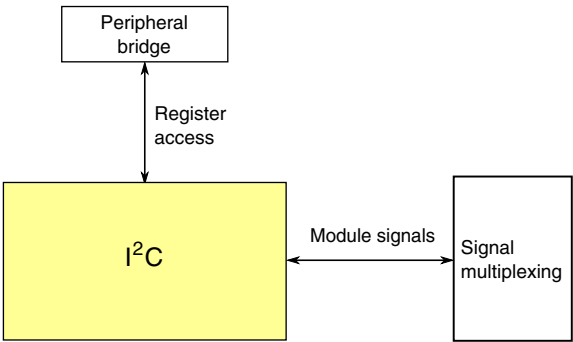


Figure 3-45. I2C configuration

Table 3-60. Reference links to related information

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Full description | I2C | I2C |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Power management | | Power management |
| Signal Multiplexing | Port control | Signal Multiplexing |

3.9.2.1 Number of I2C modules

This device has two I2C modules.

3.9.3 UART Configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

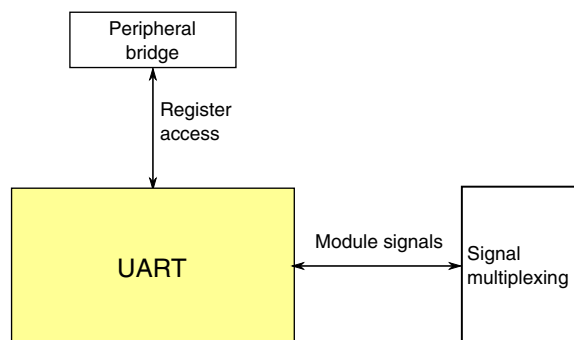


Figure 3-46. UART configuration

Table 3-61. Reference links to related information

| Topic | Related module | Reference |
|---------------------|----------------|-------------------------------------|
| Full description | UART | UART |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Power management | | Power management |
| Signal Multiplexing | Port control | Signal Multiplexing |

3.9.3.1 UART configuration information

This chip contains four UART modules. This section describes how each module is configured on this device.

- Standard features of all UARTs:
 - RS-485 support
 - Hardware flow control (RTS/CTS)
 - 9-bit UART to support address mark with parity
 - MSB/LSB configuration on data
- UART0 and UART1 are clocked from the core clock, the remaining UARTs are clocked on the bus clock. The maximum baud rate is 1/16 of related source clock frequency.
- IrDA is available on all UARTs
- UART0 contains the standard features plus ISO7816
- UART0 contain 8-entry transmit and 8-entry receive FIFOs
- All other UARTs contain a 1-entry transmit and receive FIFOs

3.9.3.2 UART wakeup

The UART can be configured to generate an interrupt/wakeup on the first active edge that it receives.

3.9.3.3 UART interrupts

The UART has multiple sources of interrupt requests. However, some of these sources are OR'd together to generate a single interrupt request. See below for the mapping of the individual interrupt sources to the interrupt request:

The status interrupt combines the following interrupt sources:

| Source | UART 0 | UART 1 | UART 2 | UART 3 |
|--------------------------|--------|--------|--------|--------|
| Transmit data empty | x | x | x | x |
| Transmit complete | x | x | x | x |
| Idle line | x | x | x | x |
| Receive data full | x | x | x | x |
| LIN break detect | x | x | x | x |
| RxD pin active edge | x | x | x | x |
| Initial character detect | x | — | — | — |

The error interrupt combines the following interrupt sources:

| Source | UART 0 | UART 1 | UART 2 | UART 3 |
|------------------------------|--------|--------|--------|--------|
| Receiver overrun | x | x | x | x |
| Noise flag | x | x | x | x |
| Framing error | x | x | x | x |
| Parity error | x | x | x | x |
| Transmitter buffer overflow | x | x | x | x |
| Receiver buffer overflow | x | x | x | x |
| Receiver buffer underflow | x | x | x | x |
| Transmit threshold (ISO7816) | x | — | — | — |
| Receiver threshold (ISO7816) | x | — | — | — |
| Wait timer (ISO7816) | x | — | — | — |

Table continues on the next page...

Communication interfaces

| Source | UART 0 | UART 1 | UART 2 | UART 3 |
|--------------------------------|--------|--------|--------|--------|
| Character wait timer (ISO7816) | x | — | — | — |
| Block wait timer (ISO7816) | x | — | — | — |
| Guard time violation (ISO7816) | x | — | — | — |

3.9.4 I²S configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module’s dedicated chapter.

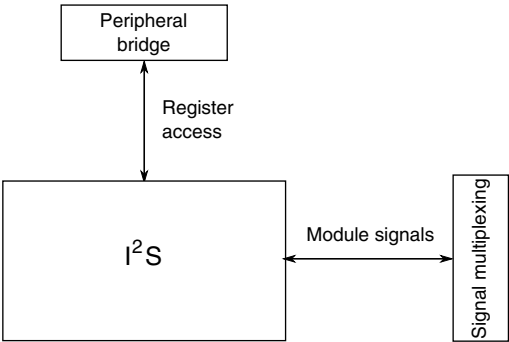


Figure 3-47. I²S configuration

Table 3-62. Reference links to related information

| Topic | Related module | Reference |
|---------------------|------------------|-------------------------------------|
| Full description | I ² S | I²S |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Power management | | Power management |
| Signal multiplexing | Port control | Signal Multiplexing |

3.9.4.1 Instantiation information

This device contains one I²S module.

As configured on the device, module features include:

- TX data lines: 1
- RX data lines: 1
- FIFO size (words): 8

- Maximum words per frame: 16
- Maximum bit clock divider: 512

3.9.4.2 I²S/SAI clocking

3.9.4.2.1 Audio Master Clock

The audio master clock (MCLK) is used to generate the bit clock when the receiver or transmitter is configured for an internally generated bit clock. The audio master clock can also be output to or input from a pin. The transmitter and receiver have the same audio master clock inputs.

3.9.4.2.2 Bit Clock

The I²S/SAI transmitter and receiver support asynchronous bit clocks (BCLKs) that can be generated internally from the audio master clock or supplied externally. The module also supports the option for synchronous operation between the receiver and transmitter product.

3.9.4.2.3 Bus Clock

The bus clock is used by the control registers and to generate synchronous interrupts and DMA requests.

3.9.4.2.4 I²S/SAI clock generation

Each SAI peripheral can control the input clock selection, pin direction and divide ratio of one audio master clock.

The MCLK Input Clock Select bit of the MCLK Control Register (MCR[MICS]) selects the clock input to the I²S/SAI module's MCLK divider.

The module's MCLK Divide Register (MDR) configures the MCLK divide ratio.

The module's MCLK Output Enable bit of the MCLK Control Register (MCR[MOE]) controls the direction of the MCLK pin. The pin is the input from the pin when MOE is 0, and the pin is the output from the clock divider when MOE is 1.

The transmitter and receiver can independently select between the bus clock and the audio master clock to generate the bit clock. Each module's Clocking Mode field of the Transmit Configuration 2 Register and Receive Configuration 2 Register (TCR2[MSEL] and RCR2[MSEL]) selects the master clock.

3.9.4.2.5 Clock gating and I²S/SAI initialization

The clock to the I²S/SAI module can be gated using a bit in the SIM. To minimize power consumption, these bits are cleared after any reset, which disables the clock to the corresponding module. The clock enable bit should be set by software at the beginning of the module initialization routine to enable the module clock before initialization of any of the I²S/SAI registers.

3.9.4.3 I²S/SAI operation in low power modes

3.9.4.3.1 Stop and very low power modes

In Stop mode, the SAI transmitter and/or receiver can continue operating provided the appropriate Stop Enable bit is set (TCSR[STOPE] and/or RCSR[STOPE], respectively), and provided the transmitter and/or receiver is/are using an externally generated bit clock or an Audio Master Clock that remains operating in Stop mode. The SAI transmitter and/or receiver can generate an asynchronous interrupt to wake the CPU from Stop mode.

In VLPS mode, the module behaves as it does in stop mode if VLPS mode is entered from run mode. However, if VLPS mode is entered from VLPR mode, the FIFO might underflow or overflow before wakeup from stop mode due to the limits in bus bandwidth. In VLPW and VLPR modes, the module is limited by the maximum bus clock frequencies.

When operating from an internally generated bit clock or Audio Master Clock that is disabled in stop modes:

In Stop mode, if the Transmitter Stop Enable (TCSR[STOPE]) bit is clear, the transmitter is disabled after completing the current transmit frame, and, if the Receiver Stop Enable (RCSR[STOPE]) bit is clear, the receiver is disabled after completing the current receive frame. Entry into Stop mode is prevented—not acknowledged—while waiting for the transmitter and receiver to be disabled at the end of the current frame.

3.9.4.3.2 Low-leakage modes

When entering low-leakage modes, the Stop Enable (TCSR[STOPE] and RCSR[STOPE]) bits are ignored and the SAI is disabled after completing the current transmit and receive Frames. Entry into stop mode is prevented (not acknowledged) while waiting for the transmitter and receiver to be disabled at the end of the current frame.

3.10 Human-machine interfaces

3.10.1 GPIO configuration

This section summarizes how the module has been configured in the chip. For a comprehensive description of the module itself, see the module's dedicated chapter.

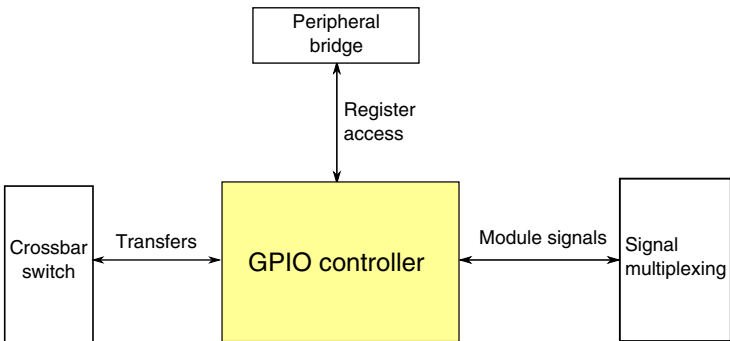


Figure 3-48. GPIO configuration

Table 3-63. Reference links to related information

| Topic | Related module | Reference |
|---------------------|-----------------|-------------------------------------|
| Full description | GPIO | GPIO |
| System memory map | | System memory map |
| Clocking | | Clock Distribution |
| Power management | | Power management |
| Transfers | Crossbar switch | Clock Distribution |
| Signal Multiplexing | Port control | Signal Multiplexing |

3.10.1.1 GPIO access protection

The GPIO module does not have access protection because it is not connected to a peripheral bridge slot.

3.10.1.2 Number of GPIO signals

The number of GPIO signals available on the devices covered by this document are detailed in [Orderable part numbers](#).



Chapter 4 Memory Map

4.1 Introduction

This device contains various memories and memory-mapped peripherals which are located in one 32-bit contiguous memory space. This chapter describes the memory and peripheral locations within that memory space.

4.2 System memory map

The following table shows the high-level device memory map. This map provides the complete architectural address space definition for the various sections. Based on the physical sizes of the memories and peripherals, the actual address regions used may be smaller.

Table 4-1. System memory map

| System 32-bit Address Range | Destination Slave | Access |
|-----------------------------|---|---------------------|
| 0x0000_0000–0x07FF_FFFF | Program flash and read-only data (Includes exception vectors in first 1024 bytes) | All masters |
| 0x0800_0000–0x0FFF_FFFF | Reserved | — |
| 0x1000_0000–0x13FF_FFFF | <ul style="list-style-type: none"> For MK11DX128VMC5: FlexNVM For MK11DX256VMC5: FlexNVM For MK11DN512VMC5: Reserved | All masters |
| 0x1400_0000–0x17FF_FFFF | For devices with FlexNVM: FlexRAM For devices with program flash only: Programming acceleration RAM | All masters |
| 0x1FFF_8000–0x1FFF_FFFF | SRAM_L: Lower SRAM (ICODE/DCODE) | All masters |
| 0x2000_0000–0x2000_7FFF | SRAM_U: Upper SRAM bitband region | All masters |
| 0x2010_0000–0x21FF_FFFF | Reserved | — |
| 0x2200_0000–0x23FF_FFFF | Aliased to SRAM_U bitband | Cortex-M4 core only |
| 0x2400_0000–0x3FFF_FFFF | Reserved | — |

Table continues on the next page...

Table 4-1. System memory map (continued)

| System 32-bit Address Range | Destination Slave | Access |
|-----------------------------|--|-----------------------------|
| 0x4000_0000–0x4007_FFFF | Bitband region for peripheral bridge 0 (AIPS-Lite0) | Cortex-M4 core & DMA/EzPort |
| 0x4008_0000–0x400F_FFFF | Reserved | – |
| 0x400F_F000–0x400F_FFFF | Bitband region for general purpose input/output (GPIO) | Cortex-M4 core & DMA/EzPort |
| 0x4010_0000–0x41FF_FFFF | Reserved | – |
| 0x4200_0000–0x43FF_FFFF | Aliased to peripheral bridge (AIPS-Lite) and general purpose input/output (GPIO) bitband | Cortex-M4 core only |
| 0x4400_0000–0xDFFF_FFFF | Reserved | – |
| 0xE000_0000–0xE00F_FFFF | Private peripherals | Cortex-M4 core only |
| 0xE010_0000–0xFFFF_FFFF | Reserved | – |

NOTE

1. EzPort master port is statically muxed with DMA master port. Access rights to AIPS-Lite peripheral bridge and general purpose input/output (GPIO) module address space is limited to the core, DMA and EzPort.
2. ARM Cortex-M4 core access privileges also includes accesses via the debug interface.

4.2.1 Aliased bit-band regions

The SRAM_U, AIPS-Lite, and general purpose input/output (GPIO) module resources reside in the Cortex-M4 processor bit-band regions.

The processor also includes two 32 MB aliased bit-band regions associated with the two 1 MB bit-band spaces. Each 32-bit location in the 32 MB space maps to an individual bit in the bit-band region. A 32-bit write in the alias region has the same effect as a read-modify-write operation on the targeted bit in the bit-band region.

Bit 0 of the value written to the alias region determines what value is written to the target bit:

- Writing a value with bit 0 set writes a 1 to the target bit.
- Writing a value with bit 0 clear writes a 0 to the target bit.

A 32-bit read in the alias region returns either:

- a value of 0x0000_0000 to indicate the target bit is clear
- a value of 0x0000_0001 to indicate the target bit is set

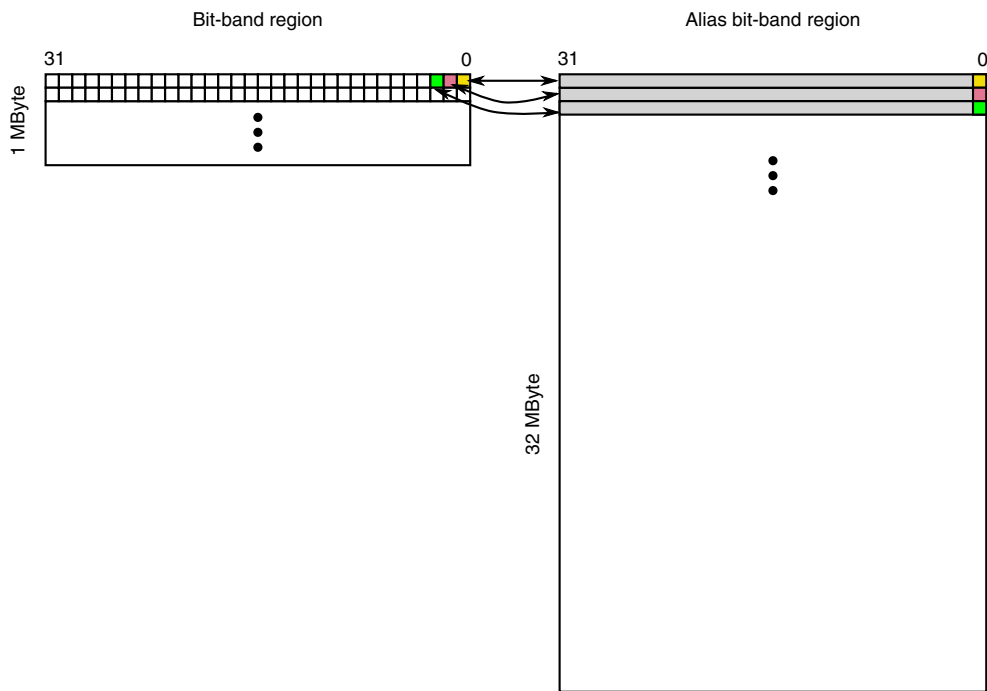


Figure 4-1. Alias bit-band mapping

NOTE

Each bit in bit-band region has an equivalent bit that can be manipulated through bit 0 in a corresponding long word in the alias bit-band region.

4.3 Flash Memory Map

The various flash memories and the flash registers are located at different base addresses as shown in the following figure. The base address for each is specified in [System memory map](#).

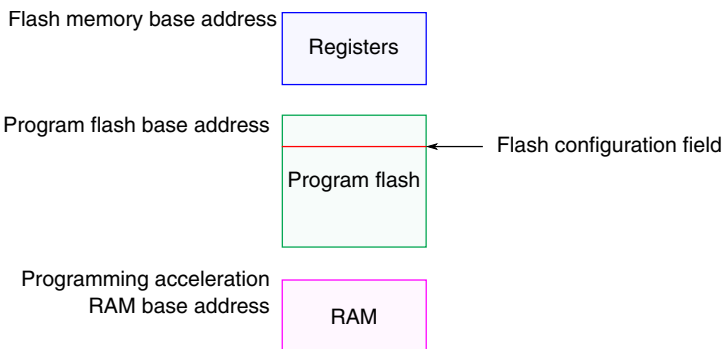


Figure 4-2. Flash memory map for devices containing only program flash

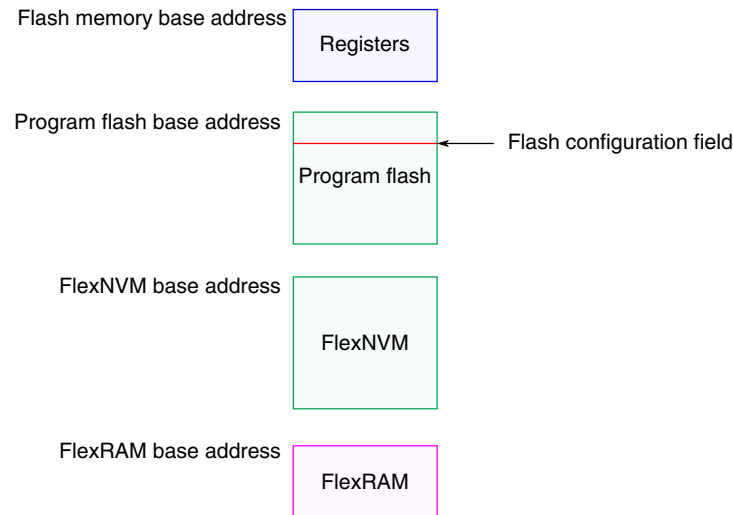


Figure 4-3. Flash memory map for devices containing FlexNVM

4.3.1 Alternate Non-Volatile IRC User Trim Description

The following non-volatile locations (4 bytes) are reserved for custom IRC user trim supported by some development tools. An alternate IRC trim to the factory loaded trim can be stored at this location. To override the factory trim, user software must load new values into the MCG trim registers.

| Non-Volatile Byte Address | Alternate IRC Trim Value |
|---------------------------|--------------------------|
| 0x0000_03FC | Reserved |
| 0x0000_03FD | Reserved |
| 0x0000_03FE (bit 0) | SCFTRIM |
| 0x0000_03FE (bit 4:1) | FCTRIM |
| 0x0000_03FF | SCTRIM |

4.4 SRAM memory map

The on-chip RAM is split in two regions: SRAM_L and SRAM_U. The RAM is implemented such that the SRAM_L and SRAM_U ranges form a contiguous block in the memory map. See [SRAM Configuration](#) for details.

Accesses to the SRAM_L and SRAM_U memory ranges outside the amount of RAM on the device causes the bus cycle to be terminated with an error followed by the appropriate response in the requesting bus master.

4.5 Peripheral bridge (AIPS-Lite) memory map

The peripheral memory map is accessible via one slave port on the crossbar in the 0x4000_0000–0x4007_FFFF region. The device implements one peripheral bridge that defines a 512 KB address space.

Modules that are disabled via their clock gate control bits in the SIM registers disable the associated AIPS slots. Access to any address within an unimplemented or disabled peripheral bridge slot results in a transfer error termination.

For programming model accesses via the peripheral bridges, there is generally only a small range within the 4 KB slots that is implemented. Accessing an address that is not implemented in the peripheral results in a transfer error termination.

4.5.1 Read-after-write sequence and required serialization of memory operations

In some situations, a write to a peripheral must be completed fully before a subsequent action can occur. Examples of such situations include:

- Exiting an interrupt service routine (ISR)
- Changing a mode
- Configuring a function

In these situations, the application software must perform a read-after-write sequence to guarantee the required serialization of the memory operations:

1. Write the peripheral register.
2. Read the written peripheral register to verify the write.
3. Continue with subsequent operations.

4.5.2 Peripheral Bridge 0 (AIPS-Lite 0) Memory Map

Table 4-2. Peripheral bridge 0 slot assignments

| System 32-bit base address | Slot number | Module |
|----------------------------|-------------|-----------------------------------|
| 0x4000_0000 | 0 | Peripheral bridge 0 (AIPS-Lite 0) |
| 0x4000_1000 | 1 | — |
| 0x4000_2000 | 2 | — |
| 0x4000_3000 | 3 | — |

Table continues on the next page...

Table 4-2. Peripheral bridge 0 slot assignments (continued)

| System 32-bit base address | Slot number | Module |
|----------------------------|-------------|---|
| 0x4000_4000 | 4 | — |
| 0x4000_5000 | 5 | — |
| 0x4000_6000 | 6 | — |
| 0x4000_7000 | 7 | — |
| 0x4000_8000 | 8 | DMA controller |
| 0x4000_9000 | 9 | DMA controller transfer control descriptors |
| 0x4000_A000 | 10 | — |
| 0x4000_B000 | 11 | — |
| 0x4000_C000 | 12 | — |
| 0x4000_D000 | 13 | — |
| 0x4000_E000 | 14 | — |
| 0x4000_F000 | 15 | — |
| 0x4001_0000 | 16 | — |
| 0x4001_1000 | 17 | — |
| 0x4001_2000 | 18 | — |
| 0x4001_3000 | 19 | — |
| 0x4001_4000 | 20 | — |
| 0x4001_5000 | 21 | — |
| 0x4001_6000 | 22 | — |
| 0x4001_7000 | 23 | — |
| 0x4001_8000 | 24 | — |
| 0x4001_9000 | 25 | — |
| 0x4001_A000 | 26 | — |
| 0x4001_B000 | 27 | — |
| 0x4001_C000 | 28 | — |
| 0x4001_D000 | 29 | — |
| 0x4001_E000 | 30 | — |
| 0x4001_F000 | 31 | Flash memory controller |
| 0x4002_0000 | 32 | Flash memory |
| 0x4002_1000 | 33 | DMA channel mutiplexer |
| 0x4002_2000 | 34 | — |
| 0x4002_3000 | 35 | — |
| 0x4002_4000 | 36 | — |
| 0x4002_5000 | 37 | — |
| 0x4002_6000 | 38 | — |
| 0x4002_7000 | 39 | — |
| 0x4002_8000 | 40 | — |
| 0x4002_9000 | 41 | Random Number Generator (RNGA) |
| 0x4002_A000 | 42 | — |

Table continues on the next page...

Table 4-2. Peripheral bridge 0 slot assignments (continued)

| System 32-bit base address | Slot number | Module |
|----------------------------|-------------|-------------------------------------|
| 0x4002_B000 | 43 | — |
| 0x4002_C000 | 44 | SPI 0 |
| 0x4002_D000 | 45 | SPI 1 |
| 0x4002_E000 | 46 | — |
| 0x4002_F000 | 47 | I2S 0 |
| 0x4003_0000 | 48 | — |
| 0x4003_1000 | 49 | — |
| 0x4003_2000 | 50 | CRC |
| 0x4003_3000 | 51 | — |
| 0x4003_4000 | 52 | — |
| 0x4003_5000 | 53 | — |
| 0x4003_6000 | 54 | Programmable delay block (PDB) |
| 0x4003_7000 | 55 | Periodic interrupt timers (PIT) |
| 0x4003_8000 | 56 | FlexTimer (FTM) 0 |
| 0x4003_9000 | 57 | FlexTimer (FTM) 1 |
| 0x4003_A000 | 58 | FlexTimer (FTM) 2 |
| 0x4003_B000 | 59 | Analog-to-digital converter (ADC) 0 |
| 0x4003_C000 | 60 | — |
| 0x4003_D000 | 61 | Real-time clock (RTC) |
| 0x4003_E000 | 62 | VBAT register file |
| 0x4003_F000 | 63 | DAC0 |
| 0x4004_0000 | 64 | Low-power timer (LPTMR) |
| 0x4004_1000 | 65 | System register file |
| 0x4004_2000 | 66 | — |
| 0x4004_3000 | 67 | — |
| 0x4004_4000 | 68 | — |
| 0x4004_5000 | 69 | — |
| 0x4004_6000 | 70 | — |
| 0x4004_7000 | 71 | SIM low-power logic |
| 0x4004_8000 | 72 | System integration module (SIM) |
| 0x4004_9000 | 73 | Port A multiplexing control |
| 0x4004_A000 | 74 | Port B multiplexing control |
| 0x4004_B000 | 75 | Port C multiplexing control |
| 0x4004_C000 | 76 | Port D multiplexing control |
| 0x4004_D000 | 77 | Port E multiplexing control |
| 0x4004_E000 | 78 | — |
| 0x4004_F000 | 79 | — |
| 0x4005_0000 | 80 | — |
| 0x4005_1000 | 81 | — |

Table continues on the next page...

Table 4-2. Peripheral bridge 0 slot assignments (continued)

| System 32-bit base address | Slot number | Module |
|----------------------------|-------------|---|
| 0x4005_2000 | 82 | Software watchdog |
| 0x4005_3000 | 83 | — |
| 0x4005_4000 | 84 | — |
| 0x4005_5000 | 85 | — |
| 0x4005_6000 | 86 | — |
| 0x4005_7000 | 87 | — |
| 0x4005_8000 | 88 | — |
| 0x4005_9000 | 89 | — |
| 0x4005_A000 | 90 | — |
| 0x4005_B000 | 91 | — |
| 0x4005_C000 | 92 | — |
| 0x4005_D000 | 93 | — |
| 0x4005_E000 | 94 | — |
| 0x4005_F000 | 95 | — |
| 0x4006_0000 | 96 | — |
| 0x4006_1000 | 97 | External watchdog |
| 0x4006_2000 | 98 | Carrier modulator timer (CMT) |
| 0x4006_3000 | 99 | — |
| 0x4006_4000 | 100 | Multi-purpose Clock Generator (MCG) |
| 0x4006_5000 | 101 | System oscillator (OSC) |
| 0x4006_6000 | 102 | I ² C 0 |
| 0x4006_7000 | 103 | I ² C 1 |
| 0x4006_8000 | 104 | — |
| 0x4006_9000 | 105 | — |
| 0x4006_A000 | 106 | UART 0 |
| 0x4006_B000 | 107 | UART 1 |
| 0x4006_C000 | 108 | UART 2 |
| 0x4006_D000 | 109 | UART 3 |
| 0x4006_E000 | 110 | — |
| 0x4006_F000 | 111 | — |
| 0x4007_0000 | 112 | — |
| 0x4007_1000 | 113 | — |
| 0x4007_2000 | 114 | — |
| 0x4007_3000 | 115 | Analog comparator (CMP) / 6-bit digital-to-analog converter (DAC) |
| 0x4007_4000 | 116 | Voltage reference (VREF) |
| 0x4007_5000 | 117 | — |
| 0x4007_6000 | 118 | — |
| 0x4007_7000 | 119 | — |
| 0x4007_8000 | 120 | — |

Table continues on the next page...

Table 4-2. Peripheral bridge 0 slot assignments (continued)

| System 32-bit base address | Slot number | Module |
|----------------------------|-------------|-----------------------------------|
| 0x4007_9000 | 121 | — |
| 0x4007_A000 | 122 | — |
| 0x4007_B000 | 123 | — |
| 0x4007_C000 | 124 | Low-leakage wakeup unit (LLWU) |
| 0x4007_D000 | 125 | Power management controller (PMC) |
| 0x4007_E000 | 126 | System Mode controller (SMC) |
| 0x4007_F000 | 127 | Reset Control Module (RCM) |
| 0x400F_F000 | | GPIO controller |

4.6 Private Peripheral Bus (PPB) memory map

The PPB is part of the defined ARM bus architecture and provides access to select processor-local modules. These resources are only accessible from the core; other system masters do not have access to them.

Table 4-3. PPB memory map

| System 32-bit Address Range | Resource |
|-----------------------------|---|
| 0xE000_0000–0xE000_0FFF | Instrumentation Trace Macrocell (ITM) |
| 0xE000_1000–0xE000_1FFF | Data Watchpoint and Trace (DWT) |
| 0xE000_2000–0xE000_2FFF | Flash Patch and Breakpoint (FPB) |
| 0xE000_3000–0xE000_DFFF | Reserved |
| 0xE000_E000–0xE000_EFFF | System Control Space (SCS) (for NVIC) |
| 0xE000_F000–0xE003_FFFF | Reserved |
| 0xE004_0000–0xE004_0FFF | Trace Port Interface Unit (TPIU) |
| 0xE004_1000–0xE004_1FFF | Embedded Trace Macrocell (ETM) |
| 0xE004_2000–0xE004_2FFF | Reserved |
| 0xE004_3000–0xE004_3FFF | Reserved |
| 0xE004_4000–0xE007_FFFF | Reserved |
| 0xE008_0000–0xE008_0FFF | Miscellaneous Control Module (MCM) |
| 0xE008_1000–0xE008_1FFF | Memory Mapped Cryptographic Acceleration Unit (MMCAU) |
| 0xE008_2000–0xE00F_EFFF | Reserved |
| 0xE00F_F000–0xE00F_FFFF | ROM Table - allows auto-detection of debug components |



Chapter 5

Clock Distribution

5.1 Introduction

The MCG module controls which clock source is used to derive the system clocks. The clock generation logic divides the selected clock source into a variety of clock domains, including the clocks for the system bus masters, system bus slaves, and flash memory . The clock generation logic also implements module-specific clock gating to allow granular shutoff of modules.

The primary clocks for the system are generated from the MCGOUTCLK clock. The clock generation circuitry provides several clock dividers that allow different portions of the device to be clocked at different frequencies. This allows for trade-offs between performance and power dissipation.

Various modules have module-specific clocks that can be generated from the MCGPLLCLK or MCGFLLCLK clock. In addition, there are various other module-specific clocks that have other alternate sources. Clock selection for most modules is controlled by the SOPT registers in the SIM module.

5.2 Programming model

The selection and multiplexing of system clock sources is controlled and programmed via the MCG module. The setting of clock dividers and module clock gating for the system are programmed via the SIM module. Reference those sections for detailed register and bit descriptions.

5.3 High-Level device clocking diagram

The following [system oscillator](#), [MCG](#), and [SIM](#) module registers control the multiplexers, dividers, and clock gates shown in the below figure:

Clock definitions

| | OSC | MCG | SIM |
|--------------|--------|--------|----------------------|
| Multiplexers | MCG_Cx | MCG_Cx | SIM_SOPT1, SIM_SOPT2 |
| Dividers | — | MCG_Cx | SIM_CLKDIVx |
| Clock gates | OSC_CR | MCG_C1 | SIM_SCGCx |

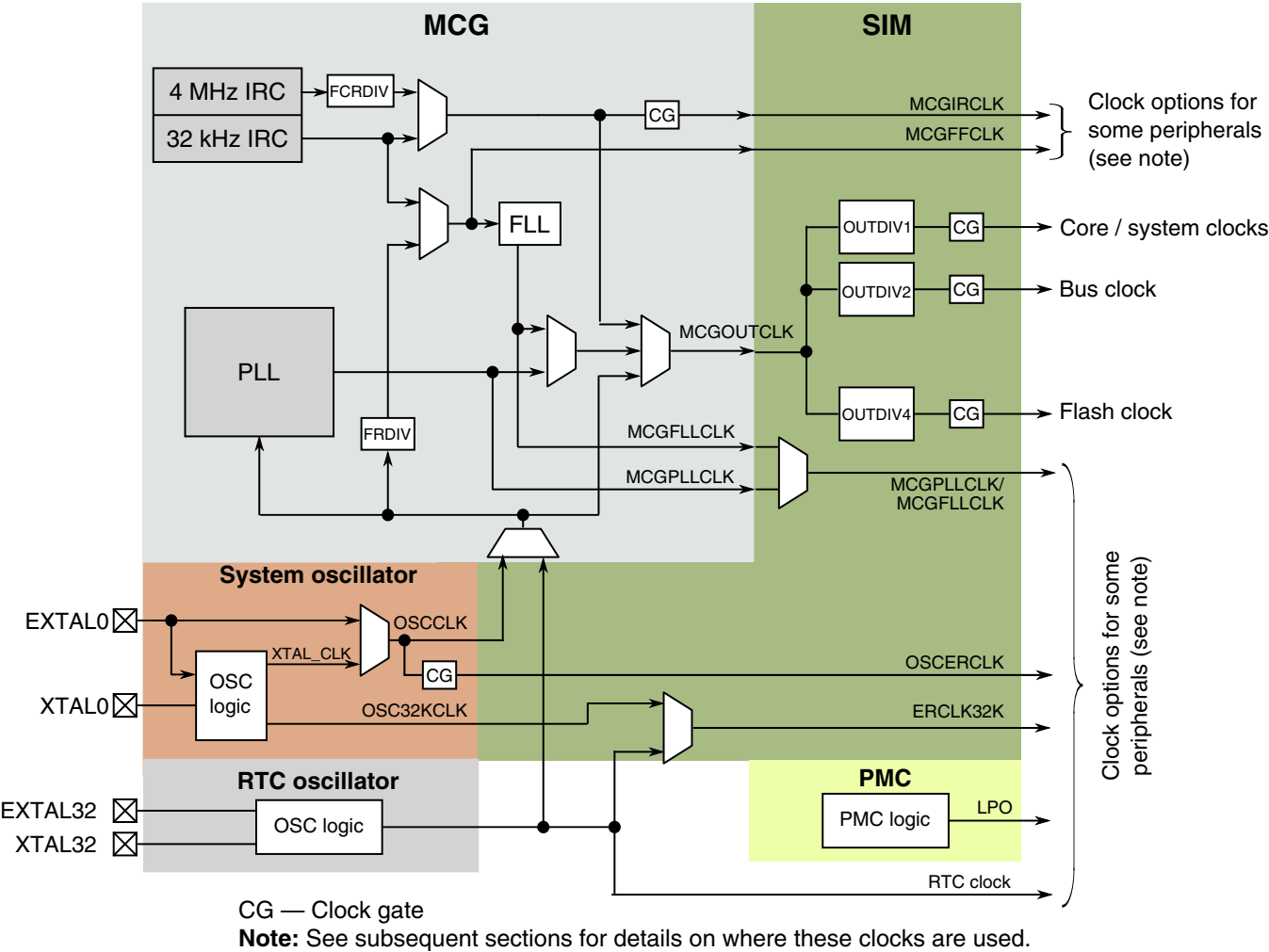


Figure 5-1. Clocking diagram

5.4 Clock definitions

The following table describes the clocks in the previous block diagram.

| Clock name | Description |
|------------|--|
| Core clock | MCGOUTCLK divided by OUTDIV1 clocks the ARM Cortex-M4 core |

Table continues on the next page...

| Clock name | Description |
|--------------|---|
| System clock | MCGOUTCLK divided by OUTDIV1 clocks the crossbar switch and bus masters directly connected to the crossbar. In addition, this clock is used for UART0 and UART1. |
| Bus clock | MCGOUTCLK divided by OUTDIV2 clocks the bus slaves and peripheral (excluding memories) |
| Flash clock | MCGOUTCLK divided by OUTDIV4 clocks the flash memory |
| MCGIRCLK | MCG output of the slow or fast internal reference clock |
| MCGFFCLK | MCG output of the slow internal reference clock or a divided MCG external reference clock. |
| MCGOUTCLK | MCG output of either IRC, MCGFLLCLK, MCGPLLCLK or MCG's external reference clock that sources the core, system, bus, and flash clock. It is also an option for the debug trace clock. |
| MCGFLLCLK | MCG output of the FLL. MCGFLLCLK may clock some modules. |
| MCGPLLCLK | MCG output of the PLL. MCGFLLCLK or MCGPLLCLK may clock some modules. |
| OSCCLK | System oscillator output of the internal oscillator or sourced directly from EXTAL |
| OSCERCLK | System oscillator output sourced from OSCCLK that may clock some on-chip modules |
| OSC32KCLK | System oscillator 32kHz output |
| ERCLK32K | Clock source for some modules that is chosen as OSC32KCLK or the RTC clock. |
| RTC clock | RTC oscillator output for the RTC module and the Drylce module |
| LPO | PMC 1kHz output |

5.4.1 Device clock summary

The following table provides more information regarding the on-chip clocks.

Table 5-1. Clock Summary

| Clock name | Run mode clock frequency | VLPR mode clock frequency | Clock source | Clock is disabled when... |
|--------------|--------------------------|--|-------------------------|----------------------------|
| MCGOUTCLK | Up to 50 MHz | Up to 4 MHz | MCG | In all stop modes |
| Core clock | Up to 50 MHz | Up to 4 MHz | MCGOUTCLK clock divider | In all wait and stop modes |
| System clock | Up to 50 MHz | Up to 4 MHz | MCGOUTCLK clock divider | In all stop modes |
| Bus clock | Up to 50 MHz | Up to 4 MHz | MCGOUTCLK clock divider | In all stop modes |
| Flash clock | Up to 25 MHz | Up to 1 MHz in BLPE, Up to 800 kHz in BLPI | MCGOUTCLK clock divider | In all stop modes |

Table continues on the next page...

Table 5-1. Clock Summary (continued)

| Clock name | Run mode clock frequency | VLPR mode clock frequency | Clock source | Clock is disabled when... |
|---|---|--|---|---|
| Internal reference (MCGIRCLK) | 30-40 kHz or 4 MHz | 4 MHz only | MCG | MCG_C1[IRCLKEN] cleared, Stop mode and MCG_C1[IREFSTEN] cleared, or VLPS/LLS/VLLS mode |
| External reference (OSCERCLK) | Up to 50 MHz (bypass), 30-40 kHz, or 3-32 MHz (crystal) | Up to 4 MHz (bypass), 30-40 kHz (low-range crystal) or Up to 4 MHz (high- range crystal) | System OSC | System OSC's OSC_CR[ERCLKEN] cleared, or Stop mode and OSC_CR[EREFSTEN] cleared |
| External reference 32kHz (ERCLK32K) | 30-40 kHz | 30-40 kHz | System OSC or RTC OSC depending on SIM_SOPT1[OSC32KS EL] | System OSC's OSC_CR[ERCLKEN] cleared or RTC's RTC_CR[OSCE] cleared |
| RTC_CLKOUT | 1 Hz or 32 kHz | 1 Hz or 32 kHz | RTC clock | Clock is disabled in LLS and VLLSx modes |
| LPO | 1 kHz | 1 kHz | PMC | in VLLS0 |
| I ² S master clock | Up to 25 MHz | N/A | System clock , MCGPLLCLK , , OSCERCLK with fractional clock divider, or I ² S_CLKIN | I ² S is disabled |
| TRACE clock | Up to 50 MHz | Up to 4 MHz | System clock or MCGOUTCLK | Trace is disabled |

5.5 Internal clocking requirements

The clock dividers are programmed via the SIM module's CLKDIV registers. Each divider is programmable from a divide-by-1 through divide-by-16 setting. The following requirements must be met when configuring the clocks for this device:

1. The core and system clock frequencies must be 50 MHz or slower.
2. The bus clock frequency must be programmed to 50 MHz or less and an integer divide of the core clock.
3. The flash clock frequency must be programmed to 25 MHz or less and an integer divide of the bus clock.

The following are a few of the more common clock configurations for this device:

Option 1:

| Clock | Frequency |
|--------------|-----------|
| Core clock | 50 MHz |
| System clock | 50 MHz |
| Bus clock | 50 MHz |
| Flash clock | 25 MHz |

5.5.1 Clock divider values after reset

Each clock divider is programmed via the SIM module's CLKDIV n registers. The flash memory's FTF_FOPT[LPBOOT] bit controls the reset value of the core clock, system clock, bus clock, and flash clock dividers as shown below:

| FTF_FOPT [LPBOOT] | Core/system clock | Bus clock | Flash clock | Description |
|----------------------|-------------------|-------------------|--------------------|-----------------|
| 0 | 0x7 (divide by 8) | 0x7 (divide by 8) | 0xF (divide by 16) | Low power boot |
| 1 | 0x0 (divide by 1) | 0x0 (divide by 1) | 0x1 (divide by 2) | Fast clock boot |

This gives the user flexibility for a lower frequency, low-power boot option. The flash erased state defaults to fast clocking mode, since where the low power boot (FTF_FOPT[LPBOOT]) bit resides in flash is logic 1 in the flash erased state.

To enable the low power boot option program FTF_FOPT[LPBOOT] to zero. During the reset sequence, if LPBOOT is cleared, the system is in a slow clock configuration. Upon any system reset, the clock dividers return to this configurable reset state.

5.5.2 VLPR mode clocking

The clock dividers cannot be changed while in VLPR mode. They must be programmed prior to entering VLPR mode to guarantee:

- the core/system and bus clocks are less than or equal to 4 MHz, and
- the flash memory clock is less than or equal to 1 MHz

NOTE

When the MCG is in BLPI and clocking is derived from the Fast IRC, the clock divider controls, MCG_SC[FCRDIV] and SIM_CLKDIV1[OUTDIV4], must be programmed such that

the resulting flash clock nominal frequency is 800 kHz or less. In this case, one example of correct configuration is MCG_SC[FCRDIV]=000b and SIM_CLKDIV1[OUTDIV4]=0100b, resulting in a divide by 5 setting.

5.6 Clock Gating

The clock to each module can be individually gated on and off using the SIM module's SCGCx registers. These bits are cleared after any reset, which disables the clock to the corresponding module to conserve power. Prior to initializing a module, set the corresponding bit in SCGCx register to enable the clock. Before turning off the clock, make sure to disable the module.

Any bus access to a peripheral that has its clock disabled generates an error termination.

5.7 Module clocks

The following table summarizes the clocks associated with each module.

Table 5-2. Module clocks

| Module | Bus interface clock | Internal clocks | I/O interface clocks |
|-----------------------|---------------------|------------------------|----------------------|
| Core modules | | | |
| ARM Cortex-M4 core | System clock | Core clock | — |
| NVIC | System clock | — | — |
| DAP | System clock | — | — |
| ITM | System clock | — | — |
| ETM | System clock | TRACE clock | TRACE_CLKOUT |
| cJTAG, JTAGC | — | — | JTAG_CLK |
| System modules | | | |
| DMA | System clock | — | — |
| DMA Mux | Bus clock | — | — |
| Port control | Bus clock | LPO | — |
| Crossbar Switch | System clock | — | — |
| Peripheral bridges | System clock | Bus clock, Flash clock | — |
| LLWU, PMC, SIM, RCM | Flash clock | LPO | — |
| Mode controller | Flash clock | — | — |
| MCM | System clock | — | — |
| EWM | Bus clock | LPO | — |

Table continues on the next page...

Table 5-2. Module clocks (continued)

| Module | Bus interface clock | Internal clocks | I/O interface clocks |
|-------------------------------------|---------------------|---|--------------------------|
| Watchdog timer | Bus clock | LPO | — |
| Clocks | | | |
| MCG | Bus clock | MCGOUTCLK, MCGPLLCLK, MCGFLLCLK, MCGIRCLK, OSCERCLK | — |
| OSC | Bus clock | OSCERCLK | — |
| Memory and memory interfaces | | | |
| Flash Controller | System clock | Flash clock | — |
| Flash memory | Flash clock | — | — |
| EzPort | System clock | — | EZP_CLK |
| Security | | | |
| CRC | Bus clock | — | — |
| MMCAU | System clock | — | — |
| RNGA | Bus clock | — | — |
| Analog | | | |
| ADC | Bus clock | OSCERCLK | — |
| CMP | Bus clock | — | — |
| VREF | Bus clock | — | — |
| Timers | | | |
| PDB | Bus clock | — | — |
| FlexTimers | Bus clock | MCGFFCLK | FTM_CLKINx |
| PIT | Bus clock | — | — |
| LPTMR | Flash clock | LPO, OSCERCLK, MCGIRCLK, ERCLK32K | — |
| CMT | Bus clock | — | — |
| RTC | Flash clock | EXTAL32 | — |
| Communication interfaces | | | |
| DSPI | Bus clock | — | DSPI_SCK |
| I ² C | Bus clock | — | I2C_SCL |
| UART0, UART1 | System clock | — | — |
| UART2-3 | Bus clock | — | — |
| I ² S | Bus clock | I ² S master clock | I2S_TX_BCLK, I2S_RX_BCLK |
| Human-machine interfaces | | | |
| GPIO | System clock | — | — |

5.7.1 PMC 1-kHz LPO clock

The Power Management Controller (PMC) generates a 1-kHz clock that is enabled in all modes of operation, including all low power modes. This 1-kHz source is commonly referred to as LPO clock or 1-kHz LPO clock.

5.7.2 WDOG clocking

The WDOG may be clocked from two clock sources as shown in the following figure.

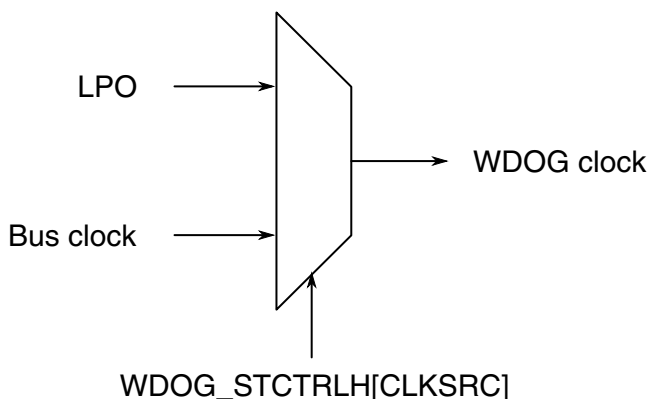


Figure 5-2. WDOG clock generation

5.7.3 Debug trace clock

The debug trace clock source can be clocked as shown in the following figure.

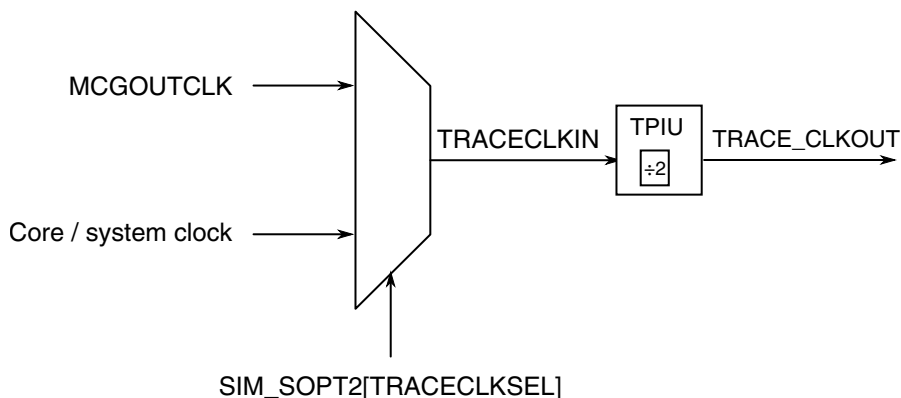


Figure 5-3. Trace clock generation

NOTE

The trace clock frequency observed at the TRACE_CLKOUT pin will be half that of the selected clock source.

5.7.4 PORT digital filter clocking

The digital filters in each of the PORT x modules can be clocked as shown in the following figure.

NOTE

In stop mode, the digital input filters are bypassed unless they are configured to run from the 1 kHz LPO clock source.

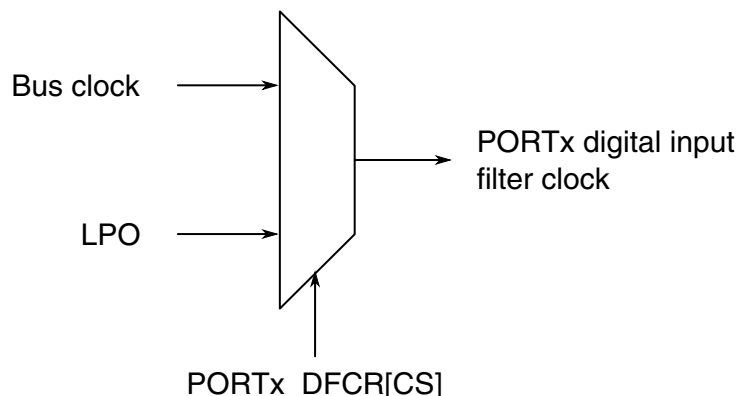


Figure 5-4. PORT x digital input filter clock generation

5.7.5 LPTMR clocking

The prescaler and glitch filters in each of the LPTMR x modules can be clocked as shown in the following figure.

NOTE

The chosen clock must remain enabled if the LPTMR x is to continue operating in all required low-power modes.

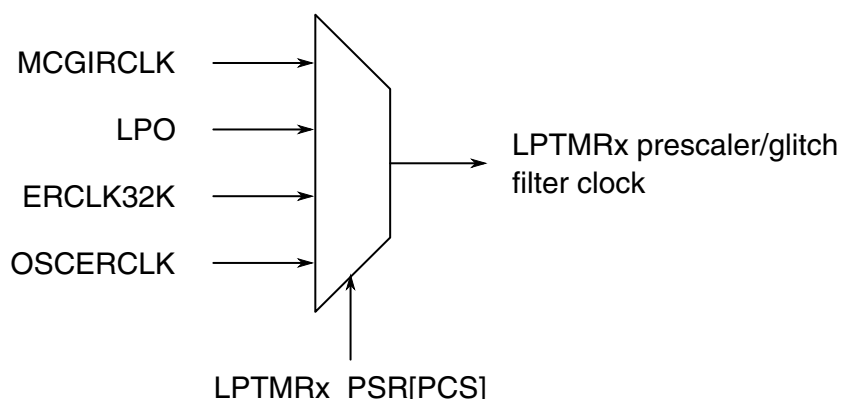


Figure 5-5. LPTMR x prescaler/glitch filter clock generation

5.7.6 UART clocking

UART0 and UART1 modules operate from the core/system clock, which provides higher performance level for these modules. All other UART modules operate from the bus clock.

5.7.7 I²S/SAI clocking

The audio master clock (MCLK) is used to generate the bit clock when the receiver or transmitter is configured for an internally generated bit clock. The audio master clock can also be output to or input from a pin. The transmitter and receiver have the same audio master clock inputs.

Each SAI peripheral can control the input clock selection, pin direction and divide ratio of one audio master clock.

The I²S/SAI transmitter and receiver support asynchronous bit clocks (BCLKs) that can be generated internally from the audio master clock or supplied externally. The module also supports the option for synchronous operation between the receiver and transmitter product.

The transmitter and receiver can independently select between the bus clock and the audio master clock to generate the bit clock.

The MCLK and BCLK source options appear in the following figure.

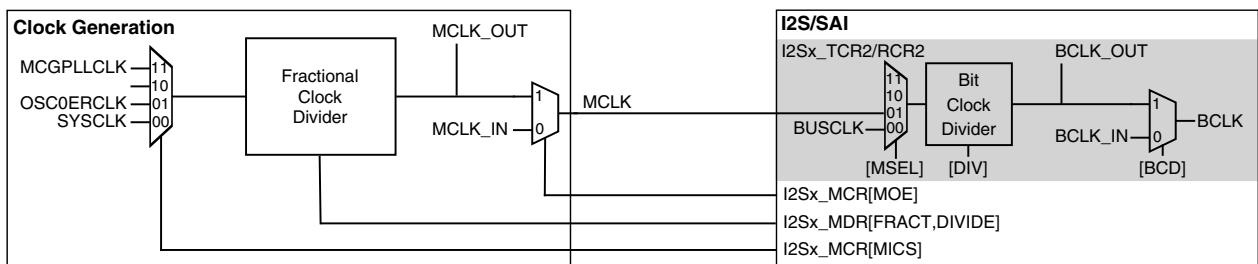


Figure 5-6. I²S/SAI clock generation

Chapter 6

Reset and Boot

6.1 Introduction

The following reset sources are supported in this MCU:

Table 6-1. Reset sources

| Reset sources | Description |
|---------------|---|
| POR reset | <ul style="list-style-type: none"> • Power-on reset (POR) |
| System resets | <ul style="list-style-type: none"> • External pin reset (PIN) • Low-voltage detect (LVD) • Computer operating properly (COP) watchdog reset • Low leakage wakeup (LLWU) reset • Multipurpose clock generator loss of clock (LOC) reset • Multipurpose clock generator loss of lock (LOL) reset • Stop mode acknowledge error (SACKERR) • Software reset (SW) • Lockup reset (LOCKUP) • EzPort reset • MDM DAP system reset |
| Debug reset | <ul style="list-style-type: none"> • JTAG reset • nTRST reset |

Each of the system reset sources has an associated bit in the system reset status (SRS) registers. See the [Reset Control Module](#) for register details.

The MCU exits reset in functional mode that is controlled by $\overline{\text{EZP_CS}}$ pin to select between the single chip (default) or serial flash programming (EzPort) modes. See [Boot options](#) for more details.

6.2 Reset

This section discusses basic reset mechanisms and sources. Some modules that cause resets can be configured to cause interrupts instead. Consult the individual peripheral chapters for more information.

6.2.1 Power-on reset (POR)

When power is initially applied to the MCU or when the supply voltage drops below the power-on reset re-arm voltage level (V_{POR}), the POR circuit causes a POR reset condition.

As the supply voltage rises, the LVD circuit holds the MCU in reset until the supply has risen above the LVD low threshold (V_{LVDL}). The POR and LVD bits in SRS0 register are set following a POR.

6.2.2 System reset sources

Resetting the MCU provides a way to start processing from a known set of initial conditions. System reset begins with the on-chip regulator in full regulation and system clocking generation from an internal reference. When the processor exits reset, it performs the following:

- Reads the start SP (SP_main) from vector-table offset 0
- Reads the start PC from vector-table offset 4
- LR is set to 0xFFFF_FFFF

The on-chip peripheral modules are disabled and the non-analog I/O pins are initially configured as disabled. The pins with analog functions assigned to them default to their analog function after reset.

During and following a reset, the JTAG pins have their associated input pins configured as:

- TDI in pull-up (PU)
- TCK in pull-down (PD)
- TMS in PU

and associated output pin configured as:

- TDO with no pull-down or pull-up

Note that the nTRST signal is initially configured as disabled, however once configured to its JTAG functionality its associated input pin is configured as:

- nTRST in PU

6.2.2.1 External pin reset (PIN)

On this device, $\overline{\text{RESET}}$ is a dedicated pin. This pin is open drain and has an internal pullup device. Asserting $\overline{\text{RESET}}$ wakes the device from any mode. During a pin reset, the RCM's SRS0[PIN] bit is set.

6.2.2.1.1 Reset pin filter

The $\overline{\text{RESET}}$ pin filter supports filtering from both the 1 kHz LPO clock and the bus clock. A separate filter is implemented for each clock source. In stop and VLPS mode operation, this logic either switches to bypass operation or has continued filtering operation depending on the filtering mode selected. In low leakage stop modes, a separate LPO filter in the LLWU can continue filtering the $\overline{\text{RESET}}$ pin.

The RPFC[RSTFLTSS], RPFC[RSTFLTSRW], and RPFW[RSTFLTSEL] fields in the reset control (RCM) register set control this functionality; see the RCM chapter. The filters are asynchronously reset by Chip POR. The reset value for each filter assumes the $\overline{\text{RESET}}$ pin is negated.

The two clock options for the $\overline{\text{RESET}}$ pin filter when the chip is not in low leakage modes are the LPO (1 kHz) and bus clock. For low leakage modes VLLS3, VLLS2, VLLS1, VLLS0, the LLWU provides control (in the LLWU_RST register) of an optional fixed digital filter running the LPO. When entering VLLS0, the $\overline{\text{RESET}}$ pin filter is disabled and bypassed.

The LPO filter has a fixed filter value of 3. Due to a synchronizer on the input data, there is also some associated latency (2 cycles). As a result, 5 cycles are required to complete a transition from low to high or high to low.

The bus filter initializes to off (logic 1) when the bus filter is not enabled. The bus clock is used when the filter selects bus clock, and the number of counts is controlled by the RCM's RPFW[RSTFLTSEL] field.

6.2.2.2 Low-voltage detect (LVD)

The chip includes a system for managing low voltage conditions to protect memory contents and control MCU system states during supply voltage variations. The system consists of a power-on reset (POR) circuit and an LVD circuit with a user-selectable trip voltage. The LVD system is always enabled in normal run, wait, or stop mode. The LVD system is disabled when entering VLPx, LLS, or VLLSx modes.

The LVD can be configured to generate a reset upon detection of a low voltage condition by setting the PMC's LVDSC1[LVDRE] bit to 1. The low voltage detection threshold is determined by the PMC's LVDSC1[LVDV] field. After an LVD reset has occurred, the LVD system holds the MCU in reset until the supply voltage has risen above the low voltage detection threshold. The RCM's SRS0[LVD] bit is set following either an LVD reset or POR.

6.2.2.3 Computer operating properly (COP) watchdog timer

The computer operating properly (COP) watchdog timer (WDOG) monitors the operation of the system by expecting periodic communication from the software. This communication is generally known as servicing (or refreshing) the COP watchdog. If this periodic refreshing does not occur, the watchdog issues a system reset. The COP reset causes the RCM's SRS0[WDOG] bit to set.

6.2.2.4 Low leakage wakeup (LLWU)

The LLWU module provides the means for a number of external pins, the $\overline{\text{RESET}}$ pin, and a number of internal peripherals to wake the MCU from low leakage power modes. The LLWU module is functional only in low leakage power modes.

- In LLS mode, only the $\overline{\text{RESET}}$ pin via the LLWU can generate a system reset.
- In VLLSx modes, all enabled inputs to the LLWU can generate a system reset.

After a system reset, the LLWU retains the flags indicating the input source of the last wakeup until the user clears them.

NOTE

Some flags are cleared in the LLWU and some flags are required to be cleared in the peripheral module. Refer to the individual peripheral chapters for more information.

6.2.2.5 Multipurpose clock generator loss-of-clock (LOC)

The MCG module supports an external reference clock.

If the C6[CME] bit in the MCG module is set, the clock monitor is enabled. If the external reference falls below f_{loc_low} or f_{loc_high} , as controlled by the C2[RANGE] field in the MCG module, the MCU resets. The RCM's SRS0[LOC] bit is set to indicate this reset source.

NOTE

To prevent unexpected loss of clock reset events, all clock monitors should be disabled before entering any low power modes, including VLPR and VLPW.

6.2.2.6 MCG loss-of-lock (LOL) reset

The MCG includes a PLL loss-of-lock detector. The detector is enabled when configured for PEE and lock has been achieved. If the MCG_C8[LOLRE] bit in the MCG module is set and the PLL lock status bit (MCG_S[LOLS0]) becomes set, the MCU resets. The RCM_SRS0[LOL] bit is set to indicate this reset source.

NOTE

This reset source does not cause a reset if the chip is in any stop mode.

6.2.2.7 Stop mode acknowledge error (SACKERR)

This reset is generated if the core attempts to enter stop mode, but not all modules acknowledge stop mode within 1025 cycles of the 1 kHz LPO clock.

A module might not acknowledge the entry to stop mode if an error condition occurs. The error can be caused by a failure of an external clock input to a module.

6.2.2.8 Software reset (SW)

The SYSRESETREQ bit in the NVIC application interrupt and reset control register can be set to force a software reset on the device. (See ARM's NVIC documentation for the full description of the register fields, especially the VECTKEY field requirements.) Setting SYSRESETREQ generates a software reset request. This reset forces a system reset of all major components except for the debug module. A software reset causes the RCM's SRS1[SW] bit to set.

6.2.2.9 Lockup reset (LOCKUP)

The LOCKUP gives immediate indication of seriously errant kernel software. This is the result of the core being locked because of an unrecoverable exception following the activation of the processor's built in system state protection hardware.

The LOCKUP condition causes a system reset and also causes the RCM's SRS1[LOCKUP] bit to set.

6.2.2.10 Tamper detect reset (TAMPER)

A tamper detect condition can optionally cause a system reset and also causes the RCM's SRS1[TAMPER] bit to set.

6.2.2.11 EzPort reset

The EzPort supports a system reset request via EzPort signaling. The EzPort generates a system reset request following execution of a Reset Chip (RESET) command via the EzPort interface. This method of reset allows the chip to boot from flash memory after it has been programmed by an external source. The EzPort is enabled or disabled by the $\overline{\text{EZP_CS}}$ pin.

An EzPort reset causes the RCM's SRS1[EZPT] bit to set.

6.2.2.12 MDM-AP system reset request

Set the system reset request bit in the MDM-AP control register to initiate a system reset. This is the primary method for resets via the JTAG/SWD interface. The system reset is held until this bit is cleared.

Set the core hold reset bit in the MDM-AP control register to hold the core in reset as the rest of the chip comes out of system reset.

6.2.3 MCU Resets

A variety of resets are generated by the MCU to reset different modules.

6.2.3.1 VBAT POR

The VBAT POR asserts on a VBAT POR reset source. It affects only the modules within the VBAT power domain: RTC, DryIce, and VBAT Register File. These modules are not affected by the other reset types.

6.2.3.2 POR Only

The POR Only reset asserts on the POR reset source only. It resets the PMC and System Register File.

The POR Only reset also causes all other reset types (except VBAT POR) to occur.

6.2.3.3 Chip POR not VLLS

The Chip POR not VLLS reset asserts on POR and LVD reset sources. It resets parts of the SMC and SIM. It also resets the LPTMR.

The Chip POR not VLLS reset also causes these resets to occur: Chip POR, Chip Reset not VLLS, and Chip Reset (including Early Chip Reset).

6.2.3.4 Chip POR

The Chip POR asserts on POR, LVD, and VLLS Wakeup reset sources. It resets the Reset Pin Filter registers and parts of the SIM and MCG.

The Chip POR also causes the Chip Reset (including Early Chip Reset) to occur.

6.2.3.5 Chip Reset not VLLS

The Chip Reset not VLLS reset asserts on all reset sources except a VLLS Wakeup that does not occur via the $\overline{\text{RESET}}$ pin. It resets parts of the SMC, LLWU, and other modules that remain powered during VLLS mode.

The Chip Reset not VLLS reset also causes the Chip Reset (including Early Chip Reset) to occur.

6.2.3.6 Early Chip Reset

The Early Chip Reset asserts on all reset sources. It resets only the flash memory module. It negates before flash memory initialization begins ("earlier" than when the Chip Reset negates).

6.2.3.7 Chip Reset

Chip Reset asserts on all reset sources and only negates after flash initialization has completed and the $\overline{\text{RESET}}$ pin has also negated. It resets the remaining modules (the modules not reset by other reset types).

6.2.4 Reset Pin

For all reset sources except a VLLS Wakeup that does not occur via the $\overline{\text{RESET}}$ pin, the $\overline{\text{RESET}}$ pin is driven low by the MCU for at least 128 bus clock cycles and until flash initialization has completed.

After flash initialization has completed, the $\overline{\text{RESET}}$ pin is released, and the internal Chip Reset negates after the $\overline{\text{RESET}}$ pin is pulled high. Keeping the $\overline{\text{RESET}}$ pin asserted externally delays the negation of the internal Chip Reset.

6.2.5 Debug resets

The following sections detail the debug resets available on the device.

6.2.5.1 JTAG reset

The JTAG module generate a system reset when certain IR codes are selected. This functional reset is asserted when EzPort, EXTEST, HIGHZ and CLAMP instructions are active. The reset source from the JTAG module is released when any other IR code is selected. A JTAG reset causes the RCM's SRS1[JTAG] bit to set.

6.2.5.2 nTRST reset

The nTRST pin causes a reset of the JTAG logic when asserted. Asserting the nTRST pin allows the debugger to gain control of the TAP controller state machine (after exiting LLS or VLLSx) without resetting the state of the debug modules.

The nTRST pin does not cause a system reset.

6.2.5.3 Resetting the Debug subsystem

Use the CDBGIRSTREQ bit within the SWJ-DP CTRL/STAT register to reset the debug modules. However, as explained below, using the CDBGIRSTREQ bit does not reset all debug-related registers.

CDBGIRSTREQ resets the debug-related registers within the following modules:

- SWJ-DP
- AHB-AP
- ETM
- TPIU
- MDM-AP (MDM control and status registers)

CDBGIRSTREQ does not reset the debug-related registers within the following modules:

- CM4 core (core debug registers: DHCSR, DCRSR, DCRDR, DEMCR)
- FPB
- DWT
- ITM
- NVIC
- Crossbar bus switch¹
- AHB-AP¹
- Private peripheral bus¹

6.3 Boot

This section describes the boot sequence, including sources and options.

6.3.1 Boot sources

1. CDBGIRSTREQ does not affect AHB resources so that debug resources on the private peripheral bus are available during System Reset.

This device only supports booting from internal flash. Any secondary boot must go through an initialization sequence in flash.

6.3.2 Boot options

The device's functional mode is controlled by the state of the EzPort chip select ($\overline{\text{EZP_CS}}$) pin during reset.

The device can be in single chip (default) or serial flash programming mode (EzPort). While in single chip mode the device can be in run or various low power modes mentioned in [Power mode transitions](#).

Table 6-2. Mode select decoding

| EzPort chip select ($\overline{\text{EZP_CS}}$) | Description |
|--|--|
| 0 | Serial flash programming mode (EzPort) |
| 1 | Single chip (default) |

6.3.3 FOPT boot options

The flash option register (FOPT) in the flash memory module allows the user to customize the operation of the MCU at boot time. The register contains read-only bits that are loaded from the NVM's option byte in the flash configuration field. The user can reprogram the option byte in flash to change the FOPT values that are used for subsequent resets. For more details on programming the option byte, refer to the flash memory chapter.

The MCU uses the FOPT register bits to configure the device at reset as shown in the following table.

Table 6-3. Flash Option Register Bit Definitions

| Bit Num | Field | Value | Definition |
|---------|----------|-------|--|
| 7-3 | Reserved | | Reserved for future expansion. |
| 2 | NMI_DIS | | Enable/disable control for the NMI function. |
| | | 0 | NMI interrupts are always blocked. The associated pin continues to default to NMI pin controls with internal pullup enabled. |
| | | 1 | NMI pin/interrupts reset default to enabled. |

Table continues on the next page...

Table 6-3. Flash Option Register Bit Definitions (continued)

| Bit Num | Field | Value | Definition |
|---------|------------|-------|--|
| 1 | EZPORT_DIS | | Enable/disable EzPort function. |
| | | 0 | EzPort operation is disabled. The device always boots to normal CPU execution and the state of $\overline{\text{EZP_CS}}$ signal during reset is ignored. This option avoids inadvertent resets into EzPort mode if the $\overline{\text{EZP_CS}}$ /NMI pin is used for its NMI function. |
| | | 1 | EzPort operation is enabled. The state of $\overline{\text{EZP_CS}}$ pin during reset determines if device enters EzPort mode. |
| 0 | LPBOOT | | Control the reset value of OUTDIVx values in SIM_CLKDIV1 register. Larger divide value selections produce lower average power consumption during POR, VLLSx recoveries and reset sequencing and after reset exit. |
| | | 0 | Low-power boot: OUTDIVx values in SIM_CLKDIV1 register are auto-configured at reset exit for higher divide values that produce lower power consumption at reset exit. <ul style="list-style-type: none"> Core and system clock divider (OUTDIV1) and bus clock divider (OUTDIV2) are 0x7 (divide by 8) Flash clock divider (OUTDIV4) is 0xF (divide by 16) |
| | | 1 | Normal boot: OUTDIVx values in SIM_CLKDIV1 register are auto-configured at reset exit for higher frequency values that produce faster operating frequencies at reset exit. <ul style="list-style-type: none"> Core and system clock divider (OUTDIV1) and bus clock divider (OUTDIV2) are 0x0 (divide by 1) Flash clock divider (OUTDIV4) is 0x1 (divide by 2) |

6.3.4 Boot sequence

At power up, the on-chip regulator holds the system in a POR state until the input supply is above the POR threshold. The system continues to be held in this static state until the internally regulated supplies have reached a safe operating voltage as determined by the LVD. The Mode Controller reset logic then controls a sequence to exit reset.

1. A system reset is held on internal logic, the $\overline{\text{RESET}}$ pin is driven out low, and the MCG is enabled in its default clocking mode.
2. Required clocks are enabled (Core Clock, System Clock, Flash Clock, and any Bus Clocks that do not have clock gate control).
3. The system reset on internal logic continues to be held, but the Flash Controller is released from reset and begins initialization operation while the Mode Control logic continues to drive the $\overline{\text{RESET}}$ pin out low for a count of ~128 Bus Clock cycles.
4. The $\overline{\text{RESET}}$ pin is released, but the system reset of internal logic continues to be held until the Flash Controller finishes initialization. EzPort mode is selected instead of the normal CPU execution if $\overline{\text{EZP_CS}}$ is low when the internal reset is deasserted. EzPort mode can be disabled by programming the FOPT[EZPORT_DIS] field in the Flash Memory module.

5. When Flash Initialization completes, the $\overline{\text{RESET}}$ pin is observed. If $\overline{\text{RESET}}$ continues to be asserted (an indication of a slow rise time on the $\overline{\text{RESET}}$ pin or external drive in low), the system continues to be held in reset. Once the $\overline{\text{RESET}}$ pin is detected high, the system is released from reset.
6. At release of system reset, clocking is switched to a slow clock if the FOPT[LPBOOT] field in the Flash Memory module is configured for Low Power Boot
7. When the system exits reset, the processor sets up the stack, program counter (PC), and link register (LR). The processor reads the start SP (SP_main) from vector-table offset 0. The core reads the start PC from vector-table offset 4. LR is set to 0xFFFF_FFFF. What happens next depends on the NMI input and the FOPT[NMI_DIS] field in the Flash Memory module:
 - If the NMI input is high or the NMI function is disabled in the NMI_DIS field, the CPU begins execution at the PC location.
 - If the NMI input is low and the NMI function is enabled in the NMI_DIS field, this results in an NMI interrupt. The processor executes an Exception Entry and reads the NMI interrupt handler address from vector-table offset 8. The CPU begins execution at the NMI interrupt handler.
8. If FlexNVM is enabled, the flash controller continues to restore the FlexNVM data. This data is not available immediately out of reset and the system should not access this data until the flash controller completes this initialization step as indicated by the EEERDY flag.

Subsequent system resets follow this reset flow beginning with the step where system clocks are enabled.

Chapter 7

Power Management

7.1 Introduction

This chapter describes the various chip power modes and functionality of the individual modules in these modes.

7.2 Power Modes Description

The power management controller (PMC) provides multiple power options to allow the user to optimize power consumption for the level of functionality needed.

Depending on the stop requirements of the user application, a variety of stop modes are available that provide state retention, partial power down or full power down of certain logic and/or memory. I/O states are held in all modes of operation. The following table compares the various power modes available.

For Run and VLPR mode there is a corresponding wait and stop mode. Wait modes are similar to ARM sleep modes. Stop modes (VLPS, STOP) are similar to ARM sleep deep mode. The very low power run (VLPR) operating mode can drastically reduce runtime power when the maximum bus frequency is not required to handle the application needs.

The three primary modes of operation are run, wait and stop. The WFI instruction invokes both wait and stop modes for the chip. The primary modes are augmented in a number of ways to provide lower power based on application needs.

Table 7-1. Chip power modes

| Chip mode | Description | Core mode | Normal recovery method |
|------------|---|-----------|------------------------|
| Normal run | Allows maximum performance of chip. Default mode out of reset; on-chip voltage regulator is on. | Run | - |

Table continues on the next page...

Table 7-1. Chip power modes (continued)

| Chip mode | Description | Core mode | Normal recovery method |
|-------------------------------------|--|------------|-------------------------------|
| Normal Wait - via WFI | Allows peripherals to function while the core is in sleep mode, reducing power. NVIC remains sensitive to interrupts; peripherals continue to be clocked. | Sleep | Interrupt |
| Normal Stop - via WFI | Places chip in static state. Lowest power mode that retains all registers while maintaining LVD protection. NVIC is disabled; AWIC is used to wake up from interrupt; peripheral clocks are stopped. | Sleep Deep | Interrupt |
| VLPR (Very Low Power Run) | On-chip voltage regulator is in a low power mode that supplies only enough power to run the chip at a reduced frequency. Reduced frequency Flash access mode (1 MHz); LVD off; internal oscillator provides a low power 4 MHz source for the core, the bus and the peripheral clocks. | Run | Interrupt |
| VLPW (Very Low Power Wait) -via WFI | Same as VLPR but with the core in sleep mode to further reduce power; NVIC remains sensitive to interrupts (FCLK = ON). On-chip voltage regulator is in a low power mode that supplies only enough power to run the chip at a reduced frequency. | Sleep | Interrupt |
| VLPS (Very Low Power Stop)-via WFI | Places chip in static state with LVD operation off. Lowest power mode with ADC and pin interrupts functional. Peripheral clocks are stopped, but LPTimer, RTC, CMP, DAC can be used. NVIC is disabled (FCLK = OFF); AWIC is used to wake up from interrupt. On-chip voltage regulator is in a low power mode that supplies only enough power to run the chip at a reduced frequency. All SRAM is operating (content retained and I/O states held). | Sleep Deep | Interrupt |
| LLS (Low Leakage Stop) | State retention power mode. Most peripherals are in state retention mode (with clocks stopped), but LLWU, LPTimer, RTC, CMP, DAC can be used. NVIC is disabled; LLWU is used to wake up. NOTE: The LLWU interrupt must not be masked by the interrupt controller to avoid a scenario where the system does not fully exit stop mode on an LLS recovery. All SRAM is operating (content retained and I/O states held). | Sleep Deep | Wakeup Interrupt ¹ |
| VLLS3 (Very Low Leakage Stop3) | Most peripherals are disabled (with clocks stopped), but LLWU, LPTimer, RTC, CMP, DAC can be used. NVIC is disabled; LLWU is used to wake up. SRAM_U and SRAM_L remain powered on (content retained and I/O states held). | Sleep Deep | Wakeup Reset ² |
| VLLS2 (Very Low Leakage Stop2) | Most peripherals are disabled (with clocks stopped), but LLWU, LPTimer, RTC, CMP, DAC can be used. NVIC is disabled; LLWU is used to wake up. SRAM_L is powered off. A portion of SRAM_U remains powered on (content retained and I/O states held). | Sleep Deep | Wakeup Reset ² |
| VLLS1 (Very Low Leakage Stop1) | Most peripherals are disabled (with clocks stopped), but LLWU, LPTimer, RTC, CMP, DAC can be used. NVIC is disabled; LLWU is used to wake up. All of SRAM_U and SRAM_L are powered off. The 32-byte system register file and the 32-byte VBAT register file remain powered for customer-critical data. | Sleep Deep | Wakeup Reset ² |

Table continues on the next page...

Table 7-1. Chip power modes (continued)

| Chip mode | Description | Core mode | Normal recovery method |
|---------------------------------|--|------------|---------------------------|
| VLLS0 (Very Low Leakage Stop 0) | Most peripherals are disabled (with clocks stopped), but LLWU and RTC can be used. NVIC is disabled; LLWU is used to wake up. All of SRAM_U and SRAM_L are powered off. The 32-byte system register file and the 32-byte VBAT register file remain powered for customer-critical data. The POR detect circuit can be optionally powered off. | Sleep Deep | Wakeup Reset ² |
| BAT (backup battery only) | The chip is powered down except for the VBAT supply. The RTC and the 32-byte VBAT register file for customer-critical data remain powered. | Off | Power-up Sequence |

1. Resumes normal run mode operation by executing the LLWU interrupt service routine.
2. Follows the reset flow with the LLWU interrupt flag set for the NVIC.

7.3 Entering and exiting power modes

The WFI instruction invokes wait and stop modes for the chip. The processor exits the low-power mode via an interrupt. The [Nested Vectored Interrupt Controller \(NVIC\)](#) describes interrupt operation and what peripherals can cause interrupts.

NOTE

The WFE instruction can have the side effect of entering a low-power mode, but that is not its intended usage. See ARM documentation for more on the WFE instruction.

Recovery from VLLSx is through the wake-up Reset event. The chip wake-ups from VLLSx by means of reset, an enabled pin or enabled module. See the table "LLWU inputs" in the LLWU configuration section for a list of the sources.

The wake-up flow from VLLSx is through reset. The wakeup bit in the SRS registers in the RCM is set indicating that the chip is recovering from a low power mode. Code execution begins; however, the I/O pins are held in their pre low power mode entry states, and the system oscillator and MCG registers are reset (even if EREFSTEN had been set before entering VLLSx). Software must clear this hold by writing a 1 to the ACKISO bit in the Regulator Status and Control Register in the PMC module.

NOTE

To avoid unwanted transitions on the pins, software must re-initialize the I/O pins to their pre-low-power mode entry states *before* releasing the hold.

If the oscillator was configured to continue running during VLLSx modes, it must be re-configured before the ACKISO bit is cleared. The oscillator configuration within the MCG is cleared after VLLSx recovery and the oscillator will stop when ACKISO is cleared unless the register is re-configured.

7.4 Power mode transitions

The following figure shows the power mode transitions. Any reset always brings the chip back to the normal run state. In run, wait, and stop modes active power regulation is enabled. The VLPx modes offer a lower power operating mode than normal modes. VLPR and VLPW are limited in frequency. The LLS and VLLSx modes are the lowest power stop modes based on amount of logic or memory that is required to be retained by the application.

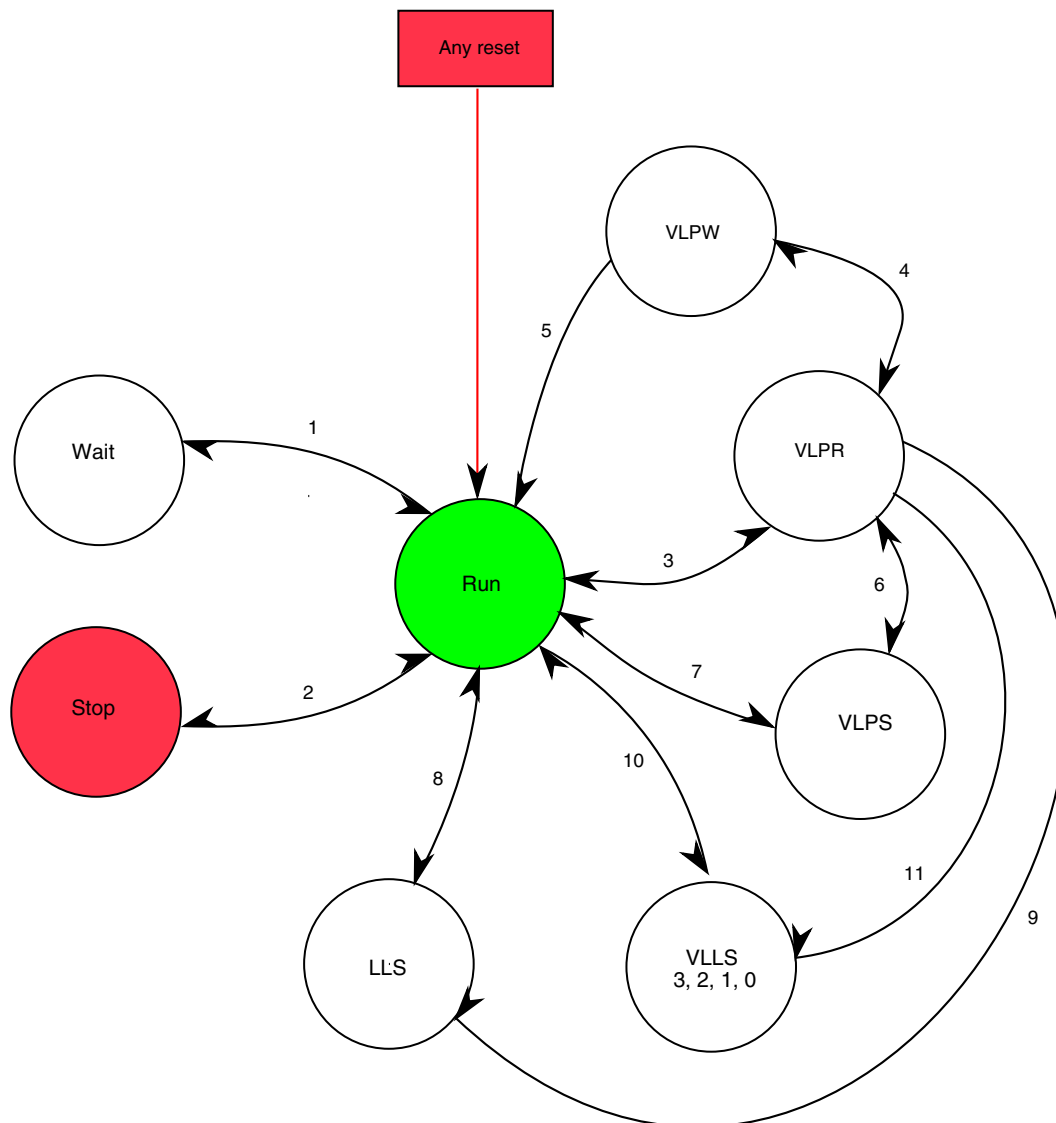


Figure 7-1. Power mode state transition diagram

7.5 Power modes shutdown sequencing

When entering stop or other low-power modes, the clocks are shut off in an orderly sequence to safely place the chip in the targeted low-power state. All low-power entry sequences are initiated by the core executing an WFI instruction. The ARM core's outputs, SLEEPDEEP and SLEEPING, trigger entry to the various low-power modes:

- System level wait and VLPW modes equate to: SLEEPING & $\overline{\text{SLEEPDEEP}}$
- All other low power modes equate to: SLEEPING & SLEEPDEEP

When entering the non-wait modes, the chip performs the following sequence:

- Shuts off Core Clock and System Clock to the ARM Cortex-M4 core immediately.
- Polls stop acknowledge indications from the non-core crossbar masters (DMA), supporting peripherals (SPI, PIT, RNG) and the Flash Controller for indications that System Clocks, Bus Clock and/or Flash Clock need to be left enabled to complete a previously initiated operation, effectively stalling entry to the targeted low power mode. When all acknowledges are detected, System Clock, Bus Clock and Flash Clock are turned off at the same time.
- MCG and Mode Controller shut off clock sources and/or the internal supplies driven from the on-chip regulator as defined for the targeted low power mode.

In wait modes, most of the system clocks are not affected by the low power mode entry. The Core Clock to the ARM Cortex-M4 core is shut off. Some modules support stop-in-wait functionality and have their clocks disabled under these configurations.

The debugger modules support a transition from stop, wait, VLPS, and VLPW back to a halted state when the debugger is enabled. This transition is initiated by setting the Debug Request bit in MDM-AP control register. As part of this transition, system clocking is re-established and is equivalent to normal run/VLPR mode clocking configuration.

7.6 Module Operation in Low Power Modes

The following table illustrates the functionality of each module while the chip is in each of the low power modes. (Debug modules are discussed separately; see [Debug in Low Power Modes](#).) Number ratings (such as 2 MHz and 1 Mbit/s) represent the maximum frequencies or maximum data rates per mode. Also, these terms are used:

- FF = Full functionality. In VLPR and VLPW the system frequency is limited, but if a module does not have a limitation in its functionality, it is still listed as FF.
- static = Module register states and associated memories are retained.
- powered = Memory is powered to retain contents.
- low power = Flash has a low power state that retains configuration registers to support faster wakeup.
- OFF = Modules are powered off; module is in reset state upon wakeup.
- wakeup = Modules can serve as a wakeup source for the chip.

Table 7-2. Module operation in low power modes

| Modules | Stop | VLPR | VLPW | VLPS | LLS | VLLSx |
|-----------------|--------|------|------|--------|--------|-------|
| Core modules | | | | | | |
| NVIC | static | FF | FF | static | static | OFF |
| System modules | | | | | | |
| Mode Controller | FF | FF | FF | FF | FF | FF |

Table continues on the next page...

Table 7-2. Module operation in low power modes (continued)

| Modules | Stop | VLPR | VLPW | VLPS | LLS | VLLSx |
|-------------------------------------|---|-------------------------------|-------------------------------|-------------------------------|--------------------------------|--|
| LLWU ¹ | static | static | static | static | FF | FF ² |
| Regulator | ON | low power | low power | low power | low power | low power in VLLS2/3, OFF in VLLS0/1 |
| LVD | ON | disabled | disabled | disabled | disabled | disabled |
| Brown-out Detection | ON | ON | ON | ON | ON | ON in VLLS1/2/3, optionally disabled in VLLS0 ³ |
| DMA | static | FF | FF | static | static | OFF |
| Watchdog | FF | FF | FF | FF | static | OFF |
| EWM | static | FF | static | static | static | OFF |
| Clocks | | | | | | |
| 1kHz LPO | ON | ON | ON | ON | ON | ON in VLLS1/2/3, OFF in VLLS0 |
| System oscillator (OSC) | OSCERCLK optional | OSCERCLK max of 4 MHz crystal | OSCERCLK max of 4 MHz crystal | OSCERCLK max of 4 MHz crystal | limited to low range/low power | limited to low range/low power in VLLS1/2/3, OFF in VLLS0 |
| MCG | static - MCGIRCLK optional; PLL optionally on but gated | 4 MHz IRC | 4 MHz IRC | static - no clock output | static - no clock output | OFF |
| Core clock | OFF | 4 MHz max | OFF | OFF | OFF | OFF |
| System clock | OFF | 4 MHz max | 4 MHz max | OFF | OFF | OFF |
| Bus clock | OFF | 4 MHz max | 4 MHz max | OFF | OFF | OFF |
| Memory and memory interfaces | | | | | | |
| Flash | powered | 1 MHz max access - no pgm | low power | low power | OFF | OFF |
| Portion of SRAM_U ⁴ | low power | low power | low power | low power | low power | low power in VLLS3,2; otherwise OFF |
| Remaining SRAM_U and all of SRAM_L | low power | low power | low power | low power | low power | low power in VLLS3; otherwise OFF |
| FlexMemory | low power | low power ⁵ | low power | low power | low power | OFF |
| VBAT Register file ⁶ | powered | powered | powered | powered | powered | powered |
| System Register files | powered | powered | powered | powered | powered | powered |
| EzPort | disabled | disabled | disabled | disabled | disabled | disabled |
| Communication interfaces | | | | | | |

Table continues on the next page...

Table 7-2. Module operation in low power modes (continued)

| Modules | Stop | VLPR | VLPW | VLPS | LLS | VLLSx |
|---------------------------------|-------------------------------------|------------|------------|-------------------------------------|----------------------|---|
| UART | static, wakeup on edge | 125 kbit/s | 125 kbit/s | static, wakeup on edge | static | OFF |
| SPI | static | 1 Mbit/s | 1 Mbit/s | static | static | OFF |
| I ² C | static, address match wakeup | 100 kbit/s | 100 kbit/s | static, address match wakeup | static | OFF |
| I ² S | FF with external clock ⁷ | FF | FF | FF with external clock ⁷ | static | OFF |
| Security | | | | | | |
| CRC | static | FF | FF | static | static | OFF |
| RNG | static | FF | static | static | static | OFF |
| DryIce ⁶ | FF | FF | FF | FF | FF | FF |
| Timers | | | | | | |
| FTM | static | FF | FF | static | static | OFF |
| PIT | static | FF | FF | static | static | OFF |
| PDB | static | FF | FF | static | static | OFF |
| LPTMR | FF | FF | FF | FF | FF | FF ⁸ |
| RTC - 32kHz OSC ⁶ | FF | FF | FF | FF | FF ⁹ | FF ⁹ |
| CMT | static | FF | FF | static | static | OFF |
| Analog | | | | | | |
| 16-bit ADC | ADC internal clock only | FF | FF | ADC internal clock only | static | OFF |
| CMP ¹⁰ | HS or LS level compare | FF | FF | HS or LS level compare | LS level compare | LS level compare in VLLS1/2/3, OFF in VLLS0 |
| 6-bit DAC | static | FF | FF | static | static | static |
| VREF | FF | FF | FF | FF | static | OFF |
| 12-bit DAC | static | FF | FF | static | static | static |
| Human-machine interfaces | | | | | | |
| GPIO | wakeup | FF | FF | wakeup | static, pins latched | OFF, pins latched |

- Using the LLWU module, the external pins available for this chip do not require the associated peripheral function to be enabled. It only requires the function controlling the pin (GPIO or peripheral) to be configured as an input to allow a transition to occur to the LLWU.
- Since LPO clock source is disabled, filters will be bypassed during VLLS0
- The VLLSCTRL[PORPO] bit in the SMC module controls this option.
- A KB portion of SRAM_U block is left powered on in low power mode VLLS2.
- FlexRAM enabled as EEPROM is not writable in VLPR and writes are ignored. Read accesses to FlexRAM as EEPROM while in VLPR are allowed. There are no access restrictions for FlexRAM configured as traditional RAM.
- These components remain powered in BAT power mode.
- Use an externally generated bit clock or an externally generated audio master clock (including EXTAL).
- System OSC and LPO clock sources are not available in VLLS0
- RTC_CLKOUT is not available.

10. CMP in stop or VLPS supports high speed or low speed external pin to pin or external pin to DAC compares. CMP in LLS or VLLSx only supports low speed external pin to pin or external pin to DAC compares. Windowed, sampled & filtered modes of operation are not available while in stop, VLPS, LLS, or VLLSx modes.

7.7 Clock Gating

To conserve power, the clocks to most modules can be turned off using the SCGCx registers in the SIM module. These bits are cleared after any reset, which disables the clock to the corresponding module. Prior to initializing a module, set the corresponding bit in the SCGCx register to enable the clock. Before turning off the clock, make sure to disable the module. For more details, refer to the clock distribution and SIM chapters.



Chapter 8 Security

8.1 Introduction

This device implements security based on the mode selected from the flash module. The following sections provide an overview of flash security and details the effects of security on non-flash modules.

8.2 Flash Security

The flash module provides security information to the MCU based on the state held by the FSEC[SEC] bits. The MCU, in turn, confirms the security request and limits access to flash resources. During reset, the flash module initializes the FSEC register using data read from the security byte of the flash configuration field.

NOTE

The security features apply only to external accesses via debug and EzPort. CPU accesses to the flash are not affected by the status of FSEC.

In the unsecured state all flash commands are available to the programming interfaces (JTAG and EzPort), as well as user code execution of Flash Controller commands. When the flash is secured (FSEC[SEC] = 00, 01, or 11), programmer interfaces are only allowed to launch mass erase operations and have no access to memory locations.

Further information regarding the flash security options and enabling/disabling flash security is available in the [Flash Memory Module](#).

8.3 Security Interactions with other Modules

The flash security settings are used by the SoC to determine what resources are available. The following sections describe the interactions between modules and the flash security settings or the impact that the flash security has on non-flash modules.

8.3.1 Security Interactions with EzPort

When flash security is active the MCU can still boot in EzPort mode. The EzPort holds the flash logic in NVM special mode and thus limits flash operation when flash security is active. While in EzPort mode and security is active, flash bulk erase (BE) can still be executed. The write FCCOB registers (WRFCCOB) command is limited to the mass erase (Erase All Blocks) and verify all 1s (Read 1s All Blocks) commands. Read accesses to internal memories via the EzPort are blocked when security is enabled.

The mass erase can be used to disable flash security, but all of the flash contents are lost in the process. A mass erase via the EzPort is allowed even when some memory locations are protected.

When mass erase has been disabled, mass erase via the EzPort is blocked and cannot be defeated.

8.3.2 Security Interactions with Debug

When flash security is active the JTAG port cannot access the memory resources of the MCU. Boundary scan chain operations work, but debugging capabilities are disabled so that the debug port cannot read flash contents.

Although most debug functions are disabled, the debugger can write to the Flash Mass Erase in Progress bit in the MDM-AP Control register to trigger a mass erase (Erase All Blocks) command. A mass erase via the debugger is allowed even when some memory locations are protected.

When mass erase is disabled, mass erase via the debugger is blocked.

Chapter 9

Debug

9.1 Introduction

This device's debug is based on the ARM coresight architecture and is configured in each device to provide the maximum flexibility as allowed by the restrictions of the pinout and other available resources.

Four debug interfaces are supported:

- IEEE 1149.1 JTAG
- IEEE 1149.7 JTAG (cJTAG)
- Serial Wire Debug (SWD)
- ARM Real-Time Trace Interface

The basic Cortex-M4 debug architecture is very flexible. The following diagram shows the topology of the core debug architecture and its components.

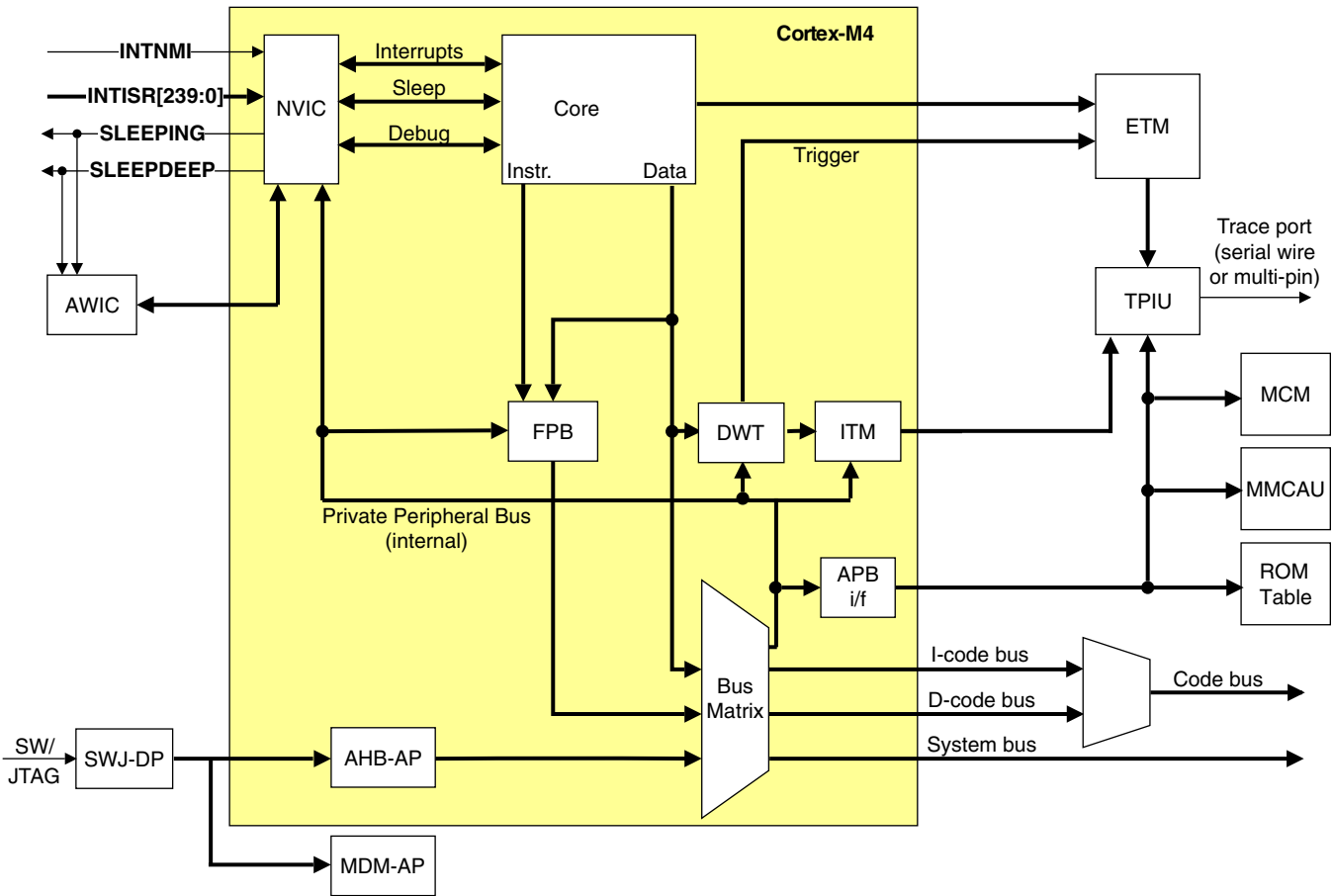


Figure 9-1. Cortex-M4 Debug Topology

The following table presents a brief description of each one of the debug components.

Table 9-1. Debug Components Description

| Module | Description |
|------------------------------------|---|
| SWJ-DP+ cJTAG | Modified Debug Port with support for SWD, JTAG, cJTAG |
| AHB-AP | AHB Master Interface from JTAG to debug module and SOC system memory maps |
| MDM-AP | Provides centralized control and status registers for an external debugger to control the device. |
| ROM Table | Identifies which debug IP is available. |
| Core Debug | Singlestep, Register Access, Run, Core Status |
| ETM (Embedded Trace Macrocell) | ETMv3.5 Architecture |
| ITM | S/W Instrumentation Messaging + Simple Data Trace Messaging + Watchpoint Messaging |
| DWT (Data and Address Watchpoints) | 4 data and address watchpoints |

Table continues on the next page...

Table 9-1. Debug Components Description (continued)

| Module | Description |
|--|--|
| FPB (Flash Patch and Breakpoints) | <p>The FPB implements hardware breakpoints and patches code and data from code space to system space.</p> <p>The FPB unit contains two literal comparators for matching against literal loads from Code space, and remapping to a corresponding area in System space.</p> <p>The FBP also contains six instruction comparators for matching against instruction fetches from Code space, and remapping to a corresponding area in System space. Alternatively, the six instruction comparators can individually configure the comparators to return a Breakpoint Instruction (BKPT) to the processor core on a match, so providing hardware breakpoint capability.</p> |
| TPIU (Trace Port Interface Unit) | <p>Synchronous Mode (5-pin) = TRACE_D[3:0] + TRACE_CLKOUT</p> <p>Synchronous Mode (3-pin) = TRACE_D[1:0] + TRACE_CLKOUT</p> <p>Asynchronous Mode (1-pin) = TRACE_SWO (available on JTAG_TDO)</p> |
| MCM (Miscellaneous Control Module) | The MCM provides miscellaneous control functions . |

9.1.1 References

For more information on ARM debug components, see these documents:

- ARMv7-M Architecture Reference Manual
- ARM Debug Interface v5.1
- ARM CoreSight Architecture Specification
- ARM ETM Architecture Specification v3.5

9.2 The Debug Port

The configuration of the cJTAG module, JTAG controller, and debug port is illustrated in the following figure:

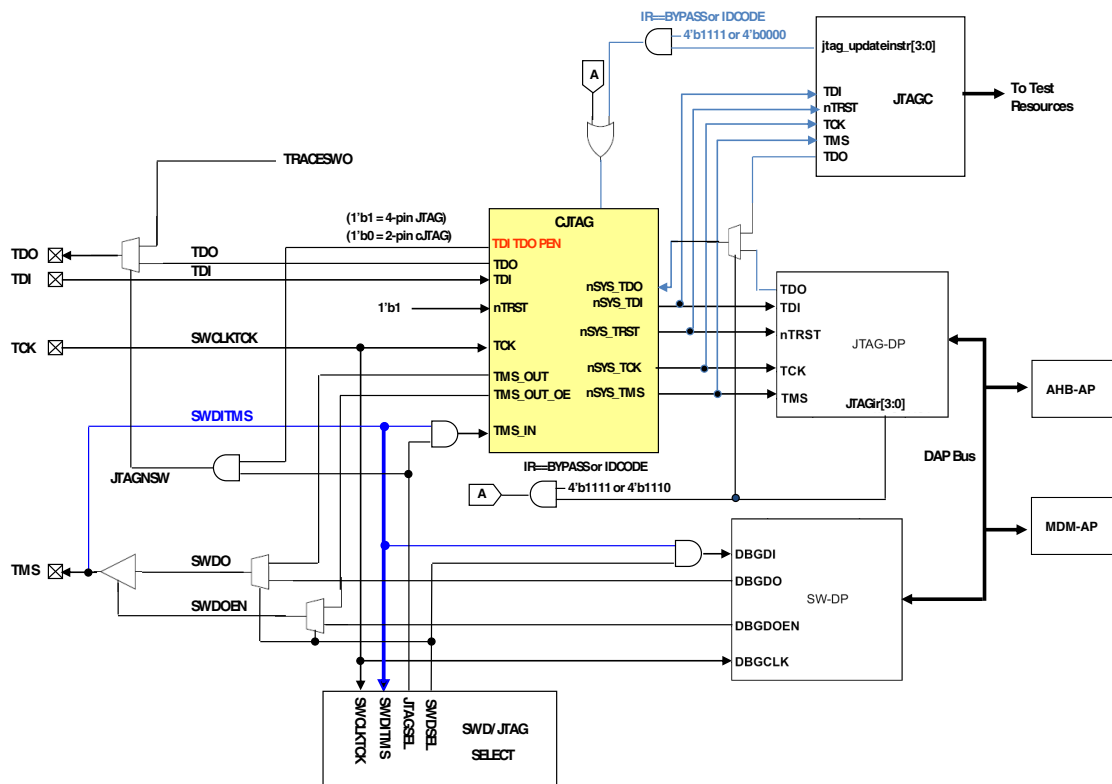


Figure 9-2. Modified Debug Port

The debug port comes out of reset in standard JTAG mode and is switched into either cJTAG or SWD mode by the following sequences. Once the mode has been changed, unused debug pins can be reassigned to any of their alternative muxed functions.

9.2.1 JTAG-to-SWD change sequence

1. Send more than 50 TCK cycles with TMS (SWDIO) = 1
2. Send the 16-bit sequence on TMS (SWDIO) = 0111_1001_1110_0111 (MSB transmitted first)
3. Send more than 50 TCK cycles with TMS (SWDIO) = 1

NOTE

See the ARM documentation for the CoreSight DAP Lite for restrictions.

9.2.2 JTAG-to-cJTAG change sequence

1. Reset the debug port

2. Set the control level to 2 via zero-bit scans
3. Execute the Store Format (STFMT) command (00011) to set the scan format register to 1149.7 scan format

9.3 Debug Port Pin Descriptions

The debug port pins default after POR to their JTAG functionality with the exception of JTAG_TRST_b and can be later reassigned to their alternate functionalities. In cJTAG and SWD modes JTAG_TDI and JTAG_TRST_b can be configured to alternate GPIO functions.

Table 9-2. Debug port pins

| Pin Name | JTAG Debug Port | | cJTAG Debug Port | | SWD Debug Port | | Internal Pull-up\Down |
|------------------------|-----------------|--------------------------|------------------|--------------------------------|----------------|--------------------------------|-----------------------|
| | Type | Description | Type | Description | Type | Description | |
| JTAG_TMS/ SWD_DIO | I/O | JTAG Test Mode Selection | I/O | cJTAG Data | I/O | Serial Wire Data | Pull-up |
| JTAG_TCLK/ SWD_CLK | I | JTAG Test Clock | I | cJTAG Clock | I | Serial Wire Clock | Pull-down |
| JTAG_TDI | I | JTAG Test Data Input | - | - | - | - | Pull-up |
| JTAG_TDO/ TRACE_SWO | O | JTAG Test Data Output | O | Trace output over a single pin | O | Trace output over a single pin | N/C |
| JTAG_TRST_b | I | JTAG Reset | I | cJTAG Reset | - | - | Pull-up |

9.4 System TAP connection

The system JTAG controller is connected in parallel to the ARM TAP controller. The system JTAG controller IR codes overlay the ARM JTAG controller IR codes without conflict. Refer to the IR codes table for a list of the available IR codes. The output of the TAPs (TDO) are muxed based on the IR code which is selected. This design is fully JTAG compliant and appears to the JTAG chain as a single TAP. At power on reset, ARM's IDCODE (IR=4'b1110) is selected.

9.4.1 IR Codes

Table 9-3. JTAG Instructions

| Instruction | Code[3:0] | Instruction Summary |
|------------------------|------------------------|---|
| IDCODE | 0000 | Selects device identification register for shift |
| SAMPLE/PRELOAD | 0010 | Selects boundary scan register for shifting, sampling, and preloading without disturbing functional operation |
| SAMPLE | 0011 | Selects boundary scan register for shifting and sampling without disturbing functional operation |
| EXTEST | 0100 | Selects boundary scan register while applying preloaded values to output pins and asserting functional reset |
| HIGHZ | 1001 | Selects bypass register while three-stating all output pins and asserting functional reset |
| CLAMP | 1100 | Selects bypass register while applying preloaded values to output pins and asserting functional reset |
| EZPORT | 1101 | Enables the EZPORT function for the SoC and asserts functional reset. |
| ARM_IDCODE | 1110 | ARM JTAG-DP Instruction |
| BYPASS | 1111 | Selects bypass register for data operations |
| Factory debug reserved | 0101, 0110, 0111 | Intended for factory debug only |
| ARM JTAG-DP Reserved | 1000, 1010, 1011, 1110 | These instructions will go the ARM JTAG-DP controller. Please look at ARM JTAG-DP documentation for more information on these instructions. |
| Reserved ¹ | All other opcodes | Decoded to select bypass register |

1. The manufacturer reserves the right to change the decoding of reserved instruction codes in the future

9.5 JTAG status and control registers

Through the ARM Debug Access Port (DAP), the debugger has access to the status and control elements, implemented as registers on the DAP bus as shown in the following figure. These registers provide additional control and status for low power mode recovery and typical run-control scenarios. The status register bits also provide a means for the debugger to get updated status of the core without having to initiate a bus transaction across the crossbar switch, thus remaining less intrusive during a debug session.

It is important to note that these DAP control and status registers are not memory mapped within the system memory map and are only accessible via the Debug Access Port (DAP) using JTAG, cJTAG, or SWD. The MDM-AP is accessible as Debug Access Port 1 with the available registers shown in the table below.

Table 9-4. MDM-AP Register Summary

| Address | Register | Description |
|---------|----------|-------------|
|---------|----------|-------------|

Table continues on the next page...

Table 9-4. MDM-AP Register Summary (continued)

| | | |
|-------------|---------|--|
| 0x0100_0000 | Status | See MDM-AP Status Register |
| 0x0100_0004 | Control | See MDM-AP Control Register |
| 0x0100_00FC | ID | Read-only identification register that always reads as 0x001C_0000 |

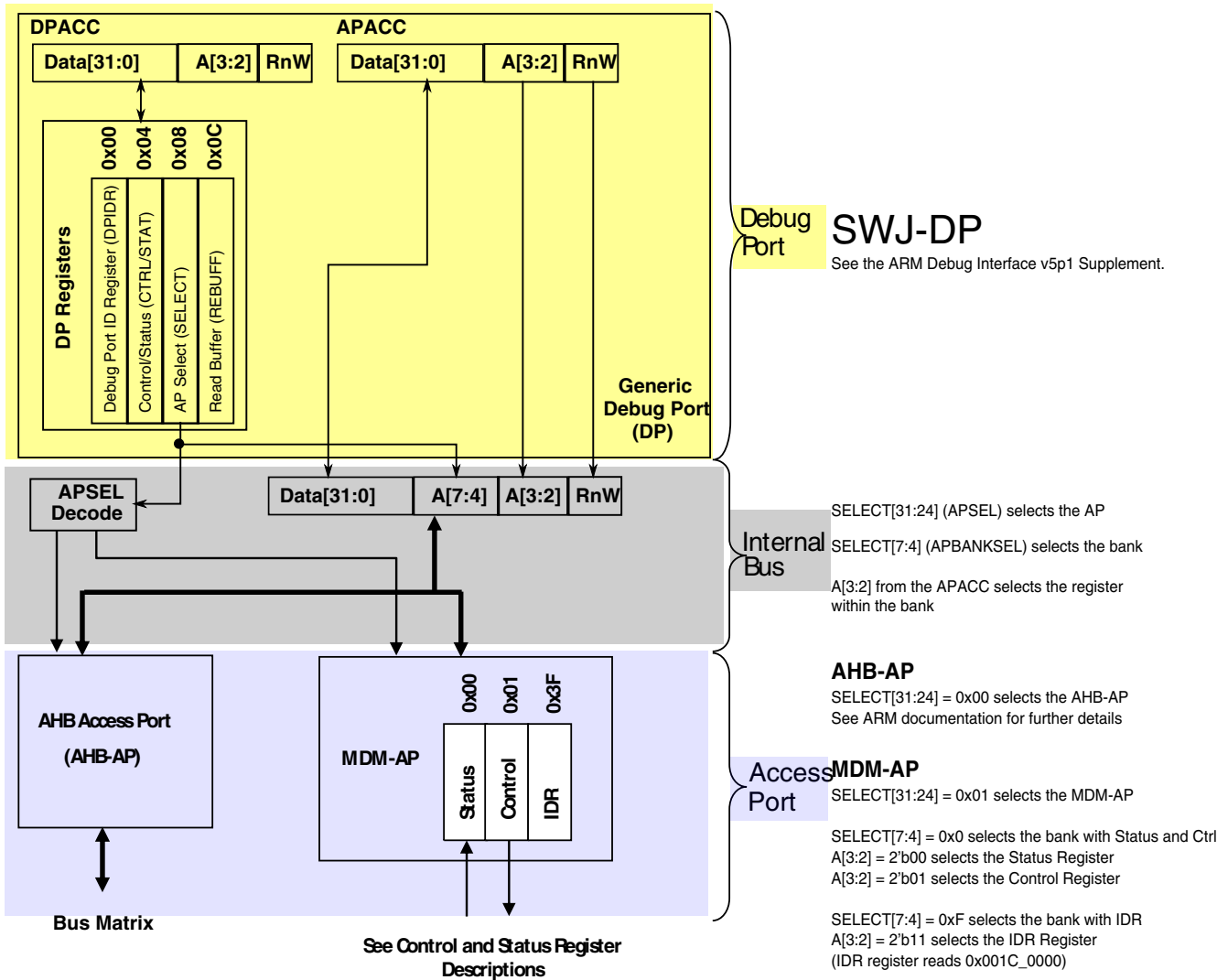


Figure 9-3. MDM AP Addressing

9.5.1 MDM-AP Control Register

Table 9-5. MDM-AP Control register assignments

| Bit | Name | Secure ¹ | Description |
|-----|-------------------------------------|---------------------|--|
| 0 | Flash Mass Erase in Progress | Y | Set to cause mass erase. Cleared by hardware after mass erase operation completes. When mass erase is disabled (via MEEN and SEC settings), the erase request does not occur and the Flash Mass Erase in Progress bit continues to assert until the next system reset. |
| 1 | Debug Disable | N | Set to disable debug. Clear to allow debug operation. When set it overrides the C_DEBUGEN bit within the DHCSR and force disables Debug logic. |
| 2 | Debug Request | N | Set to force the Core to halt. If the Core is in a stop or wait mode, this bit can be used to wakeup the core and transition to a halted state. |
| 3 | System Reset Request | N | Set to force a system reset. The system remains held in reset until this bit is cleared. |
| 4 | Core Hold Reset | N | Configuration bit to control Core operation at the end of system reset sequencing. 0 Normal operation - release the Core from reset along with the rest of the system at the end of system reset sequencing. 1 Suspend operation - hold the Core in reset at the end of reset sequencing. Once the system enters this suspended state, clearing this control bit immediately releases the Core from reset and CPU operation begins. |
| 5 | VLLSx Debug Request (VLLDBGREQ) | N | Set to configure the system to be held in reset after the next recovery from a VLLSx mode. This bit holds the in reset when VLLSx modes are exited to allow the debugger time to re-initialize debug IP before the debug session continues. The Mode Controller captures this bit logic on entry to VLLSx modes. Upon exit from VLLSx modes, the Mode Controller will hold the in reset until VLLDBGACK is asserted. The VLLDBGREQ bit clears automatically due to the POR reset generated as part of the VLLSx recovery. |
| 6 | VLLSx Debug Acknowledge (VLLDBGACK) | N | Set to release a being held in reset following a VLLSx recovery This bit is used by the debugger to release the system reset when it is being held on VLLSx mode exit. The debugger re-initializes all debug IP and then assert this control bit to allow the Mode Controller to release the from reset and allow CPU operation to begin. The VLLDBGACK bit is cleared by the debugger or can be left set because it clears automatically due to the POR reset generated as part of the next VLLSx recovery. |
| 7 | LLS, VLLSx Status Acknowledge | N | Set this bit to acknowledge the DAP LLS and VLLS Status bits have been read. This acknowledge automatically clears the status bits. This bit is used by the debugger to clear the sticky LLS and VLLSx mode entry status bits. This bit is asserted and cleared by the debugger. |

Table continues on the next page...

Table 9-5. MDM-AP Control register assignments (continued)

| Bit | Name | Secure ¹ | Description |
|--------|-------------------------|---------------------|--|
| 8 | Timestamp Disable | N | Set this bit to disable the 48-bit global trace timestamp counter during debug halt mode when the core is halted. 0 The timestamp counter continues to count assuming trace is enabled and the ETM is enabled. (default) 1 The timestamp counter freezes when the core has halted (debug halt mode). |
| 9 – 31 | Reserved for future use | N | |

1. Command available in secure mode

9.5.2 MDM-AP Status Register

Table 9-6. MDM-AP Status register assignments

| Bit | Name | Description |
|-----|------------------------------|---|
| 0 | Flash Mass Erase Acknowledge | The Flash Mass Erase Acknowledge bit is cleared after any system reset. The bit is also cleared at launch of a mass erase command due to write of Flash Mass Erase in Progress bit in MDM AP Control Register. The Flash Mass Erase Acknowledge is set after Flash control logic has started the mass erase operation. When mass erase is disabled (via MEEN and SEC settings), an erase request due to setting of Flash Mass Erase in Progress bit is not acknowledged. |
| 1 | Flash Ready | Indicate Flash has been initialized and debugger can be configured even if system is continuing to be held in reset via the debugger. |
| 2 | System Security | Indicates the security state. When secure, the debugger does not have access to the system bus or any memory mapped peripherals. This bit indicates when the part is locked and no system bus access is possible. |
| 3 | System Reset | Indicates the system reset state. 0 System is in reset 1 System is not in reset |
| 4 | Reserved | |
| 5 | Mass Erase Enable | Indicates if the MCU can be mass erased or not 0 Mass erase is disabled 1 Mass erase is enabled |
| 6 | Backdoor Access Key Enable | Indicates if the MCU has the backdoor access key enabled. 0 Disabled 1 Enabled |

Table continues on the next page...

Table 9-6. MDM-AP Status register assignments (continued)

| Bit | Name | Description |
|---------|-------------------------|--|
| 7 | LP Enabled | <p>Decode of LPLLSM control bits to indicate that VLPS, LLS, or VLLSx are the selected power mode the next time the ARM Core enters Deep Sleep.</p> <p>0 Low Power Stop Mode is not enabled</p> <p>1 Low Power Stop Mode is enabled</p> <p>Usage intended for debug operation in which Run to VLPS is attempted. Per debug definition, the system actually enters the Stop state. A debugger should interpret deep sleep indication (with SLEEPDEEP and SLEEPING asserted), in conjunction with this bit asserted as the debugger-VLPS status indication.</p> |
| 8 | Very Low Power Mode | <p>Indicates current power mode is VLPx. This bit is not 'sticky' and should always represent whether VLPx is enabled or not.</p> <p>This bit is used to throttle JTAG TCK frequency up/down.</p> |
| 9 | LLS Mode Exit | <p>This bit indicates an exit from LLS mode has occurred. The debugger will lose communication while the system is in LLS (including access to this register). Once communication is reestablished, this bit indicates that the system had been in LLS. Since the debug modules held their state during LLS, they do not need to be reconfigured.</p> <p>This bit is set during the LLS recovery sequence. The LLS Mode Exit bit is held until the debugger has had a chance to recognize that LLS was exited and is cleared by a write of 1 to the LLS, VLLSx Status Acknowledge bit in MDM AP Control register.</p> |
| 10 | VLLSx Modes Exit | <p>This bit indicates an exit from VLLSx mode has occurred. The debugger will lose communication while the system is in VLLSx (including access to this register). Once communication is reestablished, this bit indicates that the system had been in VLLSx. Since the debug modules lose their state during VLLSx modes, they need to be reconfigured.</p> <p>This bit is set during the VLLSx recovery sequence. The VLLSx Mode Exit bit is held until the debugger has had a chance to recognize that a VLLS mode was exited and is cleared by a write of 1 to the LLS, VLLSx Status Acknowledge bit in MDM AP Control register.</p> |
| 11 – 15 | Reserved for future use | Always read 0. |
| 16 | Core Halted | Indicates the Core has entered debug halt mode |
| 17 | Core SLEEPDEEP | Indicates the Core has entered a low power mode |
| 18 | Core SLEEPING | <p>SLEEPING==1 and SLEEPDEEP==0 indicates wait or VLPW mode.</p> <p>SLEEPING==1 and SLEEPDEEP==1 indicates stop or VLPS mode.</p> |
| 19 – 31 | Reserved for future use | Always read 0. |

9.6 Debug Resets

The debug system receives the following sources of reset:

- JTAG_TRST_b from an external signal. This signal is optional and may not be available in all packages.

- Debug reset (CDBGSTREQ bit within the SWJ-DP CTRL/STAT register) in the TCLK domain that allows the debugger to reset the debug logic.
- TRST asserted via the cJTAG escape command.
- System POR reset

Conversely the debug system is capable of generating system reset using the following mechanism:

- A system reset in the DAP control register which allows the debugger to hold the system in reset.
- SYSRESETREQ bit in the NVIC application interrupt and reset control register
- A system reset in the DAP control register which allows the debugger to hold the Core in reset.

9.7 AHB-AP

AHB-AP provides the debugger access to all memory and registers in the system, including processor registers through the NVIC. System access is independent of the processor status. AHB-AP does not do back-to-back transactions on the bus, so all transactions are non-sequential. AHB-AP can perform unaligned and bit-band transactions. AHB-AP transactions bypass the FPB, so the FPB cannot remap AHB-AP transactions. SWJ/SW-DP-initiated transaction aborts drive an AHB-AP-supported sideband signal called HABORT. This signal is driven into the Bus Matrix, which resets the Bus Matrix state, so that AHB-AP can access the Private Peripheral Bus for last ditch debugging such as read/stop/reset the core. AHB-AP transactions are little endian.

For a short period at the start of a system reset event the system security status is being determined and debugger access to all AHB-AP transactions is blocked. The MDM-AP Status register is accessible and can be monitored to determine when this initial period is completed. After this initial period, if system reset is held via assertion of the RESET pin, the debugger has access via the bus matrix to the private peripheral bus to configure the debug IP even while system reset is asserted. While in system reset, access to other memory and register resources, accessed over the Crossbar Switch, is blocked.

9.8 ITM

The ITM is an application-driven trace source that supports printf style debugging to trace Operating System (OS) and application events, and emits diagnostic system information. The ITM emits trace information as packets. There are four sources that can

generate packets. If multiple sources generate packets at the same time, the ITM arbitrates the order in which packets are output. The four sources in decreasing order of priority are:

1. Software trace -- Software can write directly to ITM stimulus registers. This emits packets.
2. Hardware trace -- The DWT generates these packets, and the ITM emits them.
3. Time stamping -- Timestamps are emitted relative to packets. The ITM contains a 21-bit counter to generate the timestamp. The Cortex-M4 clock or the bitclock rate of the Serial Wire Viewer (SWV) output clocks the counter.
4. Global system timestamping. Timestamps can optionally be generated using a system-wide 48-bit count value. The same count value can be used to insert timestamps in the ETM trace stream, allowing coarse-grain correlation.

9.9 Core Trace Connectivity

The ETM and ITM can route its data to the ETB or the TPIU. (See the [MCM \(Miscellaneous Control Module\)](#) for controlling the routing to the TPIU.) This configuration enables the use of trace with low cost tools while maintaining the compatibility with trace probes. The arbitration between the ETM and ITM is performed inside the TPIU.

9.10 Embedded Trace Macrocell v3.5 (ETM)

The Cortex-M4 Embedded Trace Macrocell (ETM-M4) is a debug component that enables a debugger to reconstruct program execution. The CoreSight ETM-M4 supports only instruction trace. You can use it either with the Cortex-M4 Trace Port Interface Unit (M4-TPIU).

The main features of an ETM are:

- tracing of 16-bit and 32-bit Thumb instructions
- four EmbeddedICE watchpoint inputs
- a Trace Start/Stop block with EmbeddedICE inputs
- one reduced function counter
- two external inputs
- a 24-byte FIFO queue
- global timestamping

9.11 TPIU

The TPIU acts as a bridge between the on-chip trace data from the Embedded Trace Macrocell (ETM) and the Instrumentation Trace Macrocell (ITM), with separate IDs, to a data stream, encapsulating IDs where required, that is then captured by a Trace Port Analyzer (TPA). The TPIU is specially designed for low-cost debug.

9.12 DWT

The DWT is a unit that performs the following debug functionality:

- It contains four comparators that you can configure as a hardware watchpoint, an ETM trigger, a PC sampler event trigger, or a data address sampler event trigger. The first comparator, DWT_COMP0, can also compare against the clock cycle counter, CYCCNT. The second comparator, DWT_COMP1, can also be used as a data comparator.
- The DWT contains counters for:
 - Clock cycles (CYCCNT)
 - Folded instructions
 - Load store unit (LSU) operations
 - Sleep cycles
 - CPI (all instruction cycles except for the first cycle)
 - Interrupt overhead

NOTE

An event is emitted each time a counter overflows.

- The DWT can be configured to emit PC samples at defined intervals, and to emit interrupt event information.

9.13 Debug in Low Power Modes

In low power modes in which the debug modules are kept static or powered off, the debugger cannot gather any debug data for the duration of the low power mode. In the case that the debugger is held static, the debug port returns to full functionality as soon as the low power mode exits and the system returns to a state with active debug. In the case that the debugger logic is powered off, the debugger is reset on recovery and must be reconfigured once the low power mode is exited.

Power mode entry logic monitors Debug Power Up and System Power Up signals from the debug port as indications that a debugger is active. These signals can be changed in RUN, VLPR, WAIT and VLPW. If the debug signal is active and the system attempts to enter stop or VLPS, FCLK continues to run to support core register access. In these modes in which FCLK is left active the debug modules have access to core registers but not to system memory resources accessed via the crossbar.

With debug enabled, transitions from Run directly to VLPS are not allowed and result in the system entering Stop mode instead. Status bits within the MDM-AP Status register can be evaluated to determine this pseudo-VLPS state. Note with the debug enabled, transitions from Run--> VLPR --> VLPS are still possible but also result in the system entering Stop mode instead.

In VLLS mode all debug modules are powered off and reset at wakeup. In LLS mode, the debug modules retain their state but no debug activity is possible.

NOTE

When using cJTAG and entering LLS mode, the cJTAG controller must be reset on exit from LLS mode.

Going into a VLLSx mode causes all the debug controls and settings to be reset. To give time to the debugger to sync up with the HW, the MDM-AP Control register can be configured hold the system in reset on recovery so that the debugger can regain control and reconfigure debug logic prior to the system exiting reset and resuming operation.

9.13.1 Debug Module State in Low Power Modes

The following table shows the state of the debug modules in low power modes. These terms are used:

- FF = Full functionality. In VLPR and VLPW the system frequency is limited, but if a module does not have a limitation in its functionality, it is still listed as FF.
- static = Module register states and associated memories are retained.
- OFF = Modules are powered off; module is in reset state upon wakeup.

Table 9-7. Debug Module State in Low Power Modes

| Module | STOP | VLPR | VLPW | VLPS | LLS | VLLSx |
|------------|------|------|------|------|--------|-------|
| Debug Port | FF | FF | FF | OFF | static | OFF |
| AHB-AP | FF | FF | FF | OFF | static | OFF |
| ITM | FF | FF | FF | OFF | static | OFF |
| TPIU | FF | FF | FF | OFF | static | OFF |
| DWT | FF | FF | FF | OFF | static | OFF |

9.14 Debug & Security

When security is enabled (FSEC[SEC] != 10), the debug port capabilities are limited in order to prevent exploitation of secure data. In the secure state the debugger still has access to the MDM-AP Status Register and can determine the current security state of the device. In the case of a secure device, the debugger also has the capability of performing a mass erase operation via writes to the MDM-AP Control Register. In the case of a secure device that has mass erase disabled (FSEC[MEEN] = 10), attempts to mass erase via the debug interface are blocked.



Chapter 10

Signal Multiplexing and Signal Descriptions

10.1 Introduction

To optimize functionality in small packages, pins have several functions available via signal multiplexing. This chapter illustrates which of this device's signals are multiplexed on which external pin.

The [Port Control](#) block controls which signal is present on the external pin. Reference that chapter to find which register controls the operation of a specific pin.

10.2 Signal Multiplexing Integration

This section summarizes how the module is integrated into the device. For a comprehensive description of the module itself, see the module's dedicated chapter.

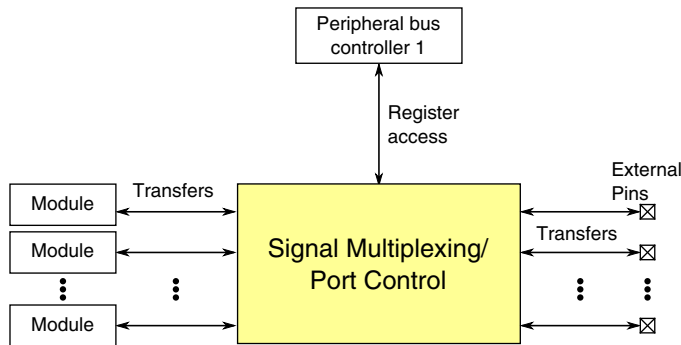


Figure 10-1. Signal multiplexing integration

Table 10-1. Reference links to related information

| Topic | Related module | Reference |
|-------------------|----------------|-----------------------------------|
| Full description | Port control | Port control |
| System memory map | | System memory map |

Table continues on the next page...

Table 10-1. Reference links to related information (continued)

| Topic | Related module | Reference |
|-----------------|---------------------------|------------------------------------|
| Clocking | | Clock Distribution |
| Register access | Peripheral bus controller | Peripheral bridge |

10.2.1 Port control and interrupt module features

- Five 32-pin ports

NOTE

Not all pins are available on the device. See the following section for details.

- Each 32-pin port is assigned one interrupt.
- The digital filter option has two clock source options: bus clock and 1-kHz LPO. The 1-kHz LPO option gives users this feature in low power modes.
- The digital filter is configurable from 1 to 32 clock cycles when enabled.

10.2.2 PCRn reset values for port A

PCRn bit reset values for port A are 1 for the following bits:

- For PCR0: bits 1, 6, 8, 9, and 10.
- For PCR1 to PCR4: bits 0, 1, 6, 8, 9, and 10.
- For PCR5 : bits 0, 1, and 6.

All other PCRn bit reset values for port A are 0.

10.2.3 Clock gating

The clock to the port control module can be gated on and off using the SCGC5[PORTx] bits in the SIM module. These bits are cleared after any reset, which disables the clock to the corresponding module to conserve power. Prior to initializing the corresponding module, set SCGC5[PORTx] in the SIM module to enable the clock. Before turning off the clock, make sure to disable the module. For more details, refer to the clock distribution chapter.

10.2.4 Signal multiplexing constraints

1. A given peripheral function must be assigned to a maximum of one package pin. Do not program the same function to more than one pin.
2. To ensure the best signal timing for a given peripheral's interface, choose the pins in closest proximity to each other.

10.3 Pinout

10.3.1 K11 Signal Multiplexing and Pin Assignments

The following table shows the signals available on each pin and the locations of these pins on the devices supported by this document. The Port Control Module is responsible for selecting which ALT functionality is available on each pin.

NOTE

- The analog input signals ADC0_SE10, ADC0_SE11, ADC0_DP1, and ADC0_DM1 are available only for K11, K12, K21, and K22 devices and are not present on K10 and K20 devices.
- The TRACE signals on PTE0, PTE1, PTE2, PTE3, and PTE4 are available only for K11, K12, K21, and K22 devices and are not present on K10 and K20 devices.
- If the VBAT pin is not used, the VBAT pin should be left floating. Do not connect VBAT pin to VSS.
- The FTM_CLKIN signals on PTB16 and PTB17 are available only for K11, K12, K21, and K22 devices and is not present on K10 and K20 devices. For K22D devices this signal is on ALT4, and for K22F devices, this signal is on ALT7.
- The FTM0_CH2 signal on PTC5/LLWU_P9 is available only for K11, K12, K21, and K22 devices and is not present on K10 and K20 devices.
- The I2C0_SCL signal on PTD2/LLWU_P13 and I2C0_SDA signal on PTD3 are available only for K11, K12, K21, and K22 devices and are not present on K10 and K20 devices.

Pinout

| 121 MAP BGA | Pin Name | Default | ALT0 | ALT1 | ALT2 | ALT3 | ALT4 | ALT5 | ALT6 | ALT7 | EzPort |
|-------------------|-------------------------------------|-------------------------------------|-------------------------------------|------------------|-------------|-------------|------------|--------------|-------------|-----------------------|---------|
| E4 | PTE0 | ADC0_SE10 | ADC0_SE10 | PTE0 | SPI1_PCS1 | UART1_TX | | TRACE_CLKOUT | I2C1_SDA | RTC_CLKOUT | |
| E3 | PTE1/ LLWU_P0 | ADC0_SE11 | ADC0_SE11 | PTE1/ LLWU_P0 | SPI1_SOUT | UART1_RX | | TRACE_D3 | I2C1_SCL | SPI1_SIN | |
| E2 | PTE2/ LLWU_P1 | ADC0_DP1 | ADC0_DP1 | PTE2/ LLWU_P1 | SPI1_SCK | UART1_CTS_b | | TRACE_D2 | | | |
| F4 | PTE3 | ADC0_DM1 | ADC0_DM1 | PTE3 | SPI1_SIN | UART1_RTS_b | | TRACE_D1 | | SPI1_SOUT | |
| H7 | PTE4/ LLWU_P2 | DISABLED | | PTE4/ LLWU_P2 | SPI1_PCS0 | UART3_TX | | TRACE_D0 | | | |
| G4 | PTE5 | DISABLED | | PTE5 | SPI1_PCS2 | UART3_RX | | | | | |
| E6 | VDD | VDD | VDD | | | | | | | | |
| G7 | VSS | VSS | VSS | | | | | | | | |
| K3 | PTE16 | ADC0_SE4a | ADC0_SE4a | PTE16 | SPI0_PCS0 | UART2_TX | FTM_CLKIN0 | | FTM0_FLT3 | | |
| H4 | PTE17 | ADC0_SE5a | ADC0_SE5a | PTE17 | SPI0_SCK | UART2_RX | FTM_CLKIN1 | | LPTMR0_ALT3 | | |
| A11 | PTE18 | ADC0_SE6a | ADC0_SE6a | PTE18 | SPI0_SOUT | UART2_CTS_b | I2C0_SDA | | | | |
| A10 | PTE19 | ADC0_SE7a | ADC0_SE7a | PTE19 | SPI0_SIN | UART2_RTS_b | I2C0_SCL | | | | |
| L6 | VSS | VSS | VSS | | | | | | | | |
| K1 | ADC0_DP0 | ADC0_DP0 | ADC0_DP0 | | | | | | | | |
| K2 | ADC0_DM0 | ADC0_DM0 | ADC0_DM0 | | | | | | | | |
| L1 | ADC0_DP3 | ADC0_DP3 | ADC0_DP3 | | | | | | | | |
| L2 | ADC0_DM3 | ADC0_DM3 | ADC0_DM3 | | | | | | | | |
| F5 | VDDA | VDDA | VDDA | | | | | | | | |
| G5 | VREFH | VREFH | VREFH | | | | | | | | |
| G6 | VREFL | VREFL | VREFL | | | | | | | | |
| F6 | VSSA | VSSA | VSSA | | | | | | | | |
| L3 | VREF_OUT/ CMP1_IN5/ CMP0_IN5 | VREF_OUT/ CMP1_IN5/ CMP0_IN5 | VREF_OUT/ CMP1_IN5/ CMP0_IN5 | | | | | | | | |
| K5 | DAC0_OUT/ CMP1_IN3/ ADC0_SE23 | DAC0_OUT/ CMP1_IN3/ ADC0_SE23 | DAC0_OUT/ CMP1_IN3/ ADC0_SE23 | | | | | | | | |
| L7 | TAMPER0/ RTC_ WAKEUP_B | TAMPER0/ RTC_ WAKEUP_B | TAMPER0/ RTC_ WAKEUP_B | | | | | | | | |
| H5 | TAMPER1 | TAMPER1 | TAMPER1 | | | | | | | | |
| J5 | TAMPER2 | TAMPER2 | TAMPER2 | | | | | | | | |
| L4 | XTAL32 | XTAL32 | XTAL32 | | | | | | | | |
| L5 | EXTAL32 | EXTAL32 | EXTAL32 | | | | | | | | |
| K6 | VBAT | VBAT | VBAT | | | | | | | | |
| J6 | PTA0 | JTAG_TCLK/ SWD_CLK/ EZP_CLK | | PTA0 | UART0_CTS_b | FTM0_CH5 | | | | JTAG_TCLK/ SWD_CLK | EZP_CLK |
| H8 | PTA1 | JTAG_TDI/ EZP_DI | | PTA1 | UART0_RX | FTM0_CH6 | | | | JTAG_TDI | EZP_DI |

| 121 MAP BGA | Pin Name | Default | ALT0 | ALT1 | ALT2 | ALT3 | ALT4 | ALT5 | ALT6 | ALT7 | EzPort |
|-------------------|-------------------|-----------------------------------|------------------------|-------------------|-------------|-------------|--------------|--------|-----------------|------------------------|----------|
| J7 | PTA2 | JTAG_TDO/ TRACE_SWO/ EZP_DO | | PTA2 | UART0_TX | FTM0_CH7 | | | | JTAG_TDO/ TRACE_SWO | EZP_DO |
| H9 | PTA3 | JTAG_TMS/ SWD_DIO | | PTA3 | UART0_RTS_b | FTM0_CH0 | | | | JTAG_TMS/ SWD_DIO | |
| J8 | PTA4/ LLWU_P3 | NMI_b/ EZP_CS_b | | PTA4/ LLWU_P3 | | FTM0_CH1 | | | | NMI_b | EZP_CS_b |
| K7 | PTA5 | DISABLED | | PTA5 | | FTM0_CH2 | | | I2S0_TX_BCLK | JTAG_TRST_b | |
| K8 | PTA12 | DISABLED | | PTA12 | | FTM1_CH0 | | | I2S0_TXD0 | FTM1_QD_ PHA | |
| L8 | PTA13/ LLWU_P4 | DISABLED | | PTA13/ LLWU_P4 | | FTM1_CH1 | | | I2S0_TX_FS | FTM1_QD_ PHB | |
| K9 | PTA14 | DISABLED | | PTA14 | SPI0_PCS0 | UART0_TX | | | I2S0_RX_BCLK | I2S0_TXD1 | |
| L9 | PTA15 | DISABLED | | PTA15 | SPI0_SCK | UART0_RX | | | I2S0_RXD0 | | |
| J10 | PTA16 | DISABLED | | PTA16 | SPI0_SOUT | UART0_CTS_b | | | I2S0_RX_FS | I2S0_RXD1 | |
| H10 | PTA17 | DISABLED | | PTA17 | SPI0_SIN | UART0_RTS_b | | | I2S0_MCLK | | |
| L10 | VDD | VDD | VDD | | | | | | | | |
| K10 | VSS | VSS | VSS | | | | | | | | |
| L11 | PTA18 | EXTAL0 | EXTAL0 | PTA18 | | FTM0_FLT2 | FTM_CLKIN0 | | | | |
| K11 | PTA19 | XTAL0 | XTAL0 | PTA19 | | FTM1_FLT0 | FTM_CLKIN1 | | LPTMR0_ALT1 | | |
| J11 | RESET_b | RESET_b | RESET_b | | | | | | | | |
| G11 | PTB0/ LLWU_P5 | ADC0_SE8 | ADC0_SE8 | PTB0/ LLWU_P5 | I2C0_SCL | FTM1_CH0 | | | FTM1_QD_ PHA | | |
| G10 | PTB1 | ADC0_SE9 | ADC0_SE9 | PTB1 | I2C0_SDA | FTM1_CH1 | | | FTM1_QD_ PHB | | |
| G9 | PTB2 | ADC0_SE12 | ADC0_SE12 | PTB2 | I2C0_SCL | UART0_RTS_b | | | FTM0_FLT3 | | |
| G8 | PTB3 | ADC0_SE13 | ADC0_SE13 | PTB3 | I2C0_SDA | UART0_CTS_b | | | FTM0_FLT0 | | |
| D10 | PTB10 | DISABLED | | PTB10 | SPI1_PCS0 | UART3_RX | | | FTM0_FLT1 | | |
| C10 | PTB11 | DISABLED | | PTB11 | SPI1_SCK | UART3_TX | | | FTM0_FLT2 | | |
| B11 | PTB12 | DISABLED | | PTB12 | UART3_RTS_b | FTM1_CH0 | FTM0_CH4 | | FTM1_QD_ PHA | | |
| C11 | PTB13 | DISABLED | | PTB13 | UART3_CTS_b | FTM1_CH1 | FTM0_CH5 | | FTM1_QD_ PHB | | |
| B10 | PTB16 | DISABLED | | PTB16 | SPI1_SOUT | UART0_RX | | | EWM_IN | FTM_CLKIN0 | |
| E9 | PTB17 | DISABLED | | PTB17 | SPI1_SIN | UART0_TX | | | EWM_OUT_b | FTM_CLKIN1 | |
| D9 | PTB18 | DISABLED | | PTB18 | | FTM2_CH0 | I2S0_TX_BCLK | | | | |
| C9 | PTB19 | DISABLED | | PTB19 | | FTM2_CH1 | I2S0_TX_FS | | | | |
| B9 | PTC0 | ADC0_SE14 | ADC0_SE14 | PTC0 | SPI0_PCS4 | PDB0_EXTRG | | | I2S0_TXD1 | | |
| D8 | PTC1/ LLWU_P6 | ADC0_SE15 | ADC0_SE15 | PTC1/ LLWU_P6 | SPI0_PCS3 | UART1_RTS_b | FTM0_CH0 | | I2S0_TXD0 | | |
| C8 | PTC2 | ADC0_SE4b/ CMP1_IN0 | ADC0_SE4b/ CMP1_IN0 | PTC2 | SPI0_PCS2 | UART1_CTS_b | FTM0_CH1 | | I2S0_TX_FS | | |
| B8 | PTC3/ LLWU_P7 | CMP1_IN1 | CMP1_IN1 | PTC3/ LLWU_P7 | SPI0_PCS1 | UART1_RX | FTM0_CH2 | CLKOUT | I2S0_TX_BCLK | | |

Pinout

| 121 MAP BGA | Pin Name | Default | ALT0 | ALT1 | ALT2 | ALT3 | ALT4 | ALT5 | ALT6 | ALT7 | EzPort |
|-------------------|--------------------|-----------|-----------|--------------------|-----------|-------------|--------------|------|-----------|----------|--------|
| G3 | VSS | VSS | VSS | | | | | | | | |
| E5 | VDD | VDD | VDD | | | | | | | | |
| A8 | PTC4/ LLWU_P8 | DISABLED | | PTC4/ LLWU_P8 | SPI0_PCS0 | UART1_TX | FTM0_CH3 | | CMP1_OUT | | |
| D7 | PTC5/ LLWU_P9 | DISABLED | | PTC5/ LLWU_P9 | SPI0_SCK | LPTMR0_ALT2 | I2S0_RXD0 | | CMP0_OUT | FTM0_CH2 | |
| C7 | PTC6/ LLWU_P10 | CMP0_IN0 | CMP0_IN0 | PTC6/ LLWU_P10 | SPI0_SOUT | PDB0_EXTRG | I2S0_RX_BCLK | | I2S0_MCLK | | |
| B7 | PTC7 | CMP0_IN1 | CMP0_IN1 | PTC7 | SPI0_SIN | | I2S0_RX_FS | | | | |
| A7 | PTC8 | CMP0_IN2 | CMP0_IN2 | PTC8 | | | I2S0_MCLK | | | | |
| D6 | PTC9 | CMP0_IN3 | CMP0_IN3 | PTC9 | | | I2S0_RX_BCLK | | FTM2_FLT0 | | |
| C6 | PTC10 | DISABLED | | PTC10 | I2C1_SCL | | I2S0_RX_FS | | | | |
| C5 | PTC11/ LLWU_P11 | DISABLED | | PTC11/ LLWU_P11 | I2C1_SDA | | I2S0_RXD1 | | | | |
| B6 | PTC12 | DISABLED | | PTC12 | | | | | | | |
| A6 | PTC13 | DISABLED | | PTC13 | | | | | | | |
| D5 | PTC16 | DISABLED | | PTC16 | | UART3_RX | | | | | |
| C4 | PTC17 | DISABLED | | PTC17 | | UART3_TX | | | | | |
| D4 | PTD0/ LLWU_P12 | DISABLED | | PTD0/ LLWU_P12 | SPI0_PCS0 | UART2_RTS_b | | | | | |
| D3 | PTD1 | ADC0_SE5b | ADC0_SE5b | PTD1 | SPI0_SCK | UART2_CTS_b | | | | | |
| C3 | PTD2/ LLWU_P13 | DISABLED | | PTD2/ LLWU_P13 | SPI0_SOUT | UART2_RX | I2C0_SCL | | | | |
| B3 | PTD3 | DISABLED | | PTD3 | SPI0_SIN | UART2_TX | I2C0_SDA | | | | |
| A3 | PTD4/ LLWU_P14 | ADC0_SE21 | ADC0_SE21 | PTD4/ LLWU_P14 | SPI0_PCS1 | UART0_RTS_b | FTM0_CH4 | | EWM_IN | | |
| A2 | PTD5 | ADC0_SE6b | ADC0_SE6b | PTD5 | SPI0_PCS2 | UART0_CTS_b | FTM0_CH5 | | EWM_OUT_b | | |
| B2 | PTD6/ LLWU_P15 | ADC0_SE7b | ADC0_SE7b | PTD6/ LLWU_P15 | SPI0_PCS3 | UART0_RX | FTM0_CH6 | | FTM0_FLT0 | | |
| A1 | PTD7 | ADC0_SE22 | ADC0_SE22 | PTD7 | CMT_IRO | UART0_TX | FTM0_CH7 | | FTM0_FLT1 | | |
| F3 | NC | NC | NC | | | | | | | | |
| H1 | NC | NC | NC | | | | | | | | |
| H2 | NC | NC | NC | | | | | | | | |
| J1 | NC | NC | NC | | | | | | | | |
| J2 | NC | NC | NC | | | | | | | | |
| J3 | NC | NC | NC | | | | | | | | |
| H3 | NC | NC | NC | | | | | | | | |
| K4 | NC | NC | NC | | | | | | | | |
| H6 | NC | NC | NC | | | | | | | | |
| J9 | NC | NC | NC | | | | | | | | |
| J4 | NC | NC | NC | | | | | | | | |
| H11 | NC | NC | NC | | | | | | | | |
| F11 | NC | NC | NC | | | | | | | | |

| 121 MAP BGA | Pin Name | Default | ALT0 | ALT1 | ALT2 | ALT3 | ALT4 | ALT5 | ALT6 | ALT7 | EzPort |
|-------------------|----------|---------|------|------|------|------|------|------|------|------|--------|
| E11 | NC | NC | NC | | | | | | | | |
| D11 | NC | NC | NC | | | | | | | | |
| E10 | NC | NC | NC | | | | | | | | |
| F10 | NC | NC | NC | | | | | | | | |
| F9 | NC | NC | NC | | | | | | | | |
| F8 | NC | NC | NC | | | | | | | | |
| E8 | NC | NC | NC | | | | | | | | |
| E7 | NC | NC | NC | | | | | | | | |
| F7 | NC | NC | NC | | | | | | | | |
| A5 | NC | NC | NC | | | | | | | | |
| B5 | NC | NC | NC | | | | | | | | |
| B4 | NC | NC | NC | | | | | | | | |
| A4 | NC | NC | NC | | | | | | | | |
| A9 | NC | NC | NC | | | | | | | | |
| B1 | NC | NC | NC | | | | | | | | |
| C2 | NC | NC | NC | | | | | | | | |
| C1 | NC | NC | NC | | | | | | | | |
| D2 | NC | NC | NC | | | | | | | | |
| D1 | NC | NC | NC | | | | | | | | |
| E1 | NC | NC | NC | | | | | | | | |

10.3.2 K11 Pinouts

The below figure shows the pinout diagram for the devices supported by this document. Many signals may be multiplexed onto a single pin. To determine what signals can be used on which pin, see the previous section.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |
|---|----------|-------------------|------------------------------------|-------------------|-------------------------------------|-------|------------------------------|-------------------|-------|-------|------------------|---|
| A | PTD7 | PTD5 | PTD4/ LLWU_P14 | NC | NC | PTC13 | PTC8 | PTC4/ LLWU_P8 | NC | PTE19 | PTE18 | A |
| B | NC | PTD6/ LLWU_P15 | PTD3 | NC | NC | PTC12 | PTC7 | PTC3/ LLWU_P7 | PTC0 | PTB16 | PTB12 | B |
| C | NC | NC | PTD2/ LLWU_P13 | PTC17 | PTC11/ LLWU_P11 | PTC10 | PTC6/ LLWU_P10 | PTC2 | PTB19 | PTB11 | PTB13 | C |
| D | NC | NC | PTD1 | PTD0/ LLWU_P12 | PTC16 | PTC9 | PTC5/ LLWU_P9 | PTC1/ LLWU_P6 | PTB18 | PTB10 | NC | D |
| E | NC | PTE2/ LLWU_P1 | PTE1/ LLWU_P0 | PTE0 | VDD | VDD | NC | NC | PTB17 | NC | NC | E |
| F | NC | NC | NC | PTE3 | VDDA | VSSA | NC | NC | NC | NC | NC | F |
| G | NC | NC | VSS | PTE5 | VREFH | VREFL | VSS | PTB3 | PTB2 | PTB1 | PTB0/ LLWU_P5 | G |
| H | NC | NC | NC | PTE17 | TAMPER1 | NC | PTE4/ LLWU_P2 | PTA1 | PTA3 | PTA17 | NC | H |
| J | NC | NC | NC | NC | TAMPER2 | PTA0 | PTA2 | PTA4/ LLWU_P3 | NC | PTA16 | RESET_b | J |
| K | ADC0_DP0 | ADC0_DM0 | PTE16 | NC | DAC0_OUT/ CMP1_IN3/ ADC0_SE23 | VBAT | PTA5 | PTA12 | PTA14 | VSS | PTA19 | K |
| L | ADC0_DP3 | ADC0_DM3 | VREF_OUT/ CMP1_IN5/ CMP0_IN5 | XTAL32 | EXTAL32 | VSS | TAMPER0/ RTC_ WAKEUP_B | PTA13/ LLWU_P4 | PTA15 | VDD | PTA18 | L |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |

Figure 10-2. K11 121 MAPBGA Pinout Diagram

10.4 Module Signal Description Tables

The following sections correlate the chip-level signal name with the signal name used in the module's chapter. They also briefly describe the signal function and direction.

10.4.1 Core Modules

Table 10-2. JTAG Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|------------------------|--------------------------|-----|
| JTAG_TMS | JTAG_TMS/ SWD_DIO | JTAG Test Mode Selection | I/O |
| JTAG_TCLK | JTAG_TCLK/ SWD_CLK | JTAG Test Clock | I |
| JTAG_TDI | JTAG_TDI | JTAG Test Data Input | I |
| JTAG_TDO | JTAG_TDO/ TRACE_SWO | JTAG Test Data Output | O |
| JTAG_TRST | JTAG_TRST_b | JTAG Reset | I |

Table 10-3. SWD Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|-----------------------|-------------------|-----|
| SWD_DIO | JTAG_TMS/ SWD_DIO | Serial Wire Data | I/O |
| SWD_CLK | JTAG_TCLK/ SWD_CLK | Serial Wire Clock | I |

Table 10-4. TPIU Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|------------------------|---|-----|
| TRACE_CLKOUT | TRACECLK | Trace clock output from the ARM CoreSight debug block | O |
| TRACE_D[3:2] | TRACEDATA | Trace output data from the ARM CoreSight debug block used for 5-pin interface | O |
| TRACE_D[1:0] | TRACEDATA | Trace output data from the ARM CoreSight debug block used for both 5-pin and 3-pin interfaces | O |
| TRACE_SWO | JTAG_TDO/ TRACE_SWO | Trace output data from the ARM CoreSight debug block over a single pin | O |

10.4.2 System Modules

Table 10-5. EWM Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|--|-----|
| EWM_IN | EWM_in | EWM input for safety status of external safety circuits. The polarity of EWM_in is programmable using the EWM_CTRL[ASSIN] bit. The default polarity is active-low. | I |
| EWM_OUT | EWM_out | EWM reset out signal | O |

10.4.3 Clock Modules

Table 10-6. OSC Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|---------------------------------|-----|
| EXTAL0 | EXTAL | External clock/Oscillator input | I |
| XTAL0 | XTAL | Oscillator output | O |

Table 10-7. RTC OSC Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|------------------------------|-----|
| EXTAL32 | EXTAL32 | 32.768 kHz oscillator input | I |
| XTAL32 | XTAL32 | 32.768 kHz oscillator output | O |

10.4.4 Memories and Memory Interfaces

Table 10-8. EzPort Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|------------------------|--------|
| EZP_CLK | EZP_CK | EzPort Clock | Input |
| EZP_CS | EZP_CS | EzPort Chip Select | Input |
| EZP_DI | EZP_D | EzPort Serial Data In | Input |
| EZP_DO | EZP_Q | EzPort Serial Data Out | Output |

10.4.5 Security Modules

Table 10-9. Tamper Detect Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|---|-----|
| TAMPER[2:0] | TAMPER[7:0] | External tamper input or active tamper output | I/O |

10.4.6 Analog

Table 10-10. ADC 0 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|---------------------|--------------------|------------------------------------|-----|
| ADC0_DP1 | DADP3–DADP0 | Differential Analog Channel Inputs | I |
| ADC0_DM1 | DADM3–DADM0 | Differential Analog Channel Inputs | I |
| ADC0_SE[23:21,15:4] | AD n | Single-Ended Analog Channel Inputs | I |
| VREFH | V _{REFSH} | Voltage Reference Select High | I |
| VREFL | V _{REFSL} | Voltage Reference Select Low | I |
| VDDA | V _{DDA} | Analog Power Supply | I |
| VSSA | V _{SSA} | Analog Ground | I |

Table 10-11. CMP 0 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|-----------------------|-----|
| CMP0_IN[5:0] | IN[5:0] | Analog voltage inputs | I |
| CMP0_OUT | CMPO | Comparator output | O |

Table 10-12. CMP 1 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|-----------------------|-----|
| CMP1_IN[5:0] | IN[5:0] | Analog voltage inputs | I |
| CMP1_OUT | CMPO | Comparator output | O |

Table 10-13. DAC 0 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|-------------|-----|
| DAC0_OUT | — | DAC output | O |

Table 10-14. VREF Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|---|-----|
| VREF_OUT | VREF_OUT | Internally-generated Voltage Reference output | O |

10.4.7 Timer Modules

Table 10-15. FTM 0 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|--|-----|
| FTM_CLKIN[1:0] | EXTCLK | External clock. FTM external clock can be selected to drive the FTM counter. | I |
| FTM0_CH[7:0] | CHn | FTM channel (n), where n can be 7-0 | I/O |
| FTM0_FLT[3:0] | FAULTj | Fault input (j), where j can be 3-0 | I |

Table 10-16. FTM 1 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|---|-----|
| FTM_CLKIN[1:0] | EXTCLK | External clock. FTM external clock can be selected to drive the FTM counter. | I |
| FTM1_CH[1:0] | CHn | FTM channel (n), where n can be 7-0 | I/O |
| FTM1_FLT0 | FAULTj | Fault input (j), where j can be 3-0 | I |
| FTM1_QD_PHA | PHA | Quadrature decoder phase A input. Input pin associated with quadrature decoder phase A. | I |
| FTM1_QD_PHB | PHB | Quadrature decoder phase B input. Input pin associated with quadrature decoder phase B. | I |

Table 10-17. FTM 2 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|--|-----|
| FTM_CLKIN[1:0] | EXTCLK | External clock. FTM external clock can be selected to drive the FTM counter. | I |
| FTM2_CH[1:0] | CHn | FTM channel (n), where n can be 7-0 | I/O |
| FTM2_FLT0 | FAULTj | Fault input (j), where j can be 3-0 | I |

Table 10-18. CMT Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|-----------------|-----|
| CMT_IRO | CMT_IRO | Infrared Output | O |

Table 10-19. PDB 0 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|--|-----|
| PDB0_EXTRG | EXTRG | External Trigger Input Source If the PDB is enabled and external trigger input source is selected, a positive edge on the EXTRG signal resets and starts the counter. | I |

Table 10-20. LPTMR 0 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|-------------------------|-----|
| LPTMR0_ALT[3:1] | LPTMR_ALT <i>n</i> | Pulse Counter Input pin | I |

Table 10-21. RTC Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|--|-----|
| VBAT | — | Backup battery supply for RTC and VBAT register file | I |
| RTC_CLKOUT | RTC_CLKOUT | 1 Hz square-wave output | O |

10.4.8 Communication Interfaces

Table 10-22. SPI 0 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|------------------------------|-----|
| SPI0_PCS0 | PCS0/SS | Peripheral Chip Select 0 (O) | I/O |
| SPI0_PCS[3:1] | PCS[1:3] | Peripheral Chip Selects 1–3 | O |
| SPI0_PCS4 | PCS4 | Peripheral Chip Select 4 | O |
| SPI0_SIN | SIN | Serial Data In | I |
| SPI0_SOUT | SOUT | Serial Data Out | O |
| SPI0_SCK | SCK | Serial Clock (O) | I/O |

Table 10-23. SPI 1 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|------------------------------|-----|
| SPI1_PCS0 | PCS0/SS | Peripheral Chip Select 0 (O) | I/O |
| SPI1_PCS[2:1] | PCS[2:1] | Peripheral Chip Select 1 – 2 | O |
| SPI1_SIN | SIN | Serial Data In | I |
| SPI1_SOUT | SOUT | Serial Data Out | O |
| SPI1_SCK | SCK | Serial Clock (O) | I/O |

Table 10-24. I²C 0 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|---|-----|
| I2C0_SCL | SCL | Bidirectional serial clock line of the I ² C system. | I/O |
| I2C0_SDA | SDA | Bidirectional serial data line of the I ² C system. | I/O |

Table 10-25. I²C 1 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|---|-----|
| I2C1_SCL | SCL | Bidirectional serial clock line of the I ² C system. | I/O |
| I2C1_SDA | SDA | Bidirectional serial data line of the I ² C system. | I/O |

Table 10-26. UART 0 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|-----------------|-----|
| UART0_CTS | CTS | Clear to send | I |
| UART0_RTS | RTS | Request to send | O |
| UART0_TX | TXD | Transmit data | O |
| UART0_RX | RXD | Receive data | I |

Table 10-27. UART 1 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|-----------------|-----|
| UART1_CTS | CTS | Clear to send | I |
| UART1_RTS | RTS | Request to send | O |
| UART1_TX | TXD | Transmit data | O |
| UART1_RX | RXD | Receive data | I |

Table 10-28. UART 2 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|-----------------|-----|
| UART2_CTS | CTS | Clear to send | I |
| UART2_RTS | RTS | Request to send | O |
| UART2_TX | TXD | Transmit data | O |
| UART2_RX | RXD | Receive data | I |

Table 10-29. UART 3 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|-----------------|-----|
| UART3_CTS | CTS | Clear to send | I |
| UART3_RTS | RTS | Request to send | O |
| UART3_TX | TXD | Transmit data | O |
| UART3_RX | RXD | Receive data | I |

Table 10-30. I²S0 Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------|--------------------|--|-----|
| I2S0_MCLK | SAI_MCLK | Audio Master Clock. The master clock is an input when externally generated and an output when internally generated. | I/O |
| I2S0_RX_BCLK | SAI_RX_BCLK | Receive Bit Clock. The bit clock is an input when externally generated and an output when internally generated. | I/O |
| I2S0_RX_FS | SAI_RX_SYNC | Receive Frame Sync. The frame sync is an input sampled synchronously by the bit clock when externally generated and an output generated synchronously by the bit clock when internally generated. | I/O |
| I2S0_RXD | SAI_RX_DATA | Receive Data. The receive data is sampled synchronously by the bit clock. | I |
| I2S0_TX_BCLK | SAI_TX_BCLK | Transmit Bit Clock. The bit clock is an input when externally generated and an output when internally generated. | I/O |
| I2S0_TX_FS | SAI_TX_SYNC | Transmit Frame Sync. The frame sync is an input sampled synchronously by the bit clock when externally generated and an output generated synchronously by the bit clock when internally generated. | I/O |
| I2S0_TXD | SAI_TX_DATA | Transmit Data. The transmit data is generated synchronously by the bit clock and is tristated whenever not transmitting a word. | O |

10.4.9 Human-Machine Interfaces (HMI)

Table 10-31. GPIO Signal Descriptions

| Chip signal name | Module signal name | Description | I/O |
|------------------------|--------------------|------------------------------|-----|
| PTA[31:0] ¹ | PORT2[31:0] | General-purpose input/output | I/O |
| PTB[31:0] ¹ | PORTB31–PORTB0 | General-purpose input/output | I/O |
| PTC[31:0] ¹ | PORTC31–PORTC0 | General-purpose input/output | I/O |
| PTD[31:0] ¹ | PORTD31–PORTD0 | General-purpose input/output | I/O |
| PTE[31:0] ¹ | PORTE31–PORTE0 | General-purpose input/output | I/O |

1. The available GPIO pins depends on the specific package. See the signal multiplexing section for which exact GPIO signals are available.



Chapter 11

Port Control and Interrupts (PORT)

11.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

11.2 Overview

The Port Control and Interrupt (PORT) module provides support for port control, digital filtering, and external interrupt functions.

Most functions can be configured independently for each pin in the 32-bit port and affect the pin regardless of its pin muxing state.

There is one instance of the PORT module for each port. Not all pins within each port are implemented on a specific device.

11.2.1 Features

The PORT module has the following features:

- Pin interrupt
 - Interrupt flag and enable registers for each pin
 - Support for edge sensitive (rising, falling, both) or level sensitive (low, high) configured per pin
 - Support for interrupt or DMA request configured per pin
 - Asynchronous wake-up in low-power modes
 - Pin interrupt is functional in all digital pin muxing modes
- Digital input filter on selected pins

- Digital input filter for each pin, usable by any digital peripheral muxed onto the pin
- Individual enable or bypass control field per pin
- Selectable clock source for digital input filter with a five bit resolution on filter size
- Functional in all digital pin multiplexing modes
- Port control
 - Individual pull control fields with pullup, pulldown, and pull-disable support
 - Individual drive strength field supporting high and low drive strength
 - Individual slew rate field supporting fast and slow slew rates
 - Individual input passive filter field supporting enable and disable of the individual input passive filter
 - Individual open drain field supporting enable and disable of the individual open drain output
 - Individual mux control field supporting analog or pin disabled, GPIO, and up to six chip-specific digital functions
 - Pad configuration fields are functional in all digital pin muxing modes.

11.2.2 Modes of operation

11.2.2.1 Run mode

In Run mode, the PORT operates normally.

11.2.2.2 Wait mode

In Wait mode, PORT continues to operate normally and may be configured to exit the Low-Power mode if an enabled interrupt is detected. DMA requests are still generated during the Wait mode, but do not cause an exit from the Low-Power mode.

11.2.2.3 Stop mode

In Stop mode, the PORT can be configured to exit the Low-Power mode via an asynchronous wake-up signal if an enabled interrupt is detected.

In Stop mode, the digital input filters are bypassed unless they are configured to run from the 1-kHz LPO clock source.

11.2.2.4 Debug mode

In Debug mode, PORT operates normally.

11.3 External signal description

The table found here describes the PORT external signal.

Table 11-1. Signal properties

| Name | Function | I/O | Reset | Pull |
|-------------|--------------------|-----|-------|------|
| PORTx[31:0] | External interrupt | I/O | 0 | - |

NOTE

Not all pins within each port are implemented on each device.

11.4 Detailed signal description

The table found here contains the detailed signal description for the PORT interface.

Table 11-2. PORT interface—detailed signal description

| Signal | I/O | Description | |
|-------------|-----|---------------------|---|
| PORTx[31:0] | I/O | External interrupt. | |
| | | State meaning | Asserted—pin is logic 1. Negated—pin is logic 0. |
| | | Timing | Assertion—may occur at any time and can assert asynchronously to the system clock. Negation—may occur at any time and can assert asynchronously to the system clock. |

11.5 Memory map and register definition

Any read or write access to the PORT memory space that is outside the valid memory map results in a bus error. All register accesses complete with zero wait states.

PORT memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|-----------------------|-----------------------------|----------------------------|
| 4004_9000 | Pin Control Register n (PORTA_PCR0) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9004 | Pin Control Register n (PORTA_PCR1) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9008 | Pin Control Register n (PORTA_PCR2) | 32 | R/W | See section | 11.5.1/210 |
| 4004_900C | Pin Control Register n (PORTA_PCR3) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9010 | Pin Control Register n (PORTA_PCR4) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9014 | Pin Control Register n (PORTA_PCR5) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9018 | Pin Control Register n (PORTA_PCR6) | 32 | R/W | See section | 11.5.1/210 |
| 4004_901C | Pin Control Register n (PORTA_PCR7) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9020 | Pin Control Register n (PORTA_PCR8) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9024 | Pin Control Register n (PORTA_PCR9) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9028 | Pin Control Register n (PORTA_PCR10) | 32 | R/W | See section | 11.5.1/210 |
| 4004_902C | Pin Control Register n (PORTA_PCR11) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9030 | Pin Control Register n (PORTA_PCR12) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9034 | Pin Control Register n (PORTA_PCR13) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9038 | Pin Control Register n (PORTA_PCR14) | 32 | R/W | See section | 11.5.1/210 |
| 4004_903C | Pin Control Register n (PORTA_PCR15) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9040 | Pin Control Register n (PORTA_PCR16) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9044 | Pin Control Register n (PORTA_PCR17) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9048 | Pin Control Register n (PORTA_PCR18) | 32 | R/W | See section | 11.5.1/210 |
| 4004_904C | Pin Control Register n (PORTA_PCR19) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9050 | Pin Control Register n (PORTA_PCR20) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9054 | Pin Control Register n (PORTA_PCR21) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9058 | Pin Control Register n (PORTA_PCR22) | 32 | R/W | See section | 11.5.1/210 |
| 4004_905C | Pin Control Register n (PORTA_PCR23) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9060 | Pin Control Register n (PORTA_PCR24) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9064 | Pin Control Register n (PORTA_PCR25) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9068 | Pin Control Register n (PORTA_PCR26) | 32 | R/W | See section | 11.5.1/210 |
| 4004_906C | Pin Control Register n (PORTA_PCR27) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9070 | Pin Control Register n (PORTA_PCR28) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9074 | Pin Control Register n (PORTA_PCR29) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9078 | Pin Control Register n (PORTA_PCR30) | 32 | R/W | See section | 11.5.1/210 |
| 4004_907C | Pin Control Register n (PORTA_PCR31) | 32 | R/W | See section | 11.5.1/210 |
| 4004_9080 | Global Pin Control Low Register (PORTA_GPCLR) | 32 | W (always reads 0) | 0000_0000h | 11.5.2/212 |
| 4004_9084 | Global Pin Control High Register (PORTA_GPCHR) | 32 | W (always reads 0) | 0000_0000h | 11.5.3/213 |
| 4004_90A0 | Interrupt Status Flag Register (PORTA_ISFR) | 32 | w1c | 0000_0000h | 11.5.4/214 |

Table continues on the next page...

PORT memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|-----------------------|-----------------------------|----------------------------|
| 4004_90C0 | Digital Filter Enable Register (PORTA_DFER) | 32 | R/W | 0000_0000h | 11.5.5/214 |
| 4004_90C4 | Digital Filter Clock Register (PORTA_DFCR) | 32 | R/W | 0000_0000h | 11.5.6/215 |
| 4004_90C8 | Digital Filter Width Register (PORTA_DFWR) | 32 | R/W | 0000_0000h | 11.5.7/215 |
| 4004_A000 | Pin Control Register n (PORTB_PCR0) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A004 | Pin Control Register n (PORTB_PCR1) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A008 | Pin Control Register n (PORTB_PCR2) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A00C | Pin Control Register n (PORTB_PCR3) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A010 | Pin Control Register n (PORTB_PCR4) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A014 | Pin Control Register n (PORTB_PCR5) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A018 | Pin Control Register n (PORTB_PCR6) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A01C | Pin Control Register n (PORTB_PCR7) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A020 | Pin Control Register n (PORTB_PCR8) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A024 | Pin Control Register n (PORTB_PCR9) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A028 | Pin Control Register n (PORTB_PCR10) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A02C | Pin Control Register n (PORTB_PCR11) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A030 | Pin Control Register n (PORTB_PCR12) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A034 | Pin Control Register n (PORTB_PCR13) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A038 | Pin Control Register n (PORTB_PCR14) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A03C | Pin Control Register n (PORTB_PCR15) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A040 | Pin Control Register n (PORTB_PCR16) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A044 | Pin Control Register n (PORTB_PCR17) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A048 | Pin Control Register n (PORTB_PCR18) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A04C | Pin Control Register n (PORTB_PCR19) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A050 | Pin Control Register n (PORTB_PCR20) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A054 | Pin Control Register n (PORTB_PCR21) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A058 | Pin Control Register n (PORTB_PCR22) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A05C | Pin Control Register n (PORTB_PCR23) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A060 | Pin Control Register n (PORTB_PCR24) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A064 | Pin Control Register n (PORTB_PCR25) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A068 | Pin Control Register n (PORTB_PCR26) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A06C | Pin Control Register n (PORTB_PCR27) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A070 | Pin Control Register n (PORTB_PCR28) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A074 | Pin Control Register n (PORTB_PCR29) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A078 | Pin Control Register n (PORTB_PCR30) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A07C | Pin Control Register n (PORTB_PCR31) | 32 | R/W | See section | 11.5.1/210 |
| 4004_A080 | Global Pin Control Low Register (PORTB_GPCLR) | 32 | W (always reads 0) | 0000_0000h | 11.5.2/212 |

Table continues on the next page...

PORT memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|-----------------------|-----------------------------|----------------------------|
| 4004_A084 | Global Pin Control High Register (PORTB_GPCHR) | 32 | W (always reads 0) | 0000_0000h | 11.5.3/213 |
| 4004_A0A0 | Interrupt Status Flag Register (PORTB_ISFR) | 32 | w1c | 0000_0000h | 11.5.4/214 |
| 4004_A0C0 | Digital Filter Enable Register (PORTB_DFER) | 32 | R/W | 0000_0000h | 11.5.5/214 |
| 4004_A0C4 | Digital Filter Clock Register (PORTB_DFCR) | 32 | R/W | 0000_0000h | 11.5.6/215 |
| 4004_A0C8 | Digital Filter Width Register (PORTB_DFWR) | 32 | R/W | 0000_0000h | 11.5.7/215 |
| 4004_B000 | Pin Control Register n (PORTC_PCR0) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B004 | Pin Control Register n (PORTC_PCR1) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B008 | Pin Control Register n (PORTC_PCR2) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B00C | Pin Control Register n (PORTC_PCR3) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B010 | Pin Control Register n (PORTC_PCR4) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B014 | Pin Control Register n (PORTC_PCR5) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B018 | Pin Control Register n (PORTC_PCR6) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B01C | Pin Control Register n (PORTC_PCR7) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B020 | Pin Control Register n (PORTC_PCR8) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B024 | Pin Control Register n (PORTC_PCR9) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B028 | Pin Control Register n (PORTC_PCR10) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B02C | Pin Control Register n (PORTC_PCR11) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B030 | Pin Control Register n (PORTC_PCR12) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B034 | Pin Control Register n (PORTC_PCR13) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B038 | Pin Control Register n (PORTC_PCR14) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B03C | Pin Control Register n (PORTC_PCR15) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B040 | Pin Control Register n (PORTC_PCR16) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B044 | Pin Control Register n (PORTC_PCR17) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B048 | Pin Control Register n (PORTC_PCR18) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B04C | Pin Control Register n (PORTC_PCR19) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B050 | Pin Control Register n (PORTC_PCR20) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B054 | Pin Control Register n (PORTC_PCR21) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B058 | Pin Control Register n (PORTC_PCR22) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B05C | Pin Control Register n (PORTC_PCR23) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B060 | Pin Control Register n (PORTC_PCR24) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B064 | Pin Control Register n (PORTC_PCR25) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B068 | Pin Control Register n (PORTC_PCR26) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B06C | Pin Control Register n (PORTC_PCR27) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B070 | Pin Control Register n (PORTC_PCR28) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B074 | Pin Control Register n (PORTC_PCR29) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B078 | Pin Control Register n (PORTC_PCR30) | 32 | R/W | See section | 11.5.1/210 |

Table continues on the next page...

PORT memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|-----------------------|-----------------------------|----------------------------|
| 4004_B07C | Pin Control Register n (PORTC_PCR31) | 32 | R/W | See section | 11.5.1/210 |
| 4004_B080 | Global Pin Control Low Register (PORTC_GPCLR) | 32 | W (always reads 0) | 0000_0000h | 11.5.2/212 |
| 4004_B084 | Global Pin Control High Register (PORTC_GPCHR) | 32 | W (always reads 0) | 0000_0000h | 11.5.3/213 |
| 4004_B0A0 | Interrupt Status Flag Register (PORTC_ISFR) | 32 | w1c | 0000_0000h | 11.5.4/214 |
| 4004_B0C0 | Digital Filter Enable Register (PORTC_DFER) | 32 | R/W | 0000_0000h | 11.5.5/214 |
| 4004_B0C4 | Digital Filter Clock Register (PORTC_DFCL) | 32 | R/W | 0000_0000h | 11.5.6/215 |
| 4004_B0C8 | Digital Filter Width Register (PORTC_DFWR) | 32 | R/W | 0000_0000h | 11.5.7/215 |
| 4004_C000 | Pin Control Register n (PORTD_PCR0) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C004 | Pin Control Register n (PORTD_PCR1) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C008 | Pin Control Register n (PORTD_PCR2) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C00C | Pin Control Register n (PORTD_PCR3) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C010 | Pin Control Register n (PORTD_PCR4) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C014 | Pin Control Register n (PORTD_PCR5) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C018 | Pin Control Register n (PORTD_PCR6) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C01C | Pin Control Register n (PORTD_PCR7) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C020 | Pin Control Register n (PORTD_PCR8) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C024 | Pin Control Register n (PORTD_PCR9) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C028 | Pin Control Register n (PORTD_PCR10) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C02C | Pin Control Register n (PORTD_PCR11) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C030 | Pin Control Register n (PORTD_PCR12) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C034 | Pin Control Register n (PORTD_PCR13) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C038 | Pin Control Register n (PORTD_PCR14) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C03C | Pin Control Register n (PORTD_PCR15) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C040 | Pin Control Register n (PORTD_PCR16) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C044 | Pin Control Register n (PORTD_PCR17) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C048 | Pin Control Register n (PORTD_PCR18) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C04C | Pin Control Register n (PORTD_PCR19) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C050 | Pin Control Register n (PORTD_PCR20) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C054 | Pin Control Register n (PORTD_PCR21) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C058 | Pin Control Register n (PORTD_PCR22) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C05C | Pin Control Register n (PORTD_PCR23) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C060 | Pin Control Register n (PORTD_PCR24) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C064 | Pin Control Register n (PORTD_PCR25) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C068 | Pin Control Register n (PORTD_PCR26) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C06C | Pin Control Register n (PORTD_PCR27) | 32 | R/W | See section | 11.5.1/210 |

Table continues on the next page...

PORT memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|--|-----------------|-----------------------|-----------------------------|----------------------------|
| 4004_C070 | Pin Control Register n (PORTD_PCR28) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C074 | Pin Control Register n (PORTD_PCR29) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C078 | Pin Control Register n (PORTD_PCR30) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C07C | Pin Control Register n (PORTD_PCR31) | 32 | R/W | See section | 11.5.1/210 |
| 4004_C080 | Global Pin Control Low Register (PORTD_GPCLR) | 32 | W (always reads 0) | 0000_0000h | 11.5.2/212 |
| 4004_C084 | Global Pin Control High Register (PORTD_GPCHR) | 32 | W (always reads 0) | 0000_0000h | 11.5.3/213 |
| 4004_C0A0 | Interrupt Status Flag Register (PORTD_ISFR) | 32 | w1c | 0000_0000h | 11.5.4/214 |
| 4004_C0C0 | Digital Filter Enable Register (PORTD_DFER) | 32 | R/W | 0000_0000h | 11.5.5/214 |
| 4004_C0C4 | Digital Filter Clock Register (PORTD_DFCR) | 32 | R/W | 0000_0000h | 11.5.6/215 |
| 4004_C0C8 | Digital Filter Width Register (PORTD_DFWR) | 32 | R/W | 0000_0000h | 11.5.7/215 |
| 4004_D000 | Pin Control Register n (PORTE_PCR0) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D004 | Pin Control Register n (PORTE_PCR1) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D008 | Pin Control Register n (PORTE_PCR2) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D00C | Pin Control Register n (PORTE_PCR3) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D010 | Pin Control Register n (PORTE_PCR4) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D014 | Pin Control Register n (PORTE_PCR5) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D018 | Pin Control Register n (PORTE_PCR6) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D01C | Pin Control Register n (PORTE_PCR7) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D020 | Pin Control Register n (PORTE_PCR8) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D024 | Pin Control Register n (PORTE_PCR9) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D028 | Pin Control Register n (PORTE_PCR10) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D02C | Pin Control Register n (PORTE_PCR11) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D030 | Pin Control Register n (PORTE_PCR12) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D034 | Pin Control Register n (PORTE_PCR13) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D038 | Pin Control Register n (PORTE_PCR14) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D03C | Pin Control Register n (PORTE_PCR15) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D040 | Pin Control Register n (PORTE_PCR16) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D044 | Pin Control Register n (PORTE_PCR17) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D048 | Pin Control Register n (PORTE_PCR18) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D04C | Pin Control Register n (PORTE_PCR19) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D050 | Pin Control Register n (PORTE_PCR20) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D054 | Pin Control Register n (PORTE_PCR21) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D058 | Pin Control Register n (PORTE_PCR22) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D05C | Pin Control Register n (PORTE_PCR23) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D060 | Pin Control Register n (PORTE_PCR24) | 32 | R/W | See section | 11.5.1/210 |

Table continues on the next page...

PORT memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|-----------------------|-----------------------------|----------------------------|
| 4004_D064 | Pin Control Register n (PORTE_PCR25) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D068 | Pin Control Register n (PORTE_PCR26) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D06C | Pin Control Register n (PORTE_PCR27) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D070 | Pin Control Register n (PORTE_PCR28) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D074 | Pin Control Register n (PORTE_PCR29) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D078 | Pin Control Register n (PORTE_PCR30) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D07C | Pin Control Register n (PORTE_PCR31) | 32 | R/W | See section | 11.5.1/210 |
| 4004_D080 | Global Pin Control Low Register (PORTE_GPCLR) | 32 | W (always reads 0) | 0000_0000h | 11.5.2/212 |
| 4004_D084 | Global Pin Control High Register (PORTE_GPCHR) | 32 | W (always reads 0) | 0000_0000h | 11.5.3/213 |
| 4004_D0A0 | Interrupt Status Flag Register (PORTE_ISFR) | 32 | w1c | 0000_0000h | 11.5.4/214 |
| 4004_D0C0 | Digital Filter Enable Register (PORTE_DFER) | 32 | R/W | 0000_0000h | 11.5.5/214 |
| 4004_D0C4 | Digital Filter Clock Register (PORTE_DFCR) | 32 | R/W | 0000_0000h | 11.5.6/215 |
| 4004_D0C8 | Digital Filter Width Register (PORTE_DFWR) | 32 | R/W | 0000_0000h | 11.5.7/215 |

11.5.1 Pin Control Register n (PORTx_PCRn)

NOTE

See the Signal Multiplexing and Pin Assignment chapter for the reset value of this device.

See the GPIO Configuration section for details on the available functions for each pin.

Do not modify pin configuration registers associated with pins not available in your selected package. All unbonded pins not available in your package will default to DISABLE state for lowest power consumption.

Address: Base address + 0h offset + (4d × i), where i=0d to 31d

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | |
|-------|----|----|----|----|----|----|----|----|-----|----|----|----|----|------|----|----|--|
| R | 0 | | | | | | | | ISF | 0 | | | | IRQC | | | |
| W | | | | | | | | | w1c | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|-----|---|---|---|-----|-----|-----|---|-----|----|----|
| R | LK | 0 | | | | MUX | | | 0 | DSE | ODE | PFE | 0 | SRE | PE | PS |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | * | * | * | 0 | * | 0 | * | 0 | * | * | * |

* Notes:

- MUX field: Varies by port. See Signal Multiplexing and Signal Descriptions chapter for reset values per port.
- DSE field: Varies by port. See the Signal Multiplexing and Signal Descriptions chapter for reset values per port.
- PFE field: Varies by port. See Signal Multiplexing and Signal Descriptions chapter for reset values per port.
- SRE field: Varies by port. See Signal Multiplexing and Signal Descriptions chapter for reset values per port.
- PE field: Varies by port. See Signal Multiplexing and Signal Descriptions chapter for reset values per port.
- PS field: Varies by port. See Signal Multiplexing and Signal Descriptions chapter for reset values per port.

PORTx_PCRn field descriptions

| Field | Description |
|-------------------|--|
| 31–25 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 24 ISF | Interrupt Status Flag The pin interrupt configuration is valid in all digital pin muxing modes. |

Table continues on the next page...

PORTx_PCRn field descriptions (continued)

| Field | Description |
|-------------------|--|
| | <p>0 Configured interrupt is not detected.</p> <p>1 Configured interrupt is detected. If the pin is configured to generate a DMA request, then the corresponding flag will be cleared automatically at the completion of the requested DMA transfer. Otherwise, the flag remains set until a logic 1 is written to the flag. If the pin is configured for a level sensitive interrupt and the pin remains asserted, then the flag is set again immediately after it is cleared.</p> |
| 23–20 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 19–16 IRQC | <p>Interrupt Configuration</p> <p>The pin interrupt configuration is valid in all digital pin muxing modes. The corresponding pin is configured to generate interrupt/DMA request as follows:</p> <p>0000 Interrupt/DMA request disabled.</p> <p>0001 DMA request on rising edge.</p> <p>0010 DMA request on falling edge.</p> <p>0011 DMA request on either edge.</p> <p>1000 Interrupt when logic 0.</p> <p>1001 Interrupt on rising-edge.</p> <p>1010 Interrupt on falling-edge.</p> <p>1011 Interrupt on either edge.</p> <p>1100 Interrupt when logic 1.</p> <p>Others Reserved.</p> |
| 15 LK | <p>Lock Register</p> <p>0 Pin Control Register fields [15:0] are not locked.</p> <p>1 Pin Control Register fields [15:0] are locked and cannot be updated until the next system reset.</p> |
| 14–11 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 10–8 MUX | <p>Pin Mux Control</p> <p>Not all pins support all pin muxing slots. Unimplemented pin muxing slots are reserved and may result in configuring the pin for a different pin muxing slot.</p> <p>The corresponding pin is configured in the following pin muxing slot as follows:</p> <p>000 Pin disabled (analog).</p> <p>001 Alternative 1 (GPIO).</p> <p>010 Alternative 2 (chip-specific).</p> <p>011 Alternative 3 (chip-specific).</p> <p>100 Alternative 4 (chip-specific).</p> <p>101 Alternative 5 (chip-specific).</p> <p>110 Alternative 6 (chip-specific).</p> <p>111 Alternative 7 (chip-specific).</p> |
| 7 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 6 DSE | <p>Drive Strength Enable</p> <p>Drive strength configuration is valid in all digital pin muxing modes.</p> |

Table continues on the next page...

PORTx_PCRn field descriptions (continued)

| Field | Description |
|---------------|--|
| | 0 Low drive strength is configured on the corresponding pin, if pin is configured as a digital output. 1 High drive strength is configured on the corresponding pin, if pin is configured as a digital output. |
| 5 ODE | Open Drain Enable Open drain configuration is valid in all digital pin muxing modes. 0 Open drain output is disabled on the corresponding pin. 1 Open drain output is enabled on the corresponding pin, if the pin is configured as a digital output. |
| 4 PFE | Passive Filter Enable Passive filter configuration is valid in all digital pin muxing modes. 0 Passive input filter is disabled on the corresponding pin. 1 Passive input filter is enabled on the corresponding pin, if the pin is configured as a digital input. Refer to the device data sheet for filter characteristics. |
| 3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 SRE | Slew Rate Enable Slew rate configuration is valid in all digital pin muxing modes. 0 Fast slew rate is configured on the corresponding pin, if the pin is configured as a digital output. 1 Slow slew rate is configured on the corresponding pin, if the pin is configured as a digital output. |
| 1 PE | Pull Enable Pull configuration is valid in all digital pin muxing modes. 0 Internal pullup or pulldown resistor is not enabled on the corresponding pin. 1 Internal pullup or pulldown resistor is enabled on the corresponding pin, if the pin is configured as a digital input. |
| 0 PS | Pull Select Pull configuration is valid in all digital pin muxing modes. 0 Internal pulldown resistor is enabled on the corresponding pin, if the corresponding PE field is set. 1 Internal pullup resistor is enabled on the corresponding pin, if the corresponding PE field is set. |

11.5.2 Global Pin Control Low Register (PORTx_GPCLR)

Only 32-bit writes are supported to this register.

Address: Base address + 80h offset

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | 0 | | | | | | | | | | | | | | | | 0 | | | | | | | | | | | | | | | |
| W | GPWE | | | | | | | | | | | | | | | | GPWD | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PORTx_GPCLR field descriptions

| Field | Description |
|---------------|---|
| 31–16 GPWE | Global Pin Write Enable Selects which Pin Control Registers (15 through 0) bits [15:0] update with the value in GPWD. If a selected Pin Control Register is locked then the write to that register is ignored. 0 Corresponding Pin Control Register is not updated with the value in GPWD. 1 Corresponding Pin Control Register is updated with the value in GPWD. |
| 15–0 GPWD | Global Pin Write Data Write value that is written to all Pin Control Registers bits [15:0] that are selected by GPWE. |

11.5.3 Global Pin Control High Register (PORTx_GPCHR)

Only 32-bit writes are supported to this register.

Address: Base address + 84h offset

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | 0 | | | | | | | | | | | | | | | |
| W | GPWE | | | | | | | | | | | | | | | | GPWD | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

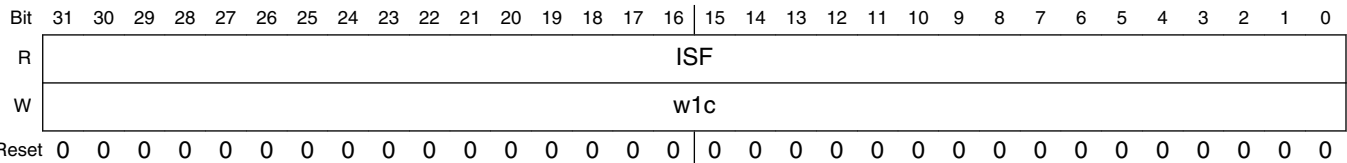
PORTx_GPCHR field descriptions

| Field | Description |
|---------------|--|
| 31–16 GPWE | Global Pin Write Enable Selects which Pin Control Registers (31 through 16) bits [15:0] update with the value in GPWD. If a selected Pin Control Register is locked then the write to that register is ignored. 0 Corresponding Pin Control Register is not updated with the value in GPWD. 1 Corresponding Pin Control Register is updated with the value in GPWD. |
| 15–0 GPWD | Global Pin Write Data Write value that is written to all Pin Control Registers bits [15:0] that are selected by GPWE. |

11.5.4 Interrupt Status Flag Register (PORTx_ISFR)

The pin interrupt configuration is valid in all digital pin muxing modes. The Interrupt Status Flag for each pin is also visible in the corresponding Pin Control Register, and each flag can be cleared in either location.

Address: Base address + A0h offset



PORTx_ISFR field descriptions

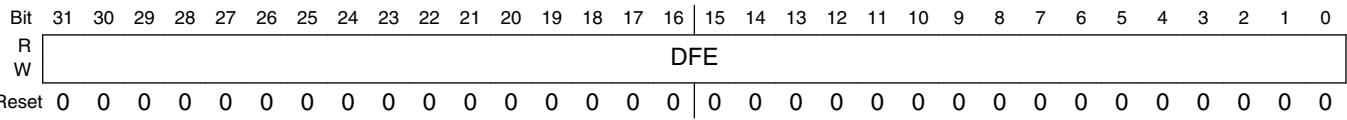
| Field | Description |
|-------------|--|
| 31–0 ISF | <p>Interrupt Status Flag</p> <p>Each bit in the field indicates the detection of the configured interrupt of the same number as the field.</p> <p>0 Configured interrupt is not detected.</p> <p>1 Configured interrupt is detected. If the pin is configured to generate a DMA request, then the corresponding flag will be cleared automatically at the completion of the requested DMA transfer. Otherwise, the flag remains set until a logic 1 is written to the flag. If the pin is configured for a level sensitive interrupt and the pin remains asserted, then the flag is set again immediately after it is cleared.</p> |

11.5.5 Digital Filter Enable Register (PORTx_DFER)

The corresponding bit is read only for pins that do not support a digital filter. Refer to the Chapter of Signal Multiplexing and Signal Descriptions for the pins that support digital filter.

The digital filter configuration is valid in all digital pin muxing modes.

Address: Base address + C0h offset



PORTx_DFER field descriptions

| Field | Description |
|-------------|-----------------------|
| 31–0 DFE | Digital Filter Enable |

PORTx_DFER field descriptions (continued)

| Field | Description |
|-------|--|
| | The digital filter configuration is valid in all digital pin muxing modes. The output of each digital filter is reset to zero at system reset and whenever the digital filter is disabled. Each bit in the field enables the digital filter of the same number as the field. |
| 0 | Digital filter is disabled on the corresponding pin and output of the digital filter is reset to zero. |
| 1 | Digital filter is enabled on the corresponding pin, if the pin is configured as a digital input. |

11.5.6 Digital Filter Clock Register (PORTx_DFRCR)

This register is read only for ports that do not support a digital filter.

The digital filter configuration is valid in all digital pin muxing modes.

Address: Base address + C4h offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | CS |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PORTx_DFRCR field descriptions

| Field | Description |
|------------------|---|
| 31–1 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 0 CS | Clock Source The digital filter configuration is valid in all digital pin muxing modes. Configures the clock source for the digital input filters. Changing the filter clock source must be done only when all digital filters are disabled. 0 Digital filters are clocked by the bus clock. 1 Digital filters are clocked by the 1-kHz LPO clock. |

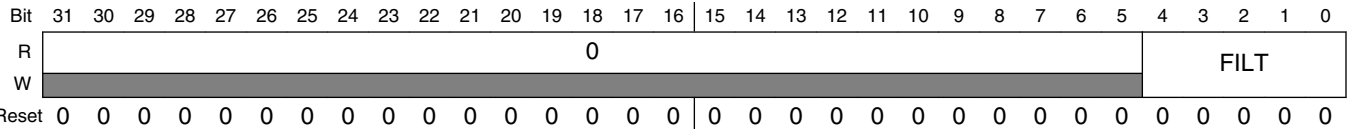
11.5.7 Digital Filter Width Register (PORTx_DFWR)

This register is read only for ports that do not support a digital filter.

The digital filter configuration is valid in all digital pin muxing modes.

functional description

Address: Base address + C8h offset



PORTx_DFWR field descriptions

| Field | Description |
|------------------|---|
| 31–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4–0 FILT | Filter Length The digital filter configuration is valid in all digital pin muxing modes. Configures the maximum size of the glitches, in clock cycles, that the digital filter absorbs for the enabled digital filters. Glitches that are longer than this register setting will pass through the digital filter, and glitches that are equal to or less than this register setting are filtered. Changing the filter length must be done only after all filters are disabled. |

11.6 Functional description

11.6.1 Pin control

Each port pin has a corresponding Pin Control register, PORT_PCRn, associated with it.

The upper half of the Pin Control register configures the pin's capability to either interrupt the CPU or request a DMA transfer, on a rising/falling edge or both edges as well as a logic level occurring on the port pin. It also includes a flag to indicate that an interrupt has occurred.

The lower half of the Pin Control register configures the following functions for each pin within the 32-bit port.

- Pullup or pulldown enable
- Drive strength and slew rate configuration
- Open drain enable
- Passive input filter enable
- Pin Muxing mode

The functions apply across all digital pin muxing modes and individual peripherals do not override the configuration in the Pin Control register. For example, if an I²C function is enabled on a pin, that does not override the pullup or open drain configuration for that pin.

When the Pin Muxing mode is configured for analog or is disabled, all the digital functions on that pin are disabled. This includes the pullup and pulldown enables, output buffer enable, input buffer enable, and passive filter enable.

A lock field also exists that allows the configuration for each pin to be locked until the next system reset. When locked, writes to the lower half of that pin control register are ignored, although a bus error is not generated on an attempted write to a locked register.

The configuration of each Pin Control register is retained when the PORT module is disabled.

Whenever a pin is configured in any digital pin muxing mode, the input buffer for that pin is enabled allowing the pin state to be read via the corresponding GPIO Port Data Input Register (PDIR) or allowing a pin interrupt or DMA request to be generated. If a pin is ever floating when its input buffer is enabled, then this can cause an increase in power consumption and should be avoided. A pin can be floating due to an input pin that is not connected or an output pin that has tristated (output buffer is disabled).

Enabling the internal pull resistor (or implementing an external pull resistor) will ensure a pin does not float when its input buffer is enabled; note that the internal pull resistor is automatically disabled whenever the output buffer is enabled allowing the Pull Enable bit to remain set. Configuring the Pin Muxing mode to disabled or analog will disable the pin's input buffer and results in the lowest power consumption.

11.6.2 Global pin control

The two global pin control registers allow a single register write to update the lower half of the pin control register on up to 16 pins, all with the same value. Registers that are locked cannot be written using the global pin control registers.

The global pin control registers are designed to enable software to quickly configure multiple pins within the one port for the same peripheral function. However, the interrupt functions cannot be configured using the global pin control registers.

The global pin control registers are write-only registers, that always read as 0.

11.6.3 External interrupts

The external interrupt capability of the PORT module is available in all digital pin muxing modes provided the PORT module is enabled.

Each pin can be individually configured for any of the following external interrupt modes:

- Interrupt disabled, default out of reset
- Active high level sensitive interrupt
- Active low level sensitive interrupt
- Rising edge sensitive interrupt
- Falling edge sensitive interrupt
- Rising and falling edge sensitive interrupt
- Rising edge sensitive DMA request
- Falling edge sensitive DMA request
- Rising and falling edge sensitive DMA request

The interrupt status flag is set when the configured edge or level is detected on the pin or at the output of the digital input filter, if the digital input digital filter is enabled. When not in Stop mode, the input is first synchronized to the bus clock to detect the configured level or edge transition.

The PORT module generates a single interrupt that asserts when the interrupt status flag is set for any enabled interrupt for that port. The interrupt negates after the interrupt status flags for all enabled interrupts have been cleared by writing a logic 1 to the ISF flag in either the PORT_ISFR or PORT_PCRn registers.

The PORT module generates a single DMA request that asserts when the interrupt status flag is set for any enabled DMA request in that port. The DMA request negates after the DMA transfer is completed, because that clears the interrupt status flags for all enabled DMA requests.

During Stop mode, the interrupt status flag for any enabled interrupt is asynchronously set if the required level or edge is detected. This also generates an asynchronous wake-up signal to exit the Low-Power mode.

11.6.4 Digital filter

The digital filter capabilities of the PORT module are available in all digital Pin Muxing modes if the PORT module is enabled.

The clock used for all digital filters within one port can be configured between the bus clock or the 1-kHz LPO clock. This selection must be changed only when all digital filters for that port are disabled. If the digital filters for a port are configured to use the bus clock, then the digital filters are bypassed for the duration of Stop mode. While the digital filters are bypassed, the output of each digital filter always equals the input pin, but the internal state of the digital filters remains static and does not update due to any change on the input pin.

The filter width in clock size is the same for all enabled digital filters within one port and must be changed only when all digital filters for that port are disabled.

The output of each digital filter is logic zero after system reset and whenever a digital filter is disabled. After a digital filter is enabled, the input is synchronized to the filter clock, either the bus clock or the 1-kHz LPO clock. If the synchronized input and the output of the digital filter remain different for a number of filter clock cycles equal to the filter width register configuration, then the output of the digital filter updates to equal the synchronized filter input.

The minimum latency through a digital filter equals two or three filter clock cycles plus the filter width configuration register.



Chapter 12

System Integration Module (SIM)

12.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The System Integration Module (SIM) provides system control and chip configuration registers.

12.1.1 Features

Features of the SIM include:

- System clocking configuration
 - System clock divide values
 - Architectural clock gating control
- Flash and system RAM size configuration
- FlexTimer external clock, hardware trigger, and fault source selection
- UART0 and UART1 receive/transmit source selection/configuration

12.2 Memory map and register definition

The SIM module contains many fields for selecting the clock source and dividers for various module clocks. See the [Clock Distribution](#) chapter for more information, including block diagrams and clock definitions.

NOTE

The SIM_SOPT1 and SIM_SOPT1CFG registers are located at a different base address than the other SIM registers.

SIM memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-----------------------------|-----------------------------|
| 4004_7000 | System Options Register 1 (SIM_SOPT1) | 32 | R/W | See section | 12.2.1/223 |
| 4004_7004 | SOPT1 Configuration Register (SIM_SOPT1CFG) | 32 | R/W | 0000_0000h | 12.2.2/224 |
| 4004_8004 | System Options Register 2 (SIM_SOPT2) | 32 | R/W | 0000_1000h | 12.2.3/225 |
| 4004_800C | System Options Register 4 (SIM_SOPT4) | 32 | R/W | 0000_0000h | 12.2.4/227 |
| 4004_8010 | System Options Register 5 (SIM_SOPT5) | 32 | R/W | 0000_0000h | 12.2.5/229 |
| 4004_8018 | System Options Register 7 (SIM_SOPT7) | 32 | R/W | 0000_0000h | 12.2.6/231 |
| 4004_8024 | System Device Identification Register (SIM_SDID) | 32 | R | See section | 12.2.7/232 |
| 4004_8034 | System Clock Gating Control Register 4 (SIM_SCGC4) | 32 | R/W | F010_0030h | 12.2.8/233 |
| 4004_8038 | System Clock Gating Control Register 5 (SIM_SCGC5) | 32 | R/W | 0004_0182h | 12.2.9/235 |
| 4004_803C | System Clock Gating Control Register 6 (SIM_SCGC6) | 32 | R/W | 4000_0001h | 12.2.10/237 |
| 4004_8040 | System Clock Gating Control Register 7 (SIM_SCGC7) | 32 | R/W | 0000_0002h | 12.2.11/240 |
| 4004_8044 | System Clock Divider Register 1 (SIM_CLKDIV1) | 32 | R/W | See section | 12.2.12/240 |
| 4004_804C | Flash Configuration Register 1 (SIM_FCFG1) | 32 | R | See section | 12.2.13/242 |
| 4004_8050 | Flash Configuration Register 2 (SIM_FCFG2) | 32 | R | See section | 12.2.14/245 |
| 4004_8054 | Unique Identification Register High (SIM_UIDH) | 32 | R | See section | 12.2.15/246 |
| 4004_8058 | Unique Identification Register Mid-High (SIM_UIDMH) | 32 | R | See section | 12.2.16/247 |
| 4004_805C | Unique Identification Register Mid Low (SIM_UIDML) | 32 | R | See section | 12.2.17/247 |
| 4004_8060 | Unique Identification Register Low (SIM_UIDL) | 32 | R | See section | 12.2.18/248 |

12.2.1 System Options Register 1 (SIM_SOPT1)

NOTE

The SOPT1 register is only reset on POR or LVD.

Address: 4004_7000h base + 0h offset = 4004_7000h

| | | | | | | | | | | | | | | | | |
|-------|----------|----|----|----|----------|----|----|----|-----------|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | Reserved | | | | | | | | 0 | | | | | | | |
| W | Reserved | | | | | | | | OSC32KSEL | | | | | | | |
| Reset | x* | x* | x* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | RAMSIZE | | | | 0 | | | | Reserved | | | | | | | |
| W | Reserved | | | | Reserved | | | | Reserved | | | | | | | |
| Reset | x* | x* | x* | x* | 0* | 0* | 0* | 0* | 0* | 0* | x* | x* | x* | x* | x* | x* |

* Notes:

- Reset value loaded during System Reset from Flash IFR.
- x = Undefined at reset.

SIM_SOPT1 field descriptions

| Field | Description |
|--------------------|---|
| 31–29 Reserved | This field is reserved. |
| 28–20 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 19–18 OSC32KSEL | 32K oscillator clock select Selects the 32 kHz clock source (ERCLK32K) for LPTMR. This field is reset only on POR/LVD. 00 System oscillator (OSC32KCLK) 01 Reserved 10 RTC 32.768kHz oscillator 11 LPO 1 kHz |
| 17–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–12 RAMSIZE | RAM size This field specifies the amount of system RAM available on the device. 0001 8 KB 0011 16 KB 0100 24 KB 0101 32 KB 0110 48 KB |

Table continues on the next page...

SIM_SOPT1 field descriptions (continued)

| Field | Description |
|------------------|---|
| | 0111 64 KB 1000 96 KB 1001 128 KB 1011 256 KB |
| 11–6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5–0 Reserved | This field is reserved. |

12.2.2 SOPT1 Configuration Register (SIM_SOPT1CFG)

NOTE

The SOPT1CFG register is reset on System Reset not VLLS.

Address: 4004_7000h base + 4h offset = 4004_7004h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SIM_SOPT1CFG field descriptions

| Field | Description |
|-------------------|---|
| 31–27 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 26–24 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 23–10 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 9–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

12.2.3 System Options Register 2 (SIM_SOPT2)

SOPT2 contains the controls for selecting many of the module clock source options on this device. See the Clock Distribution chapter for more information including clocking diagrams and definitions of device clocks.

Address: 4004_7000h base + 1004h offset = 4004_8004h

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|----|----|----|-------------|---------|----|----|----|----|----|----|--------------|----|----|----|----------|
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | PLLFLSEL |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | TRACECLKSEL | PTD7PAD | 0 | 0 | | | | | RTCCLKOUTSEL | | 0 | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SIM_SOPT2 field descriptions

| Field | Description |
|-------------------|---|
| 31–30 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 29–28 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 27–26 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 25–24 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 23–22 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 21–19 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 18 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 17 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 16 PLLFLSEL | PLL/FLL clock select Selects the MCGPLLCLK or MCGFLLCLK clock for various peripheral clocking options. |

Table continues on the next page...

SIM_SOPT2 field descriptions (continued)

| Field | Description |
|-------------------|---|
| | 0 MCGFLLCLK clock 1 MCGPLLCLK clock |
| 15–13 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 12 TRACECLKSEL | Debug trace clock select Selects the core/system clock or MCG output clock (MCGOUTCLK) as the trace clock source. 0 MCGOUTCLK 1 Core/system clock |
| 11 PTD7PAD | PTD7 pad drive strength Controls the output drive strength of the PTD7 pin by selecting either one or two pads to drive it. 0 Single-pad drive strength for PTD7. 1 Double pad drive strength for PTD7. |
| 10 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 9–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–5 CLKOUTSEL | CLKOUT select Selects the clock to output on the CLKOUT pin. 000 Reserved 001 Reserved 010 Flash clock 011 LPO clock (1 kHz) 100 MCGIRCLK 101 RTC 32.768kHz clock 110 OSCERCLK0 111 Reserved |
| 4 RTCCLKOUTSEL | RTC clock out select Selects either the RTC 1 Hz clock or the 32.768kHz clock to be output on the RTC_CLKOUT pin. 0 RTC 1 Hz clock is output on the RTC_CLKOUT pin. 1 RTC 32.768kHz clock is output on the RTC_CLKOUT pin. |
| 3–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

12.2.4 System Options Register 4 (SIM_SOPT4)

Address: 4004_7000h base + 100Ch offset = 4004_800Ch

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|----|----|------------|------------|----|------------|------------|------------|----|----|------------|------------|----|----|----|----|
| R | 0 | | FTM0TRG1SR | FTM0TRG0SR | 0 | FTM2CLKSEL | FTM1CLKSEL | FTM0CLKSEL | 0 | 0 | FTM2CH0SRC | FTM1CH0SRC | | | 0 | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|---|----------|---|---|---|----------|---|---|----------|----------|
| R | | | | 0 | | | | FTM2FLT0 | | 0 | | FTM1FLT0 | 0 | 0 | FTM0FLT1 | FTM0FLT0 |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SIM_SOPT4 field descriptions

| Field | Description |
|-------------------|---|
| 31–30 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 29 FTM0TRG1SRC | FlexTimer 0 Hardware Trigger 1 Source Select Selects the source of FTM0 hardware trigger 1. 0 PDB output trigger 1 drives FTM0 hardware trigger 1 1 FTM2 channel match drives FTM0 hardware trigger 1 |
| 28 FTM0TRG0SRC | FlexTimer 0 Hardware Trigger 0 Source Select Selects the source of FTM0 hardware trigger 0. 0 HSCMP0 output drives FTM0 hardware trigger 0 1 FTM1 channel match drives FTM0 hardware trigger 0 |
| 27 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 26 FTM2CLKSEL | FlexTimer 2 External Clock Pin Select Selects the external pin used to drive the clock to the FTM2 module. NOTE: The selected pin must also be configured for the FTM2 module external clock function through the appropriate pin control register in the port control module. 0 FTM2 external clock driven by FTM_CLK0 pin. 1 FTM2 external clock driven by FTM_CLK1 pin. |
| 25 FTM1CLKSEL | FTM1 External Clock Pin Select Selects the external pin used to drive the clock to the FTM1 module. |

Table continues on the next page...

SIM_SOPT4 field descriptions (continued)

| Field | Description |
|---------------------|---|
| | <p>NOTE: The selected pin must also be configured for the FTM external clock function through the appropriate pin control register in the port control module.</p> <p>0 FTM_CLK0 pin 1 FTM_CLK1 pin</p> |
| 24 FTM0CLKSEL | <p>FlexTimer 0 External Clock Pin Select</p> <p>Selects the external pin used to drive the clock to the FTM0 module.</p> <p>NOTE: The selected pin must also be configured for the FTM external clock function through the appropriate pin control register in the port control module.</p> <p>0 FTM_CLK0 pin 1 FTM_CLK1 pin</p> |
| 23 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 22 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 21–20 FTM2CH0SRC | <p>FTM2 channel 0 input capture source select</p> <p>Selects the source for FTM2 channel 0 input capture.</p> <p>NOTE: When the FTM is not in input capture mode, clear this field.</p> <p>00 FTM2_CH0 signal 01 CMP0 output 10 CMP1 output 11 Reserved</p> |
| 19–18 FTM1CH0SRC | <p>FTM1 channel 0 input capture source select</p> <p>Selects the source for FTM1 channel 0 input capture.</p> <p>NOTE: When the FTM is not in input capture mode, clear this field.</p> <p>00 FTM1_CH0 signal 01 CMP0 output 10 CMP1 output 11 Reserved</p> |
| 17–9 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 8 FTM2FLT0 | <p>FTM2 Fault 0 Select</p> <p>Selects the source of FTM2 fault 0.</p> <p>NOTE: The pin source for fault 0 must be configured for the FTM module fault function through the appropriate PORTx pin control register.</p> <p>0 FTM2_FLT0 pin 1 CMP0 out</p> |
| 7–5 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |

Table continues on the next page...

SIM_SOPT4 field descriptions (continued)

| Field | Description |
|---------------|--|
| 4 FTM1FLT0 | <p>FTM1 Fault 0 Select</p> <p>Selects the source of FTM1 fault 0.</p> <p>NOTE: The pin source for fault 0 must be configured for the FTM module fault function through the appropriate pin control register in the port control module.</p> <p>0 FTM1_FLT0 pin 1 CMP0 out</p> |
| 3 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 2 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 1 FTM0FLT1 | <p>FTM0 Fault 1 Select</p> <p>Selects the source of FTM0 fault 1.</p> <p>NOTE: The pin source for fault 1 must be configured for the FTM module fault function through the appropriate pin control register in the port control module.</p> <p>0 FTM0_FLT1 pin 1 CMP1 out</p> |
| 0 FTM0FLT0 | <p>FTM0 Fault 0 Select</p> <p>Selects the source of FTM0 fault 0.</p> <p>NOTE: The pin source for fault 0 must be configured for the FTM module fault function through the appropriate pin control register in the port control module.</p> <p>0 FTM0_FLT0 pin 1 CMP0 out</p> |

12.2.5 System Options Register 5 (SIM_SOPT5)

Address: 4004_7000h base + 1010h offset = 4004_8010h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|-----------|----|-----------|----|-----------|----|-----------|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | 0 |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | UART1RXSR | | UART1TXSR | | UART0RXSR | | UART0TXSR | |
| W | | | | | | | | | C | | C | | C | | C | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SIM_SOPT5 field descriptions

| Field | Description |
|-------------------|--|
| 31–18 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 17–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–6 UART1RXSRC | UART 1 receive data source select Selects the source for the UART 1 receive data. 00 UART1_RX pin 01 CMP0 10 CMP1 11 Reserved |
| 5–4 UART1TXSRC | UART 1 transmit data source select Selects the source for the UART 1 transmit data. 00 UART1_TX pin 01 UART1_TX pin modulated with FTM1 channel 0 output 10 UART1_TX pin modulated with FTM2 channel 0 output 11 Reserved |
| 3–2 UART0RXSRC | UART 0 receive data source select Selects the source for the UART 0 receive data. 00 UART0_RX pin 01 CMP0 10 CMP1 11 Reserved |
| 1–0 UART0TXSRC | UART 0 transmit data source select Selects the source for the UART 0 transmit data. 00 UART0_TX pin 01 UART0_TX pin modulated with FTM1 channel 0 output 10 UART0_TX pin modulated with FTM2 channel 0 output 11 Reserved |

12.2.6 System Options Register 7 (SIM_SOPT7)

Address: 4004_7000h base + 1018h offset = 4004_8018h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|--------------|----|----|---------------|------------|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | ADC0ALTTRGEN | 0 | | ADC0PRETRGSEL | ADC0TRGSEL | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SIM_SOPT7 field descriptions

| Field | Description |
|--------------------|--|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 ADC0ALTTRGEN | ADC0 alternate trigger enable Enable alternative conversion triggers for ADC0. 0 PDB trigger selected for ADC0. 1 Alternate trigger selected for ADC0. |
| 6–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 ADC0PRETRGSEL | ADC0 pretrigger select Selects the ADC0 pre-trigger source when alternative triggers are enabled through ADC0ALTTRGEN. 0 Pre-trigger A 1 Pre-trigger B |
| 3–0 ADC0TRGSEL | ADC0 trigger select Selects the ADC0 trigger source when alternative triggers are functional in stop and VLPS modes. . 0000 PDB external trigger pin input (PDB0_EXTRG) 0001 High speed comparator 0 output 0010 High speed comparator 1 output 0011 Reserved |

Table continues on the next page...

SIM_SOPT7 field descriptions (continued)

| Field | Description |
|-------|---------------------------------|
| 0100 | PIT trigger 0 |
| 0101 | PIT trigger 1 |
| 0110 | PIT trigger 2 |
| 0111 | PIT trigger 3 |
| 1000 | FTM0 trigger |
| 1001 | FTM1 trigger |
| 1010 | FTM2 trigger |
| 1011 | Reserved |
| 1100 | RTC alarm |
| 1101 | RTC seconds |
| 1110 | Low-power timer (LPTMR) trigger |
| 1111 | Reserved |

12.2.7 System Device Identification Register (SIM_SDID)

Address: 4004_7000h base + 1024h offset = 4004_8024h

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-------|----|----|----|-------|----|---|---|-------|----|----|----|-------|----|----|----|
| R | 0 | | | | | | | | | | | | | | | | REVID | | | | DIEID | | | | FAMID | | | | PINID | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x* | x* | x* | x* | 0 | 0 | 1 | 0 | 0 | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

SIM_SDID field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–12 REVID | Device revision number Specifies the silicon implementation number for the device. |
| 11–7 DIEID | Device die number Specifies the silicon implementation number for the device. |
| 6–4 FAMID | Kinetis family identification Specifies the Kinetis family of the device. 000 K10 or K12 Family 001 K20 or K22 Family 010 K30 Family or K11 Family or K61 Family 011 K40 Family or K21 Family 100 K60 or K62 Family 101 K70 Family |

Table continues on the next page...

SIM_SDID field descriptions (continued)

| Field | Description |
|--------------|--|
| | 110 KW24 Family 111 Reserved |
| 3–0 PINID | Pincount identification Specifies the pincount of the device. 0000 Reserved 0001 Reserved 0010 32-pin 0011 Reserved 0100 48-pin 0101 64-pin 0110 80-pin 0111 81-pin or 121-pin 1000 100-pin 1001 121-pin 1010 144-pin 1011 Custom pinout (WLCSP) 1100 Reserved 1101 Reserved 1110 256-pin 1111 Reserved |

12.2.8 System Clock Gating Control Register 4 (SIM_SCGC4)

Address: 4004_7000h base + 1034h offset = 4004_8034h

| | | | | | | | | | | | | | | | | |
|-------|----|-------|----|-------|-------|-------|----|----|------|------|----|----|------|-----|-----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 1 | | | | 0 | | | | | | | | VREF | CMP | 0 | 0 |
| W | | | | | | | | | | | | | | | | |
| Reset | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | UART3 | | UART2 | UART1 | UART0 | 0 | | I2C1 | I2C0 | 1 | | 0 | CMT | EWM | 0 |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |

SIM_SCGC4 field descriptions

| Field | Description |
|-------------------|--|
| 31–28 Reserved | This field is reserved. This read-only field is reserved and always has the value 1. |
| 27–21 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 20 VREF | VREF Clock Gate Control This bit controls the clock gate to the VREF module. 0 Clock disabled 1 Clock enabled |
| 19 CMP | Comparator Clock Gate Control This bit controls the clock gate to the comparator module. 0 Clock disabled 1 Clock enabled |
| 18 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 17–14 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 13 UART3 | UART3 Clock Gate Control This bit controls the clock gate to the UART3 module. 0 Clock disabled 1 Clock enabled |
| 12 UART2 | UART2 Clock Gate Control This bit controls the clock gate to the UART2 module. 0 Clock disabled 1 Clock enabled |
| 11 UART1 | UART1 Clock Gate Control This bit controls the clock gate to the UART1 module. 0 Clock disabled 1 Clock enabled |
| 10 UART0 | UART0 Clock Gate Control This bit controls the clock gate to the UART0 module. 0 Clock disabled 1 Clock enabled |
| 9–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 I2C1 | I2C1 Clock Gate Control This bit controls the clock gate to the I ² C1 module. |

Table continues on the next page...

SIM_SCGC4 field descriptions (continued)

| Field | Description |
|-----------------|---|
| | 0 Clock disabled 1 Clock enabled |
| 6 I2C0 | I2C0 Clock Gate Control This bit controls the clock gate to the I ² C0 module. 0 Clock disabled 1 Clock enabled |
| 5–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 1. |
| 3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 CMT | CMT Clock Gate Control This bit controls the clock gate to the CMT module. 0 Clock disabled 1 Clock enabled |
| 1 EWM | EWM Clock Gate Control This bit controls the clock gate to the EWM module. 0 Clock disabled 1 Clock enabled |
| 0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

12.2.9 System Clock Gating Control Register 5 (SIM_SCGC5)

Address: 4004_7000h base + 1038h offset = 4004_8038h

| | | | | | | | | | | | | | | | | |
|-------|----|----|-------|-------|-------|-------|-------|----|----|----|----|----|----|----|----|-------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | 1 | 0 | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | 1 | 0 | 0 | 0 | 0 | 0 | 1 | |
| W | | | PORTE | PORTD | PORTC | PORTB | PORTA | | | | | | | | | LPTMR |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

SIM_SCGC5 field descriptions

| Field | Description |
|-------------------|--|
| 31–19 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 18 Reserved | This field is reserved. This read-only field is reserved and always has the value 1. |
| 17–14 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 13 PORTE | Port E Clock Gate Control This bit controls the clock gate to the Port E module. 0 Clock disabled 1 Clock enabled |
| 12 PORTD | Port D Clock Gate Control This bit controls the clock gate to the Port D module. 0 Clock disabled 1 Clock enabled |
| 11 PORTC | Port C Clock Gate Control This bit controls the clock gate to the Port C module. 0 Clock disabled 1 Clock enabled |
| 10 PORTB | Port B Clock Gate Control This bit controls the clock gate to the Port B module. 0 Clock disabled 1 Clock enabled |
| 9 PORTA | Port A Clock Gate Control This bit controls the clock gate to the Port A module. 0 Clock disabled 1 Clock enabled |
| 8–7 Reserved | This field is reserved. This read-only field is reserved and always has the value 1. |
| 6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3–2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 Reserved | This field is reserved. This read-only field is reserved and always has the value 1. |

Table continues on the next page...

SIM_SCGC5 field descriptions (continued)

| Field | Description |
|------------|---|
| 0 LPTMR | Low Power Timer Access Control This bit controls software access to the Low Power Timer module. 0 Access disabled 1 Access enabled |

12.2.10 System Clock Gating Control Register 6 (SIM_SCGC6)

Address: 4004_7000h base + 103Ch offset = 4004_803Ch

| | | | | | | | | | | | | | | | | |
|-------|------|----|-----|----|------|------|------|------|-----|-----|----|----|----|-----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | | 1 | | 0 | | | | | | | 0 | 0 | | | 0 | |
| W | DAC0 | | RTC | | ADC0 | FTM2 | FTM1 | FTM0 | PIT | PDB | | | | CRC | | |
| Reset | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|-----|----|------|------|----|----|------|---|---|---|---|---|---|---|--------|-----|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | 0 | | | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | | | |
| W | I2S | | SPI1 | SPI0 | | | RNGA | | | | | | | | DMAMUX | FTF |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

SIM_SCGC6 field descriptions

| Field | Description |
|----------------|--|
| 31 DAC0 | DAC0 Clock Gate Control This bit controls the clock gate to the DAC0 module. 0 Clock disabled 1 Clock enabled |
| 30 Reserved | This field is reserved. This read-only field is reserved and always has the value 1. |
| 29 RTC | RTC Access Control This bit controls software access and interrupts to the RTC module. 0 Access and interrupts disabled 1 Access and interrupts enabled |
| 28 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 27 ADC0 | ADC0 Clock Gate Control This bit controls the clock gate to the ADC0 module. |

Table continues on the next page...

SIM_SCGC6 field descriptions (continued)

| Field | Description |
|-------------------|---|
| | 0 Clock disabled 1 Clock enabled |
| 26 FTM2 | FTM2 Clock Gate Control This bit controls the clock gate to the FTM2 module. 0 Clock disabled 1 Clock enabled |
| 25 FTM1 | FTM1 Clock Gate Control This bit controls the clock gate to the FTM1 module. 0 Clock disabled 1 Clock enabled |
| 24 FTM0 | FTM0 Clock Gate Control This bit controls the clock gate to the FTM0 module. 0 Clock disabled 1 Clock enabled |
| 23 PIT | PIT Clock Gate Control This bit controls the clock gate to the PIT module. 0 Clock disabled 1 Clock enabled |
| 22 PDB | PDB Clock Gate Control This bit controls the clock gate to the PDB module. 0 Clock disabled 1 Clock enabled |
| 21 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 20–19 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 18 CRC | CRC Clock Gate Control This bit controls the clock gate to the CRC module. 0 Clock disabled 1 Clock enabled |
| 17–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15 I2S | I2S Clock Gate Control This bit controls the clock gate to the I ² S module. 0 Clock disabled 1 Clock enabled |

Table continues on the next page...

SIM_SCGC6 field descriptions (continued)

| Field | Description |
|-----------------|---|
| 14 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 13 SPI1 | SPI1 Clock Gate Control This bit controls the clock gate to the SPI1 module. 0 Clock disabled 1 Clock enabled |
| 12 SPI0 | SPI0 Clock Gate Control This bit controls the clock gate to the SPI0 module. 0 Clock disabled 1 Clock enabled |
| 11 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 10 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 9 RNGA | RNGA Clock Gate Control This bit controls the clock gate to the RNGA module. |
| 8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3–2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 DMAMUX | DMA Mux Clock Gate Control This bit controls the clock gate to the DMA Mux module. 0 Clock disabled 1 Clock enabled |
| 0 FTF | Flash Memory Clock Gate Control This bit controls the clock gate to the flash memory. Flash reads are still supported while the flash memory is clock gated, but entry into low power modes is blocked. 0 Clock disabled 1 Clock enabled |

12.2.11 System Clock Gating Control Register 7 (SIM_SCGC7)

Address: 4004_7000h base + 1040h offset = 4004_8040h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|-----|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | 0 | 0 | DMA | 0 |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

SIM_SCGC7 field descriptions

| Field | Description |
|------------------|--|
| 31–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 DMA | DMA Clock Gate Control This bit controls the clock gate to the DMA module. 0 Clock disabled 1 Clock enabled |
| 0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

12.2.12 System Clock Divider Register 1 (SIM_CLKDIV1)

When updating CLKDIV1, update all fields using the one write command.

NOTE

The CLKDIV1 register cannot be written to when the device is in VLPR mode.

Address: 4004_7000h base + 1044h offset = 4004_8044h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|---------|----|----|----|---------|----|----|----|----|----|----|----|---------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | OUTDIV1 | | | | OUTDIV2 | | | | 0 | | | | OUTDIV4 | | | | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 1* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* |

* Notes:

- Reset value loaded during System Reset from FTF_FOPT[LPBOOT].

SIM_CLKDIV1 field descriptions

| Field | Description |
|-------------------|--|
| 31–28 OUTDIV1 | <p>Clock 1 output divider value</p> <p>This field sets the divide value for the core/system clock from MCGOUTCLK. At the end of reset, it is loaded with either 0000 or 0111 depending on FTF_FOPT[LPBOOT].</p> <p>0000 Divide-by-1. 0001 Divide-by-2. 0010 Divide-by-3. 0011 Divide-by-4. 0100 Divide-by-5. 0101 Divide-by-6. 0110 Divide-by-7. 0111 Divide-by-8. 1000 Divide-by-9. 1001 Divide-by-10. 1010 Divide-by-11. 1011 Divide-by-12. 1100 Divide-by-13. 1101 Divide-by-14. 1110 Divide-by-15. 1111 Divide-by-16.</p> |
| 27–24 OUTDIV2 | <p>Clock 2 output divider value</p> <p>This field sets the divide value for the bus clock from MCGOUTCLK. At the end of reset, it is loaded with either 0000 or 0111 depending on FTF_FOPT[LPBOOT]. The bus clock frequency must be an integer divide of the core/system clock frequency.</p> <p>0000 Divide-by-1. 0001 Divide-by-2. 0010 Divide-by-3. 0011 Divide-by-4. 0100 Divide-by-5. 0101 Divide-by-6. 0110 Divide-by-7. 0111 Divide-by-8. 1000 Divide-by-9. 1001 Divide-by-10. 1010 Divide-by-11. 1011 Divide-by-12. 1100 Divide-by-13. 1101 Divide-by-14. 1110 Divide-by-15. 1111 Divide-by-16.</p> |
| 23–20 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |

Table continues on the next page...

SIM_CLKDIV1 field descriptions (continued)

| Field | Description |
|------------------|---|
| 19–16 OUTDIV4 | <p>Clock 4 output divider value</p> <p>This field sets the divide value for the flash clock from MCGOUTCLK. At the end of reset, it is loaded with either 0001 or 1111 depending on FTF_FOPT[LPBOOT]. The flash clock frequency must be an integer divide of the system clock frequency.</p> <p>0000 Divide-by-1. 0001 Divide-by-2. 0010 Divide-by-3. 0011 Divide-by-4. 0100 Divide-by-5. 0101 Divide-by-6. 0110 Divide-by-7. 0111 Divide-by-8. 1000 Divide-by-9. 1001 Divide-by-10. 1010 Divide-by-11. 1011 Divide-by-12. 1100 Divide-by-13. 1101 Divide-by-14. 1110 Divide-by-15. 1111 Divide-by-16.</p> |
| 15–0 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |

12.2.13 Flash Configuration Register 1 (SIM_FCFG1)

For devices with FlexNVM: The reset value of EESIZE and DEPART are based on user programming in user IFR via the PGMPART flash command.

For devices with program flash only:

Address: 4004_7000h base + 104Ch offset = 4004_804Ch

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|---------|----|----|----|--------|----|----|----|----|----|----|----|--------|----|----|----|
| R | NVMSIZE | | | | PFSIZE | | | | 0 | | | | EESIZE | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 1* | 1* | 1* | 1* | 1* | 1* | 1* | 1* | 0* | 0* | 0* | 0* | 1* | 1* | 1* | 1* |

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|--------|----|----|----|----|----|----|----|----|----|-----------|----------|
| R | 0 | | | | DEPART | | | | 0 | | | | | | FLASHDOZE | FLASHDIS |
| W | | | | | | | | | | | | | | | | |
| Reset | 0* | 0* | 0* | 0* | 1* | 1* | 1* | 1* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* |

- * Notes:
- Reset value loaded during System Reset from Flash IFR.

SIM_FCFG1 field descriptions

| Field | Description |
|-------------------|--|
| 31–28 NVMSIZE | <p>FlexNVM size</p> <p>This field specifies the amount of FlexNVM memory available on the device . Undefined values are reserved.</p> <p>0000 0 KB of FlexNVM 0011 32 KB of FlexNVM 0101 64 KB of FlexNVM 0111 128 KB of FlexNVM 1001 256 KB of FlexNVM 1011 512 KB of FlexNVM 1111 For devices with FlexNVM (SIM_FCFG2[PFLSH]=0): 256 KB of FlexNVM, 32 KB protection region. For devices without FlexNVM (SIM_FCFG2[PFLSH]=1): 0 KB of FlexNVM</p> |
| 27–24 PFSIZE | <p>Program flash size</p> <p>This field specifies the amount of program flash memory available on the device . Undefined values are reserved.</p> <p>0011 32 KB of program flash memory 0101 64 KB of program flash memory 0111 128 KB of program flash memory 1001 256 KB of program flash memory 1011 512 KB of program flash memory 1101 1024 KB of program flash memory 1111 512 KB of program flash memory</p> |
| 23–20 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 19–16 EESIZE | <p>EEPROM size</p> <p>EEPROM data size .</p> <p>0000 16 KB</p> |

Table continues on the next page...

SIM_FCFG1 field descriptions (continued)

| Field | Description |
|-------------------|---|
| | 0001 8 KB 0010 4 KB 0011 2 KB 0100 1 KB 0101 512 Bytes 0110 256 Bytes 0111 128 Bytes 1000 64 Bytes 1001 32 Bytes 1010-1110 Reserved 1111 0 Bytes |
| 15–12 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 11–8 DEPART | FlexNVM partition For devices with FlexNVM: Data flash / EEPROM backup split . See DEPART bit description in FTFL chapter. For devices without FlexNVM: Reserved |
| 7–2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 FLASHDOZE | Flash Doze When set, Flash memory is disabled for the duration of Wait mode. An attempt by the DMA or other bus master to access the Flash when the Flash is disabled will result in a bus error. This bit should be clear during VLP modes. The Flash will be automatically enabled again at the end of Wait mode so interrupt vectors do not need to be relocated out of Flash memory. The wakeup time from Wait mode is extended when this bit is set. 0 Flash remains enabled during Wait mode 1 Flash is disabled for the duration of Wait mode |
| 0 FLASHDIS | Flash Disable Flash accesses are disabled (and generate a bus error) and the Flash memory is placed in a low power state. This bit should not be changed during VLP modes. Relocate the interrupt vectors out of Flash memory before disabling the Flash. 0 Flash is enabled 1 Flash is disabled |

12.2.14 Flash Configuration Register 2 (SIM_FCFG2)

Address: 4004_7000h base + 1050h offset = 4004_8050h

| | | | | | | | | | | | | | | | | |
|-------|-----------|----------|----|----|----|----|----|----|-------|----------|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | SWAPPFLSH | MAXADDR0 | | | | | | | PFLSH | MAXADDR1 | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0* | 1* | 1* | 1* | 1* | 1* | 1* | 1* | 0* | 1* | 1* | 1* | 1* | 1* | 1* | 1* |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* |

* Notes:

- Reset value loaded during System Reset from Flash IFR.

SIM_FCFG2 field descriptions

| Field | Description |
|-------------------|--|
| 31 SWAPPFLSH | Swap program flash For devices without FlexNVM: Indicates that swap is active . 0 Swap is not active. 1 Swap is active. |
| 30–24 MAXADDR0 | Max address block 0 |

Table continues on the next page...

SIM_FCFG2 field descriptions (continued)

| Field | Description |
|-------------------|---|
| | <p>This field concatenated with 13 trailing zeros indicates the first invalid address of each program flash block.</p> <p>For example, if MAXADDR0 = 0x20 the first invalid address of flash block 0 is 0x0004_0000. This would be the MAXADDR0 value for a device with 256 KB program flash in flash block 0.</p> |
| 23 PFLSH | <p>Program flash only</p> <p>For devices with FlexNVM, this bit is always clear.</p> <p>For devices without FlexNVM, this bit is always set.</p> <p>0 Device supports FlexNVM 1 Program Flash only, device does not support FlexNVM</p> |
| 22–16 MAXADDR1 | <p>Max address block 1</p> <p>For devices with FlexNVM: This field concatenated with 13 trailing zeros plus the FlexNVM base address indicates the first invalid address of the FlexNVM flash block.</p> <p>For example, if MAXADDR1 = 0x20 the first invalid address of FlexNVM flash block is 0x4_0000 + 0x1000_0000 . This would be the MAXADDR1 value for a device with 256 KB FlexNVM.</p> <p>For devices with program flash only: This field equals zero if there is only one program flash block, otherwise it equals the value of the MAXADDR0 field.</p> <p>For example, with MAXADDR0 = MAXADDR1 = 0x20 the first invalid address of flash block 1 is 0x4_0000 + 0x4_0000. This would be the MAXADDR1 value for a device with 512 KB program flash memory across two flash blocks and no FlexNVM.</p> |
| 15–0 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |

12.2.15 Unique Identification Register High (SIM_UIDH)

Address: 4004_7000h base + 1054h offset = 4004_8054h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | UID | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* |

* Notes:

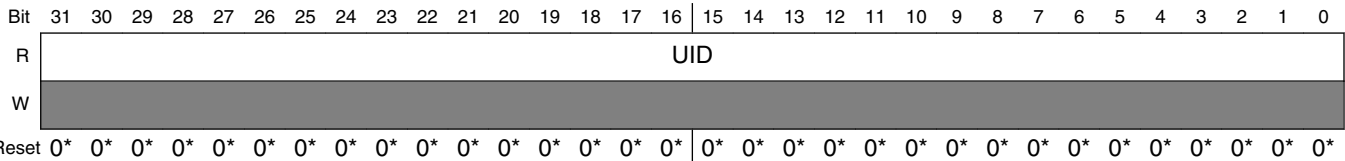
- Reset value loaded during System Reset from Flash IFR.

SIM_UIDH field descriptions

| Field | Description |
|-------------|---|
| 31–0 UID | <p>Unique Identification</p> <p>Unique identification for the device.</p> |

12.2.16 Unique Identification Register Mid-High (SIM_UIDMH)

Address: 4004_7000h base + 1058h offset = 4004_8058h



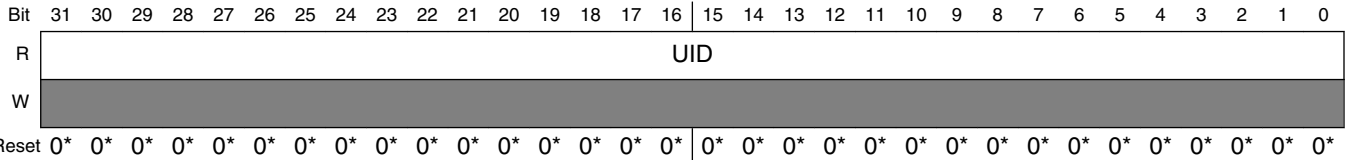
- * Notes:
- Reset value loaded during System Reset from Flash IFR.

SIM_UIDMH field descriptions

| Field | Description |
|-------------|--|
| 31–0 UID | Unique Identification Unique identification for the device. |

12.2.17 Unique Identification Register Mid Low (SIM_UIDML)

Address: 4004_7000h base + 105Ch offset = 4004_805Ch



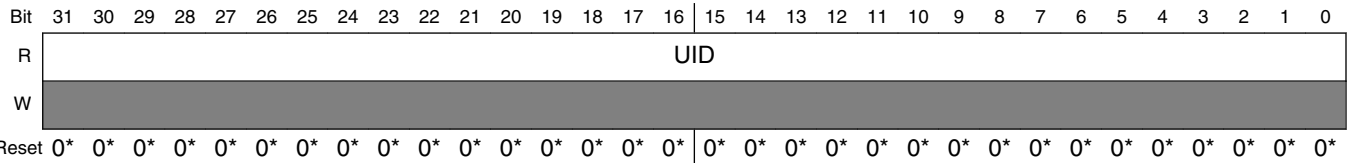
- * Notes:
- Reset value loaded during System Reset from Flash IFR.

SIM_UIDML field descriptions

| Field | Description |
|-------------|--|
| 31–0 UID | Unique Identification Unique identification for the device. |

12.2.18 Unique Identification Register Low (SIM_UIDL)

Address: 4004_7000h base + 1060h offset = 4004_8060h



- * Notes:
- Reset value loaded during System Reset from Flash IFR.

SIM_UIDL field descriptions

| Field | Description |
|-------------|--|
| 31–0 UID | Unique Identification Unique identification for the device. |

12.3 Functional description

For more information about the functions of SIM, see the [Introduction](#) section.

Chapter 13

Reset Control Module (RCM)

13.1 Introduction

Information found here describes the registers of the Reset Control Module (RCM). The RCM implements many of the reset functions for the chip. See the chip's reset chapter for more information.

See [AN4503: Power Management for Kinetis and ColdFire+ MCUs](#) for further details on using the RCM.

13.2 Reset memory map and register descriptions

The RCM Memory Map/Register Definition can be found here.

The Reset Control Module (RCM) registers provide reset status information and reset filter control.

NOTE

The RCM registers can be written only in supervisor mode. Write accesses in user mode are blocked and will result in a bus error.

RCM memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|--|-----------------|--------|-------------|----------------------------|
| 4007_F000 | System Reset Status Register 0 (RCM_SRS0) | 8 | R | 82h | 13.2.1/250 |
| 4007_F001 | System Reset Status Register 1 (RCM_SRS1) | 8 | R | 00h | 13.2.2/251 |
| 4007_F004 | Reset Pin Filter Control register (RCM_RPFC) | 8 | R/W | 00h | 13.2.3/253 |
| 4007_F005 | Reset Pin Filter Width register (RCM_RPFW) | 8 | R/W | 00h | 13.2.4/254 |
| 4007_F007 | Mode Register (RCM_MR) | 8 | R | 00h | 13.2.5/255 |

13.2.1 System Reset Status Register 0 (RCM_SRS0)

This register includes read-only status flags to indicate the source of the most recent reset. The reset state of these bits depends on what caused the MCU to reset.

NOTE

The reset value of this register depends on the reset source:

- POR (including LVD) — 0x82
- LVD (without POR) — 0x02
- VLLS mode wakeup due to $\overline{\text{RESET}}$ pin assertion — 0x41
- VLLS mode wakeup due to other wakeup sources — 0x01
- Other reset — a bit is set if its corresponding reset source caused the reset

Address: 4007_F000h base + 0h offset = 4007_F000h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-----|-----|------|---|-----|-----|-----|--------|
| Read | POR | PIN | WDOG | 0 | LOL | LOC | LVD | WAKEUP |
| Write | | | | | | | | |
| Reset | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

RCM_SRS0 field descriptions

| Field | Description |
|---------------|--|
| 7 POR | Power-On Reset Indicates a reset has been caused by the power-on detection logic. Because the internal supply voltage was ramping up at the time, the low-voltage reset (LVD) status bit is also set to indicate that the reset occurred while the internal supply was below the LVD threshold. 0 Reset not caused by POR 1 Reset caused by POR |
| 6 PIN | External Reset Pin Indicates a reset has been caused by an active-low level on the external $\overline{\text{RESET}}$ pin. 0 Reset not caused by external reset pin 1 Reset caused by external reset pin |
| 5 WDOG | Watchdog Indicates a reset has been caused by the watchdog timer timing out. 0 Reset not caused by watchdog timeout 1 Reset caused by watchdog timeout |
| 4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3 LOL | Loss-of-Lock Reset |

Table continues on the next page...

RCM_SRS0 field descriptions (continued)

| Field | Description |
|-------------|---|
| | Indicates a reset has been caused by a loss of lock in the MCG PLL. See the MCG description for information on the loss-of-clock event. 0 Reset not caused by a loss of lock in the PLL 1 Reset caused by a loss of lock in the PLL |
| 2 LOC | Loss-of-Clock Reset Indicates a reset has been caused by a loss of external clock. The MCG clock monitor must be enabled for a loss of clock to be detected. Refer to the detailed MCG description for information on enabling the clock monitor. 0 Reset not caused by a loss of external clock. 1 Reset caused by a loss of external clock. |
| 1 LVD | Low-Voltage Detect Reset If PMC_LVDSC1[LVDRE] is set and the supply drops below the LVD trip voltage, an LVD reset occurs. This field is also set by POR. 0 Reset not caused by LVD trip or POR 1 Reset caused by LVD trip or POR |
| 0 WAKEUP | Low Leakage Wakeup Reset Indicates a reset has been caused by an enabled LLWU module wakeup source while the chip was in a low leakage mode. In LLS mode, the $\overline{\text{RESET}}$ pin is the only wakeup source that can cause this reset. Any enabled wakeup source in a VLLSx mode causes a reset. This bit is cleared by any reset except WAKEUP. 0 Reset not caused by LLWU module wakeup source 1 Reset caused by LLWU module wakeup source |

13.2.2 System Reset Status Register 1 (RCM_SRS1)

This register includes read-only status flags to indicate the source of the most recent reset. The reset state of these bits depends on what caused the MCU to reset.

NOTE

The reset value of this register depends on the reset source:

- POR (including LVD) — 0x00
- LVD (without POR) — 0x00
- VLLS mode wakeup — 0x00
- Other reset — a bit is set if its corresponding reset source caused the reset

Reset memory map and register descriptions

Address: 4007_F000h base + 1h offset = 4007_F001h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|--------|---|---------|------|--------|----|--------|------|
| Read | TAMPER | 0 | SACKERR | EZPT | MDM_AP | SW | LOCKUP | JTAG |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

RCM_SRS1 field descriptions

| Field | Description |
|---------------|--|
| 7 TAMPER | <p>Tamper detect</p> <p>Indicates a reset was caused by tamper detect.</p> <p>0 Reset not caused by tamper detect</p> <p>1 Reset caused by tamper detect.</p> |
| 6 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 5 SACKERR | <p>Stop Mode Acknowledge Error Reset</p> <p>Indicates that after an attempt to enter Stop mode, a reset has been caused by a failure of one or more peripherals to acknowledge within approximately one second to enter stop mode.</p> <p>0 Reset not caused by peripheral failure to acknowledge attempt to enter stop mode</p> <p>1 Reset caused by peripheral failure to acknowledge attempt to enter stop mode</p> |
| 4 EZPT | <p>EzPort Reset</p> <p>Indicates a reset has been caused by EzPort receiving the RESET command while the device is in EzPort mode.</p> <p>0 Reset not caused by EzPort receiving the RESET command while the device is in EzPort mode</p> <p>1 Reset caused by EzPort receiving the RESET command while the device is in EzPort mode</p> |
| 3 MDM_AP | <p>MDM-AP System Reset Request</p> <p>Indicates a reset has been caused by the host debugger system setting of the System Reset Request bit in the MDM-AP Control Register.</p> <p>0 Reset not caused by host debugger system setting of the System Reset Request bit</p> <p>1 Reset caused by host debugger system setting of the System Reset Request bit</p> |
| 2 SW | <p>Software</p> <p>Indicates a reset has been caused by software setting of SYSRESETREQ bit in Application Interrupt and Reset Control Register in the ARM core.</p> <p>0 Reset not caused by software setting of SYSRESETREQ bit</p> <p>1 Reset caused by software setting of SYSRESETREQ bit</p> |
| 1 LOCKUP | <p>Core Lockup</p> <p>Indicates a reset has been caused by the ARM core indication of a LOCKUP event.</p> <p>0 Reset not caused by core LOCKUP event</p> <p>1 Reset caused by core LOCKUP event</p> |
| 0 JTAG | <p>JTAG Generated Reset</p> |

Table continues on the next page...

RCM_SRS1 field descriptions (continued)

| Field | Description |
|-------|--|
| | Indicates a reset has been caused by JTAG selection of certain IR codes: EZPORT, EXTEST, HIGHZ, and CLAMP. |
| 0 | Reset not caused by JTAG |
| 1 | Reset caused by JTAG |

13.2.3 Reset Pin Filter Control register (RCM_RPFC)

NOTE

The reset values of bits 2-0 are for Chip POR only. They are unaffected by other reset types.

NOTE

The bus clock filter is reset when disabled or when entering stop mode. The LPO filter is reset when disabled or when entering any low leakage stop mode .

Address: 4007_F000h base + 4h offset = 4007_F004h

| | | | | | | | | |
|-------|---|---|---|---|---|----------|-----------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | | RSTFLTSS | RSTFLTSRW | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

RCM_RPFC field descriptions

| Field | Description |
|------------------|---|
| 7-3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 RSTFLTSS | Reset Pin Filter Select in Stop Mode Selects how the reset pin filter is enabled in Stop and VLPS modes 0 All filtering disabled 1 LPO clock filter enabled |
| 1-0 RSTFLTSRW | Reset Pin Filter Select in Run and Wait Modes Selects how the reset pin filter is enabled in run and wait modes. 00 All filtering disabled 01 Bus clock filter enabled for normal operation 10 LPO clock filter enabled for normal operation 11 Reserved |

13.2.4 Reset Pin Filter Width register (RCM_RPFW)

NOTE

The reset values of the bits in the RSTFLTSEL field are for Chip POR only. They are unaffected by other reset types.

Address: 4007_F000h base + 5h offset = 4007_F005h

| | | | | | | | | |
|-------|---|---|---|---|-----------|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | RSTFLTSEL | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

RCM_RPFW field descriptions

| Field | Description |
|------------------|---|
| 7–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4–0 RSTFLTSEL | Reset Pin Filter Bus Clock Select Selects the reset pin bus clock filter width. 00000 Bus clock filter count is 1 00001 Bus clock filter count is 2 00010 Bus clock filter count is 3 00011 Bus clock filter count is 4 00100 Bus clock filter count is 5 00101 Bus clock filter count is 6 00110 Bus clock filter count is 7 00111 Bus clock filter count is 8 01000 Bus clock filter count is 9 01001 Bus clock filter count is 10 01010 Bus clock filter count is 11 01011 Bus clock filter count is 12 01100 Bus clock filter count is 13 01101 Bus clock filter count is 14 01110 Bus clock filter count is 15 01111 Bus clock filter count is 16 10000 Bus clock filter count is 17 10001 Bus clock filter count is 18 10010 Bus clock filter count is 19 10011 Bus clock filter count is 20 10100 Bus clock filter count is 21 10101 Bus clock filter count is 22 10110 Bus clock filter count is 23 10111 Bus clock filter count is 24 11000 Bus clock filter count is 25 |

Table continues on the next page...

RCM_RPFW field descriptions (continued)

| Field | Description |
|-------|------------------------------|
| 11001 | Bus clock filter count is 26 |
| 11010 | Bus clock filter count is 27 |
| 11011 | Bus clock filter count is 28 |
| 11100 | Bus clock filter count is 29 |
| 11101 | Bus clock filter count is 30 |
| 11110 | Bus clock filter count is 31 |
| 11111 | Bus clock filter count is 32 |

13.2.5 Mode Register (RCM_MR)

This register includes read-only status flags to indicate the state of the mode pins during the last Chip Reset.

Address: 4007_F000h base + 7h offset = 4007_F007h

| | | | | | | | | |
|-------|---|---|---|---|---|---|--------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | | | EZP_MS | 0 |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

RCM_MR field descriptions

| Field | Description |
|-----------------|--|
| 7–2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 EZP_MS | EZP_MS_B pin state Reflects the state of the $\overline{\text{EZP_MS}}$ pin during the last Chip Reset 0 Pin deasserted (logic 1) 1 Pin asserted (logic 0) |
| 0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |



Chapter 14

System Mode Controller (SMC)

14.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The System Mode Controller (SMC) is responsible for sequencing the system into and out of all low-power Stop and Run modes.

Specifically, it monitors events to trigger transitions between power modes while controlling the power, clocks, and memories of the system to achieve the power consumption and functionality of that mode.

This chapter describes all the available low-power modes, the sequence followed to enter/exit each mode, and the functionality available while in each of the modes.

The SMC is able to function during even the deepest low power modes.

See [AN4503: Power Management for Kinetis and ColdFire+ MCUs](#) for further details on using the SMC.

14.2 Modes of operation

The ARM CPU has three primary modes of operation:

- Run
- Sleep
- Deep Sleep

The WFI or WFE instruction is used to invoke Sleep and Deep Sleep modes. Run, Wait, and Stop are the common terms used for the primary operating modes of Freescale microcontrollers.

The following table shows the translation between the ARM CPU modes and the Freescale MCU power modes.

| ARM CPU mode | MCU mode |
|--------------|----------|
| Sleep | Wait |
| Deep Sleep | Stop |

Accordingly, the ARM CPU documentation refers to sleep and deep sleep, while the Freescale MCU documentation normally uses wait and stop.

In addition, Freescale MCUs also augment Stop, Wait, and Run modes in a number of ways. The power management controller (PMC) contains a run and a stop mode regulator. Run regulation is used in normal run, wait and stop modes. Stop mode regulation is used during all very low power and low leakage modes. During stop mode regulation, the bus frequencies are limited in the very low power modes.

The SMC provides the user with multiple power options. The Very Low Power Run (VLPR) mode can drastically reduce run time power when maximum bus frequency is not required to handle the application needs. From Normal Run mode, the Run Mode (RUNM) field can be modified to change the MCU into VLPR mode when limited frequency is sufficient for the application. From VLPR mode, a corresponding wait (VLPW) and stop (VLPS) mode can be entered.

Depending on the needs of the user application, a variety of stop modes are available that allow the state retention, partial power down or full power down of certain logic and/or memory. I/O states are held in all modes of operation. Several registers are used to configure the various modes of operation for the device.

The following table describes the power modes available for the device.

Table 14-1. Power modes

| Mode | Description |
|------|--|
| RUN | The MCU can be run at full speed and the internal supply is fully regulated, that is, in run regulation. This mode is also referred to as Normal Run mode. |
| WAIT | The core clock is gated off. The system clock continues to operate. Bus clocks, if enabled, continue to operate. Run regulation is maintained. |
| STOP | The core clock is gated off. System clocks to other masters and bus clocks are gated off after all stop acknowledge signals from supporting peripherals are valid. |
| VLPR | The core, system, bus, and flash clock maximum frequencies are restricted in this mode. See the Power Management chapter for details about the maximum allowable frequencies. |
| VLPW | The core clock is gated off. The system, bus, and flash clocks continue to operate, although their maximum frequency is restricted. See the Power Management chapter for details on the maximum allowable frequencies. |
| VLPS | The core clock is gated off. System clocks to other masters and bus clocks are gated off after all stop acknowledge signals from supporting peripherals are valid. |

Table continues on the next page...

Table 14-1. Power modes (continued)

| Mode | Description |
|-------|---|
| LLS | The core clock is gated off. System clocks to other masters and bus clocks are gated off after all stop acknowledge signals from supporting peripherals are valid. The MCU is placed in a low leakage mode by reducing the voltage to internal logic. All system RAM contents, internal logic and I/O states are retained. |
| VLLS3 | The core clock is gated off. System clocks to other masters and bus clocks are gated off after all stop acknowledge signals from supporting peripherals are valid. The MCU is placed in a low leakage mode by powering down the internal logic. All system RAM contents are retained and I/O states are held. Internal logic states are not retained. |
| VLLS2 | The core clock is gated off. System clocks to other masters and bus clocks are gated off after all stop acknowledge signals from supporting peripherals are valid. The MCU is placed in a low leakage mode by powering down the internal logic and the system RAM3 partition. The system RAM2 partition can be optionally retained using VLLSCTRL[RAM2PO]. The system RAM1 partition contents are retained in this mode. Internal logic states are not retained. ¹ |
| VLLS1 | The core clock is gated off. System clocks to other masters and bus clocks are gated off after all stop acknowledge signals from supporting peripherals are valid. The MCU is placed in a low leakage mode by powering down the internal logic and all system RAM. I/O states are held. Internal logic states are not retained. |
| VLLS0 | The core clock is gated off. System clocks to other masters and bus clocks are gated off after all stop acknowledge signals from supporting peripherals are valid. The MCU is placed in a low leakage mode by powering down the internal logic and all system RAM. I/O states are held. Internal logic states are not retained. The 1kHz LPO clock is disabled and the power on reset (POR) circuit can be optionally enabled using VLLSCTRL[PORPO]. |

1. See the devices' chip configuration details for the size and location of the system RAM partitions.

14.3 Memory map and register descriptions

Information about the registers related to the system mode controller can be found here.

Different SMC registers reset on different reset types. Each register's description provides details. For more information about the types of reset on this chip, refer to the Reset section details.

NOTE

The SMC registers can be written only in supervisor mode. Write accesses in user mode are blocked and will result in a bus error.

NOTE

Before executing the WFI instruction, the last register written to must be read back. This ensures that all register writes associated with setting up the low power mode being entered have completed before the MCU enters the low power mode. Failure to do this may result in the low power mode not being entered correctly.

SMC memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|---|-----------------|--------|-------------|----------------------------|
| 4007_E000 | Power Mode Protection register (SMC_PMPROT) | 8 | R/W | 00h | 14.3.1/260 |
| 4007_E001 | Power Mode Control register (SMC_PMCTRL) | 8 | R/W | 00h | 14.3.2/261 |
| 4007_E002 | VLLS Control register (SMC_VLLSCTRL) | 8 | R/W | 03h | 14.3.3/263 |
| 4007_E003 | Power Mode Status register (SMC_PMSTAT) | 8 | R | 01h | 14.3.4/264 |

14.3.1 Power Mode Protection register (SMC_PMPROT)

This register provides protection for entry into any low-power run or stop mode. The enabling of the low-power run or stop mode occurs by configuring the Power Mode Control register (PMCTRL).

The PMPROT register can be written only once after any system reset.

If the MCU is configured for a disallowed or reserved power mode, the MCU remains in its current power mode. For example, if the MCU is in normal RUN mode and AVLP is 0, an attempt to enter VLPR mode using PMCTRL[RUNM] is blocked and PMCTRL[RUNM] remains 00b, indicating the MCU is still in Normal Run mode.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the Reset section details for more information.

Address: 4007_E000h base + 0h offset = 4007_E000h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---|---|------|---|------|---|-------|---|
| Read | 0 | 0 | AVLP | 0 | ALLS | 0 | AVLLS | 0 |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SMC_PMPROT field descriptions

| Field | Description |
|---------------|---|
| 7 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5 AVLP | Allow Very-Low-Power Modes Provided the appropriate control bits are set up in PMCTRL, this write-once field allows the MCU to enter any very-low-power mode (VLPR, VLPW, and VLPS). |

Table continues on the next page...

SMC_PMPROT field descriptions (continued)

| Field | Description |
|---------------|---|
| | 0 VLPR, VLPW, and VLPS are not allowed. 1 VLPR, VLPW, and VLPS are allowed. |
| 4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3 ALLS | Allow Low-Leakage Stop Mode Provided the appropriate control bits are set up in PMCTRL, this write-once field allows the MCU to enter any low-leakage stop mode (LLS). 0 LLS is not allowed 1 LLS is allowed |
| 2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 AVLLS | Allow Very-Low-Leakage Stop Mode Provided the appropriate control bits are set up in PMCTRL, this write once bit allows the MCU to enter any very-low-leakage stop mode (VLLSx). 0 Any VLLSx mode is not allowed 1 Any VLLSx mode is allowed |
| 0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

14.3.2 Power Mode Control register (SMC_PMCTRL)

The PMCTRL register controls entry into low-power Run and Stop modes, provided that the selected power mode is allowed via an appropriate setting of the protection (PMPROT) register.

NOTE

This register is reset on Chip POR not VLLS and by reset types that trigger Chip POR not VLLS. It is unaffected by reset types that do not trigger Chip POR not VLLS. See the Reset section details for more information.

Address: 4007_E000h base + 1h offset = 4007_E001h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|---|------|---|---|-------|---|---|
| Read | LPWUI | | RUNM | | 0 | STOPA | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SMC_PMCTRL field descriptions

| Field | Description |
|---------------|--|
| 7 LPWUI | <p>Low-Power Wake Up On Interrupt</p> <p>Causes the SMC to exit to normal RUN mode when any active MCU interrupt occurs while in a VLP mode (VLPR, VLPW or VLPS).</p> <p>NOTE: If VLPS mode was entered directly from RUN mode, the SMC will always exit back to normal RUN mode regardless of the LPWUI setting.</p> <p>NOTE: LPWUI must be modified only while the system is in RUN mode, that is, when PMSTAT=RUN.</p> <p>0 The system remains in a VLP mode on an interrupt 1 The system exits to Normal RUN mode on an interrupt</p> |
| 6–5 RUNM | <p>Run Mode Control</p> <p>When written, causes entry into the selected run mode. Writes to this field are blocked if the protection level has not been enabled using the PMPROT register.</p> <p>NOTE: RUNM may be set to VLPR only when PMSTAT=RUN. After being written to VLPR, RUNM should not be written back to RUN until PMSTAT=VLPR.</p> <p>00 Normal Run mode (RUN) 01 Reserved 10 Very-Low-Power Run mode (VLPR) 11 Reserved</p> |
| 4 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 3 STOPA | <p>Stop Aborted</p> <p>When set, this read-only status bit indicates an interrupt or reset occurred during the previous stop mode entry sequence, preventing the system from entering that mode. This field is cleared by hardware at the beginning of any stop mode entry sequence and is set if the sequence was aborted.</p> <p>0 The previous stop mode entry was successful. 1 The previous stop mode entry was aborted.</p> |
| 2–0 STOPM | <p>Stop Mode Control</p> <p>When written, controls entry into the selected stop mode when Sleep-Now or Sleep-On-Exit mode is entered with SLEEPDEEP=1. Writes to this field are blocked if the protection level has not been enabled using the PMPROT register. After any system reset, this field is cleared by hardware on any successful write to the PMPROT register.</p> <p>NOTE: When set to VLLSx, the VLLSM field in the VLLSCTRL register is used to further select the particular VLLS submode which will be entered.</p> <p>NOTE:</p> <p>000 Normal Stop (STOP) 001 Reserved 010 Very-Low-Power Stop (VLPS) 011 Low-Leakage Stop (LLS) 100 Very-Low-Leakage Stop (VLLSx) 101 Reserved 110 Reserved 111 Reserved</p> |

14.3.3 VLLS Control register (SMC_VLLSCTRL)

The VLLSCTRL register controls features related to VLLS modes.

NOTE

This register is reset on Chip POR not VLLS and by reset types that trigger Chip POR not VLLS. It is unaffected by reset types that do not trigger Chip POR not VLLS. See the Reset section details for more information.

Address: 4007_E000h base + 2h offset = 4007_E002h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---|---|-------|--------|---|-------|---|---|
| Read | 0 | | PORPO | RAM2PO | 0 | VLLSM | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |

SMC_VLLSCTRL field descriptions

| Field | Description |
|-----------------|---|
| 7–6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5 PORPO | POR Power Option Controls whether the POR detect circuit (for brown-out detection) is enabled in VLLS0 mode. 0 POR detect circuit is enabled in VLLS0. 1 POR detect circuit is disabled in VLLS0. |
| 4 RAM2PO | RAM2 Power Option Controls powering of RAM partition 2 in VLLS2 mode. NOTE: See the device's chip configuration details for the size and location of RAM partition 2 0 RAM2 not powered in VLLS2 1 RAM2 powered in VLLS2 |
| 3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2–0 VLLSM | VLLS Mode Control Controls which VLLS sub-mode to enter if STOPM=VLLS. 000 VLLS0 001 VLLS1 010 VLLS2 011 VLLS3 100 Reserved 101 Reserved 110 Reserved 111 Reserved |

14.3.4 Power Mode Status register (SMC_PMSTAT)

PMSTAT is a read-only, one-hot register which indicates the current power mode of the system.

NOTE

This register is reset on Chip POR not VLLS and by reset types that trigger Chip POR not VLLS. It is unaffected by reset types that do not trigger Chip POR not VLLS. See the Reset section details for more information.

Address: 4007_E000h base + 3h offset = 4007_E003h

| | | | | | | | | |
|-------|---|--------|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | PMSTAT | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

SMC_PMSTAT field descriptions

| Field | Description |
|---------------|--|
| 7 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 6–0 PMSTAT | <p>Power Mode Status</p> <p>NOTE: When debug is enabled, the PMSTAT will not update to STOP or VLPS</p> <p>000_0001 Current power mode is RUN. 000_0010 Current power mode is STOP. 000_0100 Current power mode is VLPR. 000_1000 Current power mode is VLPW. 001_0000 Current power mode is VLPS. 010_0000 Current power mode is LLS. 100_0000 Current power mode is VLLS.</p> |

14.4 Functional description

14.4.1 Power mode transitions

The following figure shows the power mode state transitions available on the chip. Any reset always brings the MCU back to the normal RUN state.

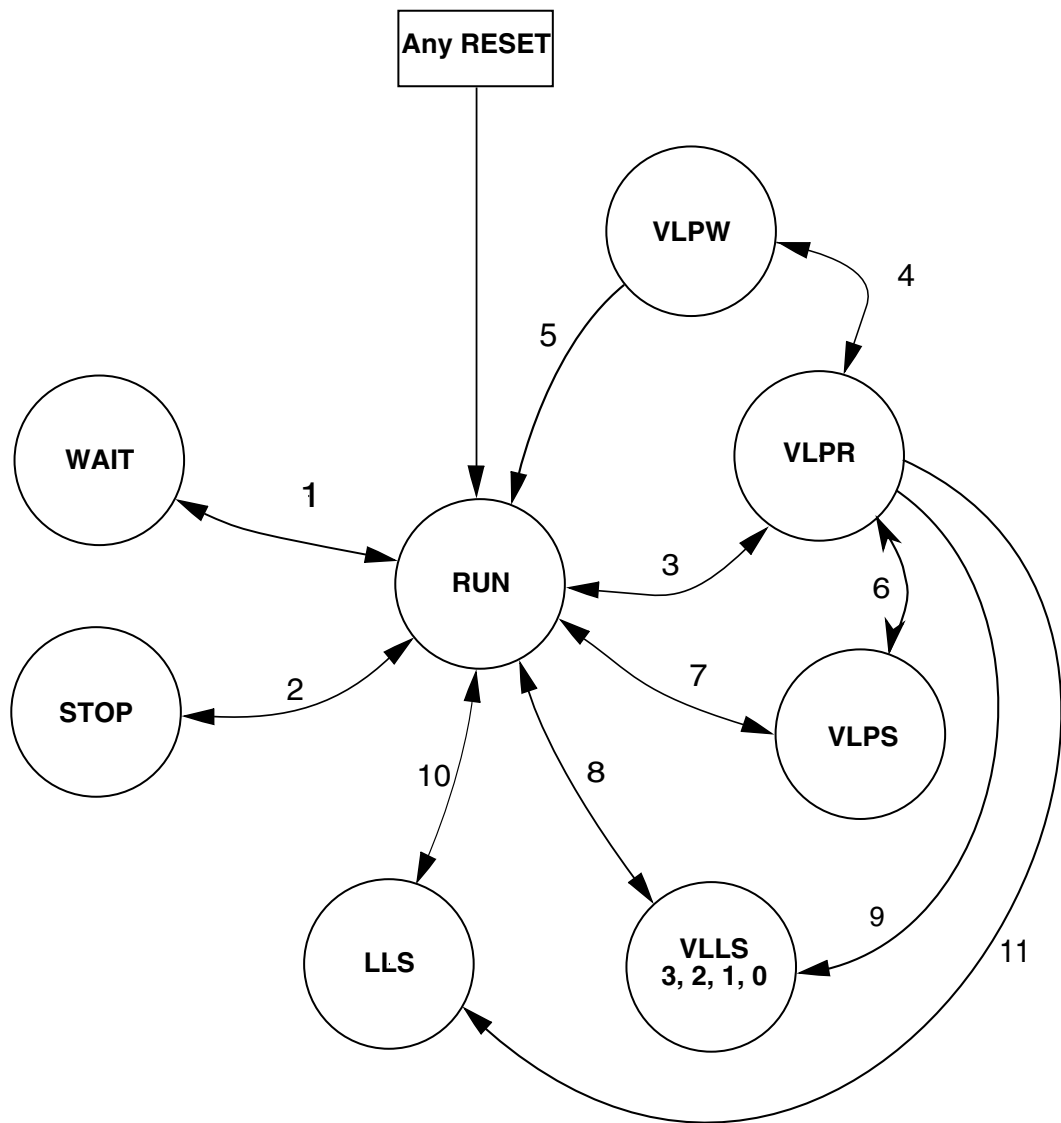


Figure 14-5. Power mode state diagram

The following table defines triggers for the various state transitions shown in the previous figure.

Table 14-7. Power mode transition triggers

| Transition # | From | To | Trigger conditions |
|--------------|------|------|---|
| 1 | RUN | WAIT | Sleep-now or sleep-on-exit modes entered with SLEEPDEEP clear, controlled in System Control Register in ARM core. See note. ¹ |
| | WAIT | RUN | Interrupt or Reset |

Table continues on the next page...

Table 14-7. Power mode transition triggers (continued)

| Transition # | From | To | Trigger conditions |
|--------------|------|------|--|
| 2 | RUN | STOP | PMCTRL[RUNM]=00, PMCTRL[STOPM]=000 Sleep-now or sleep-on-exit modes entered with SLEEPDEEP set, which is controlled in System Control Register in ARM core. See note. ¹ |
| | STOP | RUN | Interrupt or Reset |
| 3 | RUN | VLPR | The core, system, bus and flash clock frequencies and MCG clocking mode are restricted in this mode. See the Power Management chapter for the maximum allowable frequencies and MCG modes supported. Set PMPROT[AVLP]=1, PMCTRL[RUNM]=10. |
| | VLPR | RUN | Set PMCTRL[RUNM]=00 or Interrupt with PMCTRL[LPWUI] =1 or Reset. |
| 4 | VLPR | VLPW | Sleep-now or sleep-on-exit modes entered with SLEEPDEEP clear, which is controlled in System Control Register in ARM core. See note. ¹ |
| | VLPW | VLPR | Interrupt with PMCTRL[LPWUI]=0 |
| 5 | VLPW | RUN | Interrupt with PMCTRL[LPWUI]=1 or Reset |
| 6 | VLPR | VLPS | PMCTRL[STOPM]=000 or 010, Sleep-now or sleep-on-exit modes entered with SLEEPDEEP set, which is controlled in System Control Register in ARM core. See note. ¹ |
| | VLPS | VLPR | Interrupt with PMCTRL[LPWUI]=0 NOTE: If VLPS was entered directly from RUN (transition #7), hardware forces exit back to RUN and does not allow a transition to VLPR. |
| 7 | RUN | VLPS | PMPROT[AVLP]=1, PMCTRL[STOPM]=010, Sleep-now or sleep-on-exit modes entered with SLEEPDEEP set, which is controlled in System Control Register in ARM core. See note. ¹ |
| | VLPS | RUN | Interrupt with PMCTRL[LPWUI]=1 or Interrupt with PMCTRL[LPWUI]=0 and VLPS mode was entered directly from RUN or Reset |

Table continues on the next page...

Table 14-7. Power mode transition triggers (continued)

| Transition # | From | To | Trigger conditions |
|--------------|-------|-------|---|
| 8 | RUN | VLLSx | PMPROT[AVLLS]=1, PMCTRL[STOPM]=100, VLLSCTRL[VLLSM]=x (VLLSx), Sleep-now or sleep-on-exit modes entered with SLEEPDEEP set, which is controlled in System Control Register in ARM core. |
| | VLLSx | RUN | Wakeup from enabled LLWU input source or RESET pin |
| 9 | VLPR | VLLSx | PMPROT[AVLLS]=1, PMCTRL[STOPM]=100, VLLSCTRL[VLLSM]=x (VLLSx), Sleep-now or sleep-on-exit modes entered with SLEEPDEEP set, which is controlled in System Control Register in ARM core. |
| 10 | RUN | LLS | PMPROT[ALLS]=1, PMCTRL[STOPM]=011, Sleep-now or sleep-on-exit modes entered with SLEEPDEEP set, which is controlled in System Control Register in ARM core. |
| | LLS | RUN | Wakeup from enabled LLWU input source and LLS mode was entered directly from RUN or RESET pin. |
| 11 | VLPR | LLS | PMPROT[ALLS]=1, PMCTRL[STOPM]=011, Sleep-now or sleep-on-exit modes entered with SLEEPDEEP set, which is controlled in System Control Register in ARM core. |
| | LLS | VLPR | Wakeup from enabled LLWU input source and LLS mode was entered directly from VLPR NOTE: If LLS was entered directly from RUN, hardware will not allow this transition and will force exit back to RUN |

1. If debug is enabled, the core clock remains to support debug.

14.4.2 Power mode entry/exit sequencing

When entering or exiting low-power modes, the system must conform to an orderly sequence to manage transitions safely.

The SMC manages the system's entry into and exit from all power modes. This diagram illustrates the connections of the SMC with other system components in the chip that are necessary to sequence the system through all power modes.

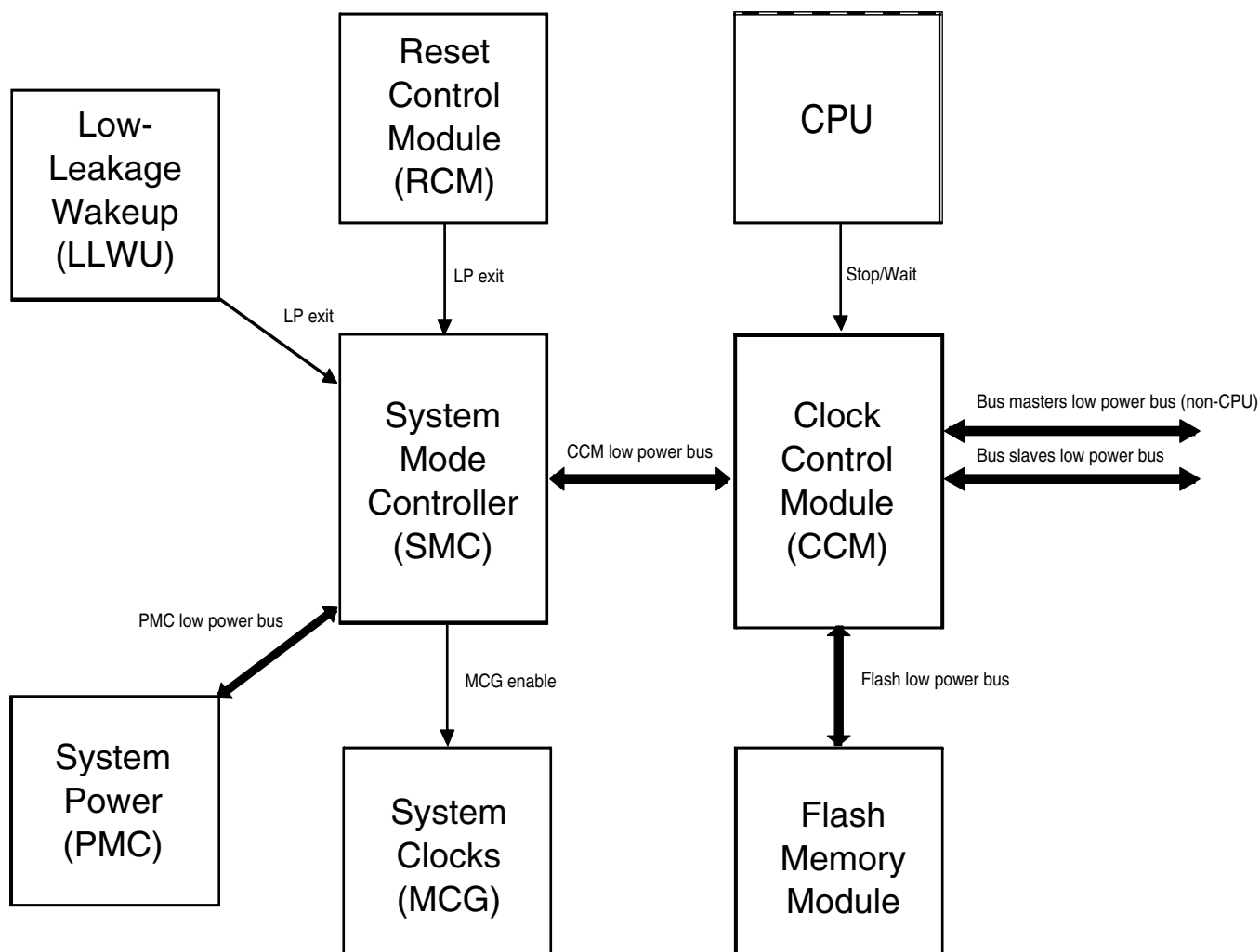


Figure 14-6. Low-power system components and connections

14.4.2.1 Stop mode entry sequence

Entry into a low-power stop mode (Stop, VLPS, LLS, VLLSx) is initiated by CPU execution of the WFI instruction. After the instruction is executed, the following sequence occurs:

1. The CPU clock is gated off immediately.

2. Requests are made to all non-CPU bus masters to enter Stop mode.
3. After all masters have acknowledged they are ready to enter Stop mode, requests are made to all bus slaves to enter Stop mode.
4. After all slaves have acknowledged they are ready to enter Stop mode, all system and bus clocks are gated off.
5. Clock generators are disabled in the MCG.
6. The on-chip regulator in the PMC and internal power switches are configured to meet the power consumption goals for the targeted low-power mode.

14.4.2.2 Stop mode exit sequence

Exit from a low-power stop mode is initiated either by a reset or an interrupt event. The following sequence then executes to restore the system to a run mode (RUN or VLPR):

1. The on-chip regulator in the PMC and internal power switches are restored.
2. Clock generators are enabled in the MCG.
3. System and bus clocks are enabled to all masters and slaves.
4. The CPU clock is enabled and the CPU begins servicing the reset or interrupt that initiated the exit from the low-power stop mode.

14.4.2.3 Aborted stop mode entry

If an interrupt or a reset occurs during a stop entry sequence, the SMC can abort the transition early and return to RUN mode without completely entering the stop mode. An aborted entry is possible only if the reset or interrupt occurs before the PMC begins the transition to stop mode regulation. After this point, the interrupt or reset is ignored until the PMC has completed its transition to stop mode regulation. When an aborted stop mode entry sequence occurs, SMC_PMCTRL[STOPA] is set to 1.

14.4.2.4 Transition to wait modes

For wait modes (WAIT and VLPW), the CPU clock is gated off while all other clocking continues, as in RUN and VLPR mode operation. Some modules that support stop-in-wait functionality have their clocks disabled in these configurations.

14.4.2.5 Transition from stop modes to Debug mode

The debugger module supports a transition from STOP, WAIT, VLPS, and VLPW back to a Halted state when the debugger has been enabled. As part of this transition, system clocking is re-established and is equivalent to the normal RUN and VLPR mode clocking configuration.

14.4.3 Run modes

The run modes supported by this device can be found here.

- Run (RUN)
- Very Low-Power Run (VLPR)

14.4.3.1 RUN mode

This is the normal operating mode for the device.

This mode is selected after any reset. When the ARM processor exits reset, it sets up the stack, program counter (PC), and link register (LR):

- The processor reads the start SP (SP_main) from vector-table offset 0x000
- The processor reads the start PC from vector-table offset 0x004
- LR is set to 0xFFFF_FFFF.

To reduce power in this mode, disable the clocks to unused modules using their corresponding clock gating control bits in the SIM's registers.

14.4.3.2 Very-Low Power Run (VLPR) mode

In VLPR mode, the on-chip voltage regulator is put into a stop mode regulation state. In this state, the regulator is designed to supply enough current to the MCU over a reduced frequency. To further reduce power in this mode, disable the clocks to unused modules using their corresponding clock gating control bits in the SIM's registers.

Before entering this mode, the following conditions must be met:

- The MCG must be configured in a mode which is supported during VLPR. See the Power Management details for information about these MCG modes.
- All clock monitors in the MCG must be disabled.
- The maximum frequencies of the system, bus, flash, and core are restricted. See the Power Management details about which frequencies are supported.

- Mode protection must be set to allow VLP modes, that is, PMPROT[AVLP] is 1.
- PMCTRL[RUNM] is set to 10b to enter VLPR.
- Flash programming/erasing is not allowed.

NOTE

Do not increase the clock frequency while in VLPR mode, because the regulator is slow in responding and cannot manage fast load transitions. In addition, do not modify the clock source in the MCG module or any clock divider registers. Module clock enables in the SIM can be set, but not cleared.

To reenter Normal Run mode, clear PMCTRL[RUNM]. PMSTAT is a read-only status register that can be used to determine when the system has completed an exit to RUN mode. When PMSTAT=RUN, the system is in run regulation and the MCU can run at full speed in any clock mode. If a higher execution frequency is desired, poll PMSTAT until it is set to RUN when returning from VLPR mode.

VLPR mode also provides the option to return to run regulation if any interrupt occurs. Implement this option by setting Low-Power Wakeup On Interrupt (LPWUI) in the PMCTRL register. Any reset always causes an exit from VLPR and returns the device to RUN mode after the MCU exits its reset flow. The RUNM bits are cleared by hardware on any interrupt when LPWUI is set or on any reset.

14.4.4 Wait modes

This device contains two different wait modes which are listed here.

- Wait
- Very-Low Power Wait (VLPW)

14.4.4.1 WAIT mode

WAIT mode is entered when the ARM core enters the Sleep-Now or Sleep-On-Exit modes while SLEEDEEP is cleared. The ARM CPU enters a low-power state in which it is not clocked, but peripherals continue to be clocked provided they are enabled. Clock gating to the peripheral is enabled via the SIM module.

When an interrupt request occurs, the CPU exits WAIT mode and resumes processing in RUN mode, beginning with the stacking operations leading to the interrupt service routine.

A system reset will cause an exit from WAIT mode, returning the device to normal RUN mode.

14.4.4.2 Very-Low-Power Wait (VLPW) mode

VLPW is entered by the entering the Sleep-Now or Sleep-On-Exit mode while SLEEPDEEP is cleared and the MCU is in VLPR mode.

In VLPW, the on-chip voltage regulator remains in its stop regulation state. In this state, the regulator is designed to supply enough current to the MCU over a reduced frequency. To further reduce power in this mode, disable the clocks to unused modules by clearing the peripherals' corresponding clock gating control bits in the SIM.

VLPR mode restrictions also apply to VLPW.

VLPW mode provides the option to return to fully-regulated normal RUN mode if any enabled interrupt occurs. This is done by setting PMCTRL[LPWUI]. Wait for the PMSTAT register to set to RUN before increasing the frequency.

If the LPWUI bit is clear, when an interrupt from VLPW occurs, the device returns to VLPR mode to execute the interrupt service routine.

A system reset will cause an exit from VLPW mode, returning the device to normal RUN mode.

14.4.5 Stop modes

This device contains a variety of stop modes to meet your application needs.

The stop modes range from:

- a stopped CPU, with all I/O, logic, and memory states retained, and certain asynchronous mode peripherals operating

to:

- a powered down CPU, with only I/O and a small register file retained, very few asynchronous mode peripherals operating, while the remainder of the MCU is powered down.

The choice of stop mode depends upon the user's application, and how power usage and state retention versus functional needs and recovery time may be traded off.

NOTE

All clock monitors must be disabled before entering these low-power modes: Stop, VLPS, VLPR, VLPW, LLS, and VLLSx.

The various stop modes are selected by setting the appropriate fields in PMPROT and PMCTRL. The selected stop mode is entered during the sleep-now or sleep-on-exit entry with the SLEEPDEEP bit set in the System Control Register in the ARM core.

The available stop modes are:

- Normal Stop (STOP)
- Very-Low Power Stop (VLPS)
- Low-Leakage Stop (LLS)
- Very-Low-Leakage Stop (VLLSx)

14.4.5.1 STOP mode

STOP mode is entered via the sleep-now or sleep-on-exit with the SLEEPDEEP bit set in the System Control Register in the ARM core.

The MCG module can be configured to leave the reference clocks running.

A module capable of providing an asynchronous interrupt to the device takes the device out of STOP mode and returns the device to normal RUN mode. Refer to the device's Power Management chapter for peripheral, I/O, and memory operation in STOP mode. When an interrupt request occurs, the CPU exits STOP mode and resumes processing, beginning with the stacking operations leading to the interrupt service routine.

A system reset will cause an exit from STOP mode, returning the device to normal RUN mode via an MCU reset.

14.4.5.2 Very-Low-Power Stop (VLPS) mode

The two ways in which VLPS mode can be entered are listed here.

- Entry into stop via the sleep-now or sleep-on-exit with the SLEEPDEEP bit set in the System Control Register in the ARM core while the MCU is in VLPR mode and PMCTRL[STOPM] = 010 or 000.
- Entry into stop via the sleep-now or sleep-on-exit with the SLEEPDEEP bit set in the System Control Register in the ARM core while the MCU is in normal RUN mode and PMCTRL[STOPM] = 010. When VLPS is entered directly from RUN mode, exit to VLPR is disabled by hardware and the system will always exit back to RUN.

In VLPS, the on-chip voltage regulator remains in its stop regulation state as in VLPR.

A module capable of providing an asynchronous interrupt to the device takes the device out of VLPS and returns the device to VLPR mode, provided LPWUI is clear.

If LPWUI is set, the device returns to normal RUN mode upon an interrupt request. PMSTAT must be set to RUN before allowing the system to return to a frequency higher than that allowed in VLPR mode.

A system reset will also cause a VLPS exit, returning the device to normal RUN mode.

14.4.5.3 Low-Leakage Stop (LLS) mode

Low-Leakage Stop (LLS) mode can be entered from normal RUN or VLPR modes.

The MCU enters LLS mode if:

- In Sleep-Now or Sleep-On-Exit mode, SLEEPDEEP is set in the System Control Register in the ARM core, and
- The device is configured as shown in [Table 14-7](#).

In LLS, the on-chip voltage regulator is in stop regulation. Most of the peripherals are put in a state-retention mode that does not allow them to operate while in LLS.

Before entering LLS mode, the user should configure the Low-Leakage Wake-up (LLWU) module to enable the desired wake-up sources. The available wake-up sources in LLS are detailed in the chip configuration details for this device.

After wakeup from LLS, the device returns to the run mode from which LLS was entered (either normal RUN or VLPR) with a pending LLWU module interrupt. In the LLWU interrupt service routine (ISR), the user can poll the LLWU module wake-up flags to determine the source of the wakeup.

NOTE

The LLWU interrupt must not be masked by the interrupt controller to avoid a scenario where the system does not fully exit Stop mode on an LLS recovery.

An asserted $\overline{\text{RESET}}$ pin will cause an exit from LLS mode, returning the device to normal RUN mode. When LLS is exiting via the $\overline{\text{RESET}}$ pin, RCM_SRS0[PIN] and RCM_SRS0[WAKEUP] are set.

14.4.5.4 Very-Low-Leakage Stop (VLLSx) modes

This device contains these very low leakage modes:

- VLLS3
- VLLS2
- VLLS1
- VLLS0

VLLSx is often used in this document to refer to all of these modes.

All VLLSx modes can be entered from normal RUN or VLPR modes.

The MCU enters the configured VLLS mode if:

- In Sleep-Now or Sleep-On-Exit mode, the SLEEPDEEP bit is set in the System Control Register in the ARM core, and
- The device is configured as shown in [Table 14-7](#).

In VLLS, the on-chip voltage regulator is in its stop-regulation state while most digital logic is powered off.

Before entering VLLS mode, the user should configure the Low-Leakage Wake-up (LLWU) module to enable the desired wakeup sources. The available wake-up sources in VLLS are detailed in the chip configuration details for this device.

After wakeup from VLLS, the device returns to normal RUN mode with a pending LLWU interrupt. In the LLWU interrupt service routine (ISR), the user can poll the LLWU module wake-up flags to determine the source of the wake-up.

When entering VLLS, each I/O pin is latched as configured before executing VLLS. Because all digital logic in the MCU is powered off, all port and peripheral data is lost during VLLS. This information must be restored before PMC_REGSC[ACKISO] is set.

An asserted $\overline{\text{RESET}}$ pin will cause an exit from any VLLS mode, returning the device to normal RUN mode. When exiting VLLS via the $\overline{\text{RESET}}$ pin, RCM_SRS0[PIN] and RCM_SRS0[WAKEUP] are set.

14.4.6 Debug in low power modes

When the MCU is secure, the device disables/limits debugger operation. When the MCU is unsecure, the ARM debugger can assert two power-up request signals:

- System power up, via SYSPWR in the Debug Port Control/Stat register
- Debug power up, via CDBGPWRUPREQ in the Debug Port Control/Stat register

When asserted while in RUN, WAIT, VLPR, or VLPW, the mode controller drives a corresponding acknowledge for each signal, that is, both CDBGPWRUPACK and CSYSPWRUPACK. When both requests are asserted, the mode controller handles attempts to enter STOP and VLPS by entering an emulated stop state. In this emulated stop state:

- the regulator is in run regulation,
- the MCG-generated clock source is enabled,
- all system clocks, except the core clock, are disabled,
- the debug module has access to core registers, and
- access to the on-chip peripherals is blocked.

No debug is available while the MCU is in LLS or VLLS modes. LLS is a state-retention mode and all debug operation can continue after waking from LLS, even in cases where system wakeup is due to a system reset event.

Entering into a VLLS mode causes all of the debug controls and settings to be powered off. To give time to the debugger to sync with the MCU, the MDM AP Control Register includes a Very-Low-Leakage Debug Request (VLLDBGREQ) bit that is set to configure the Reset Controller logic to hold the system in reset after the next recovery from a VLLS mode. This bit allows the debugger time to reinitialize the debug module before the debug session continues.

The MDM AP Control Register also includes a Very Low Leakage Debug Acknowledge (VLLDBGACK) bit that is set to release the ARM core being held in reset following a VLLS recovery. The debugger reinitializes all debug IP, and then asserts the VLLDBGACK control bit to allow the RCM to release the ARM core from reset and allow CPU operation to begin.

The VLLDBGACK bit is cleared by the debugger (or can be left set as is) or clears automatically due to the reset generated as part of the next VLLS recovery.

Chapter 15

Power Management Controller (PMC)

15.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The power management controller (PMC) contains the internal voltage regulator, power on reset (POR), and low voltage detect system.

See [AN4503: Power Management for Kinetis and ColdFire+ MCUs](#) for further details on using the PMC.

15.2 Features

A list of included PMC features can be found [here](#).

- Internal voltage regulator
- Active POR providing brown-out detect
- Low-voltage detect supporting two low-voltage trip points with four warning levels per trip point

15.3 Low-voltage detect (LVD) system

This device includes a system to guard against low-voltage conditions. This protects memory contents and controls MCU system states during supply voltage variations.

The system is comprised of a power-on reset (POR) circuit and a LVD circuit with a user-selectable trip voltage: high (V_{LVDH}) or low (V_{LVDL}). The trip voltage is selected by LVDSC1[LVDV]. The LVD is disabled upon entering VLPx, LLS, and VLLSx modes.

Two flags are available to indicate the status of the low-voltage detect system:

- The Low Voltage Detect Flag in the Low Voltage Status and Control 1 Register (LVDSC1[LVDF]) operates in a level sensitive manner. LVDSC1[LVDF] is set when the supply voltage falls below the selected trip point (VLVD). LVDSC1[LVDF] is cleared by writing 1 to LVDSC1[LVDACK], but only if the internal supply has returned above the trip point; otherwise, LVDSC1[LVDF] remains set.
- The Low Voltage Warning Flag (LVWF) in the Low Voltage Status and Control 2 Register (LVDSC2[LVWF]) operates in a level sensitive manner. LVDSC2[LVWF] is set when the supply voltage falls below the selected monitor trip point (VLVW). LVDSC2[LVWF] is cleared by writing one to LVDSC2[LVWACK], but only if the internal supply has returned above the trip point; otherwise, LVDSC2[LVWF] remains set.

15.3.1 LVD reset operation

By setting LVDSC1[LVDRE], the LVD generates a reset upon detection of a low-voltage condition. The low-voltage detection threshold is determined by LVDSC1[LVDV]. After an LVD reset occurs, the LVD system holds the MCU in reset until the supply voltage rises above this threshold. The LVD field in the SRS register of the RCM module (RCM_SRS0[LVD]) is set following an LVD or power-on reset.

15.3.2 LVD interrupt operation

By configuring the LVD circuit for interrupt operation (LVDSC1[LVDIE] set and LVDSC1[LVDRE] clear), LVDSC1[LVDF] is set and an LVD interrupt request occurs upon detection of a low voltage condition. LVDSC1[LVDF] is cleared by writing 1 to LVDSC1[LVDACK].

15.3.3 Low-voltage warning (LVW) interrupt operation

The LVD system contains a Low-Voltage Warning Flag (LVWF) in the Low Voltage Detect Status and Control 2 Register to indicate that the supply voltage is approaching, but is above, the LVD voltage. The LVW also has an interrupt, which is enabled by setting LVDSC2[LVWIE]. If enabled, an LVW interrupt request occurs when LVDSC2[LVWF] is set. LVDSC2[LVWF] is cleared by writing 1 to LVDSC2[LVWACK].

LVDSC2[LVWV] selects one of the four trip voltages:

- Highest: V_{LVW4}
- Two mid-levels: V_{LVW3} and V_{LVW2}
- Lowest: V_{LVW1}

15.4 I/O retention

When in LLS mode, the I/O pins are held in their input or output state.

Upon wakeup, the PMC is re-enabled, goes through a power up sequence to full regulation, and releases the logic from state retention mode. The I/O are released immediately after a wake-up or reset event. In the case of LLS exit via a RESET pin, the I/O default to their reset state.

When in VLLS modes, the I/O states are held on a wake-up event (with the exception of wake-up by reset event) until the wake-up has been acknowledged via a write to REGSC[ACKISO]. In the case of VLLS exit via a RESET pin, the I/O are released and default to their reset state. In this case, no write to REGSC[ACKISO] is needed.

15.5 Memory map and register descriptions

Details about the PMC registers can be found here.

NOTE

Different portions of PMC registers are reset only by particular reset types. Each register's description provides details. For more information about the types of reset on this chip, refer to the Reset section details.

The PMC registers can be written only in supervisor mode. Write accesses in user mode are blocked and will result in a bus error.

PMC memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|----------------------------|
| 4007_D000 | Low Voltage Detect Status And Control 1 register (PMC_LVDSC1) | 8 | R/W | 10h | 15.5.1/280 |

Table continues on the next page...

PMC memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|---|-----------------|--------|-------------|----------------------------|
| 4007_D001 | Low Voltage Detect Status And Control 2 register (PMC_LVDSC2) | 8 | R/W | 00h | 15.5.2/281 |
| 4007_D002 | Regulator Status And Control register (PMC_REGSC) | 8 | R/W | 04h | 15.5.3/282 |

15.5.1 Low Voltage Detect Status And Control 1 register (PMC_LVDSC1)

This register contains status and control bits to support the low voltage detect function. This register should be written during the reset initialization program to set the desired controls even if the desired settings are the same as the reset settings.

While the device is in the very low power or low leakage modes, the LVD system is disabled regardless of LVDSC1 settings. To protect systems that must have LVD always on, configure the Power Mode Protection (PMPROT) register of the SMC module (SMC_PMPROT) to disallow any very low power or low leakage modes from being enabled.

See the device's data sheet for the exact LVD trip voltages.

NOTE

The LVDV bits are reset solely on a POR Only event. The register's other bits are reset on Chip Reset Not VLLS. For more information about these reset types, refer to the Reset section details.

Address: 4007_D000h base + 0h offset = 4007_D000h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|--------|-------|-------|---|---|---|------|
| Read | LVDF | 0 | LVDIE | LVDRE | 0 | | | |
| Write | | LVDACK | | | | | | LVDV |
| Reset | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

PMC_LVDSC1 field descriptions

| Field | Description |
|-----------|--|
| 7 LVDF | Low-Voltage Detect Flag This read-only status field indicates a low-voltage detect event. 0 Low-voltage event not detected 1 Low-voltage event detected |

Table continues on the next page...

PMC_LVDSC1 field descriptions (continued)

| Field | Description |
|-----------------|---|
| 6 LVDACK | Low-Voltage Detect Acknowledge This write-only field is used to acknowledge low voltage detection errors. Write 1 to clear LVDF. Reads always return 0. |
| 5 LVDIE | Low-Voltage Detect Interrupt Enable Enables hardware interrupt requests for LVDF. 0 Hardware interrupt disabled (use polling) 1 Request a hardware interrupt when LVDF = 1 |
| 4 LVDRE | Low-Voltage Detect Reset Enable This write-once bit enables LVDF events to generate a hardware reset. Additional writes are ignored. 0 LVDF does not generate hardware resets 1 Force an MCU reset when LVDF = 1 |
| 3–2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1–0 LVDV | Low-Voltage Detect Voltage Select Selects the LVD trip point voltage (V_{LVD}). 00 Low trip point selected ($V_{LVD} = V_{LVDL}$) 01 High trip point selected ($V_{LVD} = V_{LVDH}$) 10 Reserved 11 Reserved |

15.5.2 Low Voltage Detect Status And Control 2 register (PMC_LVDSC2)

This register contains status and control bits to support the low voltage warning function.

While the device is in the very low power or low leakage modes, the LVD system is disabled regardless of LVDSC2 settings.

See the device's data sheet for the exact LVD trip voltages.

NOTE

The LVW trip voltages depend on LVWV and LVDV.

NOTE

LVWV is reset solely on a POR Only event. The other fields of the register are reset on Chip Reset Not VLLS. For more information about these reset types, refer to the Reset section details.

memory map and register descriptions

Address: 4007_D000h base + 1h offset = 4007_D001h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|--------|-------|---|---|---|---|------|
| Read | LVWF | 0 | LVWIE | | 0 | | | |
| Write | | LVWACK | | | | | | LVWV |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PMC_LVDSC2 field descriptions

| Field | Description |
|-----------------|--|
| 7 LVWF | <p>Low-Voltage Warning Flag</p> <p>This read-only status field indicates a low-voltage warning event. LVWF is set when V_{Supply} transitions below the trip point, or after reset and V_{Supply} is already below V_{LVW}. LVWF may be 1 after power-on reset, therefore, to use LVW interrupt function, before enabling LVWIE, LVWF must be cleared by writing LVWACK first.</p> <p>0 Low-voltage warning event not detected 1 Low-voltage warning event detected</p> |
| 6 LVWACK | <p>Low-Voltage Warning Acknowledge</p> <p>This write-only field is used to acknowledge low voltage warning errors. Write 1 to clear LVWF. Reads always return 0.</p> |
| 5 LVWIE | <p>Low-Voltage Warning Interrupt Enable</p> <p>Enables hardware interrupt requests for LVWF.</p> <p>0 Hardware interrupt disabled (use polling) 1 Request a hardware interrupt when LVWF = 1</p> |
| 4–2 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 1–0 LVWV | <p>Low-Voltage Warning Voltage Select</p> <p>Selects the LVW trip point voltage (V_{LVW}). The actual voltage for the warning depends on LVDSC1[LVDV].</p> <p>00 Low trip point selected ($V_{LVW} = V_{LVW1}$) 01 Mid 1 trip point selected ($V_{LVW} = V_{LVW2}$) 10 Mid 2 trip point selected ($V_{LVW} = V_{LVW3}$) 11 High trip point selected ($V_{LVW} = V_{LVW4}$)</p> |

15.5.3 Regulator Status And Control register (PMC_REGSC)

The PMC contains an internal voltage regulator. The voltage regulator design uses a bandgap reference that is also available through a buffer as input to certain internal peripherals, such as the CMP and ADC. The internal regulator provides a status bit (REGONS) indicating the regulator is in run regulation.

NOTE

This register is reset on Chip Reset Not VLLS and by reset types that trigger Chip Reset not VLLS. See the Reset section details for more information.

Address: 4007_D000h base + 2h offset = 4007_D002h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---|---|----------|------|--------|--------|----------|------|
| Read | 0 | 0 | Reserved | BGEN | ACKISO | REGONS | Reserved | BGBE |
| Write | | | | | w1c | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

PMC_REGSC field descriptions

| Field | Description |
|---------------|---|
| 7 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5 Reserved | This field is reserved. |
| 4 BGEN | Bandgap Enable In VLPx Operation BGEN controls whether the bandgap is enabled in lower power modes of operation (VLPx, LLS, and VLLSx). When on-chip peripherals require the bandgap voltage reference in low power modes of operation, set BGEN to continue to enable the bandgap operation. NOTE: When the bandgap voltage reference is not needed in low power modes, clear BGEN to avoid excess power consumption. 0 Bandgap voltage reference is disabled in VLPx , LLS , and VLLSx modes. 1 Bandgap voltage reference is enabled in VLPx , LLS , and VLLSx modes. |
| 3 ACKISO | Acknowledge Isolation Reading this field indicates whether certain peripherals and the I/O pads are in a latched state as a result of having been in a VLLS mode. Writing 1 to this field when it is set releases the I/O pads and certain peripherals to their normal run mode state. NOTE: After recovering from a VLLS mode, user should restore chip configuration before clearing ACKISO. In particular, pin configuration for enabled LLWU wakeup pins should be restored to avoid any LLWU flag from being falsely set when ACKISO is cleared. 0 Peripherals and I/O pads are in normal run state. 1 Certain peripherals and I/O pads are in an isolated and latched state. |
| 2 REGONS | Regulator In Run Regulation Status This read-only field provides the current status of the internal voltage regulator. 0 Regulator is in stop regulation or in transition to/from it 1 Regulator is in run regulation |
| 1 Reserved | This field is reserved. NOTE: This reserved bit must remain cleared (set to 0). |

Table continues on the next page...



PMC_REGSC field descriptions (continued)

| Field | Description |
|-----------|--|
| 0 BGBE | Bandgap Buffer Enable Enables the bandgap buffer. 0 Bandgap buffer not enabled 1 Bandgap buffer enabled |

Chapter 16

Low-Leakage Wakeup Unit (LLWU)

16.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The LLWU module allows the user to select up to 16 external pins and up to 8 internal modules as interrupt wake-up sources from low-leakage power modes.

The input sources are described in the device's chip configuration details. Each of the available wake-up sources can be individually enabled.

The $\overline{\text{RESET}}$ pin is an additional source for triggering an exit from low-leakage power modes, and causes the MCU to exit both LLS and VLLS through a reset flow.

The LLWU_RST[LLRSTE] bit must be set to allow an exit from low-leakage modes via the $\overline{\text{RESET}}$ pin. On a device where the $\overline{\text{RESET}}$ pin is shared with other functions, the explicit port mux control register must be set for the $\overline{\text{RESET}}$ pin before the $\overline{\text{RESET}}$ pin can be used as a low-leakage reset source.

The LLWU module also includes optional digital pin filters: two for the external wakeup pins and one for the $\overline{\text{RESET}}$ pin.

16.1.1 Features

The LLWU module features include:

- Support for up to 16 external input pins and up to 8 internal modules with individual enable bits for MCU interrupt from low leakage modes
- Input sources may be external pins or from internal peripherals capable of running in LLS or VLLS. See the chip configuration information for wakeup input sources for this device.

- External pin wake-up inputs, each of which is programmable as falling-edge, rising-edge, or any change
- Wake-up inputs that are activated after MCU enters a low-leakage power mode
- Optional digital filters provided to qualify an external pin detect and $\overline{\text{RESET}}$ pin detect. Note that when the LPO clock is disabled, the filters are disabled and bypassed.

16.1.2 Modes of operation

The LLWU module becomes functional on entry into a low-leakage power mode. After recovery from LLS, the LLWU is immediately disabled. After recovery from VLLS, the LLWU continues to detect wake-up events until the user has acknowledged the wake-up via a write to PMC_REGSC[ACKISO].

16.1.2.1 LLS mode

Wake-up events due to external pin inputs (LLWU_Px) and internal module interrupt inputs (LLWU_MxIF) result in an interrupt flow when exiting LLS. A reset event due to $\overline{\text{RESET}}$ pin assertion results in a reset flow when exiting LLS.

NOTE

The LLWU interrupt must not be masked by the interrupt controller to avoid a scenario where the system does not fully exit Stop mode on an LLS recovery.

16.1.2.2 VLLS modes

All wakeup and reset events result in VLLS exit via a reset flow.

16.1.2.3 Non-low leakage modes

The LLWU is not active in all non-low leakage modes where detection and control logic are in a static state. The LLWU registers are accessible in non-low leakage modes and are available for configuring and reading status when bus transactions are possible.

When the $\overline{\text{RESET}}$ pin filter or wake-up pin filters are enabled, filter operation begins immediately. If a low leakage mode is entered within five LPO clock cycles of an active edge, the edge event will be detected by the LLWU. For $\overline{\text{RESET}}$ pin filtering, this means that there is no restart to the minimum LPO cycle duration as the filtering transitions from a non-low leakage filter, which is implemented in the RCM, to the LLWU filter.

16.1.2.4 Debug mode

When the chip is in Debug mode and then enters LLS or a VLLSx mode, no debug logic works in the fully-functional low-leakage mode. Upon an exit from the LLS or VLLSx mode, the LLWU becomes inactive.

16.1.3 Block diagram

The following figure is the block diagram for the LLWU module.

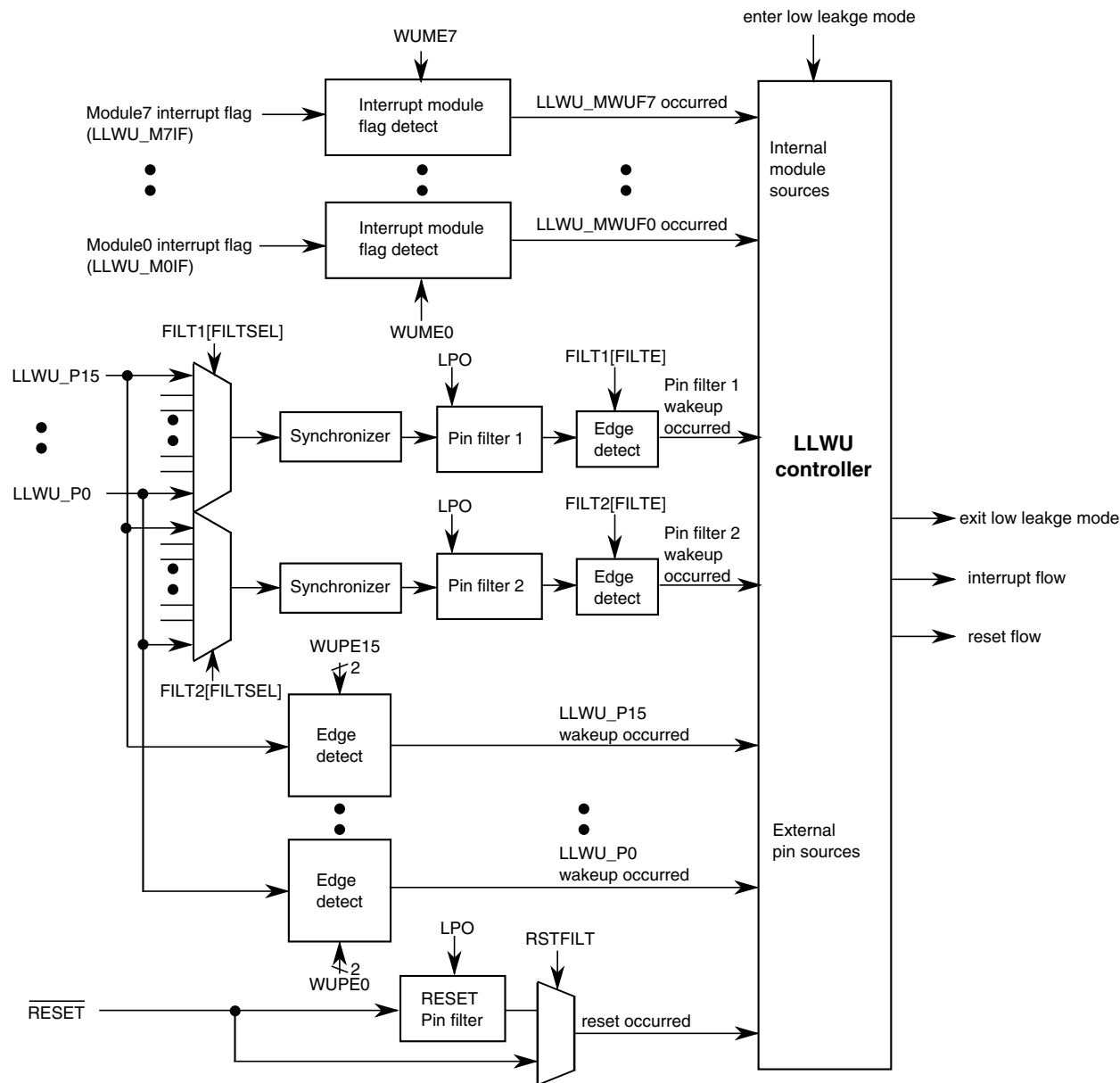


Figure 16-1. LLWU block diagram

16.2 LLWU signal descriptions

The signal properties of LLWU are shown in the table found here.

The external wakeup input pins can be enabled to detect either rising-edge, falling-edge, or on any change.

Table 16-1. LLWU signal descriptions

| Signal | Description | I/O |
|---------|--------------------------|-----|
| LLWU_Pn | Wakeup inputs (n = 0-15) | I |

16.3 Memory map/register definition

The LLWU includes the following registers:

- Wake-up source enable registers
 - Enable external pin input sources
 - Enable internal peripheral interrupt sources
- Wake-up flag registers
 - Indication of wakeup source that caused exit from a low-leakage power mode includes external pin or internal module interrupt
- Wake-up pin filter enable registers
- RESET pin filter enable register

NOTE

The LLWU registers can be written only in supervisor mode. Write accesses in user mode are blocked and will result in a bus error.

All LLWU registers are reset by Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. Each register's displayed reset value represents this subset of reset types. LLWU registers are unaffected by reset types that do not trigger Chip Reset not VLLS. For more information about the types of reset on this chip, refer to the [Introduction](#) details.

LLWU memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4007_C000 | LLWU Pin Enable 1 register (LLWU_PE1) | 8 | R/W | 00h | 16.3.1/290 |
| 4007_C001 | LLWU Pin Enable 2 register (LLWU_PE2) | 8 | R/W | 00h | 16.3.2/291 |
| 4007_C002 | LLWU Pin Enable 3 register (LLWU_PE3) | 8 | R/W | 00h | 16.3.3/292 |
| 4007_C003 | LLWU Pin Enable 4 register (LLWU_PE4) | 8 | R/W | 00h | 16.3.4/293 |
| 4007_C004 | LLWU Module Enable register (LLWU_ME) | 8 | R/W | 00h | 16.3.5/294 |
| 4007_C005 | LLWU Flag 1 register (LLWU_F1) | 8 | R/W | 00h | 16.3.6/296 |
| 4007_C006 | LLWU Flag 2 register (LLWU_F2) | 8 | R/W | 00h | 16.3.7/297 |
| 4007_C007 | LLWU Flag 3 register (LLWU_F3) | 8 | R | 00h | 16.3.8/299 |
| 4007_C008 | LLWU Pin Filter 1 register (LLWU_FILT1) | 8 | R/W | 00h | 16.3.9/301 |
| 4007_C009 | LLWU Pin Filter 2 register (LLWU_FILT2) | 8 | R/W | 00h | 16.3.10/302 |
| 4007_C00A | LLWU Reset Enable register (LLWU_RST) | 8 | R/W | 02h | 16.3.11/303 |

16.3.1 LLWU Pin Enable 1 register (LLWU_PE1)

LLWU_PE1 contains the field to enable and select the edge detect type for the external wakeup input pins LLWU_P3–LLWU_P0.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the [Introduction](#) details for more information.

Address: 4007_C000h base + 0h offset = 4007_C000h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|---|-------|---|-------|---|-------|---|
| Read | WUPE3 | | WUPE2 | | WUPE1 | | WUPE0 | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LLWU_PE1 field descriptions

| Field | Description |
|--------------|---|
| 7–6 WUPE3 | <p>Wakeup Pin Enable For LLWU_P3</p> <p>Enables and configures the edge detection for the wakeup pin.</p> <p>00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection</p> |
| 5–4 WUPE2 | <p>Wakeup Pin Enable For LLWU_P2</p> <p>Enables and configures the edge detection for the wakeup pin.</p> <p>00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection</p> |
| 3–2 WUPE1 | <p>Wakeup Pin Enable For LLWU_P1</p> <p>Enables and configures the edge detection for the wakeup pin.</p> <p>00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection</p> |
| 1–0 WUPE0 | <p>Wakeup Pin Enable For LLWU_P0</p> <p>Enables and configures the edge detection for the wakeup pin.</p> <p>00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection</p> |

Table continues on the next page...

LLWU_PE1 field descriptions (continued)

| Field | Description |
|-------|--|
| 10 | External input pin enabled with falling edge detection |
| 11 | External input pin enabled with any change detection |

16.3.2 LLWU Pin Enable 2 register (LLWU_PE2)

LLWU_PE2 contains the field to enable and select the edge detect type for the external wakeup input pins LLWU_P7–LLWU_P4.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the [Introduction](#) details for more information.

Address: 4007_C000h base + 1h offset = 4007_C001h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---|---|---|---|---|---|---|---|
| Read | | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LLWU_PE2 field descriptions

| Field | Description |
|--------------|---|
| 7–6 WUPE7 | <p>Wakeup Pin Enable For LLWU_P7</p> <p>Enables and configures the edge detection for the wakeup pin.</p> <p>00 External input pin disabled as wakeup input</p> <p>01 External input pin enabled with rising edge detection</p> <p>10 External input pin enabled with falling edge detection</p> <p>11 External input pin enabled with any change detection</p> |
| 5–4 WUPE6 | <p>Wakeup Pin Enable For LLWU_P6</p> <p>Enables and configures the edge detection for the wakeup pin.</p> <p>00 External input pin disabled as wakeup input</p> <p>01 External input pin enabled with rising edge detection</p> <p>10 External input pin enabled with falling edge detection</p> <p>11 External input pin enabled with any change detection</p> |
| 3–2 WUPE5 | <p>Wakeup Pin Enable For LLWU_P5</p> <p>Enables and configures the edge detection for the wakeup pin.</p> <p>00 External input pin disabled as wakeup input</p> <p>01 External input pin enabled with rising edge detection</p> |

Table continues on the next page...

LLWU_PE2 field descriptions (continued)

| Field | Description |
|--------------|--|
| | 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection |
| 1–0 WUPE4 | Wakeup Pin Enable For LLWU_P4 Enables and configures the edge detection for the wakeup pin. 00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection |

16.3.3 LLWU Pin Enable 3 register (LLWU_PE3)

LLWU_PE3 contains the field to enable and select the edge detect type for the external wakeup input pins LLWU_P11–LLWU_P8.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the [Introduction](#) details for more information.

Address: 4007_C000h base + 2h offset = 4007_C002h

| | | | | | | | | |
|-------|--------|---|--------|---|-------|---|-------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | WUPE11 | | WUPE10 | | WUPE9 | | WUPE8 | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LLWU_PE3 field descriptions

| Field | Description |
|---------------|---|
| 7–6 WUPE11 | Wakeup Pin Enable For LLWU_P11 Enables and configures the edge detection for the wakeup pin. 00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection |
| 5–4 WUPE10 | Wakeup Pin Enable For LLWU_P10 Enables and configures the edge detection for the wakeup pin. 00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection |

Table continues on the next page...

LLWU_PE3 field descriptions (continued)

| Field | Description |
|--------------|--|
| | 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection |
| 3–2 WUPE9 | Wakeup Pin Enable For LLWU_P9 Enables and configures the edge detection for the wakeup pin. 00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection |
| 1–0 WUPE8 | Wakeup Pin Enable For LLWU_P8 Enables and configures the edge detection for the wakeup pin. 00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection |

16.3.4 LLWU Pin Enable 4 register (LLWU_PE4)

LLWU_PE4 contains the field to enable and select the edge detect type for the external wakeup input pins LLWU_P15–LLWU_P12.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the [Introduction](#) details for more information.

Address: 4007_C000h base + 3h offset = 4007_C003h

| | | | | | | | | |
|-------|--------|---|--------|---|--------|---|--------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | WUPE15 | | WUPE14 | | WUPE13 | | WUPE12 | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LLWU_PE4 field descriptions

| Field | Description |
|---------------|---|
| 7–6 WUPE15 | Wakeup Pin Enable For LLWU_P15 Enables and configures the edge detection for the wakeup pin. 00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection |

Table continues on the next page...

LLWU_PE4 field descriptions (continued)

| Field | Description |
|---------------|---|
| | 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection |
| 5–4 WUPE14 | Wakeup Pin Enable For LLWU_P14 Enables and configures the edge detection for the wakeup pin. 00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection |
| 3–2 WUPE13 | Wakeup Pin Enable For LLWU_P13 Enables and configures the edge detection for the wakeup pin. 00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection |
| 1–0 WUPE12 | Wakeup Pin Enable For LLWU_P12 Enables and configures the edge detection for the wakeup pin. 00 External input pin disabled as wakeup input 01 External input pin enabled with rising edge detection 10 External input pin enabled with falling edge detection 11 External input pin enabled with any change detection |

16.3.5 LLWU Module Enable register (LLWU_ME)

LLWU_ME contains the bits to enable the internal module flag as a wakeup input source for inputs MWUF7–MWUF0.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the [Introduction](#) details for more information.

Address: 4007_C000h base + 4h offset = 4007_C004h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Read | WUME7 | WUME6 | WUME5 | WUME4 | WUME3 | WUME2 | WUME1 | WUME0 |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LLWU_ME field descriptions

| Field | Description |
|------------|---|
| 7 WUME7 | <p>Wakeup Module Enable For Module 7</p> <p>Enables an internal module as a wakeup source input.</p> <p>0 Internal module flag not used as wakeup source 1 Internal module flag used as wakeup source</p> |
| 6 WUME6 | <p>Wakeup Module Enable For Module 6</p> <p>Enables an internal module as a wakeup source input.</p> <p>0 Internal module flag not used as wakeup source 1 Internal module flag used as wakeup source</p> |
| 5 WUME5 | <p>Wakeup Module Enable For Module 5</p> <p>Enables an internal module as a wakeup source input.</p> <p>0 Internal module flag not used as wakeup source 1 Internal module flag used as wakeup source</p> |
| 4 WUME4 | <p>Wakeup Module Enable For Module 4</p> <p>Enables an internal module as a wakeup source input.</p> <p>0 Internal module flag not used as wakeup source 1 Internal module flag used as wakeup source</p> |
| 3 WUME3 | <p>Wakeup Module Enable For Module 3</p> <p>Enables an internal module as a wakeup source input.</p> <p>0 Internal module flag not used as wakeup source 1 Internal module flag used as wakeup source</p> |
| 2 WUME2 | <p>Wakeup Module Enable For Module 2</p> <p>Enables an internal module as a wakeup source input.</p> <p>0 Internal module flag not used as wakeup source 1 Internal module flag used as wakeup source</p> |
| 1 WUME1 | <p>Wakeup Module Enable for Module 1</p> <p>Enables an internal module as a wakeup source input.</p> <p>0 Internal module flag not used as wakeup source 1 Internal module flag used as wakeup source</p> |
| 0 WUME0 | <p>Wakeup Module Enable For Module 0</p> <p>Enables an internal module as a wakeup source input.</p> <p>0 Internal module flag not used as wakeup source 1 Internal module flag used as wakeup source</p> |

16.3.6 LLWU Flag 1 register (LLWU_F1)

LLWU_F1 contains the wakeup flags indicating which wakeup source caused the MCU to exit LLS or VLLS mode. For LLS, this is the source causing the CPU interrupt flow. For VLLS, this is the source causing the MCU reset flow.

The external wakeup flags are read-only and clearing a flag is accomplished by a write of a 1 to the corresponding WUFx bit. The wakeup flag (WUFx), if set, will remain set if the associated WUPEx bit is cleared.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the [Introduction](#) details for more information.

Address: 4007_C000h base + 5h offset = 4007_C005h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|------|------|------|------|------|------|------|
| Read | WUF7 | WUF6 | WUF5 | WUF4 | WUF3 | WUF2 | WUF1 | WUF0 |
| Write | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LLWU_F1 field descriptions

| Field | Description |
|-----------|--|
| 7 WUF7 | <p>Wakeup Flag For LLWU_P7</p> <p>Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF7.</p> <p>0 LLWU_P7 input was not a wakeup source 1 LLWU_P7 input was a wakeup source</p> |
| 6 WUF6 | <p>Wakeup Flag For LLWU_P6</p> <p>Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF6.</p> <p>0 LLWU_P6 input was not a wakeup source 1 LLWU_P6 input was a wakeup source</p> |
| 5 WUF5 | <p>Wakeup Flag For LLWU_P5</p> <p>Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF5.</p> <p>0 LLWU_P5 input was not a wakeup source 1 LLWU_P5 input was a wakeup source</p> |

Table continues on the next page...

LLWU_F1 field descriptions (continued)

| Field | Description |
|-----------|--|
| 4 WUF4 | <p>Wakeup Flag For LLWU_P4</p> <p>Indicates that an enabled external wake-up pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF4.</p> <p>0 LLWU_P4 input was not a wakeup source 1 LLWU_P4 input was a wakeup source</p> |
| 3 WUF3 | <p>Wakeup Flag For LLWU_P3</p> <p>Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF3.</p> <p>0 LLWU_P3 input was not a wake-up source 1 LLWU_P3 input was a wake-up source</p> |
| 2 WUF2 | <p>Wakeup Flag For LLWU_P2</p> <p>Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF2.</p> <p>0 LLWU_P2 input was not a wakeup source 1 LLWU_P2 input was a wakeup source</p> |
| 1 WUF1 | <p>Wakeup Flag For LLWU_P1</p> <p>Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF1.</p> <p>0 LLWU_P1 input was not a wakeup source 1 LLWU_P1 input was a wakeup source</p> |
| 0 WUF0 | <p>Wakeup Flag For LLWU_P0</p> <p>Indicates that an enabled external wake-up pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF0.</p> <p>0 LLWU_P0 input was not a wakeup source 1 LLWU_P0 input was a wakeup source</p> |

16.3.7 LLWU Flag 2 register (LLWU_F2)

LLWU_F2 contains the wakeup flags indicating which wakeup source caused the MCU to exit LLS or VLLS mode. For LLS, this is the source causing the CPU interrupt flow. For VLLS, this is the source causing the MCU reset flow.

The external wakeup flags are read-only and clearing a flag is accomplished by a write of a 1 to the corresponding WUFx bit. The wakeup flag (WUFx), if set, will remain set if the associated WUPEx bit is cleared.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the [Introduction](#) details for more information.

Address: 4007_C000h base + 6h offset = 4007_C006h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|-------|-------|-------|-------|-------|------|------|
| Read | WUF15 | WUF14 | WUF13 | WUF12 | WUF11 | WUF10 | WUF9 | WUF8 |
| Write | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LLWU_F2 field descriptions

| Field | Description |
|------------|--|
| 7 WUF15 | <p>Wakeup Flag For LLWU_P15</p> <p>Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF15.</p> <p>0 LLWU_P15 input was not a wakeup source 1 LLWU_P15 input was a wakeup source</p> |
| 6 WUF14 | <p>Wakeup Flag For LLWU_P14</p> <p>Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF14.</p> <p>0 LLWU_P14 input was not a wakeup source 1 LLWU_P14 input was a wakeup source</p> |
| 5 WUF13 | <p>Wakeup Flag For LLWU_P13</p> <p>Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF13.</p> <p>0 LLWU_P13 input was not a wakeup source 1 LLWU_P13 input was a wakeup source</p> |
| 4 WUF12 | <p>Wakeup Flag For LLWU_P12</p> <p>Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF12.</p> <p>0 LLWU_P12 input was not a wakeup source 1 LLWU_P12 input was a wakeup source</p> |
| 3 WUF11 | <p>Wakeup Flag For LLWU_P11</p> <p>Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF11.</p> <p>0 LLWU_P11 input was not a wakeup source 1 LLWU_P11 input was a wakeup source</p> |
| 2 WUF10 | <p>Wakeup Flag For LLWU_P10</p> |

Table continues on the next page...

LLWU_F2 field descriptions (continued)

| Field | Description |
|-----------|--|
| | Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF10. 0 LLWU_P10 input was not a wakeup source 1 LLWU_P10 input was a wakeup source |
| 1 WUF9 | Wakeup Flag For LLWU_P9 Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF9. 0 LLWU_P9 input was not a wakeup source 1 LLWU_P9 input was a wakeup source |
| 0 WUF8 | Wakeup Flag For LLWU_P8 Indicates that an enabled external wakeup pin was a source of exiting a low-leakage power mode. To clear the flag, write a 1 to WUF8. 0 LLWU_P8 input was not a wakeup source 1 LLWU_P8 input was a wakeup source |

16.3.8 LLWU Flag 3 register (LLWU_F3)

LLWU_F3 contains the wakeup flags indicating which internal wakeup source caused the MCU to exit LLS or VLLS mode. For LLS, this is the source causing the CPU interrupt flow. For VLLS, this is the source causing the MCU reset flow.

For internal peripherals that are capable of running in a low-leakage power mode, such as a real time clock module or CMP module, the flag from the associated peripheral is accessible as the MWUFx bit. The flag will need to be cleared in the peripheral instead of writing a 1 to the MWUFx bit.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the [Introduction](#) details for more information.

Address: 4007_C000h base + 7h offset = 4007_C007h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Read | MWUF7 | MWUF6 | MWUF5 | MWUF4 | MWUF3 | MWUF2 | MWUF1 | MWUF0 |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LLWU_F3 field descriptions

| Field | Description |
|------------|--|
| 7 MWUF7 | <p>Wakeup flag For module 7</p> <p>Indicates that an enabled internal peripheral was a source of exiting a low-leakage power mode. To clear the flag, follow the internal peripheral flag clearing mechanism.</p> <p>0 Module 7 input was not a wakeup source 1 Module 7 input was a wakeup source</p> |
| 6 MWUF6 | <p>Wakeup flag For module 6</p> <p>Indicates that an enabled internal peripheral was a source of exiting a low-leakage power mode. To clear the flag, follow the internal peripheral flag clearing mechanism.</p> <p>0 Module 6 input was not a wakeup source 1 Module 6 input was a wakeup source</p> |
| 5 MWUF5 | <p>Wakeup flag For module 5</p> <p>Indicates that an enabled internal peripheral was a source of exiting a low-leakage power mode. To clear the flag, follow the internal peripheral flag clearing mechanism.</p> <p>0 Module 5 input was not a wakeup source 1 Module 5 input was a wakeup source</p> |
| 4 MWUF4 | <p>Wakeup flag For module 4</p> <p>Indicates that an enabled internal peripheral was a source of exiting a low-leakage power mode. To clear the flag, follow the internal peripheral flag clearing mechanism.</p> <p>0 Module 4 input was not a wakeup source 1 Module 4 input was a wakeup source</p> |
| 3 MWUF3 | <p>Wakeup flag For module 3</p> <p>Indicates that an enabled internal peripheral was a source of exiting a low-leakage power mode. To clear the flag, follow the internal peripheral flag clearing mechanism.</p> <p>0 Module 3 input was not a wakeup source 1 Module 3 input was a wakeup source</p> |
| 2 MWUF2 | <p>Wakeup flag For module 2</p> <p>Indicates that an enabled internal peripheral was a source of exiting a low-leakage power mode. To clear the flag, follow the internal peripheral flag clearing mechanism.</p> <p>0 Module 2 input was not a wakeup source 1 Module 2 input was a wakeup source</p> |
| 1 MWUF1 | <p>Wakeup flag For module 1</p> <p>Indicates that an enabled internal peripheral was a source of exiting a low-leakage power mode. To clear the flag, follow the internal peripheral flag clearing mechanism.</p> <p>0 Module 1 input was not a wakeup source 1 Module 1 input was a wakeup source</p> |
| 0 MWUF0 | <p>Wakeup flag For module 0</p> |

Table continues on the next page...

LLWU_F3 field descriptions (continued)

| Field | Description |
|-------|--|
| | Indicates that an enabled internal peripheral was a source of exiting a low-leakage power mode. To clear the flag, follow the internal peripheral flag clearing mechanism. |
| 0 | Module 0 input was not a wakeup source |
| 1 | Module 0 input was a wakeup source |

16.3.9 LLWU Pin Filter 1 register (LLWU_FILT1)

LLWU_FILT1 is a control and status register that is used to enable/disable the digital filter 1 features for an external pin.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the [Introduction](#) details for more information.

Address: 4007_C000h base + 8h offset = 4007_C008h

| | | | | | | | | |
|-------|-------|-------|---|---|---|---------|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | FILTF | FILTE | | | 0 | FILTSEL | | |
| Write | w1c | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LLWU_FILT1 field descriptions

| Field | Description |
|---------------|---|
| 7 FILTF | Filter Detect Flag Indicates that the filtered external wakeup pin, selected by FILTSEL, was a source of exiting a low-leakage power mode. To clear the flag write a one to FILTF. 0 Pin Filter 1 was not a wakeup source 1 Pin Filter 1 was a wakeup source |
| 6–5 FILTE | Digital Filter On External Pin Controls the digital filter options for the external pin detect. 00 Filter disabled 01 Filter posedge detect enabled 10 Filter negedge detect enabled 11 Filter any edge detect enabled |
| 4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

Table continues on the next page...

LLWU_FILT1 field descriptions (continued)

| Field | Description |
|----------------|--|
| 3–0 FILTSEL | <p>Filter Pin Select</p> <p>Selects 1 out of the 16 wakeup pins to be muxed into the filter.</p> <p>0000 Select LLWU_P0 for filter</p> <p>... ...</p> <p>1111 Select LLWU_P15 for filter</p> |

16.3.10 LLWU Pin Filter 2 register (LLWU_FILT2)

LLWU_FILT2 is a control and status register that is used to enable/disable the digital filter 2 features for an external pin.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the [Introduction](#) details for more information.

Address: 4007_C000h base + 9h offset = 4007_C009h

| | | | | | | | | |
|-------|-------|-------|---|---|---|---------|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | FILTF | FILTE | | | 0 | FILTSEL | | |
| Write | w1c | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LLWU_FILT2 field descriptions

| Field | Description |
|---------------|--|
| 7 FILTF | <p>Filter Detect Flag</p> <p>Indicates that the filtered external wakeup pin, selected by FILTSEL, was a source of exiting a low-leakage power mode. To clear the flag write a one to FILTF.</p> <p>0 Pin Filter 2 was not a wakeup source</p> <p>1 Pin Filter 2 was a wakeup source</p> |
| 6–5 FILTE | <p>Digital Filter On External Pin</p> <p>Controls the digital filter options for the external pin detect.</p> <p>00 Filter disabled</p> <p>01 Filter posedge detect enabled</p> <p>10 Filter negedge detect enabled</p> <p>11 Filter any edge detect enabled</p> |
| 4 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |

Table continues on the next page...

LLWU_FILT2 field descriptions (continued)

| Field | Description |
|----------------|--|
| 3–0 FILTSEL | <p>Filter Pin Select</p> <p>Selects 1 out of the 16 wakeup pins to be muxed into the filter.</p> <p>0000 Select LLWU_P0 for filter</p> <p>... ...</p> <p>1111 Select LLWU_P15 for filter</p> |

16.3.11 LLWU Reset Enable register (LLWU_RST)

LLWU_RST is a control register that is used to enable/disable the digital filter for the external pin detect and RESET pin.

NOTE

This register is reset on Chip Reset not VLLS and by reset types that trigger Chip Reset not VLLS. It is unaffected by reset types that do not trigger Chip Reset not VLLS. See the [Introduction](#) details for more information.

Address: 4007_C000h base + Ah offset = 4007_C00Ah

| | | | | | | | | |
|-------|---|---|---|---|---|---|--------|---------|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | | | LLRSTE | RSTFILT |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

LLWU_RST field descriptions

| Field | Description |
|-----------------|---|
| 7–2 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 1 LLRSTE | <p>Low-Leakage Mode RESET Enable</p> <p>This bit must be set to allow the device to be reset while in a low-leakage power mode. On devices where Reset is not a dedicated pin, the RESET pin must also be enabled in the explicit port mux control.</p> <p>0 RESET pin not enabled as a leakage mode exit source</p> <p>1 RESET pin enabled as a low leakage mode exit source</p> |
| 0 RSTFILT | <p>Digital Filter On RESET Pin</p> <p>Enables the digital filter for the RESET pin during LLS, VLLS3, VLLS2, or VLLS1 modes.</p> <p>0 Filter not enabled</p> <p>1 Filter enabled</p> |

16.4 Functional description

This low-leakage wakeup unit (LLWU) module allows internal peripherals and external input pins as a source of wakeup from low-leakage modes.

It is operational only in LLS and VLLSx modes.

The LLWU module contains pin enables for each external pin and internal module. For each external pin, the user can disable or select the edge type for the wakeup with the following options:

- Falling-edge
- Rising-edge
- Either-edge

When an external pin is enabled as a wakeup source, the pin must be configured as an input pin.

The LLWU implements optional 3-cycle glitch filters, based on the LPO clock. A detected external pin, either wakeup or $\overline{\text{RESET}}$, is required to remain asserted until the enabled glitch filter times out. Additional latency of up to 2 cycles is due to synchronization, which results in a total of up to 5 cycles of delay before the detect circuit alerts the system to the wakeup or reset event when the filter function is enabled. Two wakeup detect filters are available for selected external pins. A separate reset filter is on the $\overline{\text{RESET}}$ pin. Glitch filtering is not provided on the internal modules.

For internal module interrupts, the WUMEx bit enables the associated module interrupt as a wakeup source.

16.4.1 LLS mode

Wakeup events triggered from either an external pin input or an internal module interrupt, result in a CPU interrupt flow to begin user code execution.

An LLS reset event due to RESET pin assertion causes an exit via a system reset. State retention data is lost, and the I/O states return to their reset state. The RCM_SRS[WAKEUP] and RCM_SRS[PIN] bits are set and the system executes a reset flow before CPU operation begins with a reset vector fetch.

16.4.2 VLLS modes

For any wakeup from VLLS, recovery is always via a reset flow and RCM_SRS[WAKEUP] is set indicating the low-leakage mode was active. State retention data is lost and I/O will be restored after PMC_REGSC[ACKISO] has been written.

A VLLS exit event due to $\overline{\text{RESET}}$ pin assertion causes an exit via a system reset. State retention data is lost and the I/O states immediately return to their reset state. The RCM_SRS[WAKEUP] and RCM_SRS[PIN] bits are set and the system executes a reset flow before CPU operation begins with a reset vector fetch.

16.4.3 Initialization

For an enabled peripheral wakeup input, the peripheral flag must be cleared by software before entering LLS or VLLSx mode to avoid an immediate exit from the mode.

Flags associated with external input pins, filtered and unfiltered, must also be cleared by software prior to entry to LLS or VLLSx mode.

After enabling an external pin filter or changing the source pin, wait at least five LPO clock cycles before entering LLS or VLLSx mode to allow the filter to initialize.

NOTE

After recovering from a VLLS mode, user must restore chip configuration before clearing PMC_REGSC[ACKISO]. In particular, pin configuration for enabled LLWU wake-up pins must be restored to avoid any LLWU flag from being falsely set when PMC_REGSC[ACKISO] is cleared.

The signal selected as a wake-up source pin must be a digital pin, as selected in the pin mux control.



Chapter 17

Miscellaneous Control Module (MCM)

17.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The Miscellaneous Control Module (MCM) provides a myriad of miscellaneous control functions.

17.1.1 Features

The MCM includes the following features:

- Program-visible information on the platform configuration and revision

17.2 Memory map/register descriptions

The memory map and register descriptions below describe the registers using byte addresses.

MCM memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|---|-----------------|--------|-------------|----------------------------|
| E008_0008 | Crossbar Switch (AXBS) Slave Configuration (MCM_PLASC) | 16 | R | 000Fh | 17.2.1/308 |
| E008_000A | Crossbar Switch (AXBS) Master Configuration (MCM_PLAMC) | 16 | R | 0013h | 17.2.2/308 |
| E008_000C | Crossbar Switch (AXBS) Control Register (MCM_PLACR) | 32 | R/W | 0000_0000h | 17.2.3/309 |

17.2.1 Crossbar Switch (AXBS) Slave Configuration (MCM_PLASC)

PLASC is a 16-bit read-only register identifying the presence/absence of bus slave connections to the device's crossbar switch.

Address: E008_0000h base + 8h offset = E008_0008h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|-----|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | | | | | ASC | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |

MCM_PLASC field descriptions

| Field | Description |
|------------------|---|
| 15–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–0 ASC | Each bit in the ASC field indicates whether there is a corresponding connection to the crossbar switch's slave input port. 0 A bus slave connection to AXBS input port <i>n</i> is absent 1 A bus slave connection to AXBS input port <i>n</i> is present |

17.2.2 Crossbar Switch (AXBS) Master Configuration (MCM_PLAMC)

PLAMC is a 16-bit read-only register identifying the presence/absence of bus master connections to the device's crossbar switch.

Address: E008_0000h base + Ah offset = E008_000Ah

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|-----|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | | | | | AMC | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |

MCM_PLAMC field descriptions

| Field | Description |
|------------------|--|
| 15–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–0 AMC | Each bit in the AMC field indicates whether there is a corresponding connection to the AXBS master input port. |

Table continues on the next page...

MCM_PLAMC field descriptions (continued)

| Field | Description |
|-------|--|
| 0 | A bus master connection to AXBS input port <i>n</i> is absent |
| 1 | A bus master connection to AXBS input port <i>n</i> is present |

17.2.3 Crossbar Switch (AXBS) Control Register (MCM_PLACR)

The PLACR register selects the arbitration policy for the crossbar masters.

Address: E008_0000h base + Ch offset = E008_000Ch

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|-----|----------|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | ARB | Reserved | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

MCM_PLACR field descriptions

| Field | Description |
|-------------------|---|
| 31–10 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 9 ARB | Arbitration select 0 Fixed-priority arbitration for the crossbar masters 1 Round-robin arbitration for the crossbar masters |
| 8–0 Reserved | This field is reserved. |



Chapter 18

Crossbar Switch Lite (AXBS-Lite)

18.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The information found here provides information on the layout, configuration, and programming of the crossbar switch.

The crossbar switch connects bus masters and bus slaves using a crossbar switch structure. This structure allows up to four bus masters to access different bus slaves simultaneously, while providing arbitration among the bus masters when they access the same slave.

18.1.1 Features

The crossbar switch includes these features:

- Symmetric crossbar bus switch implementation
 - Allows concurrent accesses from different masters to different slaves
- 32-bit data bus
- Operation at a 1-to-1 clock frequency with the bus masters
- Programmable configuration for fixed-priority or round-robin slave port arbitration

18.2 Memory Map / Register Definition

This crossbar switch is designed for minimal gate count. It, therefore, has no memory-mapped configuration registers.

18.3 Functional Description

18.3.1 General operation

When a master accesses the crossbar switch, the access is immediately taken. If the targeted slave port of the access is available, then the access is immediately presented on the slave port. Single-clock or zero-wait-state accesses are possible through the crossbar. If the targeted slave port of the access is busy or parked on a different master port, the requesting master simply sees wait states inserted until the targeted slave port can service the master's request. The latency in servicing the request depends on each master's priority level and the responding slave's access time.

Because the crossbar switch appears to be just another slave to the master device, the master device has no knowledge of whether it actually owns the slave port it is targeting. While the master does not have control of the slave port it is targeting, it simply waits.

A master is given control of the targeted slave port only after a previous access to a different slave port completes, regardless of its priority on the newly targeted slave port. This prevents deadlock from occurring when:

- A higher priority master has:
 - An outstanding request to one slave port that has a long response time and
 - A pending access to a different slave port, and
- A lower priority master is also making a request to the same slave port as the pending access of the higher priority master.

After the master has control of the slave port it is targeting, the master remains in control of the slave port until it relinquishes the slave port by running an IDLE cycle or by targeting a different slave port for its next access.

The master can also lose control of the slave port if another higher-priority master makes a request to the slave port.

The crossbar terminates all master IDLE transfers, as opposed to allowing the termination to come from one of the slave buses. Additionally, when no master is requesting access to a slave port, the crossbar drives IDLE transfers onto the slave bus, even though a default master may be granted access to the slave port.

When a slave bus is being idled by the crossbar, it remains parked with the last master to use the slave port. This is done to save the initial clock of arbitration delay that otherwise would be seen if the master had to arbitrate to gain control of the slave port.

18.3.2 Arbitration

The crossbar switch supports two arbitration algorithms:

- Fixed priority
- Round-robin

The selection of the global slave port arbitration is controlled by `MCM_PLACR[ARB]`. For fixed priority, set `MCM_PLACR[ARB]` to 0. For round robin, set `MCM_PLACR[ARB]` to 1. This arbitration setting applies to all slave ports.

18.3.2.1 Fixed-priority operation

When operating in fixed-priority mode, each master is assigned a unique priority level with the highest numbered master having the highest priority (for example, in a system with 5 masters, master 1 has lower priority than master 3). If two masters request access to the same slave port, the master with the highest priority gains control over the slave port.

NOTE

In this arbitration mode, a higher-priority master can monopolize a slave port, preventing accesses from any lower-priority master to the port.

When a master makes a request to a slave port, the slave port checks whether the new requesting master's priority level is higher than that of the master that currently has control over the slave port, unless the slave port is in a parked state. The slave port performs an arbitration check at every clock edge to ensure that the proper master, if any, has control of the slave port.

The following table describes possible scenarios based on the requesting master port:

Table 18-1. How the Crossbar Switch grants control of a slave port to a master

| When | Then the Crossbar Switch grants control to the requesting master |
|--|---|
| Both of the following are true: <ul style="list-style-type: none"> The current master is not running a transfer. The new requesting master's priority level is higher than that of the current master. | At the next clock edge |
| Both of the following are true: <ul style="list-style-type: none"> The current master is running an undefined length burst transfer. The requesting master's priority level is higher than that of the current master. | At the next arbitration point for the undefined length burst transfer NOTE: Arbitration points for an undefined length burst are defined in the MGPCR for each master. |
| The requesting master's priority level is lower than the current master. | At the conclusion of one of the following cycles: <ul style="list-style-type: none"> An IDLE cycle A non-IDLE cycle to a location other than the current slave port |

18.3.2.2 Round-robin priority operation

When operating in round-robin mode, each master is assigned a relative priority based on the master port number. This relative priority is compared to the master port number (ID) of the last master to perform a transfer on the slave bus. The highest priority requesting master becomes owner of the slave bus at the next transfer boundary. Priority is based on how far ahead the ID of the requesting master is to the ID of the last master.

After granted access to a slave port, a master may perform as many transfers as desired to that port until another master makes a request to the same slave port. The next master in line is granted access to the slave port at the next transfer boundary, or possibly on the next clock cycle if the current master has no pending access request.

As an example of arbitration in round-robin mode, assume the crossbar is implemented with master ports 0, 1, 4, and 5. If the last master of the slave port was master 1, and master 0, 4, and 5 make simultaneous requests, they are serviced in the order: 4 then 5 then 0.

The round-robin arbitration mode generally provides a more fair allocation of the available slave-port bandwidth (compared to fixed priority) as the fixed master priority does not affect the master selection.

18.4 Initialization/application information

No initialization is required for the crossbar switch.

See the AXBS section of the configuration chapter for the reset state of the arbitration scheme.



Chapter 19

Peripheral Bridge (AIPS-Lite)

19.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The peripheral bridge converts the crossbar switch interface to an interface that can access most of the slave peripherals on this chip.

The peripheral bridge occupies 64 MB of the address space, which is divided into peripheral slots of 4 KB. (It might be possible that all the peripheral slots are not used. See the memory map chapter for details on slot assignments.) The bridge includes separate clock enable inputs for each of the slots to accommodate slower peripherals.

19.1.1 Features

Key features of the peripheral bridge are:

- Supports peripheral slots with 8-, 16-, and 32-bit datapath width

19.1.2 General operation

The slave devices connected to the peripheral bridge are modules which contain a programming model of control and status registers. The system masters read and write these registers through the peripheral bridge. The peripheral bridge performs a bus protocol conversion of the master transactions and generates the following as inputs to the peripherals:

- Module enables
- Module addresses

- Transfer attributes
- Byte enables
- Write data

The peripheral bridge selects and captures read data from the peripheral interface and returns it to the crossbar switch.

The register maps of the peripherals are located on 4-KB boundaries. Each peripheral is allocated one or more 4-KB block(s) of the memory map.

The AIPS-Lite module uses the data width of accessed peripheral to perform proper data byte lane routing; no bus decomposition (bus sizing) is performed.

19.2 Functional description

The peripheral bridge functions as a bus protocol translator between the crossbar switch and the slave peripheral bus.

The peripheral bridge manages all transactions destined for the attached slave devices and generates select signals for modules on the peripheral bus by decoding accesses within the attached address space.

19.2.1 Access support

Aligned and misaligned 32-bit, 16-bit, and byte accesses are supported for 32-bit peripherals. Misaligned accesses are supported to allow memory to be placed on the slave peripheral bus. Peripheral registers must not be misaligned, although no explicit checking is performed by the peripheral bridge. All accesses are performed with a single transfer.

All accesses to the peripheral slots must be sized less than or equal to the designated peripheral slot size. If an access is attempted that is larger than the targeted port, an error response is generated.

Chapter 20

Direct Memory Access Multiplexer (DMAMUX)

20.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

20.1.1 Overview

The Direct Memory Access Multiplexer (DMAMUX) routes DMA sources, called slots, to any of the 16 DMA channels. This process is illustrated in the following figure.

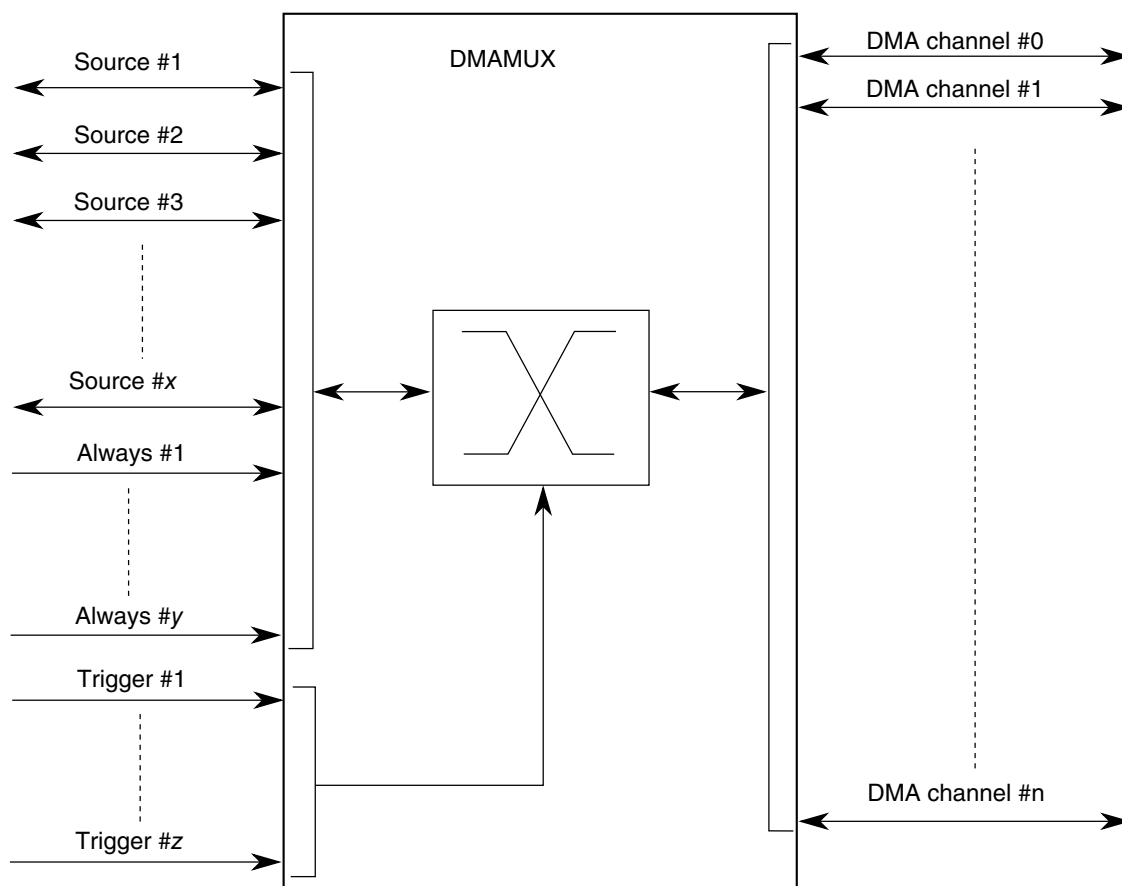


Figure 20-1. DMAMUX block diagram

20.1.2 Features

The DMAMUX module provides these features:

- Up to 52 peripheral slots and up to 10 always-on slots can be routed to 16 channels.
- 16 independently selectable DMA channel routers.
 - The first four channels additionally provide a trigger functionality.
- Each channel router can be assigned to one of the possible peripheral DMA slots or to one of the always-on slots.

20.1.3 Modes of operation

The following operating modes are available:

- Disabled mode

In this mode, the DMA channel is disabled. Because disabling and enabling of DMA channels is done primarily via the DMA configuration registers, this mode is used mainly as the reset state for a DMA channel in the DMA channel MUX. It may also be used to temporarily suspend a DMA channel while reconfiguration of the system takes place, for example, changing the period of a DMA trigger.

- Normal mode

In this mode, a DMA source is routed directly to the specified DMA channel. The operation of the DMAMUX in this mode is completely transparent to the system.

- Periodic Trigger mode

In this mode, a DMA source may only request a DMA transfer, such as when a transmit buffer becomes empty or a receive buffer becomes full, periodically. Configuration of the period is done in the registers of the periodic interrupt timer (PIT). This mode is available only for channels 0–3.

20.2 External signal description

The DMAMUX has no external pins.

20.3 Memory map/register definition

This section provides a detailed description of all memory-mapped registers in the DMAMUX.

DMAMUX memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|----------------------------|
| 4002_1000 | Channel Configuration register (DMAMUX_CHCFG0) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_1001 | Channel Configuration register (DMAMUX_CHCFG1) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_1002 | Channel Configuration register (DMAMUX_CHCFG2) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_1003 | Channel Configuration register (DMAMUX_CHCFG3) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_1004 | Channel Configuration register (DMAMUX_CHCFG4) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_1005 | Channel Configuration register (DMAMUX_CHCFG5) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_1006 | Channel Configuration register (DMAMUX_CHCFG6) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_1007 | Channel Configuration register (DMAMUX_CHCFG7) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_1008 | Channel Configuration register (DMAMUX_CHCFG8) | 8 | R/W | 00h | 20.3.1/322 |

Table continues on the next page...

DMAMUX memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|----------------------------|
| 4002_1009 | Channel Configuration register (DMAMUX_CHCFG9) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_100A | Channel Configuration register (DMAMUX_CHCFG10) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_100B | Channel Configuration register (DMAMUX_CHCFG11) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_100C | Channel Configuration register (DMAMUX_CHCFG12) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_100D | Channel Configuration register (DMAMUX_CHCFG13) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_100E | Channel Configuration register (DMAMUX_CHCFG14) | 8 | R/W | 00h | 20.3.1/322 |
| 4002_100F | Channel Configuration register (DMAMUX_CHCFG15) | 8 | R/W | 00h | 20.3.1/322 |

20.3.1 Channel Configuration register (DMAMUX_CHCFGn)

Each of the DMA channels can be independently enabled/disabled and associated with one of the DMA slots (peripheral slots or always-on slots) in the system.

NOTE

Setting multiple CHCFG registers with the same source value will result in unpredictable behavior. This is true, even if a channel is disabled (ENBL==0).

Before changing the trigger or source settings, a DMA channel must be disabled via CHCFGn[ENBL].

Address: 4002_1000h base + 0h offset + (1d × i), where i=0d to 15d

| | | | | | | | | |
|-------|------|------|--------|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | ENBL | TRIG | SOURCE | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMAMUX_CHCFGn field descriptions

| Field | Description |
|-----------|--|
| 7 ENBL | <p>DMA Channel Enable</p> <p>Enables the DMA channel.</p> <p>0 DMA channel is disabled. This mode is primarily used during configuration of the DMAMux. The DMA has separate channel enables/disables, which should be used to disable or reconfigure a DMA channel.</p> <p>1 DMA channel is enabled</p> |
| 6 TRIG | <p>DMA Channel Trigger Enable</p> <p>Enables the periodic trigger capability for the triggered DMA channel.</p> |

Table continues on the next page...

DMAMUX_CHCFGn field descriptions (continued)

| Field | Description |
|---------------|--|
| | <p>0 Triggering is disabled. If triggering is disabled and ENBL is set, the DMA Channel will simply route the specified source to the DMA channel. (Normal mode)</p> <p>1 Triggering is enabled. If triggering is enabled and ENBL is set, the DMAMUX is in Periodic Trigger mode.</p> |
| 5–0 SOURCE | <p>DMA Channel Source (Slot)</p> <p>Specifies which DMA source, if any, is routed to a particular DMA channel. See the chip-specific DMAMUX information for details about the peripherals and their slot numbers.</p> |

20.4 Functional description

The primary purpose of the DMAMUX is to provide flexibility in the system's use of the available DMA channels.

As such, configuration of the DMAMUX is intended to be a static procedure done during execution of the system boot code. However, if the procedure outlined in [Enabling and configuring sources](#) is followed, the configuration of the DMAMUX may be changed during the normal operation of the system.

Functionally, the DMAMUX channels may be divided into two classes:

- Channels that implement the normal routing functionality plus periodic triggering capability
- Channels that implement only the normal routing functionality

20.4.1 DMA channels with periodic triggering capability

Besides the normal routing functionality, the first 4 channels of the DMAMUX provide a special periodic triggering capability that can be used to provide an automatic mechanism to transmit bytes, frames, or packets at fixed intervals without the need for processor intervention. The trigger is generated by the periodic interrupt timer (PIT); as such, the configuration of the periodic triggering interval is done via configuration registers in the PIT. See the section on periodic interrupt timer for more information on this topic.

Note

Because of the dynamic nature of the system (due to DMA channel priorities, bus arbitration, interrupt service routine lengths, etc.), the number of clock cycles between a trigger and the actual DMA transfer cannot be guaranteed.

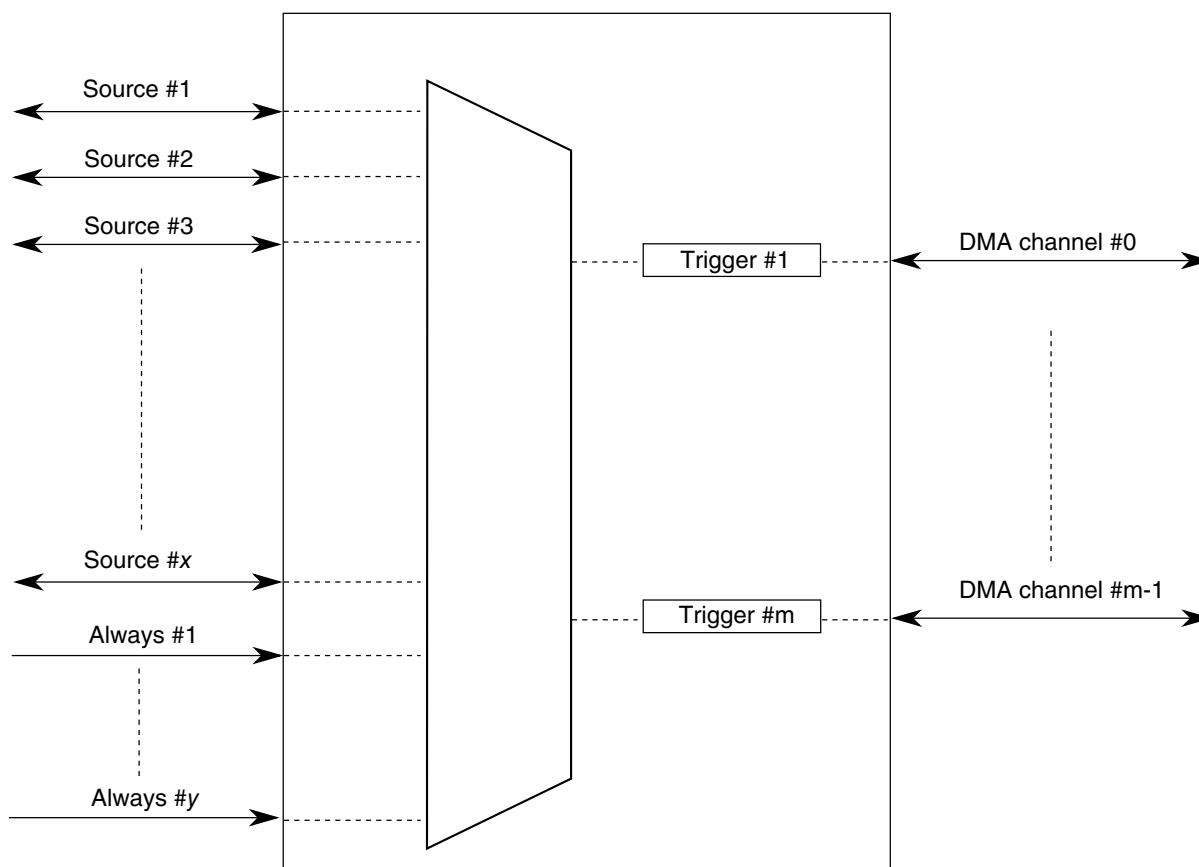


Figure 20-19. DMAMUX triggered channels

The DMA channel triggering capability allows the system to schedule regular DMA transfers, usually on the transmit side of certain peripherals, without the intervention of the processor. This trigger works by gating the request from the peripheral to the DMA until a trigger event has been seen. This is illustrated in the following figure.

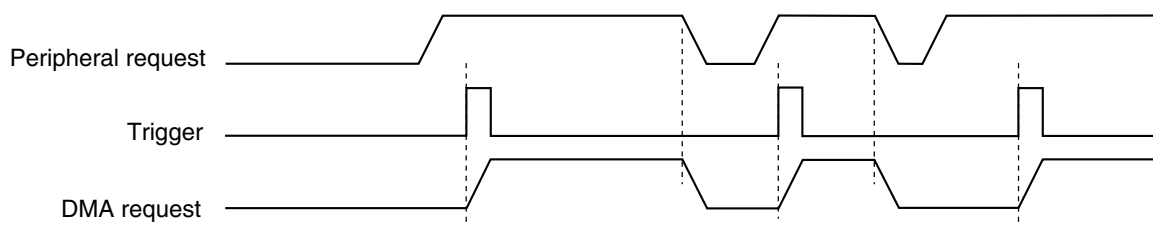


Figure 20-20. DMAMUX channel triggering: normal operation

After the DMA request has been serviced, the peripheral will negate its request, effectively resetting the gating mechanism until the peripheral reasserts its request and the next trigger event is seen. This means that if a trigger is seen, but the peripheral is not requesting a transfer, then that trigger will be ignored. This situation is illustrated in the following figure.

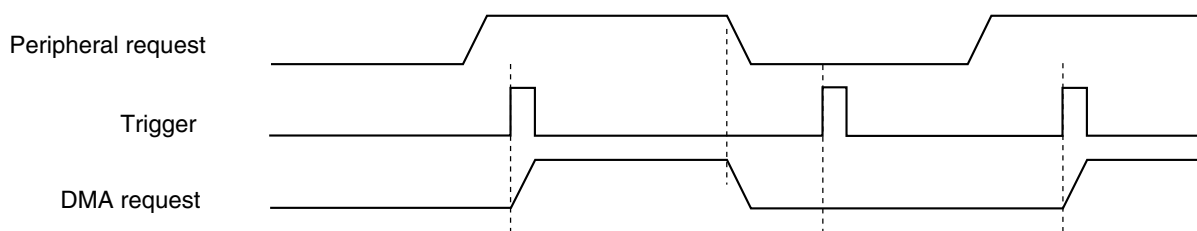


Figure 20-21. DMAMUX channel triggering: ignored trigger

This triggering capability may be used with any peripheral that supports DMA transfers, and is most useful for two types of situations:

- Periodically polling external devices on a particular bus

As an example, the transmit side of an SPI is assigned to a DMA channel with a trigger, as described above. After it has been set up, the SPI will request DMA transfers, presumably from memory, as long as its transmit buffer is empty. By using a trigger on this channel, the SPI transfers can be automatically performed every 5 μ s (as an example). On the receive side of the SPI, the SPI and DMA can be configured to transfer receive data into memory, effectively implementing a method to periodically read data from external devices and transfer the results into memory without processor intervention.

- Using the GPIO ports to drive or sample waveforms

By configuring the DMA to transfer data to one or more GPIO ports, it is possible to create complex waveforms using tabular data stored in on-chip memory. Conversely, using the DMA to periodically transfer data from one or more GPIO ports, it is possible to sample complex waveforms and store the results in tabular form in on-chip memory.

A more detailed description of the capability of each trigger, including resolution, range of values, and so on, may be found in the periodic interrupt timer section.

20.4.2 DMA channels with no triggering capability

The other channels of the DMAMUX provide the normal routing functionality as described in [Modes of operation](#).

20.4.3 Always-enabled DMA sources

In addition to the peripherals that can be used as DMA sources, there are 10 additional DMA sources that are always enabled. Unlike the peripheral DMA sources, where the peripheral controls the flow of data during DMA transfers, the sources that are always enabled provide no such "throttling" of the data transfers. These sources are most useful in the following cases:

- Performing DMA transfers to/from GPIO—Moving data from/to one or more GPIO pins, either unthrottled (that is, as fast as possible), or periodically (using the DMA triggering capability).
- Performing DMA transfers from memory to memory—Moving data from memory to memory, typically as fast as possible, sometimes with software activation.
- Performing DMA transfers from memory to the external bus, or vice-versa—Similar to memory to memory transfers, this is typically done as quickly as possible.
- Any DMA transfer that requires software activation—Any DMA transfer that should be explicitly started by software.

In cases where software should initiate the start of a DMA transfer, an always-enabled DMA source can be used to provide maximum flexibility. When activating a DMA channel via software, subsequent executions of the minor loop require that a new start event be sent. This can either be a new software activation, or a transfer request from the DMA channel MUX. The options for doing this are:

- Transfer all data in a single minor loop.

By configuring the DMA to transfer all of the data in a single minor loop (that is, major loop counter = 1), no reactivation of the channel is necessary. The disadvantage to this option is the reduced granularity in determining the load that the DMA transfer will impose on the system. For this option, the DMA channel must be disabled in the DMA channel MUX.

- Use explicit software reactivation.

In this option, the DMA is configured to transfer the data using both minor and major loops, but the processor is required to reactivate the channel by writing to the DMA registers *after every minor loop*. For this option, the DMA channel must be disabled in the DMA channel MUX.

- Use an always-enabled DMA source.

In this option, the DMA is configured to transfer the data using both minor and major loops, and the DMA channel MUX does the channel reactivation. For this option, the DMA channel should be enabled and pointing to an "always enabled" source. Note that the reactivation of the channel can be continuous (DMA triggering is disabled) or can use the DMA triggering capability. In this manner, it is possible to execute periodic transfers of packets of data from one source to another, without processor intervention.

20.5 Initialization/application information

This section provides instructions for initializing the DMA channel MUX.

20.5.1 Reset

The reset state of each individual bit is shown in [Memory map/register definition](#). In summary, after reset, all channels are disabled and must be explicitly enabled before use.

20.5.2 Enabling and configuring sources

To enable a source with periodic triggering:

1. Determine with which DMA channel the source will be associated. Note that only the first 4 DMA channels have periodic triggering capability.
2. Clear the CHCFG[ENBL] and CHCFG[TRIG] fields of the DMA channel.
3. Ensure that the DMA channel is properly configured in the DMA. The DMA channel may be enabled at this point.
4. Configure the corresponding timer.
5. Select the source to be routed to the DMA channel. Write to the corresponding CHCFG register, ensuring that the CHCFG[ENBL] and CHCFG[TRIG] fields are set.

NOTE

The following is an example. See the chip configuration details for the number of this device's DMA channels that have triggering capability.

To configure source #5 transmit for use with DMA channel 1, with periodic triggering capability:

1. Write 0x00 to CHCFG1 (base address + 0x01).

2. Configure channel 1 in the DMA, including enabling the channel.
3. Configure a timer for the desired trigger interval.
4. Write 0xC5 to CHCFG1 (base address + 0x01).

The following code example illustrates steps 1 and 4 above:

```
void DMAMUX_Init(uint8_t DMA_CH, uint8_t DMAMUX_SOURCE)
{
    DMAMUX_0.CHCFG[DMA_CH].B.SOURCE = DMAMUX_SOURCE;
    DMAMUX_0.CHCFG[DMA_CH].B.ENBL   = 1;
    DMAMUX_0.CHCFG[DMA_CH].B.TRIG   = 1;
}
```

To enable a source, without periodic triggering:

1. Determine with which DMA channel the source will be associated. Note that only the first 4 DMA channels have periodic triggering capability.
2. Clear the CHCFG[ENBL] and CHCFG[TRIG] fields of the DMA channel.
3. Ensure that the DMA channel is properly configured in the DMA. The DMA channel may be enabled at this point.
4. Select the source to be routed to the DMA channel. Write to the corresponding CHCFG register, ensuring that CHCFG[ENBL] is set while CHCFG[TRIG] is cleared.

NOTE

The following is an example. See the chip configuration details for the number of this device's DMA channels that have triggering capability.

To configure source #5 transmit for use with DMA channel 1, with no periodic triggering capability:

1. Write 0x00 to CHCFG1 (base address + 0x01).
2. Configure channel 1 in the DMA, including enabling the channel.
3. Write 0x85 to CHCFG1 (base address + 0x01).

The following code example illustrates steps 1 and 3 above:

```
In File registers.h:
#define DMAMUX_BASE_ADDR    0x40021000/* Example only ! */
/* Following example assumes char is 8-bits */
volatile unsigned char *CHCFG0 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0000);
volatile unsigned char *CHCFG1 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0001);
volatile unsigned char *CHCFG2 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0002);
volatile unsigned char *CHCFG3 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0003);
volatile unsigned char *CHCFG4 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0004);
volatile unsigned char *CHCFG5 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0005);
volatile unsigned char *CHCFG6 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0006);
volatile unsigned char *CHCFG7 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0007);
volatile unsigned char *CHCFG8 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0008);
volatile unsigned char *CHCFG9 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0009);
volatile unsigned char *CHCFG10= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000A);
volatile unsigned char *CHCFG11= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000B);
volatile unsigned char *CHCFG12= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000C);
volatile unsigned char *CHCFG13= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000D);
```

```
volatile unsigned char *CHCFG14= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000E);
volatile unsigned char *CHCFG15= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000F);
```

```
In File main.c:
#include "registers.h"
:
:
*CHCFG1 = 0x00;
*CHCFG1 = 0x85;
```

To disable a source:

A particular DMA source may be disabled by not writing the corresponding source value into any of the CHCFG registers. Additionally, some module-specific configuration may be necessary. See the appropriate section for more details.

To switch the source of a DMA channel:

1. Disable the DMA channel in the DMA and reconfigure the channel for the new source.
2. Clear the CHCFG[ENBL] and CHCFG[TRIG] bits of the DMA channel.
3. Select the source to be routed to the DMA channel. Write to the corresponding CHCFG register, ensuring that the CHCFG[ENBL] and CHCFG[TRIG] fields are set.

To switch DMA channel 8 from source #5 transmit to source #7 transmit:

1. In the DMA configuration registers, disable DMA channel 8 and reconfigure it to handle the transfers to peripheral slot 7. This example assumes channel 8 doesn't have triggering capability.
2. Write 0x00 to CHCFG8 (base address + 0x08).
3. Write 0x87 to CHCFG8 (base address + 0x08). (In this example, setting CHCFG[TRIG] would have no effect due to the assumption that channel 8 does not support the periodic triggering functionality.)

The following code example illustrates steps 2 and 3 above:

```
In File registers.h:
#define DMAMUX_BASE_ADDR      0x40021000/* Example only ! */
/* Following example assumes char is 8-bits */
volatile unsigned char *CHCFG0 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0000);
volatile unsigned char *CHCFG1 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0001);
volatile unsigned char *CHCFG2 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0002);
volatile unsigned char *CHCFG3 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0003);
volatile unsigned char *CHCFG4 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0004);
volatile unsigned char *CHCFG5 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0005);
volatile unsigned char *CHCFG6 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0006);
volatile unsigned char *CHCFG7 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0007);
volatile unsigned char *CHCFG8 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0008);
volatile unsigned char *CHCFG9 = (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x0009);
volatile unsigned char *CHCFG10= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000A);
volatile unsigned char *CHCFG11= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000B);
volatile unsigned char *CHCFG12= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000C);
volatile unsigned char *CHCFG13= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000D);
volatile unsigned char *CHCFG14= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000E);
volatile unsigned char *CHCFG15= (volatile unsigned char *) (DMAMUX_BASE_ADDR+0x000F);
```

Initialization/application information

```
In File main.c:
#include "registers.h"
:
:
*CHCFG8 = 0x00;
*CHCFG8 = 0x87;
```

Chapter 21

Enhanced Direct Memory Access (eDMA)

21.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The enhanced direct memory access (eDMA) controller is a second-generation module capable of performing complex data transfers with minimal intervention from a host processor. The hardware microarchitecture includes:

- A DMA engine that performs:
 - Source- and destination-address calculations
 - Data-movement operations
- Local memory containing transfer control descriptors for each of the 16 channels

21.1.1 eDMA system block diagram

[Figure 21-1](#) illustrates the components of the eDMA system, including the eDMA module ("engine").

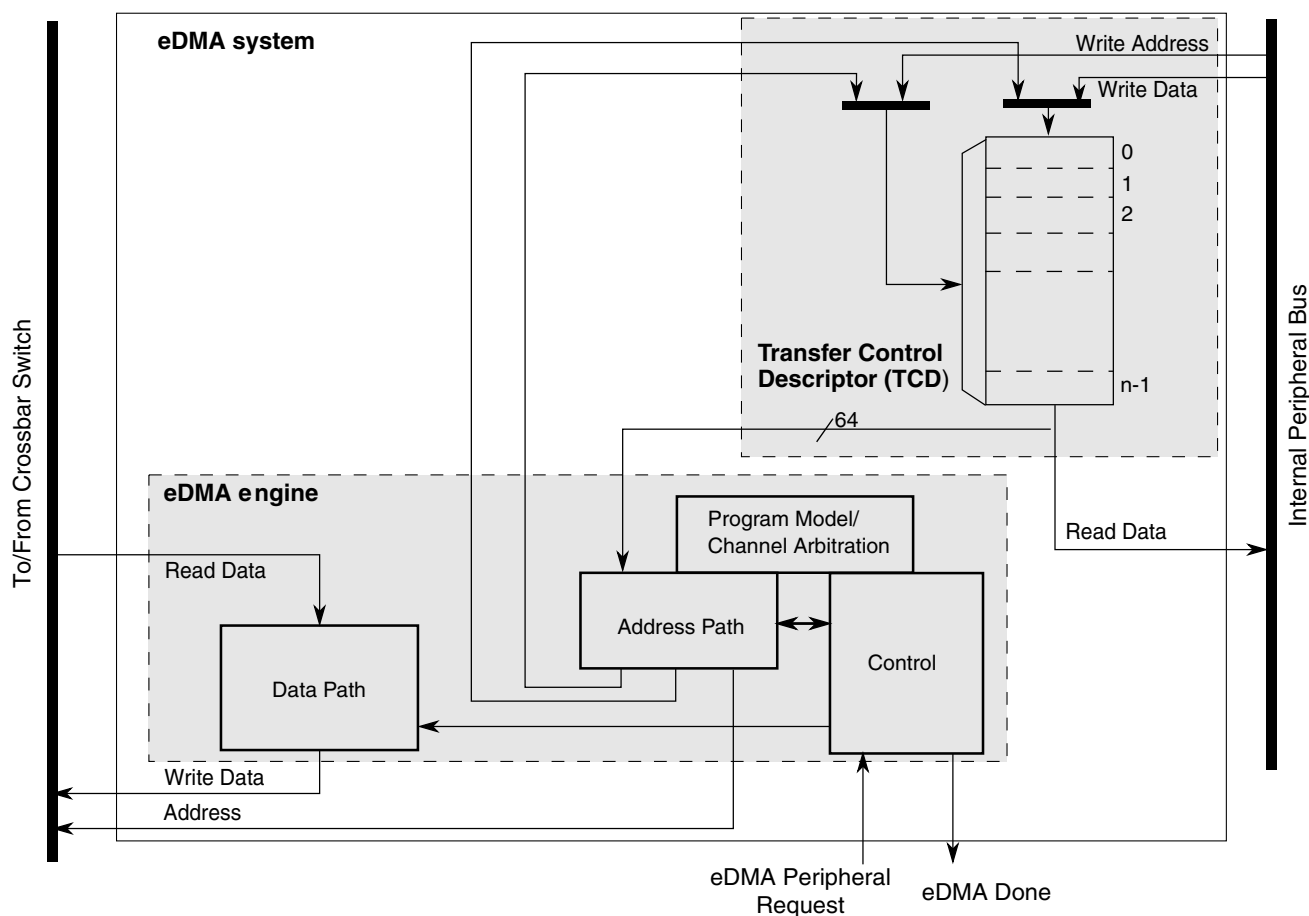


Figure 21-1. eDMA system block diagram

21.1.2 Block parts

The eDMA module is partitioned into two major modules: the eDMA engine and the transfer-control descriptor local memory.

The eDMA engine is further partitioned into four submodules:

Table 21-1. eDMA engine submodules

| Submodule | Function |
|-----------------------------------|--|
| Address path | <p>This block implements registered versions of two channel transfer control descriptors, channel x and channel y, and manages all master bus-address calculations. All the channels provide the same functionality. This structure allows data transfers associated with one channel to be preempted after the completion of a read/write sequence if a higher priority channel activation is asserted while the first channel is active. After a channel is activated, it runs until the minor loop is completed, unless preempted by a higher priority channel. This provides a mechanism (enabled by DCHPRI_n[ECP]) where a large data move operation can be preempted to minimize the time another channel is blocked from execution.</p> <p>When any channel is selected to execute, the contents of its TCD are read from local memory and loaded into the address path channel x registers for a normal start and into channel y registers for a preemption start. After the minor loop completes execution, the address path hardware writes the new values for the TCD_n{SADDR, DADDR, CITER} back to local memory. If the major iteration count is exhausted, additional processing is performed, including the final address pointer updates, reloading the TCD_n_CITER field, and a possible fetch of the next TCD_n from memory as part of a scatter/gather operation.</p> |
| Data path | <p>This block implements the bus master read/write datapath. It includes 16 bytes of register storage and the necessary multiplex logic to support any required data alignment. The internal read data bus is the primary input, and the internal write data bus is the primary output.</p> <p>The address and data path modules directly support the 2-stage pipelined internal bus. The address path module represents the 1st stage of the bus pipeline (address phase), while the data path module implements the 2nd stage of the pipeline (data phase).</p> |
| Program model/channel arbitration | <p>This block implements the first section of the eDMA programming model as well as the channel arbitration logic. The programming model registers are connected to the internal peripheral bus. The eDMA peripheral request inputs and interrupt request outputs are also connected to this block (via control logic).</p> |
| Control | <p>This block provides all the control functions for the eDMA engine. For data transfers where the source and destination sizes are equal, the eDMA engine performs a series of source read/destination write operations until the number of bytes specified in the minor loop byte count has moved. For descriptors where the sizes are not equal, multiple accesses of the smaller size data are required for each reference of the larger size. As an example, if the source size references 16-bit data and the destination is 32-bit data, two reads are performed, then one 32-bit write.</p> |

The transfer-control descriptor local memory is further partitioned into:

Table 21-2. Transfer control descriptor memory

| Submodule | Description |
|-------------------|--|
| Memory controller | <p>This logic implements the required dual-ported controller, managing accesses from the eDMA engine as well as references from the internal peripheral bus. As noted earlier, in the event of simultaneous accesses, the eDMA engine is given priority and the peripheral transaction is stalled.</p> |
| Memory array | <p>TCD storage for each channel's transfer profile.</p> |

21.1.3 Features

The eDMA is a highly programmable data-transfer engine optimized to minimize the required intervention from the host processor. It is intended for use in applications where the data size to be transferred is statically known and not defined within the data packet itself. The eDMA module features:

- All data movement via dual-address transfers: read from source, write to destination
 - Programmable source and destination addresses and transfer size
 - Support for enhanced addressing modes
- 16 -channel implementation that performs complex data transfers with minimal intervention from a host processor
 - Internal data buffer, used as temporary storage to support 16- and 32-byte transfers
 - Connections to the crossbar switch for bus mastering the data movement
- Transfer control descriptor (TCD) organized to support two-deep, nested transfer operations
 - 32-byte TCD stored in local memory for each channel
 - An inner data transfer loop defined by a minor byte transfer count
 - An outer data transfer loop defined by a major iteration count
- Channel activation via one of three methods:
 - Explicit software initiation
 - Initiation via a channel-to-channel linking mechanism for continuous transfers
 - Peripheral-paced hardware requests, one per channel
- Fixed-priority and round-robin channel arbitration
- Channel completion reported via optional interrupt requests
 - One interrupt per channel, optionally asserted at completion of major iteration count
 - Optional error terminations per channel and logically summed together to form one error interrupt to the interrupt controller
- Optional support for scatter/gather DMA processing
- Support for complex data structures

- Support to cancel transfers via software error detection and error correction
- Error detection and error correction

In the discussion of this module, n is used to reference the channel number.

21.2 Modes of operation

The eDMA operates in the following modes:

Table 21-3. Modes of operation

| Mode | Description |
|--------|---|
| Normal | <p>In Normal mode, the eDMA transfers data between a source and a destination. The source and destination can be a memory block or an I/O block capable of operation with the eDMA.</p> <p>A service request initiates a transfer of a specific number of bytes (NBYTES) as specified in the transfer control descriptor (TCD). The minor loop is the sequence of read-write operations that transfers these NBYTES per service request. Each service request executes one iteration of the major loop, which transfers NBYTES of data.</p> |
| Debug | <p>DMA operation is configurable in Debug mode via the control register:</p> <ul style="list-style-type: none"> • If CR[EDBG] is cleared, the DMA continues to operate. • If CR[EDBG] is set, the eDMA stops transferring data. If Debug mode is entered while a channel is active, the eDMA continues operation until the channel retires. |
| Wait | <p>Before entering Wait mode, the DMA attempts to complete its current transfer. After the transfer completes, the device enters Wait mode.</p> |

21.3 Memory map/register definition

The eDMA's programming model is partitioned into two regions:

- The first region defines a number of registers providing control functions
- The second region corresponds to the local transfer control descriptor (TCD) memory

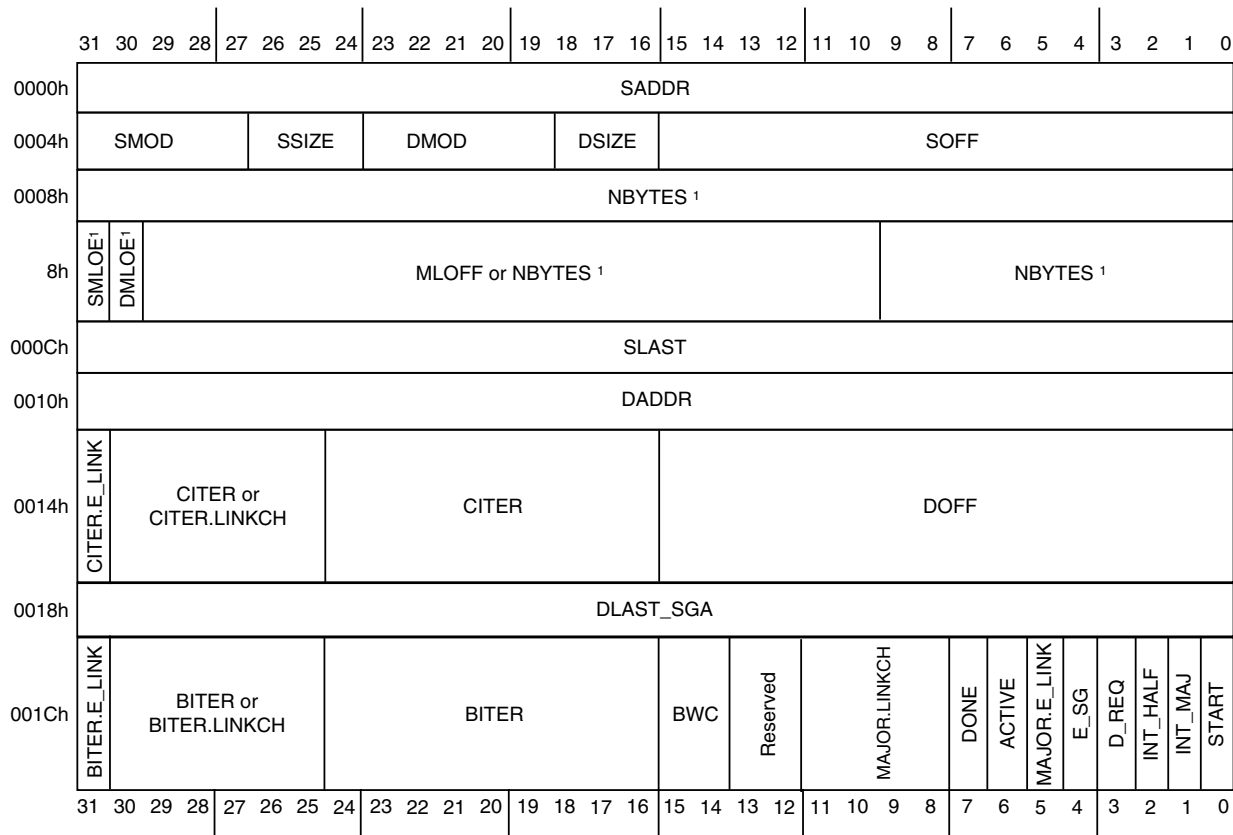
21.3.1 TCD memory

Each channel requires a 32-byte transfer control descriptor for defining the desired data movement operation. The channel descriptors are stored in the local memory in sequential order: channel 0, channel 1,... channel 15 . Each TCD_n definition is presented as 11 registers of 16 or 32 bits.

21.3.2 TCD initialization

Prior to activating a channel, you must initialize its TCD with the appropriate transfer profile.

21.3.3 TCD structure



¹ The fields implemented in Word 2 depend on whether DMA_CR[EMLM] is 0 or 1.

21.3.4 Reserved memory and bit fields

- Reading reserved bits in a register returns the value of zero.
- Writes to reserved bits in a register are ignored.
- Reading or writing a reserved memory location generates a bus error.

DMA memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|-----------------------|-----------------------------|-----------------------------|
| 4000_8000 | Control Register (DMA_CR) | 32 | R/W | 0000_0000h | 21.3.1/348 |
| 4000_8004 | Error Status Register (DMA_ES) | 32 | R | 0000_0000h | 21.3.2/351 |
| 4000_800C | Enable Request Register (DMA_ERQ) | 32 | R/W | 0000_0000h | 21.3.3/353 |
| 4000_8014 | Enable Error Interrupt Register (DMA_EEI) | 32 | R/W | 0000_0000h | 21.3.4/355 |
| 4000_8018 | Clear Enable Error Interrupt Register (DMA_CEEI) | 8 | W (always reads 0) | 00h | 21.3.5/357 |
| 4000_8019 | Set Enable Error Interrupt Register (DMA_SEEI) | 8 | W (always reads 0) | 00h | 21.3.6/358 |
| 4000_801A | Clear Enable Request Register (DMA_CERQ) | 8 | W (always reads 0) | 00h | 21.3.7/359 |
| 4000_801B | Set Enable Request Register (DMA_SERQ) | 8 | W (always reads 0) | 00h | 21.3.8/360 |
| 4000_801C | Clear DONE Status Bit Register (DMA_CDNE) | 8 | W (always reads 0) | 00h | 21.3.9/361 |
| 4000_801D | Set START Bit Register (DMA_SSRT) | 8 | W (always reads 0) | 00h | 21.3.10/362 |
| 4000_801E | Clear Error Register (DMA_CERR) | 8 | W (always reads 0) | 00h | 21.3.11/363 |
| 4000_801F | Clear Interrupt Request Register (DMA_CINT) | 8 | W (always reads 0) | 00h | 21.3.12/364 |
| 4000_8024 | Interrupt Request Register (DMA_INT) | 32 | R/W | 0000_0000h | 21.3.13/365 |
| 4000_802C | Error Register (DMA_ERR) | 32 | R/W | 0000_0000h | 21.3.14/367 |
| 4000_8034 | Hardware Request Status Register (DMA_HRS) | 32 | R | 0000_0000h | 21.3.15/370 |
| 4000_8100 | Channel n Priority Register (DMA_DCHPRI3) | 8 | R/W | See section | 21.3.16/373 |
| 4000_8101 | Channel n Priority Register (DMA_DCHPRI2) | 8 | R/W | See section | 21.3.16/373 |
| 4000_8102 | Channel n Priority Register (DMA_DCHPRI1) | 8 | R/W | See section | 21.3.16/373 |
| 4000_8103 | Channel n Priority Register (DMA_DCHPRI0) | 8 | R/W | See section | 21.3.16/373 |
| 4000_8104 | Channel n Priority Register (DMA_DCHPRI7) | 8 | R/W | See section | 21.3.16/373 |

Table continues on the next page...

DMA memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-----------------------------|-----------------------------|
| 4000_8105 | Channel n Priority Register (DMA_DCHPRI6) | 8 | R/W | See section | 21.3.16/373 |
| 4000_8106 | Channel n Priority Register (DMA_DCHPRI5) | 8 | R/W | See section | 21.3.16/373 |
| 4000_8107 | Channel n Priority Register (DMA_DCHPRI4) | 8 | R/W | See section | 21.3.16/373 |
| 4000_8108 | Channel n Priority Register (DMA_DCHPRI11) | 8 | R/W | See section | 21.3.16/373 |
| 4000_8109 | Channel n Priority Register (DMA_DCHPRI10) | 8 | R/W | See section | 21.3.16/373 |
| 4000_810A | Channel n Priority Register (DMA_DCHPRI9) | 8 | R/W | See section | 21.3.16/373 |
| 4000_810B | Channel n Priority Register (DMA_DCHPRI8) | 8 | R/W | See section | 21.3.16/373 |
| 4000_810C | Channel n Priority Register (DMA_DCHPRI15) | 8 | R/W | See section | 21.3.16/373 |
| 4000_810D | Channel n Priority Register (DMA_DCHPRI14) | 8 | R/W | See section | 21.3.16/373 |
| 4000_810E | Channel n Priority Register (DMA_DCHPRI13) | 8 | R/W | See section | 21.3.16/373 |
| 4000_810F | Channel n Priority Register (DMA_DCHPRI12) | 8 | R/W | See section | 21.3.16/373 |
| 4000_9000 | TCD Source Address (DMA_TCD0_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_9004 | TCD Signed Source Address Offset (DMA_TCD0_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_9006 | TCD Transfer Attributes (DMA_TCD0_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_9008 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD0_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_9008 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD0_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_9008 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD0_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_900C | TCD Last Source Address Adjustment (DMA_TCD0_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_9010 | TCD Destination Address (DMA_TCD0_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_9014 | TCD Signed Destination Address Offset (DMA_TCD0_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_9016 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD0_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_9016 | DMA_TCD0_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_9018 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD0_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_901C | TCD Control and Status (DMA_TCD0_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_901E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD0_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_901E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD0_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_9020 | TCD Source Address (DMA_TCD1_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_9024 | TCD Signed Source Address Offset (DMA_TCD1_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_9026 | TCD Transfer Attributes (DMA_TCD1_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_9028 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD1_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |

Table continues on the next page...

DMA memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4000_9028 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD1_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_9028 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD1_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_902C | TCD Last Source Address Adjustment (DMA_TCD1_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_9030 | TCD Destination Address (DMA_TCD1_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_9034 | TCD Signed Destination Address Offset (DMA_TCD1_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_9036 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD1_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_9036 | DMA_TCD1_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_9038 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD1_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_903C | TCD Control and Status (DMA_TCD1_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_903E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD1_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_903E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD1_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_9040 | TCD Source Address (DMA_TCD2_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_9044 | TCD Signed Source Address Offset (DMA_TCD2_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_9046 | TCD Transfer Attributes (DMA_TCD2_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_9048 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD2_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_9048 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD2_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_9048 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD2_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_904C | TCD Last Source Address Adjustment (DMA_TCD2_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_9050 | TCD Destination Address (DMA_TCD2_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_9054 | TCD Signed Destination Address Offset (DMA_TCD2_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_9056 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD2_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_9056 | DMA_TCD2_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_9058 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD2_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_905C | TCD Control and Status (DMA_TCD2_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_905E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD2_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |

Table continues on the next page...

DMA memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4000_905E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD2_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_9060 | TCD Source Address (DMA_TCD3_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_9064 | TCD Signed Source Address Offset (DMA_TCD3_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_9066 | TCD Transfer Attributes (DMA_TCD3_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_9068 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD3_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_9068 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD3_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_9068 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD3_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_906C | TCD Last Source Address Adjustment (DMA_TCD3_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_9070 | TCD Destination Address (DMA_TCD3_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_9074 | TCD Signed Destination Address Offset (DMA_TCD3_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_9076 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD3_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_9076 | DMA_TCD3_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_9078 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD3_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_907C | TCD Control and Status (DMA_TCD3_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_907E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD3_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_907E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD3_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_9080 | TCD Source Address (DMA_TCD4_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_9084 | TCD Signed Source Address Offset (DMA_TCD4_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_9086 | TCD Transfer Attributes (DMA_TCD4_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_9088 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD4_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_9088 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD4_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_9088 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD4_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_908C | TCD Last Source Address Adjustment (DMA_TCD4_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_9090 | TCD Destination Address (DMA_TCD4_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_9094 | TCD Signed Destination Address Offset (DMA_TCD4_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_9096 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD4_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |

Table continues on the next page...

DMA memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4000_9096 | DMA_TCD4_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_9098 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD4_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_909C | TCD Control and Status (DMA_TCD4_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_909E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD4_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_909E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD4_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_90A0 | TCD Source Address (DMA_TCD5_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_90A4 | TCD Signed Source Address Offset (DMA_TCD5_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_90A6 | TCD Transfer Attributes (DMA_TCD5_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_90A8 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD5_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_90A8 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD5_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_90A8 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD5_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_90AC | TCD Last Source Address Adjustment (DMA_TCD5_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_90B0 | TCD Destination Address (DMA_TCD5_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_90B4 | TCD Signed Destination Address Offset (DMA_TCD5_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_90B6 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD5_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_90B6 | DMA_TCD5_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_90B8 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD5_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_90BC | TCD Control and Status (DMA_TCD5_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_90BE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD5_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_90BE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD5_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_90C0 | TCD Source Address (DMA_TCD6_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_90C4 | TCD Signed Source Address Offset (DMA_TCD6_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_90C6 | TCD Transfer Attributes (DMA_TCD6_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_90C8 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD6_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_90C8 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD6_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_90C8 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD6_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |

Table continues on the next page...

DMA memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4000_90CC | TCD Last Source Address Adjustment (DMA_TCD6_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_90D0 | TCD Destination Address (DMA_TCD6_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_90D4 | TCD Signed Destination Address Offset (DMA_TCD6_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_90D6 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD6_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_90D6 | DMA_TCD6_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_90D8 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD6_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_90DC | TCD Control and Status (DMA_TCD6_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_90DE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD6_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_90DE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD6_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_90E0 | TCD Source Address (DMA_TCD7_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_90E4 | TCD Signed Source Address Offset (DMA_TCD7_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_90E6 | TCD Transfer Attributes (DMA_TCD7_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_90E8 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD7_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_90E8 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD7_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_90E8 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD7_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_90EC | TCD Last Source Address Adjustment (DMA_TCD7_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_90F0 | TCD Destination Address (DMA_TCD7_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_90F4 | TCD Signed Destination Address Offset (DMA_TCD7_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_90F6 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD7_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_90F6 | DMA_TCD7_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_90F8 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD7_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_90FC | TCD Control and Status (DMA_TCD7_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_90FE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD7_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_90FE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD7_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_9100 | TCD Source Address (DMA_TCD8_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_9104 | TCD Signed Source Address Offset (DMA_TCD8_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |

Table continues on the next page...

DMA memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4000_9106 | TCD Transfer Attributes (DMA_TCD8_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_9108 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD8_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_9108 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD8_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_9108 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD8_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_910C | TCD Last Source Address Adjustment (DMA_TCD8_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_9110 | TCD Destination Address (DMA_TCD8_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_9114 | TCD Signed Destination Address Offset (DMA_TCD8_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_9116 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD8_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_9116 | DMA_TCD8_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_9118 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD8_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_911C | TCD Control and Status (DMA_TCD8_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_911E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD8_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_911E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD8_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_9120 | TCD Source Address (DMA_TCD9_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_9124 | TCD Signed Source Address Offset (DMA_TCD9_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_9126 | TCD Transfer Attributes (DMA_TCD9_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_9128 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD9_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_9128 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD9_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_9128 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD9_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_912C | TCD Last Source Address Adjustment (DMA_TCD9_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_9130 | TCD Destination Address (DMA_TCD9_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_9134 | TCD Signed Destination Address Offset (DMA_TCD9_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_9136 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD9_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_9136 | DMA_TCD9_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_9138 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD9_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_913C | TCD Control and Status (DMA_TCD9_CSR) | 16 | R/W | Undefined | 21.3.29/384 |

Table continues on the next page...

DMA memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|-----------------------------|
| 4000_913E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD9_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_913E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD9_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_9140 | TCD Source Address (DMA_TCD10_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_9144 | TCD Signed Source Address Offset (DMA_TCD10_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_9146 | TCD Transfer Attributes (DMA_TCD10_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_9148 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD10_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_9148 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD10_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_9148 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD10_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_914C | TCD Last Source Address Adjustment (DMA_TCD10_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_9150 | TCD Destination Address (DMA_TCD10_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_9154 | TCD Signed Destination Address Offset (DMA_TCD10_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_9156 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD10_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_9156 | DMA_TCD10_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_9158 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD10_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_915C | TCD Control and Status (DMA_TCD10_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_915E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD10_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_915E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD10_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_9160 | TCD Source Address (DMA_TCD11_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_9164 | TCD Signed Source Address Offset (DMA_TCD11_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_9166 | TCD Transfer Attributes (DMA_TCD11_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_9168 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD11_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_9168 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD11_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_9168 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD11_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_916C | TCD Last Source Address Adjustment (DMA_TCD11_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_9170 | TCD Destination Address (DMA_TCD11_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |

Table continues on the next page...

DMA memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|-----------------------------|
| 4000_9174 | TCD Signed Destination Address Offset (DMA_TCD11_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_9176 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD11_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_9176 | DMA_TCD11_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_9178 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD11_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_917C | TCD Control and Status (DMA_TCD11_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_917E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD11_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_917E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD11_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_9180 | TCD Source Address (DMA_TCD12_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_9184 | TCD Signed Source Address Offset (DMA_TCD12_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_9186 | TCD Transfer Attributes (DMA_TCD12_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_9188 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD12_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_9188 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD12_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_9188 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD12_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_918C | TCD Last Source Address Adjustment (DMA_TCD12_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_9190 | TCD Destination Address (DMA_TCD12_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_9194 | TCD Signed Destination Address Offset (DMA_TCD12_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_9196 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD12_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_9196 | DMA_TCD12_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_9198 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD12_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_919C | TCD Control and Status (DMA_TCD12_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_919E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD12_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_919E | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD12_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_91A0 | TCD Source Address (DMA_TCD13_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_91A4 | TCD Signed Source Address Offset (DMA_TCD13_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_91A6 | TCD Transfer Attributes (DMA_TCD13_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |

Table continues on the next page...

DMA memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|-----------------------------|
| 4000_91A8 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD13_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_91A8 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD13_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_91A8 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD13_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_91AC | TCD Last Source Address Adjustment (DMA_TCD13_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_91B0 | TCD Destination Address (DMA_TCD13_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_91B4 | TCD Signed Destination Address Offset (DMA_TCD13_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_91B6 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD13_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_91B6 | DMA_TCD13_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_91B8 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD13_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_91BC | TCD Control and Status (DMA_TCD13_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_91BE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD13_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_91BE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD13_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_91C0 | TCD Source Address (DMA_TCD14_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_91C4 | TCD Signed Source Address Offset (DMA_TCD14_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_91C6 | TCD Transfer Attributes (DMA_TCD14_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_91C8 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD14_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_91C8 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD14_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_91C8 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD14_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_91CC | TCD Last Source Address Adjustment (DMA_TCD14_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_91D0 | TCD Destination Address (DMA_TCD14_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_91D4 | TCD Signed Destination Address Offset (DMA_TCD14_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_91D6 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD14_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_91D6 | DMA_TCD14_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_91D8 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD14_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_91DC | TCD Control and Status (DMA_TCD14_CSR) | 16 | R/W | Undefined | 21.3.29/384 |

Table continues on the next page...

DMA memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|-----------------------------|
| 4000_91DE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD14_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_91DE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD14_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |
| 4000_91E0 | TCD Source Address (DMA_TCD15_SADDR) | 32 | R/W | Undefined | 21.3.17/374 |
| 4000_91E4 | TCD Signed Source Address Offset (DMA_TCD15_SOFF) | 16 | R/W | Undefined | 21.3.18/374 |
| 4000_91E6 | TCD Transfer Attributes (DMA_TCD15_ATTR) | 16 | R/W | Undefined | 21.3.19/375 |
| 4000_91E8 | TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCD15_NBYTES_MLNO) | 32 | R/W | Undefined | 21.3.20/376 |
| 4000_91E8 | TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCD15_NBYTES_MLOFFNO) | 32 | R/W | Undefined | 21.3.21/377 |
| 4000_91E8 | TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCD15_NBYTES_MLOFFYES) | 32 | R/W | Undefined | 21.3.22/378 |
| 4000_91EC | TCD Last Source Address Adjustment (DMA_TCD15_SLAST) | 32 | R/W | Undefined | 21.3.23/379 |
| 4000_91F0 | TCD Destination Address (DMA_TCD15_DADDR) | 32 | R/W | Undefined | 21.3.24/380 |
| 4000_91F4 | TCD Signed Destination Address Offset (DMA_TCD15_DOFF) | 16 | R/W | Undefined | 21.3.25/380 |
| 4000_91F6 | TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD15_CITER_ELINKYES) | 16 | R/W | Undefined | 21.3.26/381 |
| 4000_91F6 | DMA_TCD15_CITER_ELINKNO | 16 | R/W | Undefined | 21.3.27/382 |
| 4000_91F8 | TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCD15_DLASTSGA) | 32 | R/W | Undefined | 21.3.28/383 |
| 4000_91FC | TCD Control and Status (DMA_TCD15_CSR) | 16 | R/W | Undefined | 21.3.29/384 |
| 4000_91FE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCD15_BITER_ELINKYES) | 16 | R/W | Undefined | 21.3.30/386 |
| 4000_91FE | TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCD15_BITER_ELINKNO) | 16 | R/W | Undefined | 21.3.31/387 |

21.3.1 Control Register (DMA_CR)

The CR defines the basic operating configuration of the DMA.

Arbitration can be configured to use either a fixed-priority or a round-robin scheme. For fixed-priority arbitration, the highest priority channel requesting service is selected to execute. The channel priority registers assign the priorities; see the DCHPRIn registers. For round-robin arbitration, the channel priorities are ignored and channels are cycled through (from high to low channel number) without regard to priority.

NOTE

For correct operation, writes to the CR register must be performed only when the DMA channels are inactive; that is, when TCDn_CSR[ACTIVE] bits are cleared.

Minor loop offsets are address offset values added to the final source address (TCDn_SADDR) or destination address (TCDn_DADDR) upon minor loop completion. When minor loop offsets are enabled, the minor loop offset (MLOFF) is added to the final source address (TCDn_SADDR), to the final destination address (TCDn_DADDR), or to both prior to the addresses being written back into the TCD. If the major loop is complete, the minor loop offset is ignored and the major loop address offsets (TCDn_SLAST and TCDn_DLAST_SGA) are used to compute the next TCDn_SADDR and TCDn_DADDR values.

When minor loop mapping is enabled (EMLM is 1), TCDn word2 is redefined. A portion of TCDn word2 is used to specify multiple fields: a source enable bit (SMLOE) to specify the minor loop offset should be applied to the source address (TCDn_SADDR) upon minor loop completion, a destination enable bit (DMLOE) to specify the minor loop offset should be applied to the destination address (TCDn_DADDR) upon minor loop completion, and the sign extended minor loop offset value (MLOFF). The same offset value (MLOFF) is used for both source and destination minor loop offsets. When either minor loop offset is enabled (SMLOE set or DMLOE set), the NBYTES field is reduced to 10 bits. When both minor loop offsets are disabled (SMLOE cleared and DMLOE cleared), the NBYTES field is a 30-bit vector.

When minor loop mapping is disabled (EMLM is 0), all 32 bits of TCDn word2 are assigned to the NBYTES field.

Address: 4000_8000h base + 0h offset = 4000_8000h

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|----|----|----|----|----|----|----|----|------|-----|------|-----|----------|------|------|----------|
| R | 0 | | | | | | | | | | | | | | CX | ECX |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | EMLM | CLM | HALT | HOE | Reserved | ERCA | EDBG | Reserved |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_CR field descriptions

| Field | Description |
|-------------------|--|
| 31–18 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 17 CX | Cancel Transfer 0 Normal operation 1 Cancel the remaining data transfer. Stop the executing channel and force the minor loop to finish. The cancel takes effect after the last write of the current read/write sequence. The CX bit clears itself after the cancel has been honored. This cancel retires the channel normally as if the minor loop was completed. |
| 16 ECX | Error Cancel Transfer 0 Normal operation 1 Cancel the remaining data transfer in the same fashion as the CX bit. Stop the executing channel and force the minor loop to finish. The cancel takes effect after the last write of the current read/write sequence. The ECX bit clears itself after the cancel is honored. In addition to cancelling the transfer, ECX treats the cancel as an error condition, thus updating the Error Status register (DMAx_ES) and generating an optional error interrupt. |
| 15–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 EMLM | Enable Minor Loop Mapping 0 Disabled. TCDn.word2 is defined as a 32-bit NBYTES field. 1 Enabled. TCDn.word2 is redefined to include individual enable fields, an offset field, and the NBYTES field. The individual enable fields allow the minor loop offset to be applied to the source address, the destination address, or both. The NBYTES field is reduced when either offset is enabled. |
| 6 CLM | Continuous Link Mode 0 A minor loop channel link made to itself goes through channel arbitration before being activated again. 1 A minor loop channel link made to itself does not go through channel arbitration before being activated again. Upon minor loop completion, the channel activates again if that channel has a minor loop channel link enabled and the link channel is itself. This effectively applies the minor loop offsets and restarts the next minor loop. |
| 5 HALT | Halt DMA Operations 0 Normal operation 1 Stall the start of any new channels. Executing channels are allowed to complete. Channel execution resumes when this bit is cleared. |
| 4 HOE | Halt On Error 0 Normal operation 1 Any error causes the HALT bit to set. Subsequently, all service requests are ignored until the HALT bit is cleared. |
| 3 Reserved | Reserved. This field is reserved. |
| 2 ERCA | Enable Round Robin Channel Arbitration 0 Fixed priority arbitration is used for channel selection . 1 Round robin arbitration is used for channel selection . |
| 1 EDBG | Enable Debug |

Table continues on the next page...

DMA_CR field descriptions (continued)

| Field | Description |
|---------------|--|
| | 0 When in debug mode, the DMA continues to operate. 1 When in debug mode, the DMA stalls the start of a new channel. Executing channels are allowed to complete. Channel execution resumes when the system exits debug mode or the EDBG bit is cleared. |
| 0 Reserved | Reserved. This field is reserved. |

21.3.2 Error Status Register (DMA_ES)

The ES provides information concerning the last recorded channel error. Channel errors can be caused by:

- A configuration error, that is:
 - An illegal setting in the transfer-control descriptor, or
 - An illegal priority register setting in fixed-arbitration
- An error termination to a bus master read or write cycle

See the Error Reporting and Handling section for more details.

Address: 4000_8000h base + 4h offset = 4000_8004h

| | | | | | | | | | | | | | | | | |
|-------|-----|-----|----|--------|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | VLD | 0 | | | | | | | | | | | | | | ECX |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | CPE | 0 | ERRCHN | | | | | SAE | SOE | DAE | DOE | NCE | SGE | SBE | DBE |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_ES field descriptions

| Field | Description |
|-------------------|---|
| 31 VLD | Logical OR of all ERR status bits 0 No ERR bits are set 1 At least one ERR bit is set indicating a valid error exists that has not been cleared |
| 30–17 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 16 ECX | Transfer Canceled 0 No canceled transfers 1 The last recorded entry was a canceled transfer by the error cancel transfer input |

Table continues on the next page...

DMA_ES field descriptions (continued)

| Field | Description |
|-------------------|---|
| 15 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 14 CPE | Channel Priority Error 0 No channel priority error 1 The last recorded error was a configuration error in the channel priorities . Channel priorities are not unique. |
| 13–12 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 11–8 ERRCHN | Error Channel Number or Canceled Channel Number The channel number of the last recorded error (excluding CPE errors) or last recorded error canceled transfer. |
| 7 SAE | Source Address Error 0 No source address configuration error. 1 The last recorded error was a configuration error detected in the TCDn_SADDR field. TCDn_SADDR is inconsistent with TCDn_ATTR[SSIZE]. |
| 6 SOE | Source Offset Error 0 No source offset configuration error 1 The last recorded error was a configuration error detected in the TCDn_SOFF field. TCDn_SOFF is inconsistent with TCDn_ATTR[SSIZE]. |
| 5 DAE | Destination Address Error 0 No destination address configuration error 1 The last recorded error was a configuration error detected in the TCDn_DADDR field. TCDn_DADDR is inconsistent with TCDn_ATTR[DSIZE]. |
| 4 DOE | Destination Offset Error 0 No destination offset configuration error 1 The last recorded error was a configuration error detected in the TCDn_DOFF field. TCDn_DOFF is inconsistent with TCDn_ATTR[DSIZE]. |
| 3 NCE | NBYTES/CITER Configuration Error 0 No NBYTES/CITER configuration error 1 The last recorded error was a configuration error detected in the TCDn_NBYTES or TCDn_CITER fields. <ul style="list-style-type: none"> • TCDn_NBYTES is not a multiple of TCDn_ATTR[SSIZE] and TCDn_ATTR[DSIZE], or • TCDn_CITER[CITER] is equal to zero, or • TCDn_CITER[ELINK] is not equal to TCDn_BITER[ELINK] |
| 2 SGE | Scatter/Gather Configuration Error 0 No scatter/gather configuration error 1 The last recorded error was a configuration error detected in the TCDn_DLASTSGA field. This field is checked at the beginning of a scatter/gather operation after major loop completion if TCDn_CSR[ESG] is enabled. TCDn_DLASTSGA is not on a 32 byte boundary. |
| 1 SBE | Source Bus Error |

Table continues on the next page...

DMA_ES field descriptions (continued)

| Field | Description |
|-------|---|
| | 0 No source bus error 1 The last recorded error was a bus error on a source read |
| 0 DBE | Destination Bus Error 0 No destination bus error 1 The last recorded error was a bus error on a destination write |

21.3.3 Enable Request Register (DMA_ERQ)

The ERQ register provides a bit map for the 16 implemented channels to enable the request signal for each channel. The state of any given channel enable is directly affected by writes to this register; it is also affected by writes to the SERQ and CERQ. The {S,C}ERQ registers are provided so the request enable for a single channel can easily be modified without needing to perform a read-modify-write sequence to the ERQ.

DMA request input signals and this enable request flag must be asserted before a channel's hardware service request is accepted. The state of the DMA enable request flag does not affect a channel service request made explicitly through software or a linked channel request.

Address: 4000_8000h base + Ch offset = 4000_800Ch

| | | | | | | | | | | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | ERQ15 | ERQ14 | ERQ13 | ERQ12 | ERQ11 | ERQ10 | ERQ9 | ERQ8 | ERQ7 | ERQ6 | ERQ5 | ERQ4 | ERQ3 | ERQ2 | ERQ1 | ERQ0 |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_ERQ field descriptions

| Field | Description |
|----------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15 ERQ15 | Enable DMA Request 15 |

Table continues on the next page...

DMA_ERQ field descriptions (continued)

| Field | Description |
|-------------|--|
| | 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 14 ERQ14 | Enable DMA Request 14 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 13 ERQ13 | Enable DMA Request 13 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 12 ERQ12 | Enable DMA Request 12 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 11 ERQ11 | Enable DMA Request 11 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 10 ERQ10 | Enable DMA Request 10 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 9 ERQ9 | Enable DMA Request 9 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 8 ERQ8 | Enable DMA Request 8 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 7 ERQ7 | Enable DMA Request 7 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 6 ERQ6 | Enable DMA Request 6 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 5 ERQ5 | Enable DMA Request 5 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 4 ERQ4 | Enable DMA Request 4 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 3 ERQ3 | Enable DMA Request 3 |

Table continues on the next page...

DMA_ERQ field descriptions (continued)

| Field | Description |
|-----------|---|
| | 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 2 ERQ2 | Enable DMA Request 2 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 1 ERQ1 | Enable DMA Request 1 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |
| 0 ERQ0 | Enable DMA Request 0 0 The DMA request signal for the corresponding channel is disabled 1 The DMA request signal for the corresponding channel is enabled |

21.3.4 Enable Error Interrupt Register (DMA_EEI)

The EEI register provides a bit map for the 16 channels to enable the error interrupt signal for each channel. The state of any given channel's error interrupt enable is directly affected by writes to this register; it is also affected by writes to the SEEI and CEEI. The {S,C}EEI are provided so the error interrupt enable for a single channel can easily be modified without the need to perform a read-modify-write sequence to the EEI register.

The DMA error indicator and the error interrupt enable flag must be asserted before an error interrupt request for a given channel is asserted to the interrupt controller.

Address: 4000_8000h base + 14h offset = 4000_8014h

| | | | | | | | | | | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | EEI15 | EEI14 | EEI13 | EEI12 | EEI11 | EEI10 | EEI9 | EEI8 | EEI7 | EEI6 | EEI5 | EEI4 | EEI3 | EEI2 | EEI1 | EEI0 |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_EEI field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15 EEI15 | Enable Error Interrupt 15 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 14 EEI14 | Enable Error Interrupt 14 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 13 EEI13 | Enable Error Interrupt 13 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 12 EEI12 | Enable Error Interrupt 12 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 11 EEI11 | Enable Error Interrupt 11 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 10 EEI10 | Enable Error Interrupt 10 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 9 EEI9 | Enable Error Interrupt 9 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 8 EEI8 | Enable Error Interrupt 8 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 7 EEI7 | Enable Error Interrupt 7 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 6 EEI6 | Enable Error Interrupt 6 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 5 EEI5 | Enable Error Interrupt 5 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 4 EEI4 | Enable Error Interrupt 4 |

Table continues on the next page...

DMA_EEI field descriptions (continued)

| Field | Description |
|-----------|---|
| | 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 3 EEI3 | Enable Error Interrupt 3 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 2 EEI2 | Enable Error Interrupt 2 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 1 EEI1 | Enable Error Interrupt 1 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |
| 0 EEI0 | Enable Error Interrupt 0 0 The error signal for corresponding channel does not generate an error interrupt 1 The assertion of the error signal for corresponding channel generates an error interrupt request |

21.3.5 Clear Enable Error Interrupt Register (DMA_CEEI)

The CEEI provides a simple memory-mapped mechanism to clear a given bit in the EEI to disable the error interrupt for a given channel. The data value on a register write causes the corresponding bit in the EEI to be cleared. Setting the CAEE bit provides a global clear function, forcing the EEI contents to be cleared, disabling all DMA request inputs. If the NOP bit is set, the command is ignored. This allows you to write multiple-byte registers as a 32-bit word. Reads of this register return all zeroes.

Address: 4000_8000h base + 18h offset = 4000_8018h

| | | | | | | | | |
|-------|-----|------|---|---|---|---|------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | 0 | | | | | 0 | |
| Write | NOP | CAEE | 0 | | | | CEEI | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_CEEI field descriptions

| Field | Description |
|----------|--|
| 7 NOP | No Op enable 0 Normal operation 1 No operation, ignore the other bits in this register |

Table continues on the next page...

DMA_CEEI field descriptions (continued)

| Field | Description |
|-----------------|--|
| 6 CAEE | Clear All Enable Error Interrupts 0 Clear only the EEI bit specified in the CEEI field 1 Clear all bits in EEI |
| 5–4 Reserved | This field is reserved. |
| 3–0 CEEI | Clear Enable Error Interrupt Clears the corresponding bit in EEI |

21.3.6 Set Enable Error Interrupt Register (DMA_SEEI)

The SEEI provides a simple memory-mapped mechanism to set a given bit in the EEI to enable the error interrupt for a given channel. The data value on a register write causes the corresponding bit in the EEI to be set. Setting the SAEE bit provides a global set function, forcing the entire EEI contents to be set. If the NOP bit is set, the command is ignored. This allows you to write multiple-byte registers as a 32-bit word. Reads of this register return all zeroes.

Address: 4000_8000h base + 19h offset = 4000_8019h

| | | | | | | | | |
|-------|-----|------|---|---|---|---|------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | 0 | | | | | 0 | |
| Write | NOP | SAEE | | 0 | | | SEEI | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_SEEI field descriptions

| Field | Description |
|-----------------|---|
| 7 NOP | No Op enable 0 Normal operation 1 No operation, ignore the other bits in this register |
| 6 SAEE | Sets All Enable Error Interrupts 0 Set only the EEI bit specified in the SEEI field. 1 Sets all bits in EEI |
| 5–4 Reserved | This field is reserved. |
| 3–0 SEEI | Set Enable Error Interrupt Sets the corresponding bit in EEI |

21.3.7 Clear Enable Request Register (DMA_CERQ)

The CERQ provides a simple memory-mapped mechanism to clear a given bit in the ERQ to disable the DMA request for a given channel. The data value on a register write causes the corresponding bit in the ERQ to be cleared. Setting the CAER bit provides a global clear function, forcing the entire contents of the ERQ to be cleared, disabling all DMA request inputs. If NOP is set, the command is ignored. This allows you to write multiple-byte registers as a 32-bit word. Reads of this register return all zeroes.

Address: 4000_8000h base + 1Ah offset = 4000_801Ah

| | | | | | | | | |
|-------|-----|------|---|---|---|---|------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | 0 | | | | | 0 | |
| Write | NOP | CAER | | 0 | | | CERQ | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_CERQ field descriptions

| Field | Description |
|-----------------|--|
| 7 NOP | No Op enable 0 Normal operation 1 No operation, ignore the other bits in this register |
| 6 CAER | Clear All Enable Requests 0 Clear only the ERQ bit specified in the CERQ field 1 Clear all bits in ERQ |
| 5–4 Reserved | This field is reserved. |
| 3–0 CERQ | Clear Enable Request Clears the corresponding bit in ERQ |

21.3.8 Set Enable Request Register (DMA_SERQ)

The SERQ provides a simple memory-mapped mechanism to set a given bit in the ERQ to enable the DMA request for a given channel. The data value on a register write causes the corresponding bit in the ERQ to be set. Setting the SAER bit provides a global set function, forcing the entire contents of ERQ to be set. If the NOP bit is set, the command is ignored. This allows you to write multiple-byte registers as a 32-bit word. Reads of this register return all zeroes.

Address: 4000_8000h base + 1Bh offset = 4000_801Bh

| | | | | | | | | |
|-------|-----|------|---|---|---|---|------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | 0 | | | | | 0 | |
| Write | NOP | SAER | 0 | | | | SERQ | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_SERQ field descriptions

| Field | Description |
|-----------------|--|
| 7 NOP | No Op enable 0 Normal operation 1 No operation, ignore the other bits in this register |
| 6 SAER | Set All Enable Requests 0 Set only the ERQ bit specified in the SERQ field 1 Set all bits in ERQ |
| 5–4 Reserved | This field is reserved. |
| 3–0 SERQ | Set enable request Sets the corresponding bit in ERQ |

21.3.9 Clear DONE Status Bit Register (DMA_CDNE)

The CDNE provides a simple memory-mapped mechanism to clear the DONE bit in the TCD of the given channel. The data value on a register write causes the DONE bit in the corresponding transfer control descriptor to be cleared. Setting the CADN bit provides a global clear function, forcing all DONE bits to be cleared. If the NOP bit is set, the command is ignored. This allows you to write multiple-byte registers as a 32-bit word. Reads of this register return all zeroes.

Address: 4000_8000h base + 1Ch offset = 4000_801Ch

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-----|------|---|---|---|---|------|---|
| Read | 0 | 0 | | | | | 0 | |
| Write | NOP | CADN | | 0 | | | CDNE | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_CDNE field descriptions

| Field | Description |
|-----------------|---|
| 7 NOP | No Op enable 0 Normal operation 1 No operation, ignore the other bits in this register |
| 6 CADN | Clears All DONE Bits 0 Clears only the TCDn_CSR[DONE] bit specified in the CDNE field 1 Clears all bits in TCDn_CSR[DONE] |
| 5–4 Reserved | This field is reserved. |
| 3–0 CDNE | Clear DONE Bit Clears the corresponding bit in TCDn_CSR[DONE] |

21.3.10 Set START Bit Register (DMA_SSRT)

The SSRT provides a simple memory-mapped mechanism to set the START bit in the TCD of the given channel. The data value on a register write causes the START bit in the corresponding transfer control descriptor to be set. Setting the SAST bit provides a global set function, forcing all START bits to be set. If the NOP bit is set, the command is ignored. This allows you to write multiple-byte registers as a 32-bit word. Reads of this register return all zeroes.

Address: 4000_8000h base + 1Dh offset = 4000_801Dh

| | | | | | | | | |
|-------|-----|------|---|---|---|---|------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | 0 | | | | | 0 | |
| Write | NOP | SAST | | 0 | | | SSRT | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_SSRT field descriptions

| Field | Description |
|-----------------|--|
| 7 NOP | No Op enable 0 Normal operation 1 No operation, ignore the other bits in this register |
| 6 SAST | Set All START Bits (activates all channels) 0 Set only the TCDn_CSR[START] bit specified in the SSRT field 1 Set all bits in TCDn_CSR[START] |
| 5–4 Reserved | This field is reserved. |
| 3–0 SSRT | Set START Bit Sets the corresponding bit in TCDn_CSR[START] |

21.3.11 Clear Error Register (DMA_CERR)

The CERR provides a simple memory-mapped mechanism to clear a given bit in the ERR to disable the error condition flag for a given channel. The given value on a register write causes the corresponding bit in the ERR to be cleared. Setting the CAEI bit provides a global clear function, forcing the ERR contents to be cleared, clearing all channel error indicators. If the NOP bit is set, the command is ignored. This allows you to write multiple-byte registers as a 32-bit word. Reads of this register return all zeroes.

Address: 4000_8000h base + 1Eh offset = 4000_801Eh

| | | | | | | | | |
|-------|-----|------|---|---|---|---|------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | 0 | | | | | 0 | |
| Write | NOP | CAEI | | 0 | | | CERR | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_CERR field descriptions

| Field | Description |
|-----------------|---|
| 7 NOP | No Op enable 0 Normal operation 1 No operation, ignore the other bits in this register |
| 6 CAEI | Clear All Error Indicators 0 Clear only the ERR bit specified in the CERR field 1 Clear all bits in ERR |
| 5–4 Reserved | This field is reserved. |
| 3–0 CERR | Clear Error Indicator Clears the corresponding bit in ERR |

21.3.12 Clear Interrupt Request Register (DMA_CINT)

The CINT provides a simple, memory-mapped mechanism to clear a given bit in the INT to disable the interrupt request for a given channel. The given value on a register write causes the corresponding bit in the INT to be cleared. Setting the CAIR bit provides a global clear function, forcing the entire contents of the INT to be cleared, disabling all DMA interrupt requests. If the NOP bit is set, the command is ignored. This allows you to write multiple-byte registers as a 32-bit word. Reads of this register return all zeroes.

Address: 4000_8000h base + 1Fh offset = 4000_801Fh

| | | | | | | | | |
|-------|-----|------|---|---|---|---|------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | 0 | | | | | 0 | |
| Write | NOP | CAIR | | 0 | | | CINT | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_CINT field descriptions

| Field | Description |
|-----------------|---|
| 7 NOP | No Op enable 0 Normal operation 1 No operation, ignore the other bits in this register |
| 6 CAIR | Clear All Interrupt Requests 0 Clear only the INT bit specified in the CINT field 1 Clear all bits in INT |
| 5–4 Reserved | This field is reserved. |
| 3–0 CINT | Clear Interrupt Request Clears the corresponding bit in INT |

21.3.13 Interrupt Request Register (DMA_INT)

The INT register provides a bit map for the 16 channels signaling the presence of an interrupt request for each channel. Depending on the appropriate bit setting in the transfer-control descriptors, the eDMA engine generates an interrupt on data transfer completion. The outputs of this register are directly routed to the interrupt controller (INTC). During the interrupt-service routine associated with any given channel, it is the software’s responsibility to clear the appropriate bit, negating the interrupt request. Typically, a write to the CINT register in the interrupt service routine is used for this purpose.

The state of any given channel’s interrupt request is directly affected by writes to this register; it is also affected by writes to the CINT register. On writes to INT, a 1 in any bit position clears the corresponding channel’s interrupt request. A zero in any bit position has no affect on the corresponding channel’s current interrupt status. The CINT register is provided so the interrupt request for a single channel can easily be cleared without the need to perform a read-modify-write sequence to the INT register.

Address: 4000_8000h base + 24h offset = 4000_8024h

| | | | | | | | | | | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | INT15 | INT14 | INT13 | INT12 | INT11 | INT10 | INT9 | INT8 | INT7 | INT6 | INT5 | INT4 | INT3 | INT2 | INT1 | INT0 |
| W | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_INT field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

Table continues on the next page...

DMA_INT field descriptions (continued)

| Field | Description |
|-------------|---|
| 15 INT15 | Interrupt Request 15 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 14 INT14 | Interrupt Request 14 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 13 INT13 | Interrupt Request 13 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 12 INT12 | Interrupt Request 12 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 11 INT11 | Interrupt Request 11 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 10 INT10 | Interrupt Request 10 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 9 INT9 | Interrupt Request 9 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 8 INT8 | Interrupt Request 8 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 7 INT7 | Interrupt Request 7 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 6 INT6 | Interrupt Request 6 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 5 INT5 | Interrupt Request 5 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 4 INT4 | Interrupt Request 4 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |

Table continues on the next page...

DMA_INT field descriptions (continued)

| Field | Description |
|-----------|--|
| 3 INT3 | Interrupt Request 3 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 2 INT2 | Interrupt Request 2 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 1 INT1 | Interrupt Request 1 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |
| 0 INT0 | Interrupt Request 0 0 The interrupt request for corresponding channel is cleared 1 The interrupt request for corresponding channel is active |

21.3.14 Error Register (DMA_ERR)

The ERR provides a bit map for the 16 channels, signaling the presence of an error for each channel. The eDMA engine signals the occurrence of an error condition by setting the appropriate bit in this register. The outputs of this register are enabled by the contents of the EEI, and then routed to the interrupt controller. During the execution of the interrupt-service routine associated with any DMA errors, it is software's responsibility to clear the appropriate bit, negating the error-interrupt request. Typically, a write to the CERR in the interrupt-service routine is used for this purpose. The normal DMA channel completion indicators (setting the transfer control descriptor DONE flag and the possible assertion of an interrupt request) are not affected when an error is detected.

The contents of this register can also be polled because a non-zero value indicates the presence of a channel error regardless of the state of the EEI. The state of any given channel's error indicators is affected by writes to this register; it is also affected by writes to the CERR. On writes to the ERR, a one in any bit position clears the corresponding channel's error status. A zero in any bit position has no affect on the corresponding channel's current error status. The CERR is provided so the error indicator for a single channel can easily be cleared.

memory map/register definition

Address: 4000_8000h base + 2Ch offset = 4000_802Ch

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | ERR15 | ERR14 | ERR13 | ERR12 | ERR11 | ERR10 | ERR9 | ERR8 | ERR7 | ERR6 | ERR5 | ERR4 | ERR3 | ERR2 | ERR1 | ERR0 |
| W | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c | w1c |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DMA_ERR field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15 ERR15 | Error In Channel 15 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 14 ERR14 | Error In Channel 14 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 13 ERR13 | Error In Channel 13 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 12 ERR12 | Error In Channel 12 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 11 ERR11 | Error In Channel 11 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 10 ERR10 | Error In Channel 10 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |

Table continues on the next page...

DMA_ERR field descriptions (continued)

| Field | Description |
|-----------|--|
| 9 ERR9 | Error In Channel 9 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 8 ERR8 | Error In Channel 8 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 7 ERR7 | Error In Channel 7 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 6 ERR6 | Error In Channel 6 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 5 ERR5 | Error In Channel 5 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 4 ERR4 | Error In Channel 4 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 3 ERR3 | Error In Channel 3 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 2 ERR2 | Error In Channel 2 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 1 ERR1 | Error In Channel 1 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |
| 0 ERR0 | Error In Channel 0 0 An error in the corresponding channel has not occurred 1 An error in the corresponding channel has occurred |

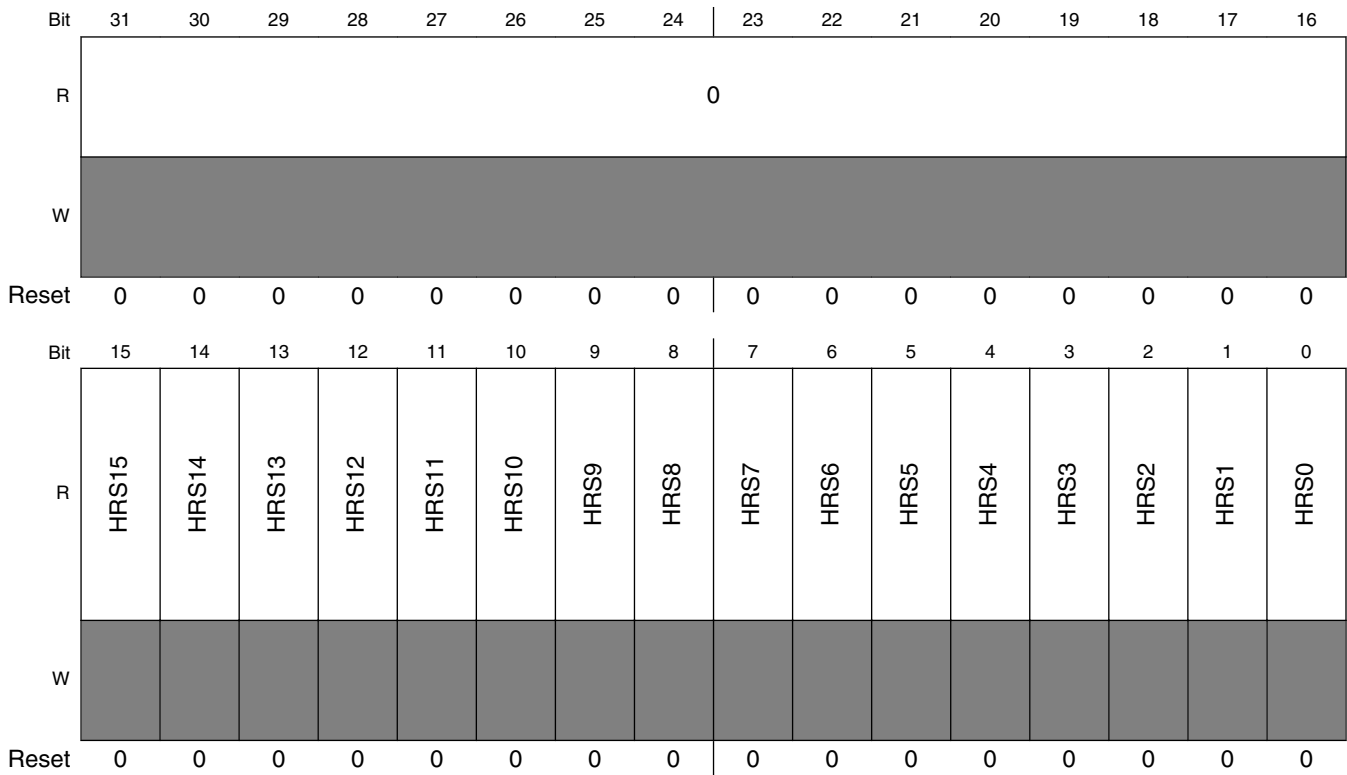
21.3.15 Hardware Request Status Register (DMA_HRS)

The HRS register provides a bit map for the DMA channels, signaling the presence of a hardware request for each channel. The hardware request status bits reflect the current state of the register and qualified (via the ERQ fields) DMA request signals as seen by the DMA’s arbitration logic. This view into the hardware request signals may be used for debug purposes.

NOTE

These bits reflect the state of the request as seen by the arbitration logic. Therefore, this status is affected by the ERQ bits.

Address: 4000_8000h base + 34h offset = 4000_8034h



DMA_HRS field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | Reserved This field is reserved. This read-only field is reserved and always has the value 0. |
| 15 HRS15 | Hardware Request Status Channel 15 |

Table continues on the next page...

DMA_HRS field descriptions (continued)

| Field | Description |
|-------------|--|
| | <p>The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware.</p> <p>0 A hardware service request for channel 15 is not present 1 A hardware service request for channel 15 is present</p> |
| 14 HRS14 | <p>Hardware Request Status Channel 14</p> <p>The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware.</p> <p>0 A hardware service request for channel 14 is not present 1 A hardware service request for channel 14 is present</p> |
| 13 HRS13 | <p>Hardware Request Status Channel 13</p> <p>The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware.</p> <p>0 A hardware service request for channel 13 is not present 1 A hardware service request for channel 13 is present</p> |
| 12 HRS12 | <p>Hardware Request Status Channel 12</p> <p>The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware.</p> <p>0 A hardware service request for channel 12 is not present 1 A hardware service request for channel 12 is present</p> |
| 11 HRS11 | <p>Hardware Request Status Channel 11</p> <p>The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware.</p> <p>0 A hardware service request for channel 11 is not present 1 A hardware service request for channel 11 is present</p> |
| 10 HRS10 | <p>Hardware Request Status Channel 10</p> <p>The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware.</p> <p>0 A hardware service request for channel 10 is not present 1 A hardware service request for channel 10 is present</p> |
| 9 HRS9 | <p>Hardware Request Status Channel 9</p> <p>The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware.</p> |

Table continues on the next page...

DMA_HRS field descriptions (continued)

| Field | Description |
|-----------|---|
| | 0 A hardware service request for channel 9 is not present 1 A hardware service request for channel 9 is present |
| 8 HRS8 | Hardware Request Status Channel 8 The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware. 0 A hardware service request for channel 8 is not present 1 A hardware service request for channel 8 is present |
| 7 HRS7 | Hardware Request Status Channel 7 The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware. 0 A hardware service request for channel 7 is not present 1 A hardware service request for channel 7 is present |
| 6 HRS6 | Hardware Request Status Channel 6 The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware. 0 A hardware service request for channel 6 is not present 1 A hardware service request for channel 6 is present |
| 5 HRS5 | Hardware Request Status Channel 5 The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware. 0 A hardware service request for channel 5 is not present 1 A hardware service request for channel 5 is present |
| 4 HRS4 | Hardware Request Status Channel 4 The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware. 0 A hardware service request for channel 4 is not present 1 A hardware service request for channel 4 is present |
| 3 HRS3 | Hardware Request Status Channel 3 The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware. 0 A hardware service request for channel 3 is not present 1 A hardware service request for channel 3 is present |
| 2 HRS2 | Hardware Request Status Channel 2 |

Table continues on the next page...

DMA_HRS field descriptions (continued)

| Field | Description |
|-----------|---|
| | <p>The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware.</p> <p>0 A hardware service request for channel 2 is not present 1 A hardware service request for channel 2 is present</p> |
| 1 HRS1 | <p>Hardware Request Status Channel 1</p> <p>The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware.</p> <p>0 A hardware service request for channel 1 is not present 1 A hardware service request for channel 1 is present</p> |
| 0 HRS0 | <p>Hardware Request Status Channel 0</p> <p>The HRS bit for its respective channel remains asserted for the period when a Hardware Request is Present on the Channel. After the Request is completed and Channel is free , the HRS bit is automatically cleared by hardware.</p> <p>0 A hardware service request for channel 0 is not present 1 A hardware service request for channel 0 is present</p> |

21.3.16 Channel n Priority Register (DMA_DCHPRIn)

When fixed-priority channel arbitration is enabled ($CR[ERCA] = 0$), the contents of these registers define the unique priorities associated with each channel . The channel priorities are evaluated by numeric value; for example, 0 is the lowest priority, 1 is the next priority, then 2, 3, etc. Software must program the channel priorities with unique values; otherwise, a configuration error is reported. The range of the priority value is limited to the values of 0 through 15.

Address: $4000_8000h \text{ base} + 100h \text{ offset} + (1d \times i)$, where $i=0d$ to $15d$

| | | | | | | | | |
|-------|-----|-----|---|---|-------|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | ECP | DPA | 0 | | CHPRI | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | * | * | * | * |

* Notes:

- CHPRI field: See bit field description.

DMA_DCHPRI_n field descriptions

| Field | Description |
|-----------------|---|
| 7 ECP | Enable Channel Preemption 0 Channel n cannot be suspended by a higher priority channel's service request 1 Channel n can be temporarily suspended by the service request of a higher priority channel |
| 6 DPA | Disable Preempt Ability 0 Channel n can suspend a lower priority channel 1 Channel n cannot suspend any channel, regardless of channel priority |
| 5–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3–0 CHPRI | Channel n Arbitration Priority Channel priority when fixed-priority arbitration is enabled NOTE: Reset value for the channel priority fields, CHPRI, is equal to the corresponding channel number for each priority register, i.e., DCHPRI15[CHPRI] equals 0b1111. |

21.3.17 TCD Source Address (DMA_TCD_n_SADDR)

Address: 4000_8000h base + 1000h offset + (32d × i), where i=0d to 15d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | <div>SADDR</div> | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | |

* Notes:

- x = Undefined at reset.

DMA_TCD_n_SADDR field descriptions

| Field | Description |
|---------------|---|
| 31–0 SADDR | Source Address Memory address pointing to the source data. |

21.3.18 TCD Signed Source Address Offset (DMA_TCD_n_SOFF)

Address: 4000_8000h base + 1004h offset + (32d × i), where i=0d to 15d

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | | | | | | | | | | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

DMA_TCDn_SOFF field descriptions

| Field | Description |
|--------------|---|
| 15–0 SOFF | Source address signed offset Sign-extended offset applied to the current source address to form the next-state value as each source read is completed. |

21.3.19 TCD Transfer Attributes (DMA_TCDn_ATTR)

Address: 4000_8000h base + 1006h offset + (32d × i), where i=0d to 15d

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | | | | | | | | | | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

DMA_TCDn_ATTR field descriptions

| Field | Description |
|---------------|---|
| 15–11 SMOD | Source Address Modulo. 0 Source address modulo feature is disabled ≠0 This value defines a specific address range specified to be the value after SADDR + SOFF calculation is performed or the original register value. The setting of this field provides the ability to implement a circular data queue easily. For data queues requiring power-of-2 size bytes, the queue should start at a 0-modulo-size address and the SMOD field should be set to the appropriate value for the queue, freezing the desired number of upper address bits. The value programmed into this field specifies the number of lower address bits allowed to change. For a circular queue application, the SOFF is typically set to the transfer size to implement post-increment addressing with the SMOD function constraining the addresses to a 0-modulo-size range. |
| 10–8 SSIZE | Source data transfer size NOTE: Using a Reserved value causes a configuration error. 000 8-bit 001 16-bit 010 32-bit 011 Reserved 100 16-byte 101 32-byte burst (4 beats of 64 bits) 110 Reserved 111 Reserved |
| 7–3 DMOD | Destination Address Modulo See the SMOD definition |

Table continues on the next page...

DMA_TCDn_ATTR field descriptions (continued)

| Field | Description |
|--------------|--|
| 2–0 DSIZE | Destination Data Transfer Size See the SSIZE definition |

21.3.20 TCD Minor Byte Count (Minor Loop Disabled) (DMA_TCDn_NBYTES_MLNO)

This register, or one of the next two registers (TCD_NBYTES_MLOFFNO, TCD_NBYTES_MLOFFYES), defines the number of bytes to transfer per request. Which register to use depends on whether minor loop mapping is disabled, enabled but not used for this channel, or enabled and used.

TCD word 2 is defined as follows if:

- Minor loop mapping is disabled (CR[EMLM] = 0)

If minor loop mapping is enabled, see the TCD_NBYTES_MLOFFNO and TCD_NBYTES_MLOFFYES register descriptions for the definition of TCD word 2.

Address: 4000_8000h base + 1008h offset + (32d × i), where i=0d to 15d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|--------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | NBYTES | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

DMA_TCDn_NBYTES_MLNO field descriptions

| Field | Description |
|----------------|--|
| 31–0 NBYTES | <p>Minor Byte Transfer Count</p> <p>Number of bytes to be transferred in each service request of the channel. As a channel activates, the appropriate TCD contents load into the eDMA engine, and the appropriate reads and writes perform until the minor byte transfer count has transferred. This is an indivisible operation and cannot be halted. (Although, it may be stalled by using the bandwidth control field, or via preemption.) After the minor count is exhausted, the SADDR and DADDR values are written back into the TCD memory, the major iteration count is decremented and restored to the TCD memory. If the major iteration count is completed, additional processing is performed.</p> <p>NOTE: An NBYTES value of 0x0000_0000 is interpreted as a 4 GB transfer.</p> |

21.3.21 TCD Signed Minor Loop Offset (Minor Loop Enabled and Offset Disabled) (DMA_TCDn_NBYTES_MLOFFNO)

One of three registers (this register, TCD_NBYTES_MLNO, or TCD_NBYTES_MLOFFYES), defines the number of bytes to transfer per request. Which register to use depends on whether minor loop mapping is disabled, enabled but not used for this channel, or enabled and used.

TCD word 2 is defined as follows if:

- Minor loop mapping is enabled (CR[EMLM] = 1) and
- SMLOE = 0 and DMLOE = 0

If minor loop mapping is enabled and SMLOE or DMLOE is set, then refer to the TCD_NBYTES_MLOFFYES register description. If minor loop mapping is disabled, then refer to the TCD_NBYTES_MLNO register description.

Address: 4000_8000h base + 1008h offset + (32d × i), where i=0d to 15d

| | | | | | | | | | | | | | | | | |
|-------|-------|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | | | | | | | | | | | | | | | | |
| W | SMLOE | DMLOE | | | | | | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

DMA_TCDn_NBYTES_MLOFFNO field descriptions

| Field | Description |
|-------------|---|
| 31 SMLOE | Source Minor Loop Offset Enable Selects whether the minor loop offset is applied to the source address upon minor loop completion. 0 The minor loop offset is not applied to the SADDR 1 The minor loop offset is applied to the SADDR |
| 30 DMLOE | Destination Minor Loop Offset enable Selects whether the minor loop offset is applied to the destination address upon minor loop completion. |

Table continues on the next page...

DMA_TCDn_NBYTES_MLOFFNO field descriptions (continued)

| Field | Description |
|----------------|---|
| | 0 The minor loop offset is not applied to the DADDR |
| | 1 The minor loop offset is applied to the DADDR |
| 29–0 NBYTES | <p>Minor Byte Transfer Count</p> <p>Number of bytes to be transferred in each service request of the channel.</p> <p>As a channel activates, the appropriate TCD contents load into the eDMA engine, and the appropriate reads and writes perform until the minor byte transfer count has transferred. This is an indivisible operation and cannot be halted; although, it may be stalled by using the bandwidth control field, or via preemption. After the minor count is exhausted, the SADDR and DADDR values are written back into the TCD memory, the major iteration count is decremented and restored to the TCD memory. If the major iteration count is completed, additional processing is performed.</p> |

21.3.22 TCD Signed Minor Loop Offset (Minor Loop and Offset Enabled) (DMA_TCDn_NBYTES_MLOFFYES)

One of three registers (this register, TCD_NBYTES_MLNO, or TCD_NBYTES_MLOFFNO), defines the number of bytes to transfer per request. Which register to use depends on whether minor loop mapping is disabled, enabled but not used for this channel, or enabled and used.

TCD word 2 is defined as follows if:

- Minor loop mapping is enabled (CR[EMLM] = 1) and
- Minor loop offset is enabled (SMLOE or DMLOE = 1)

If minor loop mapping is enabled and SMLOE and DMLOE are cleared, then refer to the TCD_NBYTES_MLOFFNO register description. If minor loop mapping is disabled, then refer to the TCD_NBYTES_MLNO register description.

Address: 4000_8000h base + 1008h offset + (32d × i), where i=0d to 15d

| | | | | | | | | | | | | | | | | |
|-------|-------|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | | | | | | | | | | | | | | | | |
| W | SMLOE | DMLOE | | | | | | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

DMA_TCDn_NBYTES_MLOFFYES field descriptions

| Field | Description |
|----------------|--|
| 31 SMLOE | Source Minor Loop Offset Enable Selects whether the minor loop offset is applied to the source address upon minor loop completion. 0 The minor loop offset is not applied to the SADDR 1 The minor loop offset is applied to the SADDR |
| 30 DMLOE | Destination Minor Loop Offset enable Selects whether the minor loop offset is applied to the destination address upon minor loop completion. 0 The minor loop offset is not applied to the DADDR 1 The minor loop offset is applied to the DADDR |
| 29–10 MLOFF | If SMLOE or DMLOE is set, this field represents a sign-extended offset applied to the source or destination address to form the next-state value after the minor loop completes. |
| 9–0 NBYTES | Minor Byte Transfer Count Number of bytes to be transferred in each service request of the channel. As a channel activates, the appropriate TCD contents load into the eDMA engine, and the appropriate reads and writes perform until the minor byte transfer count has transferred. This is an indivisible operation and cannot be halted. (Although, it may be stalled by using the bandwidth control field, or via preemption.) After the minor count is exhausted, the SADDR and DADDR values are written back into the TCD memory, the major iteration count is decremented and restored to the TCD memory. If the major iteration count is completed, additional processing is performed. |

21.3.23 TCD Last Source Address Adjustment (DMA_TCDn_SLAST)

Address: 4000_8000h base + 100Ch offset + (32d × i), where i=0d to 15d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | SLAST | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | |

* Notes:

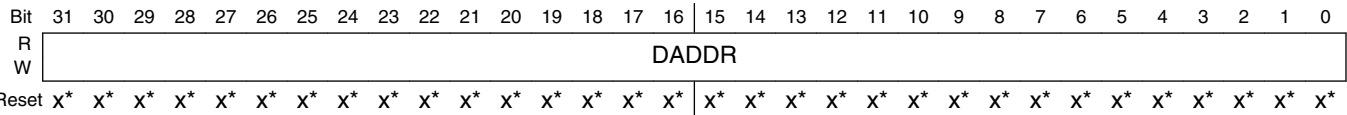
- x = Undefined at reset.

DMA_TCDn_SLAST field descriptions

| Field | Description |
|---------------|--|
| 31–0 SLAST | Last source Address Adjustment Adjustment value added to the source address at the completion of the major iteration count. This value can be applied to restore the source address to the initial value, or adjust the address to reference the next data structure. This register uses two's complement notation; the overflow bit is discarded. |

21.3.24 TCD Destination Address (DMA_TCDn_DADDR)

Address: 4000_8000h base + 1010h offset + (32d × i), where i=0d to 15d



- * Notes:
- x = Undefined at reset.

DMA_TCDn_DADDR field descriptions

| Field | Description |
|---------------|---|
| 31–0 DADDR | Destination Address Memory address pointing to the destination data. |

21.3.25 TCD Signed Destination Address Offset (DMA_TCDn_DOFF)

Address: 4000_8000h base + 1014h offset + (32d × i), where i=0d to 15d



- * Notes:
- x = Undefined at reset.

DMA_TCDn_DOFF field descriptions

| Field | Description |
|--------------|---|
| 15–0 DOFF | Destination Address Signed offset Sign-extended offset applied to the current destination address to form the next-state value as each destination write is completed. |

21.3.26 TCD Current Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCDn_CITER_ELINKYES)

If TCDn_CITER[ELINK] is set, the TCDn_CITER register is defined as follows.

Address: 4000_8000h base + 1016h offset + (32d × i), where i=0d to 15d

| | | | | | | | | | |
|-------|-------|----|----|----|--------|----|----|----|-------|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | |
| Read | ELINK | | 0 | | LINKCH | | | | CITER |
| Write | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | |
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |
| Read | CITER | | | | | | | | |
| Write | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | |

* Notes:

- x = Undefined at reset.

DMA_TCDn_CITER_ELINKYES field descriptions

| Field | Description |
|-------------------|---|
| 15 ELINK | <p>Enable channel-to-channel linking on minor-loop complete</p> <p>As the channel completes the minor loop, this flag enables linking to another channel, defined by the LINKCH field. The link target channel initiates a channel service request via an internal mechanism that sets the TCDn_CSR[START] bit of the specified channel.</p> <p>If channel linking is disabled, the CITER value is extended to 15 bits in place of a link channel number. If the major loop is exhausted, this link mechanism is suppressed in favor of the MAJORELINK channel linking.</p> <p>NOTE: This bit must be equal to the BITER[ELINK] bit; otherwise, a configuration error is reported.</p> <p>0 The channel-to-channel linking is disabled 1 The channel-to-channel linking is enabled</p> |
| 14–13 Reserved | This field is reserved. |
| 12–9 LINKCH | <p>Link Channel Number</p> <p>If channel-to-channel linking is enabled (ELINK = 1), then after the minor loop is exhausted, the eDMA engine initiates a channel service request to the channel defined by these four bits by setting that channel's TCDn_CSR[START] bit.</p> |
| 8–0 CITER | <p>Current Major Iteration Count</p> <p>This 9-bit (ELINK = 1) or 15-bit (ELINK = 0) count represents the current major loop count for the channel. It is decremented each time the minor loop is completed and updated in the transfer control descriptor memory. After the major iteration count is exhausted, the channel performs a number of operations (e.g., final source and destination address calculations), optionally generating an interrupt to signal channel completion before reloading the CITER field from the beginning iteration count (BITER) field.</p> |

Table continues on the next page...

DMA_TCDn_CITER_ELINKYES field descriptions (continued)

| Field | Description |
|-------|--|
| | <p>NOTE: When the CITER field is initially loaded by software, it must be set to the same value as that contained in the BITER field.</p> <p>NOTE: If the channel is configured to execute a single service request, the initial values of BITER and CITER should be 0x0001.</p> |

21.3.27 TCD Current Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCDn_CITER_ELINKNO)

If TCDn_CITER[ELINK] is cleared, the TCDn_CITER register is defined as follows.

Address: 4000_8000h base + 1016h offset + (32d × i), where i=0d to 15d

| | | | | | | | | |
|-------|-------|-------|----|----|----|----|----|----|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| Read | ELINK | CITER | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | CITER | | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

DMA_TCDn_CITER_ELINKNO field descriptions

| Field | Description |
|---------------|---|
| 15 ELINK | <p>Enable channel-to-channel linking on minor-loop complete</p> <p>As the channel completes the minor loop, this flag enables linking to another channel, defined by the LINKCH field. The link target channel initiates a channel service request via an internal mechanism that sets the TCDn_CSR[START] bit of the specified channel.</p> <p>If channel linking is disabled, the CITER value is extended to 15 bits in place of a link channel number. If the major loop is exhausted, this link mechanism is suppressed in favor of the MAJORELINK channel linking.</p> <p>NOTE: This bit must be equal to the BITER[ELINK] bit; otherwise, a configuration error is reported.</p> <p>0 The channel-to-channel linking is disabled 1 The channel-to-channel linking is enabled</p> |
| 14–0 CITER | <p>Current Major Iteration Count</p> <p>This 9-bit (ELINK = 1) or 15-bit (ELINK = 0) count represents the current major loop count for the channel. It is decremented each time the minor loop is completed and updated in the transfer control descriptor memory. After the major iteration count is exhausted, the channel performs a number of operations (e.g.,</p> |

Table continues on the next page...

DMA_TCDn_CITER_ELINKNO field descriptions (continued)

| Field | Description |
|-------|--|
| | <p>final source and destination address calculations), optionally generating an interrupt to signal channel completion before reloading the CITER field from the beginning iteration count (BITER) field.</p> <p>NOTE: When the CITER field is initially loaded by software, it must be set to the same value as that contained in the BITER field.</p> <p>NOTE: If the channel is configured to execute a single service request, the initial values of BITER and CITER should be 0x0001.</p> |

21.3.28 TCD Last Destination Address Adjustment/Scatter Gather Address (DMA_TCDn_DLASTSGA)

Address: 4000_8000h base + 1018h offset + (32d × i), where i=0d to 15d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | <div>DLASTSGA</div> | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | X* | |

* Notes:

- x = Undefined at reset.

DMA_TCDn_DLASTSGA field descriptions

| Field | Description |
|------------------|---|
| 31–0 DLASTSGA | <p>Destination last address adjustment or the memory address for the next transfer control descriptor to be loaded into this channel (scatter/gather).</p> <p>If (TCDn_CSR[ESG] = 0), then:</p> <ul style="list-style-type: none"> Adjustment value added to the destination address at the completion of the major iteration count. This value can apply to restore the destination address to the initial value or adjust the address to reference the next data structure. This field uses two's complement notation for the final destination address adjustment. <p>Otherwise:</p> <ul style="list-style-type: none"> This address points to the beginning of a 0-modulo-32-byte region containing the next transfer control descriptor to be loaded into this channel. This channel reload is performed as the major iteration count completes. The scatter/gather address must be 0-modulo-32-byte, else a configuration error is reported. |

21.3.29 TCD Control and Status (DMA_TCDn_CSR)

Address: 4000_8000h base + 101Ch offset + (32d × i), where i=0d to 15d

| | | | | | | | | |
|-------|-----|----|----|----|-------------|----|----|----|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| Read | BWC | | 0 | | MAJORLINKCH | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

| | | | | | | | | |
|-------|------|--------|------------|-----|------|---------|----------|-------|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | DONE | ACTIVE | MAJORELINK | ESG | DREQ | INTHALF | INTMAJOR | START |
| Write | | | | | | | | |
| Reset | 0 | 0 | x* | x* | x* | x* | x* | 0 |

* Notes:

- x = Undefined at reset.

DMA_TCDn_CSR field descriptions

| Field | Description |
|---------------------|---|
| 15–14 BWC | <p>Bandwidth Control</p> <p>Throttles the amount of bus bandwidth consumed by the eDMA. In general, as the eDMA processes the minor loop, it continuously generates read/write sequences until the minor count is exhausted. This field forces the eDMA to stall after the completion of each read/write access to control the bus request bandwidth seen by the crossbar switch.</p> <p>NOTE: If the source and destination sizes are equal, this field is ignored between the first and second transfers and after the last write of each minor loop. This behavior is a side effect of reducing start-up latency.</p> <p>00 No eDMA engine stalls 01 Reserved 10 eDMA engine stalls for 4 cycles after each r/w 11 eDMA engine stalls for 8 cycles after each r/w</p> |
| 13–12 Reserved | This field is reserved. |
| 11–8 MAJORLINKCH | <p>Link Channel Number</p> <p>If (MAJORELINK = 0) then</p> <ul style="list-style-type: none"> No channel-to-channel linking (or chaining) is performed after the major loop counter is exhausted. <p>else</p> <ul style="list-style-type: none"> After the major loop counter is exhausted, the eDMA engine initiates a channel service request at the channel defined by these six bits by setting that channel's TCDn_CSR[START] bit. |
| 7 DONE | <p>Channel Done</p> <p>This flag indicates the eDMA has completed the major loop. The eDMA engine sets it as the CITER count reaches zero; The software clears it, or the hardware when the channel is activated.</p> <p>NOTE: This bit must be cleared to write the MAJORELINK or ESG bits.</p> |
| 6 ACTIVE | Channel Active |

Table continues on the next page...

DMA_TCDn_CSR field descriptions (continued)

| Field | Description |
|-----------------|--|
| | This flag signals the channel is currently in execution. It is set when channel service begins, and the eDMA clears it as the minor loop completes or if any error condition is detected. This bit resets to zero. |
| 5 MAJORELINK | <p>Enable channel-to-channel linking on major loop complete</p> <p>As the channel completes the major loop, this flag enables the linking to another channel, defined by MAJORLINKCH. The link target channel initiates a channel service request via an internal mechanism that sets the TCDn_CSR[START] bit of the specified channel.</p> <p>NOTE: To support the dynamic linking coherency model, this field is forced to zero when written to while the TCDn_CSR[DONE] bit is set.</p> <p>0 The channel-to-channel linking is disabled 1 The channel-to-channel linking is enabled</p> |
| 4 ESG | <p>Enable Scatter/Gather Processing</p> <p>As the channel completes the major loop, this flag enables scatter/gather processing in the current channel. If enabled, the eDMA engine uses DLASTSGA as a memory pointer to a 0-modulo-32 address containing a 32-byte data structure loaded as the transfer control descriptor into the local memory.</p> <p>NOTE: To support the dynamic scatter/gather coherency model, this field is forced to zero when written to while the TCDn_CSR[DONE] bit is set.</p> <p>0 The current channel's TCD is normal format. 1 The current channel's TCD specifies a scatter gather format. The DLASTSGA field provides a memory pointer to the next TCD to be loaded into this channel after the major loop completes its execution.</p> |
| 3 DREQ | <p>Disable Request</p> <p>If this flag is set, the eDMA hardware automatically clears the corresponding ERQ bit when the current major iteration count reaches zero.</p> <p>0 The channel's ERQ bit is not affected 1 The channel's ERQ bit is cleared when the major loop is complete</p> |
| 2 INTHALF | <p>Enable an interrupt when major counter is half complete.</p> <p>If this flag is set, the channel generates an interrupt request by setting the appropriate bit in the INT register when the current major iteration count reaches the halfway point. Specifically, the comparison performed by the eDMA engine is $(CITER == (BITER >> 1))$. This halfway point interrupt request is provided to support double-buffered (aka ping-pong) schemes or other types of data movement where the processor needs an early indication of the transfer's progress. If BITER is set, do not use INTHALF. Use INTMAJOR instead.</p> <p>0 The half-point interrupt is disabled 1 The half-point interrupt is enabled</p> |
| 1 INTMAJOR | <p>Enable an interrupt when major iteration count completes</p> <p>If this flag is set, the channel generates an interrupt request by setting the appropriate bit in the INT when the current major iteration count reaches zero.</p> <p>0 The end-of-major loop interrupt is disabled 1 The end-of-major loop interrupt is enabled</p> |
| 0 START | <p>Channel Start</p> <p>If this flag is set, the channel is requesting service. The eDMA hardware automatically clears this flag after the channel begins execution.</p> |

Table continues on the next page...

DMA_TCDn_CSR field descriptions (continued)

| Field | Description |
|-------|--|
| 0 | The channel is not explicitly started |
| 1 | The channel is explicitly started via a software initiated service request |

21.3.30 TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Enabled) (DMA_TCDn_BITER_ELINKYES)

If the TCDn_BITER[ELINK] bit is set, the TCDn_BITER register is defined as follows.

Address: 4000_8000h base + 101Eh offset + (32d × i), where i=0d to 15d

| | | | | | | | | | |
|-------|-------|----|----|----|--------|----|----|----|-------|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | |
| Read | ELINK | | | | LINKCH | | | | BITER |
| Write | | 0 | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | |

| | | | | | | | | |
|-------|-------|----|----|----|----|----|----|----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | BITER | | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

DMA_TCDn_BITER_ELINKYES field descriptions

| Field | Description |
|-------------------|---|
| 15 ELINK | <p>Enables channel-to-channel linking on minor loop complete</p> <p>As the channel completes the minor loop, this flag enables the linking to another channel, defined by BITER[LINKCH]. The link target channel initiates a channel service request via an internal mechanism that sets the TCDn_CSR[START] bit of the specified channel. If channel linking disables, the BITER value extends to 15 bits in place of a link channel number. If the major loop is exhausted, this link mechanism is suppressed in favor of the MAJORELINK channel linking.</p> <p>NOTE: When the software loads the TCD, this field must be set equal to the corresponding CITER field; otherwise, a configuration error is reported. As the major iteration count is exhausted, the contents of this field is reloaded into the CITER field.</p> <p>0 The channel-to-channel linking is disabled 1 The channel-to-channel linking is enabled</p> |
| 14–13 Reserved | This field is reserved. |
| 12–9 LINKCH | <p>Link Channel Number</p> <p>If channel-to-channel linking is enabled (ELINK = 1), then after the minor loop is exhausted, the eDMA engine initiates a channel service request at the channel defined by these four bits by setting that channel's TCDn_CSR[START] bit.</p> |

Table continues on the next page...

DMA_TCDn_BITER_ELINKYES field descriptions (continued)

| Field | Description |
|--------------|---|
| | NOTE: When the software loads the TCD, this field must be set equal to the corresponding CITER field; otherwise, a configuration error is reported. As the major iteration count is exhausted, the contents of this field is reloaded into the CITER field. |
| 8–0 BITER | <p>Starting Major Iteration Count</p> <p>As the transfer control descriptor is first loaded by software, this 9-bit (ELINK = 1) or 15-bit (ELINK = 0) field must be equal to the value in the CITER field. As the major iteration count is exhausted, the contents of this field are reloaded into the CITER field.</p> <p>NOTE: When the software loads the TCD, this field must be set equal to the corresponding CITER field; otherwise, a configuration error is reported. As the major iteration count is exhausted, the contents of this field is reloaded into the CITER field. If the channel is configured to execute a single service request, the initial values of BITER and CITER should be 0x0001.</p> |

21.3.31 TCD Beginning Minor Loop Link, Major Loop Count (Channel Linking Disabled) (DMA_TCDn_BITER_ELINKNO)

If the TCDn_BITER[ELINK] bit is cleared, the TCDn_BITER register is defined as follows.

Address: 4000_8000h base + 101Eh offset + (32d × i), where i=0d to 15d

| | | | | | | | | |
|-------|-------|-------|----|----|----|----|----|----|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| Read | ELINK | BITER | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

| | | | | | | | | |
|-------|-------|----|----|----|----|----|----|----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | BITER | | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

DMA_TCDn_BITER_ELINKNO field descriptions

| Field | Description |
|-------------|--|
| 15 ELINK | <p>Enables channel-to-channel linking on minor loop complete</p> <p>As the channel completes the minor loop, this flag enables the linking to another channel, defined by BITER[LINKCH]. The link target channel initiates a channel service request via an internal mechanism that sets the TCDn_CSR[START] bit of the specified channel. If channel linking is disabled, the BITER value extends to 15 bits in place of a link channel number. If the major loop is exhausted, this link mechanism is suppressed in favor of the MAJORELINK channel linking.</p> <p>NOTE: When the software loads the TCD, this field must be set equal to the corresponding CITER field; otherwise, a configuration error is reported. As the major iteration count is exhausted, the contents of this field is reloaded into the CITER field.</p> |

Table continues on the next page...

DMA_TCDn_BITER_ELINKNO field descriptions (continued)

| Field | Description |
|---------------|--|
| | 0 The channel-to-channel linking is disabled 1 The channel-to-channel linking is enabled |
| 14–0 BITER | Starting Major Iteration Count As the transfer control descriptor is first loaded by software, this 9-bit (ELINK = 1) or 15-bit (ELINK = 0) field must be equal to the value in the CITER field. As the major iteration count is exhausted, the contents of this field are reloaded into the CITER field. NOTE: When the software loads the TCD, this field must be set equal to the corresponding CITER field; otherwise, a configuration error is reported. As the major iteration count is exhausted, the contents of this field is reloaded into the CITER field. If the channel is configured to execute a single service request, the initial values of BITER and CITER should be 0x0001. |

21.4 Functional description

The operation of the eDMA is described in the following subsections.

21.4.1 eDMA basic data flow

The basic flow of a data transfer can be partitioned into three segments.

As shown in the following diagram, the first segment involves the channel activation:

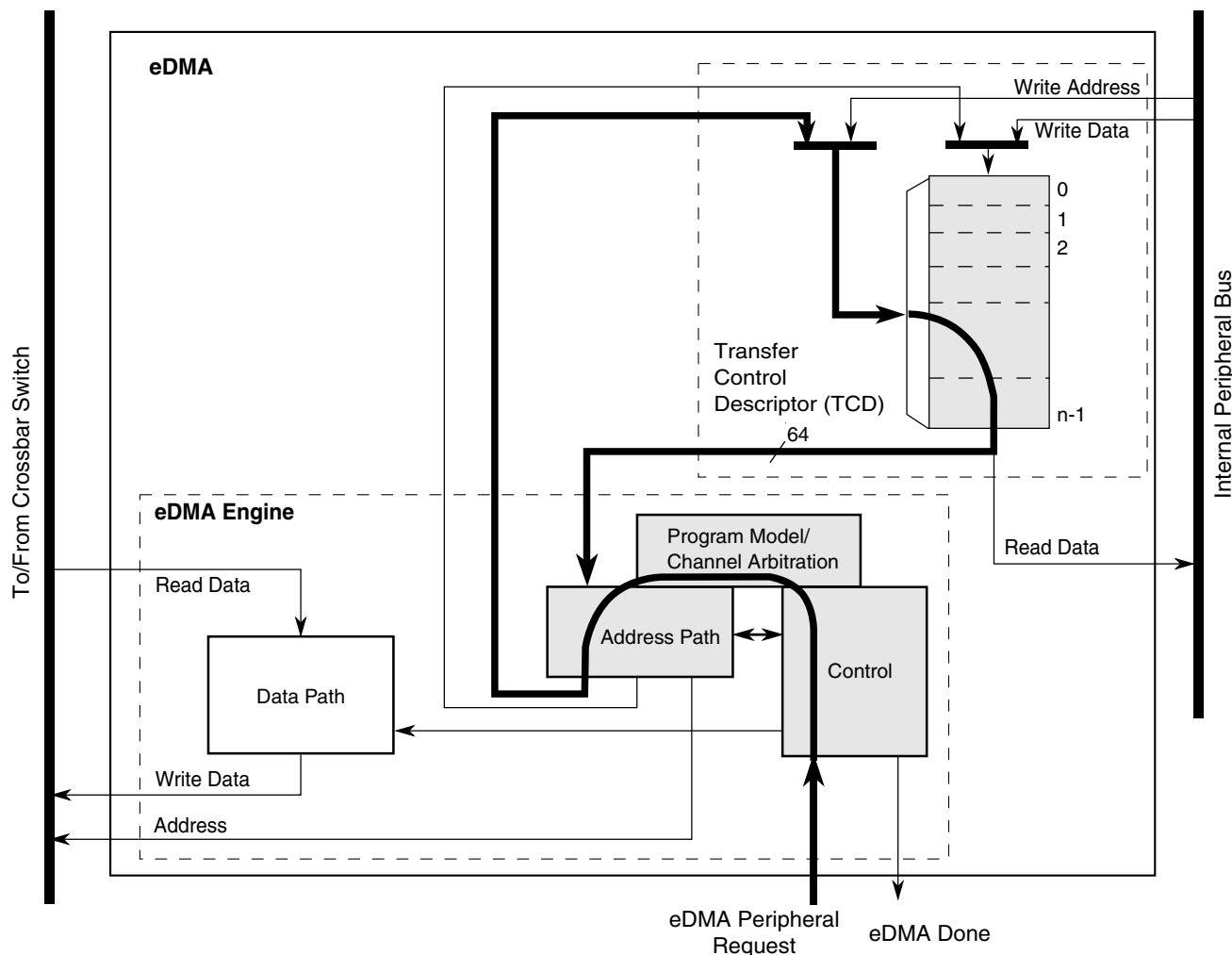


Figure 21-289. eDMA operation, part 1

This example uses the assertion of the eDMA peripheral request signal to request service for channel n . Channel activation via software and the $TCDn_CSR[START]$ bit follows the same basic flow as peripheral requests. The eDMA request input signal is registered internally and then routed through the eDMA engine: first through the control module, then into the program model and channel arbitration. In the next cycle, the channel arbitration performs, using the fixed-priority or round-robin algorithm. After arbitration is complete, the activated channel number is sent through the address path and converted into the required address to access the local memory for $TCDn$. Next, the TCD memory is accessed and the required descriptor read from the local memory and loaded into the eDMA engine address path channel x or y registers. The TCD memory is 64 bits wide to minimize the time needed to fetch the activated channel descriptor and load it into the address path channel x or y registers.

The following diagram illustrates the second part of the basic data flow:

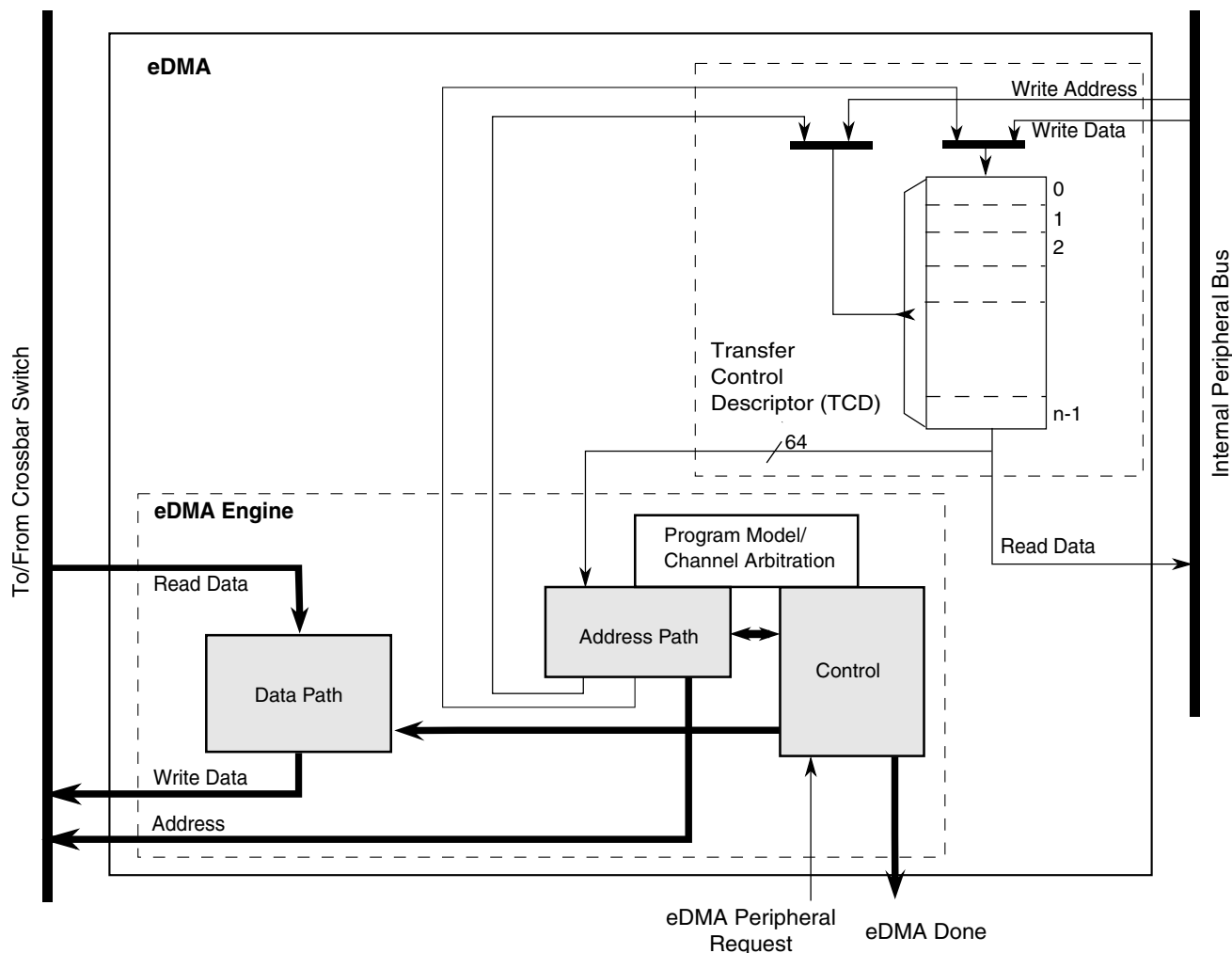


Figure 21-290. eDMA operation, part 2

The modules associated with the data transfer (address path, data path, and control) sequence through the required source reads and destination writes to perform the actual data movement. The source reads are initiated and the fetched data is temporarily stored in the data path block until it is gated onto the internal bus during the destination write. This source read/destination write processing continues until the minor byte count has transferred.

After the minor byte count has moved, the final phase of the basic data flow is performed. In this segment, the address path logic performs the required updates to certain fields in the appropriate TCD, e.g., SADDR, DADDR, CITER. If the major iteration count is exhausted, additional operations are performed. These include the final address adjustments and reloading of the BITER field into the CITER. Assertion of an optional interrupt request also occurs at this time, as does a possible fetch of a new TCD from memory using the scatter/gather address pointer included in the descriptor (if scatter/gather is enabled). The updates to the TCD memory and the assertion of an interrupt request are shown in the following diagram.

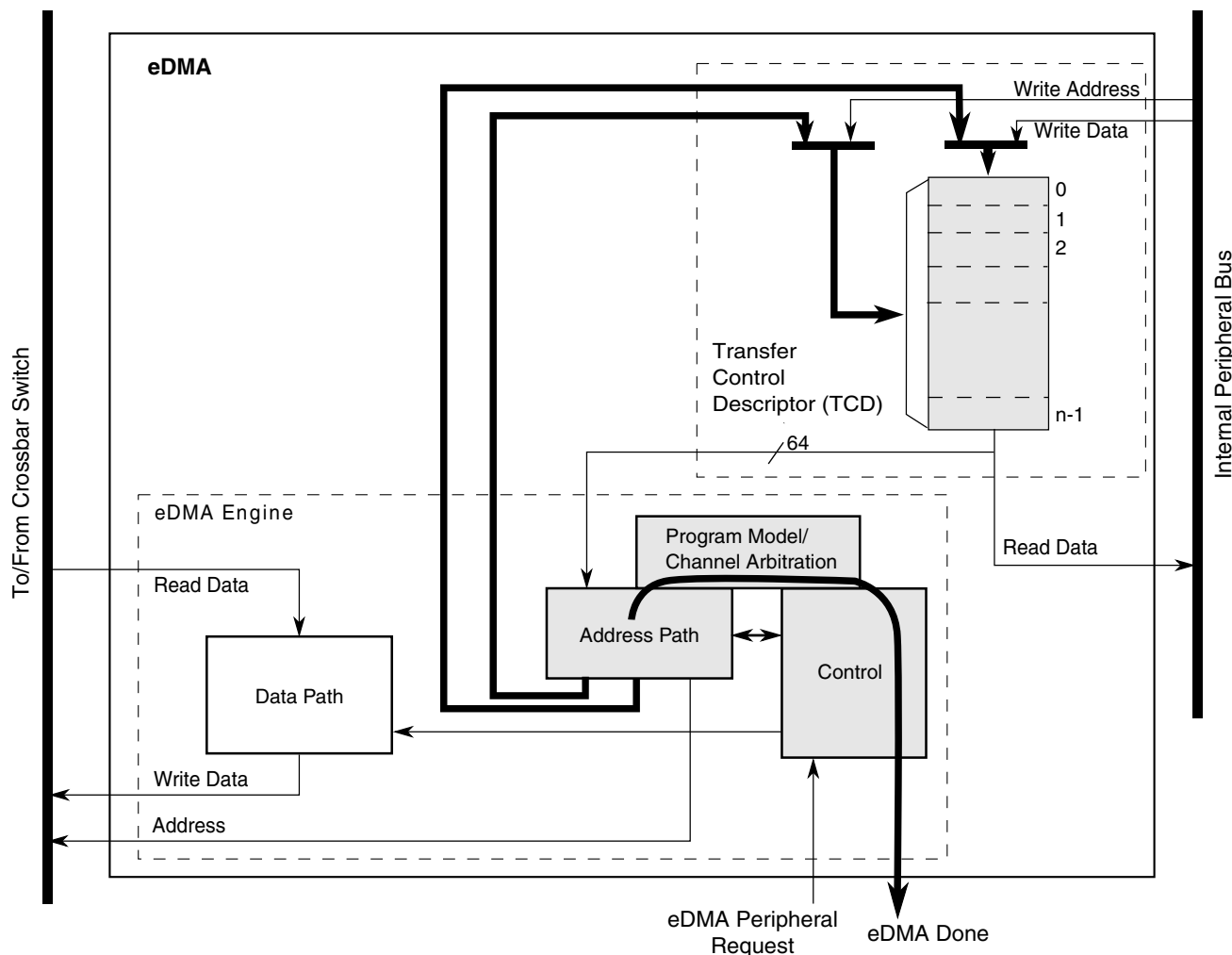


Figure 21-291. eDMA operation, part 3

21.4.2 Fault reporting and handling

Channel errors are reported in the Error Status register (DMAx_ES) and can be caused by:

- A configuration error, which is an illegal setting in the transfer-control descriptor or an illegal priority register setting in Fixed-Arbitration mode, or
- An error termination to a bus master read or write cycle

A configuration error is reported when the starting source or destination address, source or destination offsets, minor loop byte count, or the transfer size represent an inconsistent state. Each of these possible causes are detailed below:

- The addresses and offsets must be aligned on 0-modulo-transfer-size boundaries.
- The minor loop byte count must be a multiple of the source and destination transfer sizes.

- All source reads and destination writes must be configured to the natural boundary of the programmed transfer size respectively.
- In fixed arbitration mode, a configuration error is caused by any two channel priorities being equal. All channel priority levels must be unique when fixed arbitration mode is enabled.
- If a scatter/gather operation is enabled upon channel completion, a configuration error is reported if the scatter/gather address (DLAST_SGA) is not aligned on a 32-byte boundary.
- If minor loop channel linking is enabled upon channel completion, a configuration error is reported when the link is attempted if the TCDn_CITER[E_LINK] bit does not equal the TCDn_BITER[E_LINK] bit.

If enabled, all configuration error conditions, except the scatter/gather and minor-loop link errors, report as the channel activates and asserts an error interrupt request. A scatter/gather configuration error is reported when the scatter/gather operation begins at major loop completion when properly enabled. A minor loop channel link configuration error is reported when the link operation is serviced at minor loop completion.

If a system bus read or write is terminated with an error, the data transfer is stopped and the appropriate bus error flag set. In this case, the state of the channel's transfer control descriptor is updated by the eDMA engine with the current source address, destination address, and current iteration count at the point of the fault. When a system bus error occurs, the channel terminates after the next transfer. Due to pipeline effect, the next transfer is already in progress when the bus error is received by the eDMA. If a bus error occurs on the last read prior to beginning the write sequence, the write executes using the data captured during the bus error. If a bus error occurs on the last write prior to switching to the next read sequence, the read sequence executes before the channel terminates due to the destination bus error.

A transfer may be cancelled by software with the CR[CX] bit. When a cancel transfer request is recognized, the DMA engine stops processing the channel. The current read-write sequence is allowed to finish. If the cancel occurs on the last read-write sequence of a major or minor loop, the cancel request is discarded and the channel retires normally.

The error cancel transfer is the same as a cancel transfer except the Error Status register (DMAx_ES) is updated with the cancelled channel number and ECX is set. The TCD of a cancelled channel contains the source and destination addresses of the last transfer saved in the TCD. If the channel needs to be restarted, you must re-initialize the TCD because the aforementioned fields no longer represent the original parameters. When a transfer is cancelled by the error cancel transfer mechanism, the channel number is loaded into DMA_ES[ERRCHN] and ECX and VLD are set. In addition, an error interrupt may be generated if enabled.

The occurrence of any error causes the eDMA engine to stop normal processing of the active channel immediately (it goes to its error processing states and the transaction to the system bus still has pipeline effect), and the appropriate channel bit in the eDMA error register is asserted. At the same time, the details of the error condition are loaded into the Error Status register (DMAx_ES). The major loop complete indicators, setting the transfer control descriptor DONE flag and the possible assertion of an interrupt request, are not affected when an error is detected. After the error status has been updated, the eDMA engine continues operating by servicing the next appropriate channel. A channel that experiences an error condition is not automatically disabled. If a channel is terminated by an error and then issues another service request before the error is fixed, that channel executes and terminates with the same error condition.

21.4.3 Channel preemption

Channel preemption is enabled on a per-channel basis by setting the DCHPRIn[ECP] bit. Channel preemption allows the executing channel's data transfers to temporarily suspend in favor of starting a higher priority channel. After the preempting channel has completed all its minor loop data transfers, the preempted channel is restored and resumes execution. After the restored channel completes one read/write sequence, it is again eligible for preemption. If any higher priority channel is requesting service, the restored channel is suspended and the higher priority channel is serviced. Nested preemption, that is, attempting to preempt a preempting channel, is not supported. After a preempting channel begins execution, it cannot be preempted. Preemption is available only when fixed arbitration is selected.

A channel's ability to preempt another channel can be disabled by setting DCHPRIn[DPA]. When a channel's preempt ability is disabled, that channel cannot suspend a lower priority channel's data transfer, regardless of the lower priority channel's ECP setting. This allows for a pool of low priority, large data-moving channels to be defined. These low priority channels can be configured to not preempt each other, thus preventing a low priority channel from consuming the preempt slot normally available to a true, high priority channel.

21.4.4 Performance

This section addresses the performance of the eDMA module, focusing on two separate metrics:

- In the traditional data movement context, performance is best expressed as the peak data transfer rates achieved using the eDMA. In most implementations, this transfer rate is limited by the speed of the source and destination address spaces.
- In a second context where device-paced movement of single data values to/from peripherals is dominant, a measure of the requests that can be serviced in a fixed time is a more relevant metric. In this environment, the speed of the source and destination address spaces remains important. However, the microarchitecture of the eDMA also factors significantly into the resulting metric.

21.4.4.1 Peak transfer rates

The peak transfer rates for several different source and destination transfers are shown in the following tables. These tables assume:

- Internal SRAM can be accessed with zero wait-states when viewed from the system bus data phase
- All internal peripheral bus reads require two wait-states, and internal peripheral bus writes three wait-states, when viewed from the system bus data phase
- All internal peripheral bus accesses are 32-bits in size

This table compares peak transfer rates based on different possible system speeds. Specific chips/devices may not support all system speeds listed.

Table 21-292. eDMA peak transfer rates (Mbytes/sec)

| System Speed, Width | Internal SRAM-to-Internal SRAM | 32 bit internal peripheral bus-to-Internal SRAM | Internal SRAM-to-32 bit internal peripheral bus |
|---------------------|--------------------------------|---|---|
| 66.7 MHz, 32 bit | 133.3 | 66.7 | 53.3 |
| 83.3 MHz, 32 bit | 166.7 | 83.3 | 66.7 |
| 100.0 MHz, 32 bit | 200.0 | 100.0 | 80.0 |
| 133.3 MHz, 32 bit | 266.7 | 133.3 | 106.7 |
| 150.0 MHz, 32 bit | 300.0 | 150.0 | 120.0 |

Internal-SRAM-to-internal-SRAM transfers occur at the core's datapath width. For all transfers involving the internal peripheral bus, 32-bit transfer sizes are used. In all cases, the transfer rate includes the time to read the source plus the time to write the destination.

21.4.4.2 Peak request rates

The second performance metric is a measure of the number of DMA requests that can be serviced in a given amount of time. For this metric, assume that the peripheral request causes the channel to move a single internal peripheral bus-mapped operand to/from internal SRAM. The same timing assumptions used in the previous example apply to this calculation. In particular, this metric also reflects the time required to activate the channel.

The eDMA design supports the following hardware service request sequence. Note that the exact timing from Cycle 7 is a function of the response times for the channel's read and write accesses. In the case of an internal peripheral bus read and internal SRAM write, the combined data phase time is 4 cycles. For an SRAM read and internal peripheral bus write, it is 5 cycles.

Table 21-293. Hardware service request process

| Cycle | | Description |
|---|--|--|
| With internal peripheral bus read and internal SRAM write | With SRAM read and internal peripheral bus write | |
| 1 | | eDMA peripheral request is asserted. |
| 2 | | The eDMA peripheral request is registered locally in the eDMA module and qualified. TCD _n _CSR[START] bit initiated requests start at this point with the registering of the user write to TCD _n word 7. |
| 3 | | Channel arbitration begins. |
| 4 | | Channel arbitration completes. The transfer control descriptor local memory read is initiated. |
| 5–6 | | The first two parts of the activated channel's TCD is read from the local memory. The memory width to the eDMA engine is 64 bits, so the entire descriptor can be accessed in four cycles |
| 7 | | The first system bus read cycle is initiated, as the third part of the channel's TCD is read from the local memory. Depending on the state of the crossbar switch, arbitration at the system bus may insert an additional cycle of delay here. |
| 8–11 | 8–12 | The last part of the TCD is read in. This cycle represents the first data phase for the read, and the address phase for the destination write. |
| 12 | 13 | This cycle represents the data phase of the last destination write. |
| 13 | 14 | The eDMA engine completes the execution of the inner minor loop and prepares to write back the required TCD _n fields into the local memory. The TCD _n word 7 is read and checked for channel linking or scatter/gather requests. |
| 14 | 15 | The appropriate fields in the first part of the TCD _n are written back into the local memory. |

Table continues on the next page...

Table 21-293. Hardware service request process (continued)

| Cycle | | Description |
|---|--|---|
| With internal peripheral bus read and internal SRAM write | With SRAM read and internal peripheral bus write | |
| 15 | 16 | The fields in the second part of the TCD _n are written back into the local memory. This cycle coincides with the next channel arbitration cycle start. |
| 16 | 17 | The next channel to be activated performs the read of the first part of its TCD from the local memory. This is equivalent to Cycle 4 for the first channel's service request. |

Assuming zero wait states on the system bus, DMA requests can be processed every 9 cycles. Assuming an average of the access times associated with internal peripheral bus-to-SRAM (4 cycles) and SRAM-to-internal peripheral bus (5 cycles), DMA requests can be processed every 11.5 cycles ($4 + (4+5)/2 + 3$). This is the time from Cycle 4 to Cycle $x + 5$. The resulting peak request rate, as a function of the system frequency, is shown in the following table.

Table 21-294. eDMA peak request rate (MReq/sec)

| System frequency (MHz) | Request rate with zero wait states | Request rate with wait states |
|------------------------|---------------------------------------|----------------------------------|
| 66.6 | 7.4 | 5.8 |
| 83.3 | 9.2 | 7.2 |
| 100.0 | 11.1 | 8.7 |
| 133.3 | 14.8 | 11.6 |
| 150.0 | 16.6 | 13.0 |

A general formula to compute the peak request rate with overlapping requests is:

$$\text{PEAKreq} = \text{freq} / [\text{entry} + (1 + \text{read_ws}) + (1 + \text{write_ws}) + \text{exit}]$$

where:

Table 21-295. Peak request formula operands

| Operand | Description |
|----------|---|
| PEAKreq | Peak request rate |
| freq | System frequency |
| entry | Channel startup (4 cycles) |
| read_ws | Wait states seen during the system bus read data phase |
| write_ws | Wait states seen during the system bus write data phase |
| exit | Channel shutdown (3 cycles) |

21.4.4.3 eDMA performance example

Consider a system with the following characteristics:

- Internal SRAM can be accessed with one wait-state when viewed from the system bus data phase
- All internal peripheral bus reads require two wait-states, and internal peripheral bus writes three wait-states viewed from the system bus data phase
- System operates at 150 MHz

For an SRAM to internal peripheral bus transfer,

$$\text{PEAKreq} = 150 \text{ MHz} / [4 + (1 + 1) + (1 + 3) + 3] \text{ cycles} = 11.5 \text{ Mreq/sec}$$

For an internal peripheral bus to SRAM transfer,

$$\text{PEAKreq} = 150 \text{ MHz} / [4 + (1 + 2) + (1 + 1) + 3] \text{ cycles} = 12.5 \text{ Mreq/sec}$$

Assuming an even distribution of the two transfer types, the average peak request rate would be:

$$\text{PEAKreq} = (11.5 \text{ Mreq/sec} + 12.5 \text{ Mreq/sec}) / 2 = 12.0 \text{ Mreq/sec}$$

The minimum number of cycles to perform a single read/write, zero wait states on the system bus, from a cold start where no channel is executing and eDMA is idle are:

- 11 cycles for a software, that is, a TCD n _CSR[START] bit, request
- 12 cycles for a hardware, that is, an eDMA peripheral request signal, request

Two cycles account for the arbitration pipeline and one extra cycle on the hardware request resulting from the internal registering of the eDMA peripheral request signals. For the peak request rate calculations above, the arbitration and request registering is absorbed in or overlaps the previous executing channel.

Note

When channel linking or scatter/gather is enabled, a two cycle delay is imposed on the next channel selection and startup. This allows the link channel or the scatter/gather channel to be eligible and considered in the arbitration pool for next channel selection.

21.5 Initialization/application information

The following sections discuss initialization of the eDMA and programming considerations.

21.5.1 eDMA initialization

To initialize the eDMA:

1. Write to the CR if a configuration other than the default is desired.
2. Write the channel priority levels to the DCHPRI n registers if a configuration other than the default is desired.
3. Enable error interrupts in the EEI register if so desired.
4. Write the 32-byte TCD for each channel that may request service.
5. Enable any hardware service requests via the ERQH and ERQL registers.
6. Request channel service via either:
 - Software: setting the TCD n _CSR[START]
 - Hardware: slave device asserting its eDMA peripheral request signal

After any channel requests service, a channel is selected for execution based on the arbitration and priority levels written into the programmer's model. The eDMA engine reads the entire TCD, including the TCD control and status fields, as shown in the following table, for the selected channel into its internal address path module.

As the TCD is read, the first transfer is initiated on the internal bus, unless a configuration error is detected. Transfers from the source, as defined by TCD n _SADDR, to the destination, as defined by TCD n _DADDR, continue until the number of bytes specified by TCD n _NBYTES are transferred.

When the transfer is complete, the eDMA engine's local TCD n _SADDR, TCD n _DADDR, and TCD n _CITER are written back to the main TCD memory and any minor loop channel linking is performed, if enabled. If the major loop is exhausted, further post processing executes, such as interrupts, major loop channel linking, and scatter/gather operations, if enabled.

Table 21-296. TCD Control and Status fields

| TCDn_CSR field name | Description |
|---------------------|---|
| START | Control bit to start channel explicitly when using a software initiated DMA service (Automatically cleared by hardware) |
| ACTIVE | Status bit indicating the channel is currently in execution |
| DONE | Status bit indicating major loop completion (cleared by software when using a software initiated DMA service) |
| D_REQ | Control bit to disable DMA request at end of major loop completion when using a hardware initiated DMA service |
| BWC | Control bits for throttling bandwidth control of a channel |
| E_SG | Control bit to enable scatter-gather feature |
| INT_HALF | Control bit to enable interrupt when major loop is half complete |
| INT_MAJ | Control bit to enable interrupt when major loop completes |

The following figure shows how each DMA request initiates one minor-loop transfer, or iteration, without CPU intervention. DMA arbitration can occur after each minor loop, and one level of minor loop DMA preemption is allowed. The number of minor loops in a major loop is specified by the beginning iteration count (BITER).

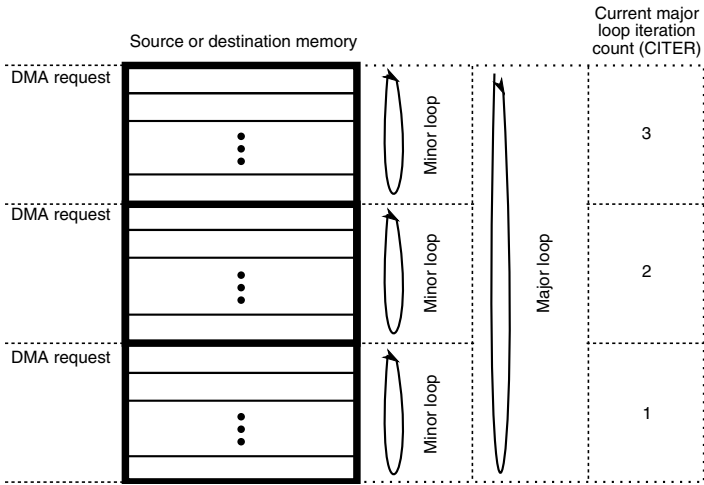


Figure 21-292. Example of multiple loop iterations

The following figure lists the memory array terms and how the TCD settings interrelate.

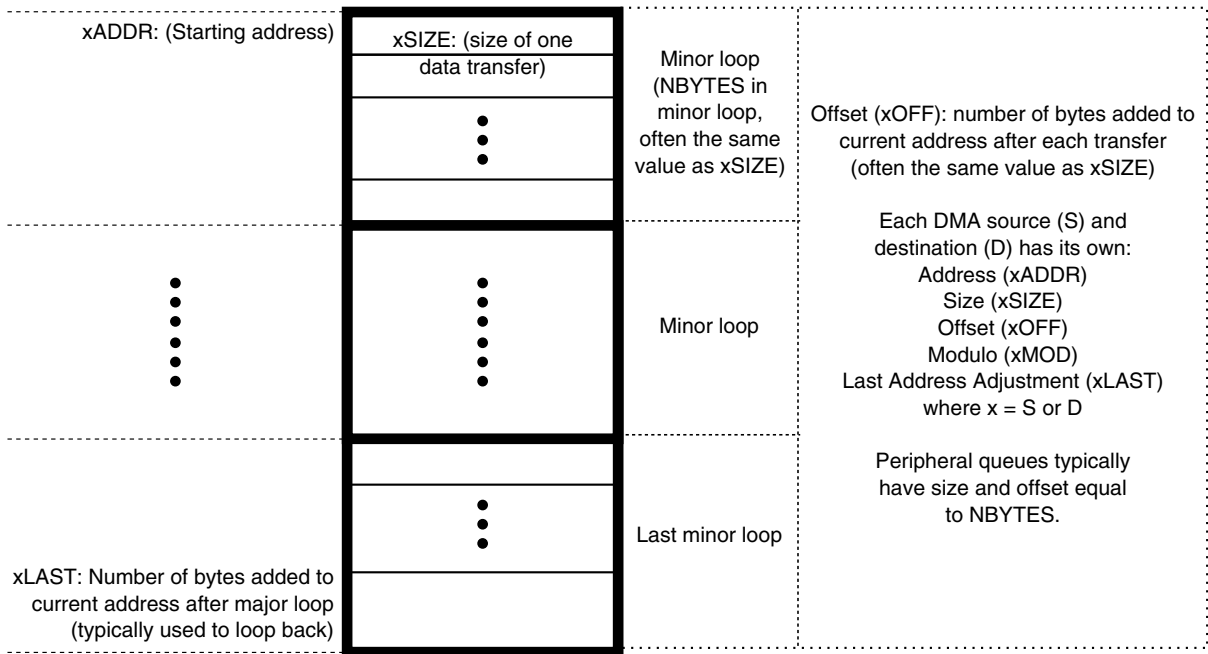


Figure 21-293. Memory array terms

21.5.2 Programming errors

The eDMA performs various tests on the transfer control descriptor to verify consistency in the descriptor data. Most programming errors are reported on a per channel basis with the exception of channel priority error (ES[CPE]).

For all error types other than channel priority error, the channel number causing the error is recorded in the Error Status register (DMAx_ES). If the error source is not removed before the next activation of the problem channel, the error is detected and recorded again.

If priority levels are not unique, when any channel requests service, a channel priority error is reported. The highest channel priority with an active request is selected, but the lowest numbered channel with that priority is selected by arbitration and executed by the eDMA engine. The hardware service request handshake signals, error interrupts, and error reporting is associated with the selected channel.

21.5.3 Arbitration mode considerations

This section discusses arbitration considerations for the eDMA.

21.5.3.1 Fixed channel arbitration

In this mode, the channel service request from the highest priority channel is selected to execute.

21.5.3.2 Round-robin channel arbitration

Channels are serviced starting with the highest channel number and rotating through to the lowest channel number without regard to the channel priority levels.

21.5.4 Performing DMA transfers

This section presents examples on how to perform DMA transfers with the eDMA.

21.5.4.1 Single request

To perform a simple transfer of n bytes of data with one activation, set the major loop to one ($TCDn_CITER = TCDn_BITER = 1$). The data transfer begins after the channel service request is acknowledged and the channel is selected to execute. After the transfer is complete, the $TCDn_CSR[DONE]$ bit is set and an interrupt generates if properly enabled.

For example, the following TCD entry is configured to transfer 16 bytes of data. The eDMA is programmed for one iteration of the major loop transferring 16 bytes per iteration. The source memory has a byte wide memory port located at 0x1000. The destination memory has a 32-bit port located at 0x2000. The address offsets are programmed in increments to match the transfer size: one byte for the source and four bytes for the destination. The final source and destination addresses are adjusted to return to their beginning values.

```
TCDn_CITER = TCDn_BITER = 1
TCDn_NBYTES = 16
TCDn_SADDR = 0x1000
TCDn_SOFF = 1
TCDn_ATTR[SSIZE] = 0
TCDn_SLAST = -16
TCDn_DADDR = 0x2000
TCDn_DOFF = 4
TCDn_ATTR[DSIZE] = 2
TCDn_DLAST_SGA = -16
TCDn_CSR[INT_MAJ] = 1
TCDn_CSR[START] = 1 (Should be written last after all other fields have been initialized)
All other TCDn fields = 0
```

This generates the following event sequence:

1. User write to the `TCDn_CSR[START]` bit requests channel service.
2. The channel is selected by arbitration for servicing.
3. eDMA engine writes: `TCDn_CSR[DONE] = 0`, `TCDn_CSR[START] = 0`, `TCDn_CSR[ACTIVE] = 1`.
4. eDMA engine reads: channel TCD data from local memory to internal register file.
5. The source-to-destination transfers are executed as follows:
 - a. Read byte from location 0x1000, read byte from location 0x1001, read byte from 0x1002, read byte from 0x1003.
 - b. Write 32-bits to location 0x2000 → first iteration of the minor loop.
 - c. Read byte from location 0x1004, read byte from location 0x1005, read byte from 0x1006, read byte from 0x1007.
 - d. Write 32-bits to location 0x2004 → second iteration of the minor loop.
 - e. Read byte from location 0x1008, read byte from location 0x1009, read byte from 0x100A, read byte from 0x100B.
 - f. Write 32-bits to location 0x2008 → third iteration of the minor loop.
 - g. Read byte from location 0x100C, read byte from location 0x100D, read byte from 0x100E, read byte from 0x100F.
 - h. Write 32-bits to location 0x200C → last iteration of the minor loop → major loop complete.
6. The eDMA engine writes: `TCDn_SADDR = 0x1000`, `TCDn_DADDR = 0x2000`, `TCDn_CITER = 1` (`TCDn_BITER`).
7. The eDMA engine writes: `TCDn_CSR[ACTIVE] = 0`, `TCDn_CSR[DONE] = 1`, `INT[n] = 1`.
8. The channel retires and the eDMA goes idle or services the next channel.

21.5.4.2 Multiple requests

The following example transfers 32 bytes via two hardware requests, but is otherwise the same as the previous example. The only fields that change are the major loop iteration count and the final address offsets. The eDMA is programmed for two iterations of the major loop transferring 16 bytes per iteration. After the channel's hardware requests are enabled in the ERQ register, the slave device initiates channel service requests.

```
TCDn_CITER = TCDn_BITER = 2
TCDn_SLAST = -32
TCDn_DLAST_SGA = -32
```

This would generate the following sequence of events:

1. First hardware, that is, eDMA peripheral, request for channel service.
2. The channel is selected by arbitration for servicing.
3. eDMA engine writes: $TCDn_CSR[DONE] = 0$, $TCDn_CSR[START] = 0$, $TCDn_CSR[ACTIVE] = 1$.
4. eDMA engine reads: channel $TCDn$ data from local memory to internal register file.
5. The source to destination transfers are executed as follows:
 - a. Read byte from location 0x1000, read byte from location 0x1001, read byte from 0x1002, read byte from 0x1003.
 - b. Write 32-bits to location 0x2000 → first iteration of the minor loop.
 - c. Read byte from location 0x1004, read byte from location 0x1005, read byte from 0x1006, read byte from 0x1007.
 - d. Write 32-bits to location 0x2004 → second iteration of the minor loop.
 - e. Read byte from location 0x1008, read byte from location 0x1009, read byte from 0x100A, read byte from 0x100B.
 - f. Write 32-bits to location 0x2008 → third iteration of the minor loop.
 - g. Read byte from location 0x100C, read byte from location 0x100D, read byte from 0x100E, read byte from 0x100F.
 - h. Write 32-bits to location 0x200C → last iteration of the minor loop.
6. eDMA engine writes: $TCDn_SADDR = 0x1010$, $TCDn_DADDR = 0x2010$, $TCDn_CITER = 1$.
7. eDMA engine writes: $TCDn_CSR[ACTIVE] = 0$.
8. The channel retires → one iteration of the major loop. The eDMA goes idle or services the next channel.
9. Second hardware, that is, eDMA peripheral, requests channel service.
10. The channel is selected by arbitration for servicing.
11. eDMA engine writes: $TCDn_CSR[DONE] = 0$, $TCDn_CSR[START] = 0$, $TCDn_CSR[ACTIVE] = 1$.

12. eDMA engine reads: channel TCD data from local memory to internal register file.
13. The source to destination transfers are executed as follows:
 - a. Read byte from location 0x1010, read byte from location 0x1011, read byte from 0x1012, read byte from 0x1013.
 - b. Write 32-bits to location 0x2010 → first iteration of the minor loop.
 - c. Read byte from location 0x1014, read byte from location 0x1015, read byte from 0x1016, read byte from 0x1017.
 - d. Write 32-bits to location 0x2014 → second iteration of the minor loop.
 - e. Read byte from location 0x1018, read byte from location 0x1019, read byte from 0x101A, read byte from 0x101B.
 - f. Write 32-bits to location 0x2018 → third iteration of the minor loop.
 - g. Read byte from location 0x101C, read byte from location 0x101D, read byte from 0x101E, read byte from 0x101F.
 - h. Write 32-bits to location 0x201C → last iteration of the minor loop → major loop complete.
14. eDMA engine writes: $TCDn_SADDR = 0x1000$, $TCDn_DADDR = 0x2000$, $TCDn_CITER = 2$ ($TCDn_BITER$).
15. eDMA engine writes: $TCDn_CSR[ACTIVE] = 0$, $TCDn_CSR[DONE] = 1$, $INT[n] = 1$.
16. The channel retires → major loop complete. The eDMA goes idle or services the next channel.

21.5.4.3 Using the modulo feature

The modulo feature of the eDMA provides the ability to implement a circular data queue in which the size of the queue is a power of 2. MOD is a 5-bit field for the source and destination in the TCD, and it specifies which lower address bits increment from their original value after the address+offset calculation. All upper address bits remain the same as in the original value. A setting of 0 for this field disables the modulo feature.

The following table shows how the transfer addresses are specified based on the setting of the MOD field. Here a circular buffer is created where the address wraps to the original value while the 28 upper address bits (0x1234567x) retain their original value. In this example the source address is set to 0x12345670, the offset is set to 4 bytes and the MOD field is set to 4, allowing for a 2⁴ byte (16-byte) size queue.

Table 21-297. Modulo example

| Transfer Number | Address |
|-----------------|------------|
| 1 | 0x12345670 |
| 2 | 0x12345674 |
| 3 | 0x12345678 |
| 4 | 0x1234567C |
| 5 | 0x12345670 |
| 6 | 0x12345674 |

21.5.5 Monitoring transfer descriptor status

This section discusses how to monitor eDMA status.

21.5.5.1 Testing for minor loop completion

There are two methods to test for minor loop completion when using software initiated service requests. The first is to read the TCD_n_CITER field and test for a change. Another method may be extracted from the sequence shown below. The second method is to test the TCD_n_CSR[START] bit and the TCD_n_CSR[ACTIVE] bit. The minor-loop-complete condition is indicated by both bits reading zero after the TCD_n_CSR[START] was set. Polling the TCD_n_CSR[ACTIVE] bit may be inconclusive, because the active status may be missed if the channel execution is short in duration.

The TCD status bits execute the following sequence for a software activated channel:

| Stage | TCD _n _CSR bits | | | State |
|-------|----------------------------|--------|------|--|
| | START | ACTIVE | DONE | |
| 1 | 1 | 0 | 0 | Channel service request via software |
| 2 | 0 | 1 | 0 | Channel is executing |
| 3a | 0 | 0 | 0 | Channel has completed the minor loop and is idle |
| 3b | 0 | 0 | 1 | Channel has completed the major loop and is idle |

The best method to test for minor-loop completion when using hardware, that is, peripheral, initiated service requests is to read the `TCDn_CITER` field and test for a change. The hardware request and acknowledge handshake signals are not visible in the programmer's model.

The TCD status bits execute the following sequence for a hardware-activated channel:

| Stage | TCD _n _CSR bits | | | State |
|-------|----------------------------|--------|------|--|
| | START | ACTIVE | DONE | |
| 1 | 0 | 0 | 0 | Channel service request via hardware (peripheral request asserted) |
| 2 | 0 | 1 | 0 | Channel is executing |
| 3a | 0 | 0 | 0 | Channel has completed the minor loop and is idle |
| 3b | 0 | 0 | 1 | Channel has completed the major loop and is idle |

For both activation types, the major-loop-complete status is explicitly indicated via the `TCDn_CSR[DONE]` bit.

The `TCDn_CSR[START]` bit is cleared automatically when the channel begins execution regardless of how the channel activates.

21.5.5.2 Reading the transfer descriptors of active channels

The eDMA reads back the true `TCDn_SADDR`, `TCDn_DADDR`, and `TCDn_NBYTES` values if read while a channel executes. The true values of the `SADDR`, `DADDR`, and `NBYTES` are the values the eDMA engine currently uses in its internal register file and not the values in the TCD local memory for that channel. The addresses, `SADDR` and `DADDR`, and `NBYTES`, which decrement to zero as the transfer progresses, can give an indication of the progress of the transfer. All other values are read back from the TCD local memory.

21.5.5.3 Checking channel preemption status

Preemption is available only when fixed arbitration is selected as the channel arbitration mode. A preemptive situation is one in which a preempt-enabled channel runs and a higher priority request becomes active. When the eDMA engine is not operating in fixed channel arbitration mode, the determination of the actively running relative priority outstanding requests become undefined. Channel priorities are treated as equal, that is, constantly rotating, when Round-Robin Arbitration mode is selected.

The TCD n _CSR[ACTIVE] bit for the preempted channel remains asserted throughout the preemption. The preempted channel is temporarily suspended while the preempting channel executes one major loop iteration. If two TCD n _CSR[ACTIVE] bits are set simultaneously in the global TCD map, a higher priority channel is actively preempting a lower priority channel.

21.5.6 Channel Linking

Channel linking (or chaining) is a mechanism where one channel sets the TCD n _CSR[START] bit of another channel (or itself), therefore initiating a service request for that channel. When properly enabled, the EDMA engine automatically performs this operation at the major or minor loop completion.

The minor loop channel linking occurs at the completion of the minor loop (or one iteration of the major loop). The TCD n _CITER[E_LINK] field determines whether a minor loop link is requested. When enabled, the channel link is made after each iteration of the major loop except for the last. When the major loop is exhausted, only the major loop channel link fields are used to determine if a channel link should be made. For example, the initial fields of:

```
TCDn_CITER[E_LINK] = 1
TCDn_CITER[LINKCH] = 0xC
TCDn_CITER[CITER] value = 0x4
TCDn_CSR[MAJOR_E_LINK] = 1
TCDn_CSR[MAJOR_LINKCH] = 0x7
```

executes as:

1. Minor loop done → set TCD12_CSR[START] bit
2. Minor loop done → set TCD12_CSR[START] bit
3. Minor loop done → set TCD12_CSR[START] bit
4. Minor loop done, major loop done → set TCD7_CSR[START] bit

When minor loop linking is enabled (TCD n _CITER[E_LINK] = 1), the TCD n _CITER[CITER] field uses a nine bit vector to form the current iteration count. When minor loop linking is disabled (TCD n _CITER[E_LINK] = 0), the TCD n _CITER[CITER] field uses a 15-bit vector to form the current iteration count. The bits associated with the TCD n _CITER[LINKCH] field are concatenated onto the CITER value to increase the range of the CITER.

Note

The TCD n _CITER[E_LINK] bit and the TCD n _BITER[E_LINK] bit must equal or a configuration error is reported. The CITER and BITER vector widths must be equal to calculate the major loop, half-way done interrupt point.

The following table summarizes how a DMA channel can link to another DMA channel, i.e, use another channel's TCD, at the end of a loop.

Table 21-298. Channel Linking Parameters

| Desired Link Behavior | TCD Control Field Name | Description |
|---------------------------|------------------------|--|
| Link at end of Minor Loop | CITER[E_LINK] | Enable channel-to-channel linking on minor loop completion (current iteration) |
| | CITER[LINKCH] | Link channel number when linking at end of minor loop (current iteration) |
| Link at end of Major Loop | CSR[MAJOR_E_LINK] | Enable channel-to-channel linking on major loop completion |
| | CSR[MAJOR_LINKCH] | Link channel number when linking at end of major loop |

21.5.7 Dynamic programming

This section provides recommended methods to change the programming model during channel execution.

21.5.7.1 Dynamically changing the channel priority

The following two options are recommended for dynamically changing channel priority levels:

1. Switch to Round-Robin Channel Arbitration mode, change the channel priorities, then switch back to Fixed Arbitration mode,
2. Disable all the channels, change the channel priorities, then enable the appropriate channels.

21.5.7.2 Dynamic channel linking

Dynamic channel linking is the process of setting the TCD.major.e_link bit during channel execution. This bit is read from the TCD local memory at the end of channel execution, thus allowing the user to enable the feature during channel execution.

Because the user is allowed to change the configuration during execution, a coherency model is needed. Consider the scenario where the user attempts to execute a dynamic channel link by enabling the TCD.major.e_link bit at the same time the eDMA engine is retiring the channel. The TCD.major.e_link would be set in the programmer's model, but it would be unclear whether the actual link was made before the channel retired.

The following coherency model is recommended when executing a dynamic channel link request.

1. Write 1 to the TCD.major.e_link bit.
2. Read back the TCD.major.e_link bit.
3. Test the TCD.major.e_link request status:
 - If TCD.major.e_link = 1, the dynamic link attempt was successful.
 - If TCD.major.e_link = 0, the attempted dynamic link did not succeed (the channel was already retiring).

For this request, the TCD local memory controller forces the TCD.major.e_link bit to zero on any writes to a channel's TCD.word7 after that channel's TCD.done bit is set, indicating the major loop is complete.

NOTE

The user must clear the TCD.done bit before writing the TCD.major.e_link bit. The TCD.done bit is cleared automatically by the eDMA engine after a channel begins execution.

21.5.7.3 Dynamic scatter/gather

Scatter/gather is the process of automatically loading a new TCD into a channel. It allows a DMA channel to use multiple TCDs; this enables a DMA channel to scatter the DMA data to multiple destinations or gather it from multiple sources. When scatter/gather is enabled and the channel has finished its major loop, a new TCD is fetched from system memory and loaded into that channel's descriptor location in eDMA programmer's model, thus replacing the current descriptor.

Because the user is allowed to change the configuration during execution, a coherency model is needed. Consider the scenario where the user attempts to execute a dynamic scatter/gather operation by enabling the TCD.e_sg bit at the same time the eDMA engine is retiring the channel. The TCD.e_sg would be set in the programmer's model, but it would be unclear whether the actual scatter/gather request was honored before the channel retired.

Two methods for this coherency model are shown in the following subsections. Method 1 has the advantage of reading the `major.linkch` field and the `e_sg` bit with a single read. For both dynamic channel linking and scatter/gather requests, the TCD local memory controller forces the `TCD.major.e_link` and `TCD.e_sg` bits to zero on any writes to a channel's `TCD.word7` if that channel's `TCD.done` bit is set indicating the major loop is complete.

NOTE

The user must clear the `TCD.done` bit before writing the `TCD.major.e_link` or `TCD.e_sg` bits. The `TCD.done` bit is cleared automatically by the eDMA engine after a channel begins execution.

21.5.7.3.1 Method 1 (channel not using major loop channel linking)

For a channel not using major loop channel linking, the coherency model described here may be used for a dynamic scatter/gather request.

When the `TCD.major.e_link` bit is zero, the `TCD.major.linkch` field is not used by the eDMA. In this case, the `TCD.major.linkch` bits may be used for other purposes. This method uses the `TCD.major.linkch` field as a TCD identification (ID).

1. When the descriptors are built, write a unique TCD ID in the `TCD.major.linkch` field for each TCD associated with a channel using dynamic scatter/gather.
2. Write 1b to the `TCD.d_req` bit.

Should a dynamic scatter/gather attempt fail, setting the `TCD.d_req` bit will prevent a future hardware activation of this channel. This stops the channel from executing with a destination address (`daddr`) that was calculated using a scatter/gather address (written in the next step) instead of a `dlast` final offset value.

3. Write the `TCD.dlast_sga` field with the scatter/gather address.
4. Write 1b to the `TCD.e_sg` bit.
5. Read back the 16 bit TCD control/status field.
6. Test the `TCD.e_sg` request status and `TCD.major.linkch` value:

If `e_sg = 1b`, the dynamic link attempt was successful.

If `e_sg = 0b` and the `major.linkch` (ID) did not change, the attempted dynamic link did not succeed (the channel was already retiring).

If `e_sg = 0b` and the `major.linkch (ID)` changed, the dynamic link attempt was successful (the new TCD's `e_sg` value cleared the `e_sg` bit).

21.5.7.3.2 Method 2 (channel using major loop channel linking)

For a channel using major loop channel linking, the coherency model described here may be used for a dynamic scatter/gather request. This method uses the `TCD.dlast_sga` field as a TCD identification (ID).

1. Write 1b to the `TCD.d_req` bit.

Should a dynamic scatter/gather attempt fail, setting the `d_req` bit will prevent a future hardware activation of this channel. This stops the channel from executing with a destination address (`daddr`) that was calculated using a scatter/gather address (written in the next step) instead of a `dlast` final offset value.

2. Write the `TCD.dlast_sga` field with the scatter/gather address.
3. Write 1b to the `TCD.e_sg` bit.
4. Read back the `TCD.e_sg` bit.
5. Test the `TCD.e_sg` request status:

If `e_sg = 1b`, the dynamic link attempt was successful.

If `e_sg = 0b`, read the 32 bit `TCD dlast_sga` field.

If `e_sg = 0b` and the `dlast_sga` did not change, the attempted dynamic link did not succeed (the channel was already retiring).

If `e_sg = 0b` and the `dlast_sga` changed, the dynamic link attempt was successful (the new TCD's `e_sg` value cleared the `e_sg` bit).



Chapter 22

External Watchdog Monitor (EWM)

22.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The watchdog is generally used to monitor the flow and execution of embedded software within an MCU. The watchdog consists of a counter that if allowed to overflow, forces an internal reset (asynchronous) to all on-chip peripherals and optionally assert the $\overline{\text{RESET}}$ pin to reset external devices/circuits. The overflow of the watchdog counter must not occur if the software code works well and services the watchdog to re-start the actual counter.

For safety, a redundant watchdog system, External Watchdog Monitor (EWM), is designed to monitor external circuits, as well as the MCU software flow. This provides a back-up mechanism to the internal watchdog that resets the MCU's CPU and peripherals.

The EWM differs from the internal watchdog in that it does not reset the MCU's CPU and peripherals. The EWM if allowed to time-out, provides an independent $\overline{\text{EWM_out}}$ pin that when asserted resets or places an external circuit into a safe mode. The CPU resets the EWM counter that is logically ANDed with an external digital input pin. This pin allows an external circuit to influence the reset_out signal.

22.1.1 Features

Features of EWM module include:

- Independent LPO clock source
- Programmable time-out period specified in terms of number of EWM LPO clock cycles.

- Windowed refresh option
 - Provides robust check that program flow is faster than expected.
 - Programmable window.
 - Refresh outside window leads to assertion of $\overline{\text{EWM_out}}$.
- Robust refresh mechanism
 - Write values of 0xB4 and 0x2C to EWM Refresh Register within 15 (EWM_service_time) peripheral bus clock cycles.
- One output port, $\overline{\text{EWM_out}}$, when asserted is used to reset or place the external circuit into safe mode.
- One Input port, EWM_in , allows an external circuit to control the $\overline{\text{EWM_out}}$ signal.

22.1.2 Modes of Operation

This section describes the module's operating modes.

22.1.2.1 Stop Mode

When the EWM is in stop mode, the CPU services to the EWM cannot occur. On entry to stop mode, the EWM's counter freezes.

There are two possible ways to exit from Stop mode:

- On exit from stop mode through a reset, the EWM remains disabled.
- On exit from stop mode by an interrupt, the EWM is re-enabled, and the counter continues to be clocked from the same value prior to entry to stop mode.

Note the following if the EWM enters the stop mode during CPU service mechanism: At the exit from stop mode by an interrupt, refresh mechanism state machine starts from the previous state which means, if first service command is written correctly and EWM enters the stop mode immediately, the next command has to be written within the next 15 (EWM_service_time) peripheral bus clocks after exiting from stop mode. User must mask all interrupts prior to executing EWM service instructions.

22.1.2.2 Wait Mode

The EWM module treats the stop and wait modes as the same. EWM functionality remains the same in both of these modes.

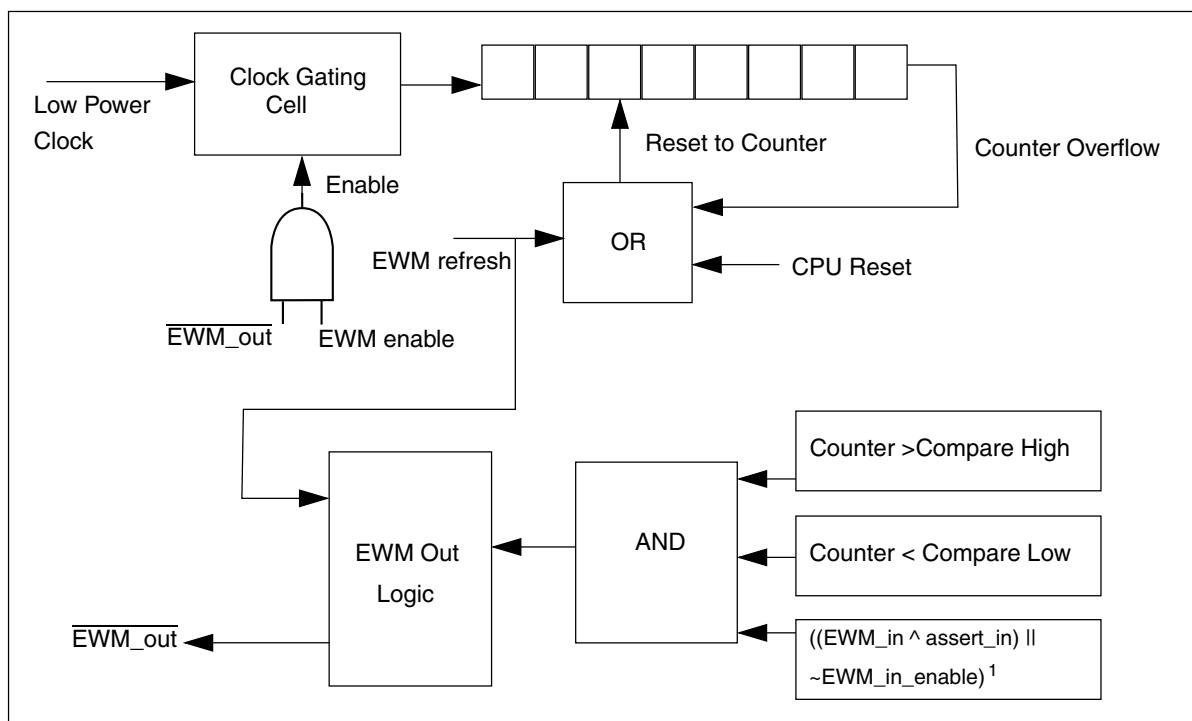
22.1.2.3 Debug Mode

Entry to debug mode has no effect on the EWM.

- If the EWM is enabled prior to entry of debug mode, it remains enabled.
- If the EWM is disabled prior to entry of debug mode, it remains disabled.

22.1.3 Block Diagram

This figure shows the EWM block diagram.



¹ Compare High > Counter > Compare Low

Figure 22-1. EWM Block Diagram

22.2 EWM Signal Descriptions

The EWM has two external signals, as shown in the following table.

Table 22-1. EWM Signal Descriptions

| Signal | Description | I/O |
|---------|--|-----|
| EWM_in | EWM input for safety status of external safety circuits. The polarity of EWM_in is programmable using the EWM_CTRL[ASSIN] bit. The default polarity is active-low. | I |
| EWM_out | EWM reset out signal | O |

22.3 Memory Map/Register Definition

This section contains the module memory map and registers.

EWM memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|----------------------------------|-----------------|-----------------------|-------------|----------------------------|
| 4006_1000 | Control Register (EWM_CTRL) | 8 | R/W | 00h | 22.3.1/416 |
| 4006_1001 | Service Register (EWM_SERV) | 8 | W (always reads 0) | 00h | 22.3.2/417 |
| 4006_1002 | Compare Low Register (EWM_CMPL) | 8 | R/W | 00h | 22.3.3/417 |
| 4006_1003 | Compare High Register (EWM_CMPH) | 8 | R/W | FFh | 22.3.4/418 |

22.3.1 Control Register (EWM_CTRL)

The CTRL register is cleared by any reset.

NOTE

INEN, ASSIN and EWMEN bits can be written once after a CPU reset. Modifying these bits more than once, generates a bus transfer error.

Address: 4006_1000h base + 0h offset = 4006_1000h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---|---|---|---|-------|------|-------|-------|
| Read | 0 | | | | INTEN | INEN | ASSIN | EWMEN |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

EWM_CTRL field descriptions

| Field | Description |
|-----------------|--|
| 7–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3 INTEN | Interrupt Enable. This bit when set and $\overline{\text{EWM_out}}$ is asserted, an interrupt request is generated. To de-assert interrupt request, user should clear this bit by writing 0. |
| 2 INEN | Input Enable. This bit when set, enables the EWM_in port. |
| 1 ASSIN | EWM_in's Assertion State Select. Default assert state of the EWM_in signal is logic zero. Setting ASSIN bit inverts the assert state to a logic one. |
| 0 EWMEN | EWM enable. This bit when set, enables the EWM module. This resets the EWM counter to zero and deasserts the $\overline{\text{EWM_out}}$ signal. Clearing EWMEN bit disables the EWM, and therefore it cannot be enabled until a reset occurs, due to the write-once nature of this bit. |

22.3.2 Service Register (EWM_SERV)

The SERV register provides the interface from the CPU to the EWM module. It is write-only and reads of this register return zero.

Address: 4006_1000h base + 1h offset = 4006_1001h

| | | | | | | | | |
|-------|---------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | | | | |
| Write | SERVICE | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

EWM_SERV field descriptions

| Field | Description |
|----------------|--|
| 7–0 SERVICE | The EWM service mechanism requires the CPU to write two values to the SERV register: a first data byte of 0xB4, followed by a second data byte of 0x2C. The EWM service is illegal if either of the following conditions is true. <ul style="list-style-type: none"> The first or second data byte is not written correctly. The second data byte is not written within a fixed number of peripheral bus cycles of the first data byte. This fixed number of cycles is called <i>EWM_service_time</i>. |

22.3.3 Compare Low Register (EWM_CMPL)

The CMPL register is reset to zero after a CPU reset. This provides no minimum time for the CPU to service the EWM counter.

NOTE

This register can be written only once after a CPU reset.
Writing this register more than once generates a bus transfer error.

Address: 4006_1000h base + 2h offset = 4006_1002h

| | | | | | | | | |
|-------|----------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | COMPAREL | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

EWM_CMPL field descriptions

| Field | Description |
|-----------------|---|
| 7-0 COMPAREL | To prevent runaway code from changing this field, software should write to this field after a CPU reset even if the (default) minimum service time is required. |

22.3.4 Compare High Register (EWM_CMPH)

The CMPH register is reset to 0xFF after a CPU reset. This provides a maximum of 256 clocks time, for the CPU to service the EWM counter.

NOTE

This register can be written only once after a CPU reset.
Writing this register more than once generates a bus transfer error.

NOTE

The valid values for CMPH are up to 0xFE because the EWM counter never expires when CMPH = 0xFF. The expiration happens only if EWM counter is greater than CMPH.

Address: 4006_1000h base + 3h offset = 4006_1003h

| | | | | | | | | |
|-------|----------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | COMPAREH | | | | | | | |
| Write | | | | | | | | |
| Reset | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

EWM_CMPH field descriptions

| Field | Description |
|-----------------|---|
| 7-0 COMPAREH | To prevent runaway code from changing this field, software should write to this field after a CPU reset even if the (default) maximum service time is required. |

22.4 Functional Description

The following sections describe functional details of the EWM module.

22.4.1 The $\overline{\text{EWM_out}}$ Signal

The $\overline{\text{EWM_out}}$ is a digital output signal used to gate an external circuit (application specific) that controls critical safety functions. For example, the $\overline{\text{EWM_out}}$ could be connected to the high voltage transistors circuits that control an AC motor in a large appliance.

The $\overline{\text{EWM_out}}$ signal remains deasserted when the EWM is being regularly serviced by the CPU within the programmable service window, indicating that the application code is executed as expected.

The $\overline{\text{EWM_out}}$ signal is asserted in any of the following conditions:

- Servicing the EWM when the counter value is less than CMPL value.
- If the EWM counter value reaches the CMPH value, and no EWM service has occurred.
- Servicing the EWM when the counter value is more than CMPL and less than CMPH values and EWM_in signal is asserted.
- If functionality of EWM_in pin is enabled and EWM_in pin is asserted while servicing the EWM.
- After any reset (by the virtue of the external pull-down mechanism on the $\overline{\text{EWM_out}}$ pin)

On a normal reset, the $\overline{\text{EWM_out}}$ is asserted. To deassert the $\overline{\text{EWM_out}}$, set EWMEN bit in the CTRL register to enable the EWM.

If the $\overline{\text{EWM_out}}$ signal shares its pad with a digital I/O pin, on reset this actual pad defers to being an input signal. It takes the $\overline{\text{EWM_out}}$ output condition only after you enable the EWM by the EWMEN bit in the CTRL register.

When the $\overline{\text{EWM_out}}$ pin is asserted, it can only be deasserted by forcing a MCU reset.

Note

$\overline{\text{EWM_out}}$ pad must be in pull down state when EWM functionality is used and when EWM is under Reset.

22.4.2 The EWM_in Signal

The EWM_in is a digital input signal that allows an external circuit to control the EWM_out signal. For example, in the application, an external circuit monitors a critical safety function, and if there is fault with this circuit's behavior, it can then actively initiate the EWM_out signal that controls the gating circuit.

The EWM_in signal is ignored if the EWM is disabled, or if INEN bit of CTRL register is cleared, as after any reset.

On enabling the EWM (setting the CTRL[EWMEN] bit) and enabling EWM_in functionality (setting the CTRL[INEN] bit), the EWM_in signal must be in the deasserted state prior to the CPU servicing the EWM. This ensures that the EWM_out stays in the deasserted state; otherwise, the EWM_out pin is asserted.

Note

You must update the CMPH and CMPL registers prior to enabling the EWM. After enabling the EWM, the counter resets to zero, therefore providing a reasonable time after a power-on reset for the external monitoring circuit to stabilize and ensure that the EWM_in pin is deasserted.

22.4.3 EWM Counter

It is an 8-bit ripple counter fed from a clock source that is independent of the peripheral bus clock source. As the preferred time-out is between 1 ms and 100 ms the actual clock source should be in the kHz range.

The counter is reset to zero, after a CPU reset, or a EWM refresh cycle. The counter value is not accessible to the CPU.

22.4.4 EWM Compare Registers

The compare registers CMPL and CMPH are write-once after a CPU reset and cannot be modified until another CPU reset occurs.

The EWM compare registers are used to create a service window, which is used by the CPU to service/refresh the EWM module.

- If the CPU services the EWM when the counter value lies between CMPL value and CMPH value, the counter is reset to zero. This is a legal service operation.
- If the CPU executes a EWM service/refresh action outside the legal service window, $\overline{\text{EWM_out}}$ is asserted.

It is illegal to program CMPL and CMPH with same value. In this case, as soon as counter reaches (CMPL + 1), $\overline{\text{EWM_out}}$ is asserted.

22.4.5 EWM Refresh Mechanism

Other than the initial configuration of the EWM, the CPU can only access the EWM by the EWM Service Register. The CPU must access the EWM service register with correct write of unique data within the windowed time frame as determined by the CMPL and CMPH registers. Therefore, three possible conditions can occur:

Table 22-7. EWM Refresh Mechanisms

| Condition | Mechanism |
|---|---|
| A unique EWM service occurs when $\text{CMPL} < \text{Counter} < \text{CMPH}$. | The software behaves as expected and the counter of the EWM is reset to zero, and $\overline{\text{EWM_out}}$ pin remains in the deasserted state. Note: $\overline{\text{EWM_in}}$ pin is also assumed to be in the deasserted state. |
| A unique EWM service occurs when $\text{Counter} < \text{CMPL}$ | The software services the EWM and therefore resets the counter to zero and asserts the $\overline{\text{EWM_out}}$ pin (irrespective of the $\overline{\text{EWM_in}}$ pin). The $\overline{\text{EWM_out}}$ pin is expected to gate critical safety circuits. |
| Counter value reaches CMPH prior to a unique EWM service | The counter value reaches the CMPH value and no service of the EWM resets the counter to zero and assert the $\overline{\text{EWM_out}}$ pin (irrespective of the $\overline{\text{EWM_in}}$ pin). The $\overline{\text{EWM_out}}$ pin is expected to gate critical safety circuits. |

Any illegal service on EWM has no effect on $\overline{\text{EWM_out}}$.

22.4.6 EWM Interrupt

When $\overline{\text{EWM_out}}$ is asserted, an interrupt request is generated to indicate the assertion of the EWM reset out signal. This interrupt is enabled when CTRL[INTEN] is set. Clearing this bit clears the interrupt request but does not affect $\overline{\text{EWM_out}}$. The $\overline{\text{EWM_out}}$ signal can be deasserted only by forcing a system reset.



Chapter 23

Watchdog Timer (WDOG)

23.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The Watchdog Timer (WDOG) keeps a watch on the system functioning and resets it in case of its failure. Reasons for failure include run-away software code and the stoppage of the system clock that in a safety critical system can lead to serious consequences. In such cases, the watchdog brings the system into a safe state of operation. The watchdog monitors the operation of the system by expecting periodic communication from the software, generally known as servicing or refreshing the watchdog. If this periodic refreshing does not occur, the watchdog resets the system.

23.2 Features

The features of the Watchdog Timer (WDOG) include:

- Clock source input independent from CPU/bus clock. Choice between two clock sources:
 - Low-power oscillator (LPO)
 - External system clock
- Unlock sequence for allowing updates to write-once WDOG control/configuration bits.
- All WDOG control/configuration bits are writable once only within 256 bus clock cycles of being unlocked.

- You need to always update these bits after unlocking within 256 bus clock cycles. Failure to update these bits resets the system.
- Programmable time-out period specified in terms of number of WDOG clock cycles.
- Ability to test WDOG timer and reset with a flag indicating watchdog test.
 - Quick test—Small time-out value programmed for quick test.
 - Byte test—Individual bytes of timer tested one at a time.
 - Read-only access to the WDOG timer—Allows dynamic check that WDOG timer is operational.

NOTE

Reading the watchdog timer counter while running the watchdog on the bus clock might not give the accurate counter value.

- Windowed refresh option
 - Provides robust check that program flow is faster than expected.
 - Programmable window.
 - Refresh outside window leads to reset.
- Robust refresh mechanism
 - Write values of 0xA602 and 0xB480 to WDOG Refresh Register within 20 bus clock cycles.
- Count of WDOG resets as they occur.
- Configurable interrupt on time-out to provide debug breadcrumbs. This is followed by a reset after 256 bus clock cycles.

23.3 Functional overview

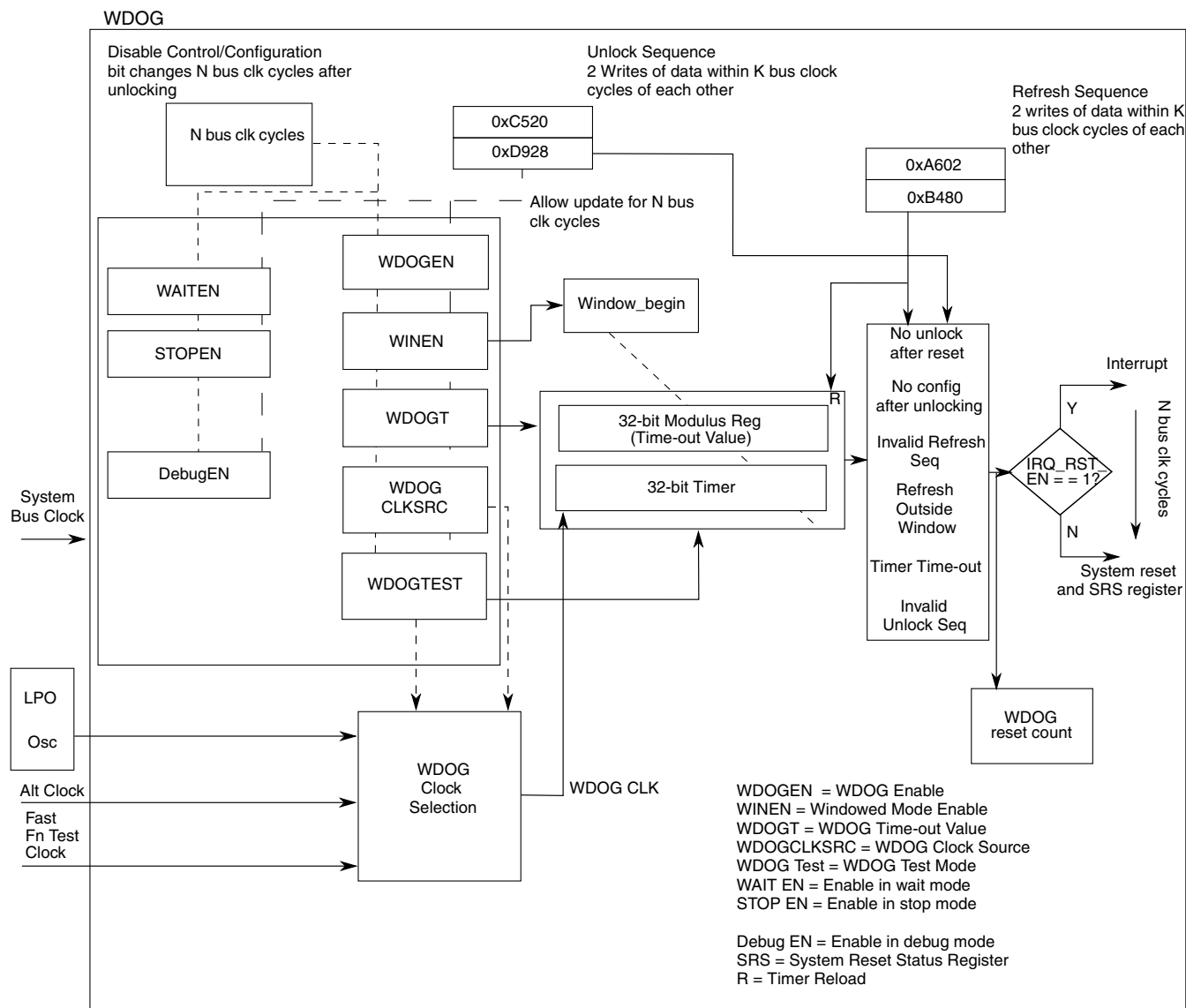


Figure 23-1. WDOG operation

The preceding figure shows the operation of the watchdog. The values for N and K are:

- N = 256
- K = 20

The watchdog is a fail safe mechanism that brings the system into a known initial state in case of its failure due to CPU clock stopping or a run-away condition in code execution. In its simplest form, the watchdog timer runs continuously off a clock source and expects

to be serviced periodically, failing which it resets the system. This ensures that the software is executing correctly and has not run away in an unintended direction. Software can adjust the period of servicing or the time-out value for the watchdog timer to meet the needs of the application.

You can select a windowed mode of operation that expects the servicing to be done only in a particular window of the time-out period. An attempted servicing of the watchdog outside this window results in a reset. By operating in this mode, you can get an indication of whether the code is running faster than expected. The window length is also user programmable.

If a system fails to update/refresh the watchdog due to an unknown and persistent cause, it will be caught in an endless cycle of resets from the watchdog. To analyze the cause of such conditions, you can program the watchdog to first issue an interrupt, followed by a reset. In the interrupt service routine, the software can analyze the system stack to aid debugging.

To enhance the independence of watchdog from the system, it runs off an independent LPO oscillator clock. You can also switch over to an alternate clock source if required, through a control register bit.

23.3.1 Unlocking and updating the watchdog

As long as `ALLOW_UPDATE` in the watchdog control register is set, you can unlock and modify the write-once-only control and configuration registers:

1. Write `0xC520` followed by `0xD928` within 20 bus clock cycles to a specific unlock register (`WDOG_UNLOCK`).
2. Wait one bus clock cycle. You cannot update registers on the bus clock cycle immediately following the write of the unlock sequence.
3. An update window equal in length to the watchdog configuration time (`WCT`) opens. Within this window, you can update the configuration and control register bits.

These register bits can be modified only once after unlocking.

If none of the configuration and control registers is updated within the update window, the watchdog issues a reset, that is, interrupt-then-reset, to the system. Trying to unlock the watchdog within the `WCT` after an initial unlock has no effect. During the update operation, the watchdog timer is not paused and continues running in the background. After the update window closes, the watchdog timer restarts and the watchdog functions according to the new configuration.

The update feature is useful for applications that have an initial, non-safety critical part, where the watchdog is kept disabled or with a conveniently long time-out period. This means the application coder does not have to frequently service the watchdog. After the critical part of the application begins, the watchdog can be reconfigured as needed.

The watchdog issues a reset, that is, interrupt-then-reset if enabled, to the system for any of these invalid unlock sequences:

- Write any value other than 0xC520 or 0xD928 to the unlock register.
- ALLOW_UPDATE is set and a gap of more than 20 bus clock cycles is inserted between the writing of the unlock sequence values.

An attempted refresh operation between the two writes of the unlock sequence and in the WCT time following a successful unlock, goes undetected. Also, see [Watchdog Operation with 8-bit access](#) for guidelines related to 8-bit accesses to the unlock register.

Note

A context switch during unlocking and refreshing may lead to a watchdog reset.

23.3.2 Watchdog configuration time (WCT)

To prevent unintended modification of the watchdog's control and configuration register bits, you are allowed to update them only within a period of 256 bus clock cycles after unlocking. This period is known as the watchdog configuration time (WCT). In addition, these register bits can be modified only once after unlocking them for editing, even after reset.

You must unlock the registers within WCT after system reset, failing which the WDOG issues a reset to the system. In other words, you must write at least the first word of the unlocking sequence within the WCT after reset. After this is done, you have a further 20 bus clock cycles, the maximum allowed gap between the words of the unlock sequence, to complete the unlocking operation. Thereafter, to make sure that you do not forget to configure the watchdog, the watchdog issues a reset if none of the WDOG control and configuration registers is updated in the WCT after unlock. After the close of this window or after the first write, these register bits are locked out from any further changes.

The watchdog timer keeps running according to its default configuration through unlocking and update operations that can extend up to a maximum total of $2 \times \text{WCT} + 20$ bus clock cycles. Therefore, it must be ensured that the time-out value for the watchdog is always greater than $2 \times \text{WCT} + 20$ bus clock cycles.

Updates in the write-once registers take effect only after the WCT window closes with the following exceptions for which changes take effect immediately:

- Stop, Wait, and Debug mode enable
- IRQ_RST_EN

The operations of refreshing the watchdog goes undetected during the WCT.

23.3.3 Refreshing the watchdog

A robust refreshing mechanism has been chosen for the watchdog. A valid refresh is a write of 0xA602 followed by 0xB480 within 20 bus clock cycles to watchdog refresh register. If these two values are written more than 20 bus cycles apart or if something other than these two values is written to the register, a watchdog reset, or interrupt-then-reset if enabled, is issued to the system. A valid refresh makes the watchdog timer restart on the next bus clock. Also, an attempted unlock operation in between the two writes of the refresh sequence goes undetected. See [Watchdog Operation with 8-bit access](#) for guidelines related to 8-bit accesses to the refresh register.

23.3.4 Windowed mode of operation

In this mode of operation, a restriction is placed on the point in time within the time-out period at which the watchdog can be refreshed. The refresh is considered valid only when the watchdog timer increments beyond a certain count as specified by the watchdog window register. This is known as refreshing the watchdog within a window of the total time-out period. If a refresh is attempted before the timer reaches the window value, the watchdog generates a reset, or interrupt-then-reset if enabled. If there is no refresh at all, the watchdog times out and generates a reset or interrupt-then-reset if enabled.

23.3.5 Watchdog disabled mode of operation

When the watchdog is disabled through the WDOG_EN bit in the watchdog status and control register, the watchdog timer is reset to zero and is disabled from counting until you enable it or it is enabled again by the system reset. In this mode, the watchdog timer cannot be refreshed—there is no requirement to do so while the timer is disabled. However, the watchdog still generates a reset, or interrupt-then-reset if enabled, on a non-

time-out exception. See [Generated Resets and Interrupts](#). You need to unlock the watchdog before enabling it. A system reset brings the watchdog out of the disabled mode.

23.3.6 Low-power modes of operation

The low-power modes of operation of the watchdog are described in the following table:

Table 23-1. Low-power modes of operation

| Mode | Behavior |
|------------|--|
| Wait | If the WDOG is enabled (WAIT_EN = 1), it can run on bus clock or low-power oscillator clock (CLK_SRC = x) to generate interrupt (IRQ_RST_EN=1) followed by a reset on time-out. After reset the WDOG reset counter increments by one. |
| Stop | Where the bus clock is gated, the WDOG can run only on low-power oscillator clock (CLK_SRC=0) if it is enabled in stop (STOP_EN=1). In this case, the WDOG runs to time-out twice, and then generates a reset from its backup circuitry. Therefore, if you program the watchdog to time-out after 100 ms and then enter such a stop mode, the reset will occur after 200 ms. Also, in this case, no interrupt will be generated irrespective of the value of IRQ_RST_EN bit. After WDOG reset, the WDOG reset counter will also not increment. |
| Power-Down | The watchdog is <ul style="list-style-type: none"> static in LLS mode powered off in VLLSx mode |

23.3.7 Debug modes of operation

You can program the watchdog to disable in debug modes through DBG_EN in the watchdog control register. This results in the watchdog timer pausing for the duration of the mode. Register read/writes are still allowed, which means that operations like refresh, unlock, and so on are allowed. Upon exit from the mode, the timer resumes its operation from the point of pausing.

The entry of the system into the debug mode does not excuse it from compulsorily configuring the watchdog in the WCT time after unlock, unless the system bus clock is gated off, in which case the internal state machine pauses too. Failing to do so still results in a reset, or interrupt-then-reset, if enabled, to the system. Also, all of the exception conditions that result in a reset to the system, as described in [Generated Resets and Interrupts](#), are still valid in this mode. So, if an exception condition occurs and the system bus clock is on, a reset occurs, or interrupt-then-reset, if enabled.

The entry into Debug mode within WCT after reset is treated differently. The WDOG timer is kept reset to zero and there is no need to unlock and configure it within WCT. You must not try to refresh or unlock the WDOG in this state or unknown behavior may result. Upon exit from this mode, the WDOG timer restarts and the WDOG has to be unlocked and configured within WCT.

23.4 Testing the watchdog

For IEC 60730 and other safety standards, the expectation is that anything that monitors a safety function must be tested, and this test is required to be fault tolerant. To test the watchdog, its main timer and its associated compare and reset logic must be tested. To this end, two tests are implemented for the watchdog, as described in [Quick Test](#) and [Byte Test](#). A control bit is provided to put the watchdog into functional test mode. There is also an overriding test-disable control bit which allows the functional test mode to be disabled permanently. After it is set, this test-disable bit can only be cleared by a reset.

These two tests achieve the overall aim of testing the counter functioning and the compare and reset logic.

Note

Do not enable the watchdog interrupt during these tests. If required, you must ensure that the effective time-out value is greater than WCT time. See [Generated Resets and Interrupts](#) for more details.

To run a particular test:

1. Select either quick test or byte test..
2. Set a certain test mode bit to put the watchdog in the functional test mode. Setting this bit automatically switches the watchdog timer to a fast clock source. The switching of the clock source is done to achieve a faster time-out and hence a faster test.

In a successful test, the timer times out after reaching the programmed time-out value and generates a system reset.

Note

After emerging from a reset due to a watchdog test, unlock and configure the watchdog. The refresh and unlock operations and interrupt are not automatically disabled in the test mode.

23.4.1 Quick test

In this test, the time-out value of watchdog timer is programmed to a very low value to achieve quick time-out. The only difference between the quick test and the normal mode of the watchdog is that TESTWDOG is set for the quick test. This allows for a faster test of the watchdog reset mechanism.

23.4.2 Byte test

The byte test is a more thorough a test of the watchdog timer. In this test, the timer is split up into its constituent byte-wide stages that are run independently and tested for time-out against the corresponding byte of the time-out value register. The following figure explains the splitting concept:

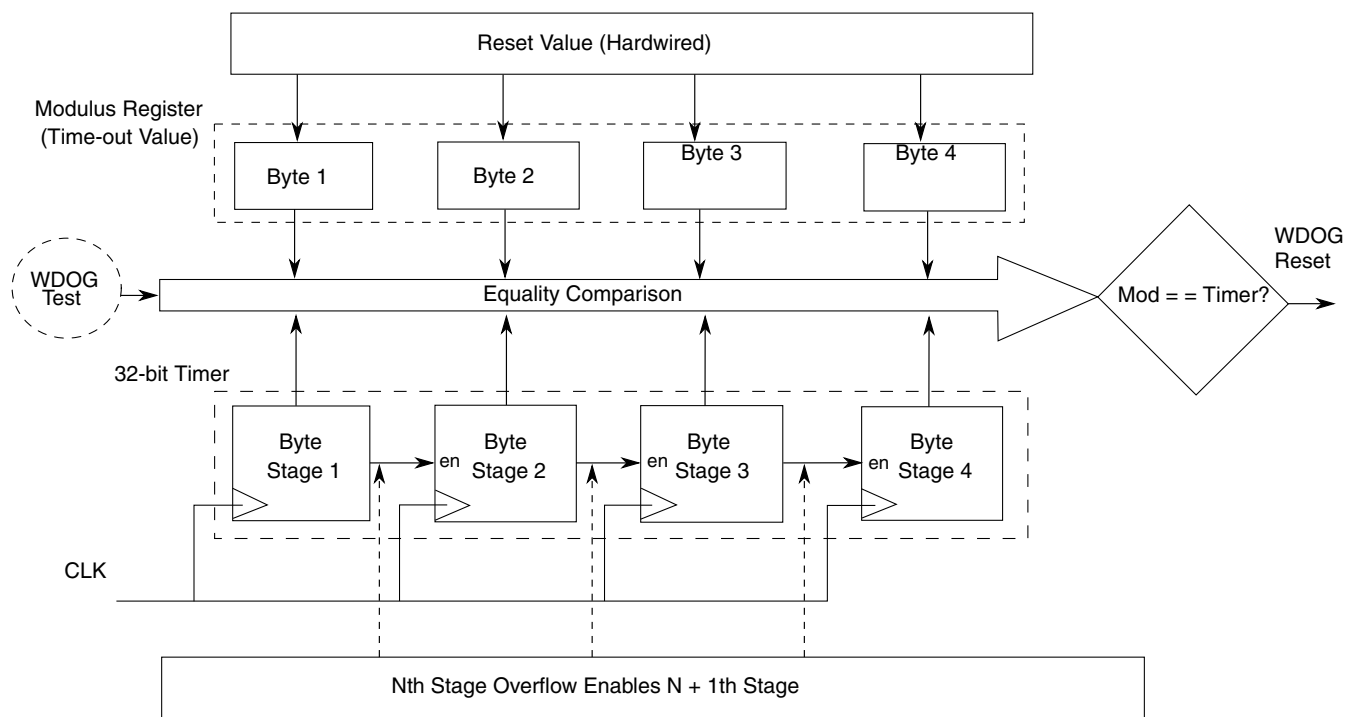


Figure 23-2. Watchdog timer byte splitting

Each stage is an 8-bit synchronous counter followed by combinational logic that generates an overflow signal. The overflow signal acts as an enable to the $N + 1$ th stage.

In the test mode, when an individual byte, N , is tested, byte $N - 1$ is loaded forcefully with 0xFF, and both these bytes are allowed to run off the clock source. By doing so, the overflow signal from stage $N - 1$ is generated immediately, enabling counter stage N . The N th stage runs and compares with the N th byte of the time-out value register. In this

way, the byte N is also tested along with the link between it and the preceding stage. No other stages, $N - 2$, $N - 3...$ and $N + 1$, $N + 2...$ are enabled for the test on byte N. These disabled stages, except the most significant stage of the counter, are loaded with a value of 0xFF.

23.5 Backup reset generator

The backup reset generator generates the final reset which goes out to the system. It has a backup mechanism which ensures that in case the bus clock stops and prevents the main state machine from generating a reset exception/interrupt, the watchdog timer's time-out is separately routed out as a reset to the system. Two successive timer time-outs without an intervening system reset result in the backup reset generator routing out the time-out signal as a reset to the system.

23.6 Generated resets and interrupts

The watchdog generates a reset in the following events, also referred to as exceptions:

- A watchdog time-out
- Failure to unlock the watchdog within WCT time after system reset deassertion
- No update of the control and configuration registers within the WCT window after unlocking. At least one of the following registers must be written to within the WCT window to avoid reset:
 - WDOG_ST_CTRL_H, WDOG_ST_CTRL_L
 - WDOG_TO_VAL_H, WDOG_TO_VAL_L
 - WDOG_WIN_H, WDOG_WIN_L
 - WDOG_PRESCALER
- A value other than the unlock sequence or the refresh sequence is written to the unlock and/or refresh registers, respectively.
- A gap of more than 20 bus cycles exists between the writes of two values of the unlock sequence.
- A gap of more than 20 bus cycles exists between the writes of two values of the refresh sequence.

The watchdog can also generate an interrupt. If `IRQ_RST_EN` is set, then on the above mentioned events `WDOG_ST_CTRL_L[INT_FLG]` is set, generating an interrupt. A watchdog reset is also generated WCT time later to ensure the watchdog is fault tolerant. The interrupt can be cleared by writing 1 to `INT_FLG`.

The gap of WCT between interrupt and reset means that the WDOG time-out value must be greater than WCT. Otherwise, if the interrupt was generated due to a time-out, a second consecutive time-out will occur in that WCT gap. This will trigger the backup reset generator to generate a reset to the system, prematurely ending the interrupt service routine execution. Also, jobs such as counting the number of watchdog resets would not be done.

23.7 Memory map and register definition

This section consists of the memory map and register descriptions.

WDOG memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|-----------------------------|
| 4005_2000 | Watchdog Status and Control Register High (WDOG_STCTRLH) | 16 | R/W | 01D3h | 23.7.1/434 |
| 4005_2002 | Watchdog Status and Control Register Low (WDOG_STCTRL_L) | 16 | R/W | 0001h | 23.7.2/435 |
| 4005_2004 | Watchdog Time-out Value Register High (WDOG_TOVALH) | 16 | R/W | 004Ch | 23.7.3/436 |
| 4005_2006 | Watchdog Time-out Value Register Low (WDOG_TOVAL_L) | 16 | R/W | 4B4Ch | 23.7.4/436 |
| 4005_2008 | Watchdog Window Register High (WDOG_WINH) | 16 | R/W | 0000h | 23.7.5/437 |
| 4005_200A | Watchdog Window Register Low (WDOG_WINL) | 16 | R/W | 0010h | 23.7.6/437 |
| 4005_200C | Watchdog Refresh register (WDOG_REFRESH) | 16 | R/W | B480h | 23.7.7/438 |
| 4005_200E | Watchdog Unlock register (WDOG_UNLOCK) | 16 | R/W | D928h | 23.7.8/438 |
| 4005_2010 | Watchdog Timer Output Register High (WDOG_TMROUTH) | 16 | R/W | 0000h | 23.7.9/438 |
| 4005_2012 | Watchdog Timer Output Register Low (WDOG_TMROUTL) | 16 | R/W | 0000h | 23.7.10/439 |
| 4005_2014 | Watchdog Reset Count register (WDOG_RSTCNT) | 16 | R/W | 0000h | 23.7.11/439 |
| 4005_2016 | Watchdog Prescaler register (WDOG_PRESC) | 16 | R/W | 0400h | 23.7.12/440 |

23.7.1 Watchdog Status and Control Register High (WDOG_STCTRLH)

Address: 4005_2000h base + 0h offset = 4005_2000h

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|-------------|--------------|----|---------|----------|---|----------|--------|--------|-------|-------------|-------|----------|--------|--------|
| Read | 0 | DISTESTWDOG | BYTESEL[1:0] | | TESTSEL | TESTWDOG | 0 | Reserved | WAITEN | STOPEN | DBGEN | ALLOWUPDATE | WINEN | IRQRSTEN | CLKSRC | WDOGEN |
| Write | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 |

WDOG_STCTRLH field descriptions

| Field | Description |
|-----------------------|---|
| 15 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 14 DISTESTWDOG | Allows the WDOG's functional test mode to be disabled permanently. After it is set, it can only be cleared by a reset. It cannot be unlocked for editing after it is set. 0 WDOG functional test mode is not disabled. 1 WDOG functional test mode is disabled permanently until reset. |
| 13–12 BYTESEL[1:0] | This 2-bit field selects the byte to be tested when the watchdog is in the byte test mode. 00 Byte 0 selected 01 Byte 1 selected 10 Byte 2 selected 11 Byte 3 selected |
| 11 TESTSEL | Effective only if TESTWDOG is set. Selects the test to be run on the watchdog timer. 0 Quick test. The timer runs in normal operation. You can load a small time-out value to do a quick test. 1 Byte test. Puts the timer in the byte test mode where individual bytes of the timer are enabled for operation and are compared for time-out against the corresponding byte of the programmed time-out value. Select the byte through BYTESEL[1:0] for testing. |
| 10 TESTWDOG | Puts the watchdog in the functional test mode. In this mode, the watchdog timer and the associated compare and reset generation logic is tested for correct operation. The clock for the timer is switched from the main watchdog clock to the fast clock input for watchdog functional test. The TESTSEL bit selects the test to be run. |
| 9 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 8 Reserved | This field is reserved. |
| 7 WAITEN | Enables or disables WDOG in Wait mode. 0 WDOG is disabled in CPU Wait mode. 1 WDOG is enabled in CPU Wait mode. |
| 6 STOPEN | Enables or disables WDOG in Stop mode. |

Table continues on the next page...

WDOG_STCTRLH field descriptions (continued)

| Field | Description |
|------------------|--|
| | 0 WDOG is disabled in CPU Stop mode. 1 WDOG is enabled in CPU Stop mode. |
| 5 DBGEN | Enables or disables WDOG in Debug mode. 0 WDOG is disabled in CPU Debug mode. 1 WDOG is enabled in CPU Debug mode. |
| 4 ALLOWUPDATE | Enables updates to watchdog write-once registers, after the reset-triggered initial configuration window (WCT) closes, through unlock sequence. 0 No further updates allowed to WDOG write-once registers. 1 WDOG write-once registers can be unlocked for updating. |
| 3 WINEN | Enables Windowing mode. 0 Windowing mode is disabled. 1 Windowing mode is enabled. |
| 2 IRQRSTEN | Used to enable the debug breadcrumbs feature. A change in this bit is updated immediately, as opposed to updating after WCT. 0 WDOG time-out generates reset only. 1 WDOG time-out initially generates an interrupt. After WCT, it generates a reset. |
| 1 CLKSRC | Selects clock source for the WDOG timer and other internal timing operations. 0 WDOG clock sourced from LPO . 1 WDOG clock sourced from alternate clock source. |
| 0 WDOGEN | Enables or disables the WDOG's operation. In the disabled state, the watchdog timer is kept in the reset state, but the other exception conditions can still trigger a reset/interrupt. A change in the value of this bit must be held for more than one WDOG_CLK cycle for the WDOG to be enabled or disabled. 0 WDOG is disabled. 1 WDOG is enabled. |

23.7.2 Watchdog Status and Control Register Low (WDOG_STCTRLLL)

Address: 4005_2000h base + 2h offset = 4005_2002h

| | | | | | | | | |
|-------|----------|----------|----|----|----|----|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 |
| Read | INTFLG | Reserved | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | Reserved | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

WDOG_STCTRL field descriptions

| Field | Description |
|------------------|---|
| 15 INTFLG | Interrupt flag. It is set when an exception occurs. IRQRSTEN = 1 is a precondition to set this flag. INTFLG = 1 results in an interrupt being issued followed by a reset, WCT later. The interrupt can be cleared by writing 1 to this bit. It also gets cleared on a system reset. |
| 14–0 Reserved | This field is reserved. NOTE: Do not modify this field value. |

23.7.3 Watchdog Time-out Value Register High (WDOG_TOVALH)

Address: 4005_2000h base + 4h offset = 4005_2004h

| | | | | | | | | | | | | | | | | |
|-------|-----------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | TOVALHIGH | | | | | | | | | | | | | | | |
| Write | TOVALHIGH | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |

WDOG_TOVALH field descriptions

| Field | Description |
|-------------------|--|
| 15–0 TOVALHIGH | Defines the upper 16 bits of the 32-bit time-out value for the watchdog timer. It is defined in terms of cycles of the watchdog clock. |

23.7.4 Watchdog Time-out Value Register Low (WDOG_TOVALL)

The time-out value of the watchdog must be set to a minimum of four watchdog clock cycles. This is to take into account the delay in new settings taking effect in the watchdog clock domain.

Address: 4005_2000h base + 6h offset = 4005_2006h

| | | | | | | | | | | | | | | | | |
|-------|--------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | TOVALL | | | | | | | | | | | | | | | |
| Write | TOVALL | | | | | | | | | | | | | | | |
| Reset | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |

WDOG_TOVALL field descriptions

| Field | Description |
|----------------|--|
| 15–0 TOVALL | Defines the lower 16 bits of the 32-bit time-out value for the watchdog timer. It is defined in terms of cycles of the watchdog clock. |

23.7.5 Watchdog Window Register High (WDOG_WINH)

NOTE

You must set the Window Register value lower than the Time-out Value Register.

Address: 4005_2000h base + 8h offset = 4005_2008h

| | | | | | | | | | | | | | | | | |
|-------|---------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | WINHIGH | | | | | | | | | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

WDOG_WINH field descriptions

| Field | Description |
|-----------------|--|
| 15–0 WINHIGH | Defines the upper 16 bits of the 32-bit window for the windowed mode of operation of the watchdog. It is defined in terms of cycles of the watchdog clock. In this mode, the watchdog can be refreshed only when the timer has reached a value greater than or equal to this window length. A refresh outside this window resets the system or if IRQRSTEN is set, it interrupts and then resets the system. |

23.7.6 Watchdog Window Register Low (WDOG_WINL)

NOTE

You must set the Window Register value lower than the Time-out Value Register.

Address: 4005_2000h base + Ah offset = 4005_200Ah

| | | | | | | | | | | | | | | | | |
|-------|--------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | WINLOW | | | | | | | | | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

WDOG_WINL field descriptions

| Field | Description |
|----------------|--|
| 15–0 WINLOW | Defines the lower 16 bits of the 32-bit window for the windowed mode of operation of the watchdog. It is defined in terms of cycles of the pre-scaled watchdog clock. In this mode, the watchdog can be refreshed only when the timer reaches a value greater than or equal to this window length value. A refresh outside of this window resets the system or if IRQRSTEN is set, it interrupts and then resets the system. |

23.7.7 Watchdog Refresh register (WDOG_REFRESH)

Address: 4005_2000h base + Ch offset = 4005_200Ch

| | | | | | | | | | | | | | | | | |
|-------|-------------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | WDOGREFRESH | | | | | | | | | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

WDOG_REFRESH field descriptions

| Field | Description |
|---------------------|--|
| 15–0 WDOGREFRESH | Watchdog refresh register. A sequence of 0xA602 followed by 0xB480 within 20 bus clock cycles written to this register refreshes the WDOG and prevents it from resetting the system. Writing a value other than the above mentioned sequence or if the sequence is longer than 20 bus cycles, resets the system, or if IRQSTEN is set, it interrupts and then resets the system. |

23.7.8 Watchdog Unlock register (WDOG_UNLOCK)

Address: 4005_2000h base + Eh offset = 4005_200Eh

| | | | | | | | | | | | | | | | | |
|-------|------------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | WDOGUNLOCK | | | | | | | | | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |

WDOG_UNLOCK field descriptions

| Field | Description |
|--------------------|---|
| 15–0 WDOGUNLOCK | Writing the unlock sequence values to this register to makes the watchdog write-once registers writable again. The required unlock sequence is 0xC520 followed by 0xD928 within 20 bus clock cycles. A valid unlock sequence opens a window equal in length to the WCT within which you can update the registers. Writing a value other than the above mentioned sequence or if the sequence is longer than 20 bus cycles, resets the system or if IRQSTEN is set, it interrupts and then resets the system. The unlock sequence is effective only if ALLOWUPDATE is set. |

23.7.9 Watchdog Timer Output Register High (WDOG_TMROUTH)

Address: 4005_2000h base + 10h offset = 4005_2010h

| | | | | | | | | | | | | | | | | |
|-------|--------------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | TIMEROUTHIGH | | | | | | | | | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

WDOG_TMROUTH field descriptions

| Field | Description |
|----------------------|---|
| 15–0 TIMEROUTHIGH | Shows the value of the upper 16 bits of the watchdog timer. |

23.7.10 Watchdog Timer Output Register Low (WDOG_TMROUTL)

During Stop mode, the WDOG_TIMER_OUT will be caught at the pre-stop value of the watchdog timer. After exiting Stop mode, a maximum delay of 1 WDOG_CLK cycle + 3 bus clock cycles will occur before the WDOG_TIMER_OUT starts following the watchdog timer.

Address: 4005_2000h base + 12h offset = 4005_2012h

| | | | | | | | | | | | | | | | | |
|-------|-------------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | TIMEROUTLOW | | | | | | | | | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

WDOG_TMROUTL field descriptions

| Field | Description |
|---------------------|---|
| 15–0 TIMEROUTLOW | Shows the value of the lower 16 bits of the watchdog timer. |

23.7.11 Watchdog Reset Count register (WDOG_RSTCNT)

Address: 4005_2000h base + 14h offset = 4005_2014h

| | | | | | | | | | | | | | | | | |
|-------|--------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | RSTCNT | | | | | | | | | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

WDOG_RSTCNT field descriptions

| Field | Description |
|----------------|---|
| 15–0 RSTCNT | Counts the number of times the watchdog resets the system. This register is reset only on a POR. Writing 1 to the bit to be cleared enables you to clear the contents of this register. |

23.7.12 Watchdog Prescaler register (WDOG_PRESC)

Address: 4005_2000h base + 16h offset = 4005_2016h

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----------|---|---|---|---|---|---|---|---|---|---|
| Read | 0 | | | | | PRESCVAL | | | 0 | | | | | | | |
| Write | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

WDOG_PRESC field descriptions

| Field | Description |
|-------------------|--|
| 15–11 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 10–8 PRESCVAL | 3-bit prescaler for the watchdog clock source. A value of zero indicates no division of the input WDOG clock. The watchdog clock is divided by (PRESCVAL + 1) to provide the prescaled WDOG_CLK. |
| 7–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

23.8 Watchdog operation with 8-bit access

23.8.1 General guideline

When performing 8-bit accesses to the watchdog's 16-bit registers where the intention is to access both the bytes of a register, place the two 8-bit accesses one after the other in your code.

23.8.2 Refresh and unlock operations with 8-bit access

One exception condition that generates a reset to the system is the write of any value other than those required for a legal refresh/update sequence to the respective refresh and unlock registers.

For an 8-bit access to these registers, writing a correct value requires at least two bus clock cycles, resulting in an invalid value in the registers for one cycle. Therefore, the system is reset even if the intention is to write a correct value to the refresh/unlock register. Keeping this in mind, the exception condition for 8-bit accesses is slightly modified.

Whereas the match for a correct value for a refresh/unlock sequence is as according to the original definition, the match for an incorrect value is done byte-wise on the refresh/unlock rather than for the whole 16-bit value. This means that if the high byte of the refresh/unlock register contains any value other than high bytes of the two values that make up the sequence, it is treated as an exception condition, leading to a reset or interrupt-then-reset. The same holds true for the lower byte of the refresh or unlock register. Take the refresh operation that expects a write of 0xA602 followed by 0xB480 to the refresh register, as an example.

Table 23-15. Refresh for 8-bit access

| | WDOG_REFRESH[15:8] | WDOG_REFRESH[7:0] | Sequence value1 or value2 match | Mismatch exception |
|----------------------|--------------------|-------------------|-------------------------------------|--------------------|
| Current Value | 0xB4 | 0x80 | Value2 match | No |
| Write 1 | 0xB4 | 0x02 | No match | No |
| Write 2 | 0xA6 | 0x02 | Value1 match | No |
| Write 3 | 0xB4 | 0x02 | No match | No |
| Write 4 | 0xB4 | 0x80 | Value2 match. Sequence complete. | No |
| Write 5 | 0x02 | 0x80 | No match | Yes |

As shown in the preceding table, the refresh register holds its reset value initially. Thereafter, two 8-bit accesses are performed on the register to write the first value of the refresh sequence. No mismatch exception is registered on the intermediate write, Write1. The sequence is completed by performing two more 8-bit accesses, writing in the second value of the sequence for a successful refresh. It must be noted that the match of value2 takes place only when the complete 16-bit value is correctly written, write4. Hence, the requirement of writing value2 of the sequence within 20 bus clock cycles of value1 is checked by measuring the gap between write2 and write4.

It is reiterated that the condition for matching values 1 and 2 of the refresh or unlock sequence remains unchanged. The difference for 8-bit accesses is that the criterion for detecting a mismatch is less strict. Any 16-bit access still needs to adhere to the original guidelines, mentioned in the sections [Refreshing the Watchdog](#).

23.9 Restrictions on watchdog operation

This section mentions some exceptions to the watchdog operation that may not be apparent to you.

- Restriction on unlock/refresh operations—In the period between the closure of the WCT window after unlock and the actual reload of the watchdog timer, unlock and refresh operations need not be attempted.
- The update and reload of the watchdog timer happens two to three watchdog clocks after WCT window closes, following a successful configuration on unlock.
- Clock Switching Delay—The watchdog uses glitch-free multiplexers at two places – one to choose between the LPO oscillator input and alternate clock input, and the other to choose between the watchdog functional clock and fast clock input for watchdog functional test. A maximum time period of ~ 2 clock A cycles plus ~ 2 clock B cycles elapses from the time a switch is requested to the occurrence of the actual clock switch, where clock A and B are the two input clocks to the clock mux.
- For the windowed mode, there is a two to three bus clock latency between the watchdog counter going past the window value and the same registering in the bus clock domain.
- For proper operation of the watchdog, the watchdog clock must be at least five times slower than the system bus clock at all times. An exception is when the watchdog clock is synchronous to the bus clock wherein the watchdog clock can be as fast as the bus clock.
- WCT must be equivalent to at least three watchdog clock cycles. If not ensured, this means that even after the close of the WCT window, you have to wait for the synchronized system reset to deassert in the watchdog clock domain, before expecting the configuration updates to take effect.
- The time-out value of the watchdog should be set to a minimum of four watchdog clock cycles. This is to take into account the delay in new settings taking effect in the watchdog clock domain.
- You must take care not only to refresh the watchdog within the watchdog timer's actual time-out period, but also provide enough allowance for the time it takes for the refresh sequence to be detected by the watchdog timer, on the watchdog clock.
- Updates cannot be made in the bus clock cycle immediately following the write of the unlock sequence, but one bus clock cycle later.
- It should be ensured that the time-out value for the watchdog is always greater than $2 \times \text{WCT time} + 20$ bus clock cycles.
- An attempted refresh operation, in between the two writes of the unlock sequence and in the WCT time following a successful unlock, will go undetected.

- Trying to unlock the watchdog within the WCT time after an initial unlock has no effect.
- The refresh and unlock operations and interrupt are not automatically disabled in the watchdog functional test mode.
- After emerging from a reset due to a watchdog functional test, you are still expected to go through the mandatory steps of unlocking and configuring the watchdog. The watchdog continues to be in its functional test mode and therefore you should pull the watchdog out of the functional test mode within WCT time of reset.
- After emerging from a reset due to a watchdog functional test, you still need to go through the mandatory steps of unlocking and configuring the watchdog.
- You must ensure that both the clock inputs to the glitchless clock multiplexers are alive during the switching of clocks. Failure to do so results in a loss of clock at their outputs.
- There is a gap of two to three watchdog clock cycles from the point that stop mode is entered to the watchdog timer actually pausing, due to synchronization. The same holds true for an exit from the stop mode, this time resulting in a two to three watchdog clock cycle delay in the timer restarting. In case the duration of the stop mode is less than one watchdog clock cycle, the watchdog timer is not guaranteed to pause.
- Consider the case when the first refresh value is written, following which the system enters stop mode with system bus clk still on. If the second refresh value is not written within 20 bus cycles of the first value, the system is reset, or interrupt-then-reset if enabled.



Chapter 24

Multipurpose Clock Generator (MCG)

24.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The multipurpose clock generator (MCG) module provides several clock source choices for the MCU.

The module contains a frequency-locked loop (FLL) and a phase-locked loop (PLL). The FLL is controllable by either an internal or an external reference clock. The PLL is controllable by the external reference clock. The module can select either an FLL or PLL output clock, or a reference clock (internal or external) as a source for the MCU system clock. The MCG operates in conjunction with a crystal oscillator, which allows an external crystal, ceramic resonator, or another external clock source to produce the external reference clock.

24.1.1 Features

Key features of the MCG module are:

- Frequency-locked loop (FLL):
 - Digitally-controlled oscillator (DCO)
 - DCO frequency range is programmable for up to four different frequency ranges.
 - Option to program and maximize DCO output frequency for a low frequency external reference clock source.
 - Option to prevent FLL from resetting its current locked frequency when switching clock modes if FLL reference frequency is not changed.

- Internal or external reference clock can be used as the FLL source.
- Can be used as a clock source for other on-chip peripherals.
- Phase-locked loop (PLL):
 - Voltage-controlled oscillator (VCO)
 - External reference clock is used as the PLL source.
 - Modulo VCO frequency divider
 - Phase/Frequency detector
 - Integrated loop filter
 - Can be used as a clock source for other on-chip peripherals.
- Internal reference clock generator:
 - Slow clock with nine trim bits for accuracy
 - Fast clock with four trim bits
 - Can be used as source clock for the FLL. In FEI mode, only the slow Internal Reference Clock (IRC) can be used as the FLL source.
 - Either the slow or the fast clock can be selected as the clock source for the MCU.
 - Can be used as a clock source for other on-chip peripherals.
- Control signals for the MCG external reference low power oscillator clock generators are provided:
 - HGO0, RANGE0, EREFS0
HGO1, RANGE1, EREFS1
- External clock from the Crystal Oscillator (OSC0):
 - Can be used as a source for the FLL and/or the PLL.
 - Can be selected as the clock source for the MCU.
- External clock from the Real Time Counter (RTC):
 - Can only be used as a source for the FLL.
 - Can be selected as the clock source for the MCU.
- External clock from the Crystal Oscillator (OSC1)
 - Can only be used as a source for the PLL.

- External clock monitor with reset and interrupt request capability to check for external clock failure when running in FBE, PEE, BLPE, or FEE modes
- Lock detector with interrupt request capability for use with the PLL
- Internal Reference Clocks Auto Trim Machine (ATM) capability using an external clock as a reference
- Reference dividers for both the FLL and the PLL are provided
- Reference dividers for the Fast Internal Reference Clock are provided
- MCG PLL Clock (MCGPLLCLK) is provided as a clock source for other on-chip peripherals
- MCG FLL Clock (MCGFLLCLK) is provided as a clock source for other on-chip peripherals
- MCG Fixed Frequency Clock (MCGFFCLK) is provided as a clock source for other on-chip peripherals
- MCG Internal Reference Clock (MCGIRCLK) is provided as a clock source for other on-chip peripherals

This figure presents the block diagram of the MCG module.

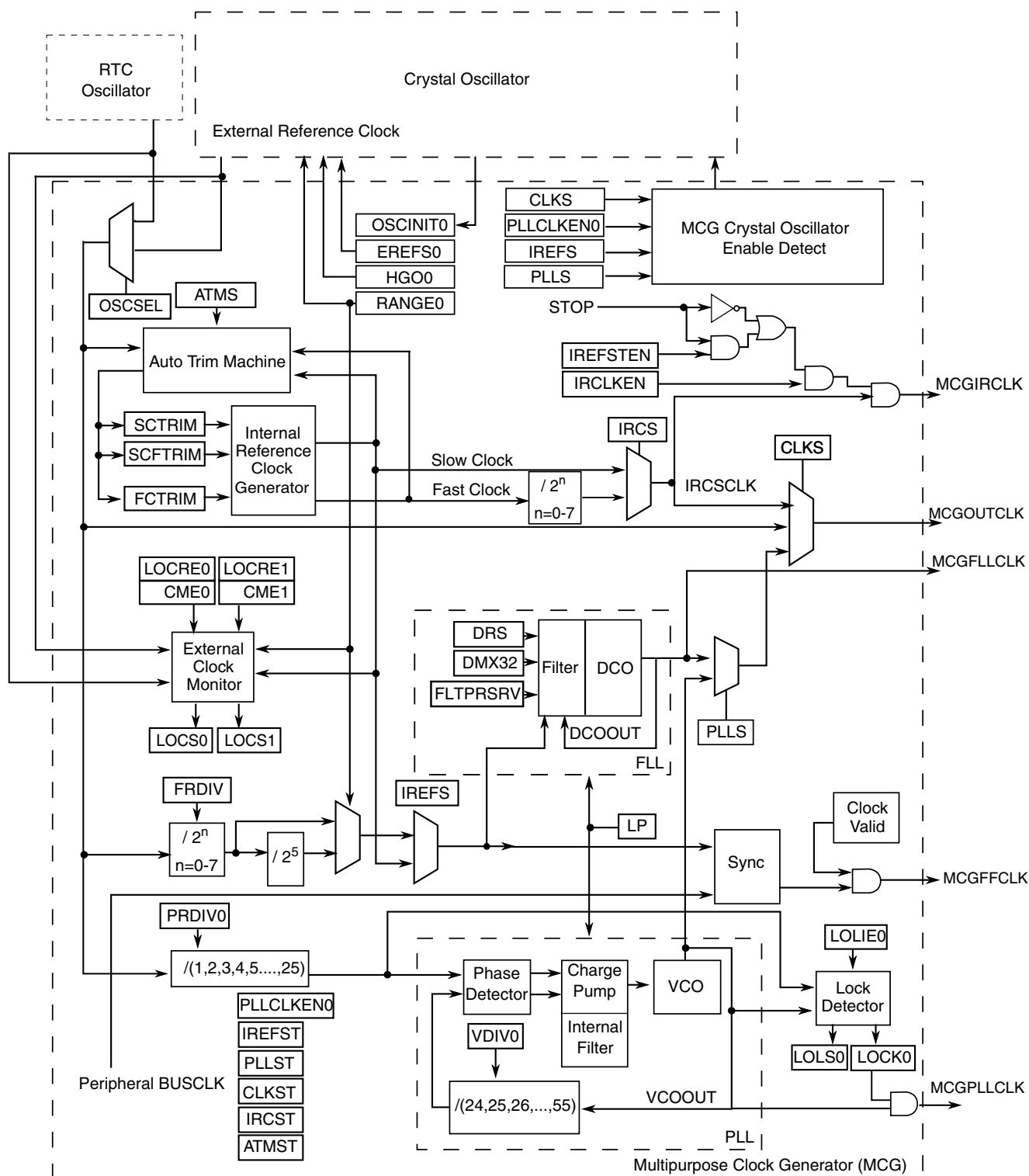


Figure 24-1. Multipurpose Clock Generator (MCG) block diagram

NOTE

Refer to the chip configuration chapter to identify the oscillator used in this MCU.

24.1.2 Modes of Operation

The MCG has the following modes of operation: FEI, FEE, FBI, FBE, PBE, PEE, BLPI, BLPE, and Stop. For details, see [MCG modes of operation](#).

24.2 External Signal Description

There are no MCG signals that connect off chip.

24.3 Memory Map/Register Definition

This section includes the memory map and register definition.

The MCG registers can only be written when in supervisor mode. Write accesses when in user mode will result in a bus error. Read accesses may be performed in both supervisor and user mode.

MCG memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4006_4000 | MCG Control 1 Register (MCG_C1) | 8 | R/W | 04h | 24.3.1/450 |
| 4006_4001 | MCG Control 2 Register (MCG_C2) | 8 | R/W | 80h | 24.3.2/451 |
| 4006_4002 | MCG Control 3 Register (MCG_C3) | 8 | R/W | Undefined | 24.3.3/452 |
| 4006_4003 | MCG Control 4 Register (MCG_C4) | 8 | R/W | Undefined | 24.3.4/453 |
| 4006_4004 | MCG Control 5 Register (MCG_C5) | 8 | R/W | 00h | 24.3.5/454 |
| 4006_4005 | MCG Control 6 Register (MCG_C6) | 8 | R/W | 00h | 24.3.6/455 |
| 4006_4006 | MCG Status Register (MCG_S) | 8 | R | 10h | 24.3.7/457 |
| 4006_4008 | MCG Status and Control Register (MCG_SC) | 8 | R/W | 02h | 24.3.8/458 |
| 4006_400A | MCG Auto Trim Compare Value High Register (MCG_ATCVH) | 8 | R/W | 00h | 24.3.9/460 |
| 4006_400B | MCG Auto Trim Compare Value Low Register (MCG_ATCVL) | 8 | R/W | 00h | 24.3.10/460 |
| 4006_400C | MCG Control 7 Register (MCG_C7) | 8 | R/W | 00h | 24.3.11/460 |
| 4006_400D | MCG Control 8 Register (MCG_C8) | 8 | R/W | 80h | 24.3.12/461 |
| 4006_400F | MCG Control 10 Register (MCG_C10) | 8 | R/W | 00h | 24.3.13/462 |

24.3.1 MCG Control 1 Register (MCG_C1)

Address: 4006_4000h base + 0h offset = 4006_4000h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---|---|---|---|---|---|---|---|
| Read | | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

MCG_C1 field descriptions

| Field | Description |
|--------------|---|
| 7–6 CLKS | <p>Clock Source Select</p> <p>Selects the clock source for MCGOUTCLK .</p> <p>00</p> <p>01 Encoding 1 — Internal reference clock is selected.</p> <p>10 Encoding 2 — External reference clock is selected.</p> <p>11 Encoding 3 — Reserved.</p> |
| 5–3 FRDIV | <p>FLL External Reference Divider</p> <p>Selects the amount to divide down the external reference clock for the FLL. The resulting frequency must be in the range 31.25 kHz to 39.0625 kHz (This is required when FLL/DCO is the clock source for MCGOUTCLK . In FBE mode, it is not required to meet this range, but it is recommended in the cases when trying to enter a FLL mode from FBE).</p> <p>000 If RANGE 0 = 0 or OSCSEL=1 , Divide Factor is 1; for all other RANGE 0 values, Divide Factor is 32.</p> <p>001 If RANGE 0 = 0 or OSCSEL=1 , Divide Factor is 2; for all other RANGE 0 values, Divide Factor is 64.</p> <p>010 If RANGE 0 = 0 or OSCSEL=1 , Divide Factor is 4; for all other RANGE 0 values, Divide Factor is 128.</p> <p>011 If RANGE 0 = 0 or OSCSEL=1 , Divide Factor is 8; for all other RANGE 0 values, Divide Factor is 256.</p> <p>100 If RANGE 0 = 0 or OSCSEL=1 , Divide Factor is 16; for all other RANGE 0 values, Divide Factor is 512.</p> <p>101 If RANGE 0 = 0 or OSCSEL=1 , Divide Factor is 32; for all other RANGE 0 values, Divide Factor is 1024.</p> <p>110 If RANGE 0 = 0 or OSCSEL=1 , Divide Factor is 64; for all other RANGE 0 values, Divide Factor is 1280 .</p> <p>111 If RANGE 0 = 0 or OSCSEL=1 , Divide Factor is 128; for all other RANGE 0 values, Divide Factor is 1536 .</p> |
| 2 IREFS | <p>Internal Reference Select</p> <p>Selects the reference clock source for the FLL.</p> <p>0 External reference clock is selected.</p> <p>1 The slow internal reference clock is selected.</p> |
| 1 IRCLKEN | <p>Internal Reference Clock Enable</p> <p>Enables the internal reference clock for use as MCGIRCLK.</p> |

Table continues on the next page...

MCG_C1 field descriptions (continued)

| Field | Description |
|---------------|--|
| | 0 MCGIRCLK inactive. 1 MCGIRCLK active. |
| 0 IREFSTEN | Internal Reference Stop Enable Controls whether or not the internal reference clock remains enabled when the MCG enters Stop mode. 0 Internal reference clock is disabled in Stop mode. 1 Internal reference clock is enabled in Stop mode if IRCLKEN is set or if MCG is in FEI, FBI, or BLPI modes before entering Stop mode. |

24.3.2 MCG Control 2 Register (MCG_C2)

Address: 4006_4000h base + 1h offset = 4006_4001h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---------|---|--------|---|------|--------|----|------|
| Read | LOCRES0 | 0 | RANGE0 | | HGO0 | EREFS0 | LP | IRCS |
| Write | | | | | | | | |
| Reset | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

MCG_C2 field descriptions

| Field | Description |
|---------------|---|
| 7 LOCRES0 | Loss of Clock Reset Enable Determines whether an interrupt or a reset request is made following a loss of OSC0 external reference clock. The LOCRES0 only has an affect when CME0 is set. 0 Interrupt request is generated on a loss of OSC0 external reference clock. 1 Generate a reset request on a loss of OSC0 external reference clock. |
| 6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5–4 RANGE0 | Frequency Range Select Selects the frequency range for the crystal oscillator or external clock source. See the Oscillator (OSC) chapter for more details and the device data sheet for the frequency ranges used. 00 Encoding 0 — Low frequency range selected for the crystal oscillator . 01 Encoding 1 — High frequency range selected for the crystal oscillator . 1X Encoding 2 — Very high frequency range selected for the crystal oscillator . |
| 3 HGO0 | High Gain Oscillator Select Controls the crystal oscillator mode of operation. See the Oscillator (OSC) chapter for more details. 0 Configure crystal oscillator for low-power operation. 1 Configure crystal oscillator for high-gain operation. |
| 2 EREFS0 | External Reference Select Selects the source for the external reference clock. See the Oscillator (OSC) chapter for more details. |

Table continues on the next page...

MCG_C2 field descriptions (continued)

| Field | Description |
|-----------|---|
| | 0 External reference clock requested. 1 Oscillator requested. |
| 1 LP | Low Power Select Controls whether the FLL or PLL is disabled in BLPI and BLPE modes. In FBE or PBE modes, setting this bit to 1 will transition the MCG into BLPE mode; in FBI mode, setting this bit to 1 will transition the MCG into BLPI mode. In any other MCG mode, LP bit has no affect. 0 FLL or PLL is not disabled in bypass modes. 1 FLL or PLL is disabled in bypass modes (lower power) |
| 0 IRCS | Internal Reference Clock Select Selects between the fast or slow internal reference clock source. 0 Slow internal reference clock selected. 1 Fast internal reference clock selected. |

24.3.3 MCG Control 3 Register (MCG_C3)

Address: 4006_4000h base + 2h offset = 4006_4002h

| | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | | | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

MCG_C3 field descriptions

| Field | Description |
|---------------|---|
| 7–0 SCTRIM | Slow Internal Reference Clock Trim Setting SCTRIM ¹ controls the slow internal reference clock frequency by controlling the slow internal reference clock period. The SCTRIM bits are binary weighted, that is, bit 1 adjusts twice as much as bit 0. Increasing the binary value increases the period, and decreasing the value decreases the period. An additional fine trim bit is available in C4 register as the SCFTRIM bit. Upon reset, this value is loaded with a factory trim value. If an SCTRIM value stored in nonvolatile memory is to be used, it is your responsibility to copy that value from the nonvolatile memory location to this register. |

1. A value for SCTRIM is loaded during reset from a factory programmed location.

24.3.4 MCG Control 4 Register (MCG_C4)

NOTE

Reset values for DRST and DMX32 bits are 0.

Address: 4006_4000h base + 3h offset = 4006_4003h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|----------|---|----|--------|----|----|---------|
| Read | DMX32 | DRST_DRS | | | FCTRIM | | | SCFTRIM |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | x* | x* | x* | x* | x* |

- * Notes:
- x = Undefined at reset.
 - A value for FCTRIM is loaded during reset from a factory programmed location. x = Undefined at reset.

MCG_C4 field descriptions

| Field | Description | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-----------------|--|-------------------|------------|-----------------|------------|-----------|----|---|-------------------|-----|-----------|---|------------|-----|--------|----|---|-------------------|------|-----------|---|------------|------|--------|----|---|-------------------|------|-----------|---|------------|------|--------|----|---|-------------------|------|------------|---|------------|------|--------|
| 7 DMX32 | <p>DCO Maximum Frequency with 32.768 kHz Reference</p> <p>The DMX32 bit controls whether the DCO frequency range is narrowed to its maximum frequency with a 32.768 kHz reference.</p> <p>The following table identifies settings for the DCO frequency range.</p> <p>NOTE: The system clocks derived from this source should not exceed their specified maximums.</p> <table><tr><th>DRST_DRS</th><th>DMX32</th><th>Reference Range</th><th>FLL Factor</th><th>DCO Range</th></tr><tr><td rowspan="2">00</td><td>0</td><td>31.25–39.0625 kHz</td><td>640</td><td>20–25 MHz</td></tr><tr><td>1</td><td>32.768 kHz</td><td>732</td><td>24 MHz</td></tr><tr><td rowspan="2">01</td><td>0</td><td>31.25–39.0625 kHz</td><td>1280</td><td>40–50 MHz</td></tr><tr><td>1</td><td>32.768 kHz</td><td>1464</td><td>48 MHz</td></tr><tr><td rowspan="2">10</td><td>0</td><td>31.25–39.0625 kHz</td><td>1920</td><td>60–75 MHz</td></tr><tr><td>1</td><td>32.768 kHz</td><td>2197</td><td>72 MHz</td></tr><tr><td rowspan="2">11</td><td>0</td><td>31.25–39.0625 kHz</td><td>2560</td><td>80–100 MHz</td></tr><tr><td>1</td><td>32.768 kHz</td><td>2929</td><td>96 MHz</td></tr></table> <p>0 DCO has a default range of 25%.</p> <p>1 DCO is fine-tuned for maximum frequency with 32.768 kHz reference.</p> | DRST_DRS | DMX32 | Reference Range | FLL Factor | DCO Range | 00 | 0 | 31.25–39.0625 kHz | 640 | 20–25 MHz | 1 | 32.768 kHz | 732 | 24 MHz | 01 | 0 | 31.25–39.0625 kHz | 1280 | 40–50 MHz | 1 | 32.768 kHz | 1464 | 48 MHz | 10 | 0 | 31.25–39.0625 kHz | 1920 | 60–75 MHz | 1 | 32.768 kHz | 2197 | 72 MHz | 11 | 0 | 31.25–39.0625 kHz | 2560 | 80–100 MHz | 1 | 32.768 kHz | 2929 | 96 MHz |
| DRST_DRS | DMX32 | Reference Range | FLL Factor | DCO Range | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00 | 0 | 31.25–39.0625 kHz | 640 | 20–25 MHz | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1 | 32.768 kHz | 732 | 24 MHz | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 01 | 0 | 31.25–39.0625 kHz | 1280 | 40–50 MHz | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1 | 32.768 kHz | 1464 | 48 MHz | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | 0 | 31.25–39.0625 kHz | 1920 | 60–75 MHz | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1 | 32.768 kHz | 2197 | 72 MHz | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | 0 | 31.25–39.0625 kHz | 2560 | 80–100 MHz | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1 | 32.768 kHz | 2929 | 96 MHz | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6–5 DRST_DRS | <p>DCO Range Select</p> <p>The DRS bits select the frequency range for the FLL output, DCOOUT. When the LP bit is set, writes to the DRS bits are ignored. The DRST read field indicates the current frequency range for DCOOUT. The DRST field does not update immediately after a write to the DRS field due to internal synchronization between clock domains. See the DCO Frequency Range table for more details.</p> <p>00 Encoding 0 — Low range (reset default).</p> | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Table continues on the next page...

MCG_C4 field descriptions (continued)

| Field | Description |
|---------------|---|
| | 01 Encoding 1 — Mid range. 10 Encoding 2 — Mid-high range. 11 Encoding 3 — High range. |
| 4–1 FCTRIM | Fast Internal Reference Clock Trim Setting FCTRIM ¹ controls the fast internal reference clock frequency by controlling the fast internal reference clock period. The FCTRIM bits are binary weighted, that is, bit 1 adjusts twice as much as bit 0. Increasing the binary value increases the period, and decreasing the value decreases the period. If an FCTRIM[3:0] value stored in nonvolatile memory is to be used, it is your responsibility to copy that value from the nonvolatile memory location to this register. |
| 0 SCFTRIM | Slow Internal Reference Clock Fine Trim SCFTRIM ² controls the smallest adjustment of the slow internal reference clock frequency. Setting SCFTRIM increases the period and clearing SCFTRIM decreases the period by the smallest amount possible. If an SCFTRIM value stored in nonvolatile memory is to be used, it is your responsibility to copy that value from the nonvolatile memory location to this bit. |

1. A value for FCTRIM is loaded during reset from a factory programmed location.
2. A value for SCFTRIM is loaded during reset from a factory programmed location .

24.3.5 MCG Control 5 Register (MCG_C5)

Address: 4006_4000h base + 4h offset = 4006_4004h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---|-----------|----------|---|---|--------|---|---|
| Read | 0 | PLLCLKEN0 | PLLSTEN0 | | | PRDIV0 | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

MCG_C5 field descriptions

| Field | Description |
|----------------|---|
| 7 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 6 PLLCLKEN0 | PLL Clock Enable Enables the PLL independent of PLLS and enables the PLL clock for use as MCGPLLCLK. (PRDIV 0 needs to be programmed to the correct divider to generate a PLL reference clock in the range of 2 - 4 MHz range prior to setting the PLLCLKEN 0 bit). Setting PLLCLKEN 0 will enable the external oscillator if not already enabled. Whenever the PLL is being enabled by means of the PLLCLKEN 0 bit, and the external oscillator is being used as the reference clock, the OSCINIT 0 bit should be checked to make sure it is set. 0 MCGPLLCLK is inactive. 1 MCGPLLCLK is active. |
| 5 PLLSTEN0 | PLL Stop Enable |

Table continues on the next page...

MCG_C5 field descriptions (continued)

| Field | Description | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---------------|---|---------|---------------|---------------|---------|---------------|---------------|---------|---------------|---------------|---------|---------------|-------|---|--|-------|---|--|-------|----|--|-------|----|-------|---|--|-------|----|--|-------|----|--|-------|----------|-------|---|--|-------|----|--|-------|----|--|-------|----------|-------|---|--|-------|----|--|-------|----|--|-------|----------|-------|---|--|-------|----|--|-------|----|--|-------|----------|-------|---|--|-------|----|--|-------|----|--|-------|----------|-------|---|--|-------|----|--|-------|----|--|-------|----------|-------|---|--|-------|----|--|-------|----|--|-------|----------|
| | <p>Enables the PLL Clock during Normal Stop. In Low Power Stop mode, the PLL clock gets disabled even if PLLSTEN 0 =1. All other power modes, PLLSTEN 0 bit has no affect and does not enable the PLL Clock to run if it is written to 1.</p> <p>0 MCGPLLCLK is disabled in any of the Stop modes.</p> <p>1 MCGPLLCLK is enabled if system is in Normal Stop mode.</p> | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4–0 PRDIV0 | <p>PLL External Reference Divider</p> <p>Selects the amount to divide down the external reference clock for the PLL. The resulting frequency must be in the range of 2 MHz to 4 MHz. After the PLL is enabled (by setting either PLLCLKEN 0 or PLLS), the PRDIV 0 value must not be changed when LOCK0 is zero.</p> <p>Table 24-7. PLL External Reference Divide Factor</p> <table><tr><td>PRDIV 0</td><td>Divide Factor</td><td></td><td>PRDIV 0</td><td>Divide Factor</td><td></td><td>PRDIV 0</td><td>Divide Factor</td><td></td><td>PRDIV 0</td><td>Divide Factor</td></tr><tr><td>00000</td><td>1</td><td></td><td>01000</td><td>9</td><td></td><td>10000</td><td>17</td><td></td><td>11000</td><td>25</td></tr><tr><td>00001</td><td>2</td><td></td><td>01001</td><td>10</td><td></td><td>10001</td><td>18</td><td></td><td>11001</td><td>Reserved</td></tr><tr><td>00010</td><td>3</td><td></td><td>01010</td><td>11</td><td></td><td>10010</td><td>19</td><td></td><td>11010</td><td>Reserved</td></tr><tr><td>00011</td><td>4</td><td></td><td>01011</td><td>12</td><td></td><td>10011</td><td>20</td><td></td><td>11011</td><td>Reserved</td></tr><tr><td>00100</td><td>5</td><td></td><td>01100</td><td>13</td><td></td><td>10100</td><td>21</td><td></td><td>11100</td><td>Reserved</td></tr><tr><td>00101</td><td>6</td><td></td><td>01101</td><td>14</td><td></td><td>10101</td><td>22</td><td></td><td>11101</td><td>Reserved</td></tr><tr><td>00110</td><td>7</td><td></td><td>01110</td><td>15</td><td></td><td>10110</td><td>23</td><td></td><td>11110</td><td>Reserved</td></tr><tr><td>00111</td><td>8</td><td></td><td>01111</td><td>16</td><td></td><td>10111</td><td>24</td><td></td><td>11111</td><td>Reserved</td></tr></table> | PRDIV 0 | Divide Factor | | PRDIV 0 | Divide Factor | | PRDIV 0 | Divide Factor | | PRDIV 0 | Divide Factor | 00000 | 1 | | 01000 | 9 | | 10000 | 17 | | 11000 | 25 | 00001 | 2 | | 01001 | 10 | | 10001 | 18 | | 11001 | Reserved | 00010 | 3 | | 01010 | 11 | | 10010 | 19 | | 11010 | Reserved | 00011 | 4 | | 01011 | 12 | | 10011 | 20 | | 11011 | Reserved | 00100 | 5 | | 01100 | 13 | | 10100 | 21 | | 11100 | Reserved | 00101 | 6 | | 01101 | 14 | | 10101 | 22 | | 11101 | Reserved | 00110 | 7 | | 01110 | 15 | | 10110 | 23 | | 11110 | Reserved | 00111 | 8 | | 01111 | 16 | | 10111 | 24 | | 11111 | Reserved |
| PRDIV 0 | Divide Factor | | PRDIV 0 | Divide Factor | | PRDIV 0 | Divide Factor | | PRDIV 0 | Divide Factor | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00000 | 1 | | 01000 | 9 | | 10000 | 17 | | 11000 | 25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00001 | 2 | | 01001 | 10 | | 10001 | 18 | | 11001 | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00010 | 3 | | 01010 | 11 | | 10010 | 19 | | 11010 | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00011 | 4 | | 01011 | 12 | | 10011 | 20 | | 11011 | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00100 | 5 | | 01100 | 13 | | 10100 | 21 | | 11100 | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00101 | 6 | | 01101 | 14 | | 10101 | 22 | | 11101 | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00110 | 7 | | 01110 | 15 | | 10110 | 23 | | 11110 | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00111 | 8 | | 01111 | 16 | | 10111 | 24 | | 11111 | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

24.3.6 MCG Control 6 Register (MCG_C6)

Address: 4006_4000h base + 5h offset = 4006_4005h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|--------|------|------|---|---|-------|---|---|
| Read | LOLIE0 | PLLS | CME0 | | | | | |
| Write | | | | | | VDIV0 | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

MCG_C6 field descriptions

| Field | Description |
|-------------|-------------------------------|
| 7 LOLIE0 | Loss of Lock Interrupt Enable |

Table continues on the next page...

MCG_C6 field descriptions (continued)

| Field | Description | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--------------|---|--------|-----------------|-----------------|--------|-----------------|-----------------|--------|-----------------|-----------------|--------|-----------------|-------|----|--|-------|----|--|-------|----|--|-------|----|-------|----|--|-------|----|--|-------|----|--|-------|----|-------|----|--|-------|----|--|-------|----|--|-------|----|-------|----|--|-------|----|--|-------|----|--|-------|----|-------|----|--|-------|----|--|-------|----|--|-------|----|-------|----|--|-------|----|--|-------|----|--|-------|----|-------|----|--|-------|----|--|-------|----|--|-------|----|-------|----|--|-------|----|--|-------|----|--|-------|----|
| | Determines if an interrupt request is made following a loss of lock indication. This bit only has an effect when LOLS 0 is set. 0 No interrupt request is generated on loss of lock. 1 Generate an interrupt request on loss of lock. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 PLLS | PLL Select Controls whether the PLL or FLL output is selected as the MCG source when CLKS[1:0]=00. If the PLLS bit is cleared and PLLCLKEN 0 is not set, the PLL is disabled in all modes. If the PLLS is set, the FLL is disabled in all modes. 0 FLL is selected. 1 PLL is selected (PRDIV 0 need to be programmed to the correct divider to generate a PLL reference clock in the range of 2–4 MHz prior to setting the PLLS bit). | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 CME0 | Clock Monitor Enable Enables the loss of clock monitoring circuit for the OSC0 external reference mux select. The LOCRE0 bit will determine if a interrupt or a reset request is generated following a loss of OSC0 indication. The CME0 bit must only be set to a logic 1 when the MCG is in an operational mode that uses the external clock (FEE, FBE, PEE, PBE, or BLPE) . Whenever the CME0 bit is set to a logic 1, the value of the RANGE0 bits in the C2 register should not be changed. CME0 bit should be set to a logic 0 before the MCG enters any Stop mode. Otherwise, a reset request may occur while in Stop mode. CME0 should also be set to a logic 0 before entering VLPR or VLPW power modes if the MCG is in BLPE mode. 0 External clock monitor is disabled for OSC0. 1 External clock monitor is enabled for OSC0. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4–0 VDIV0 | VCO 0 Divider Selects the amount to divide the VCO output of the PLL. The VDIV 0 bits establish the multiplication factor (M) applied to the reference clock frequency. After the PLL is enabled (by setting either PLLCLKEN 0 or PLLS), the VDIV 0 value must not be changed when LOCK 0 is zero. Table 24-9. PLL VCO Divide Factor <table><tr><th>VDIV 0</th><th>Multiply Factor</th><th></th><th>VDIV 0</th><th>Multiply Factor</th><th></th><th>VDIV 0</th><th>Multiply Factor</th><th></th><th>VDIV 0</th><th>Multiply Factor</th></tr><tr><td>00000</td><td>24</td><td></td><td>01000</td><td>32</td><td></td><td>10000</td><td>40</td><td></td><td>11000</td><td>48</td></tr><tr><td>00001</td><td>25</td><td></td><td>01001</td><td>33</td><td></td><td>10001</td><td>41</td><td></td><td>11001</td><td>49</td></tr><tr><td>00010</td><td>26</td><td></td><td>01010</td><td>34</td><td></td><td>10010</td><td>42</td><td></td><td>11010</td><td>50</td></tr><tr><td>00011</td><td>27</td><td></td><td>01011</td><td>35</td><td></td><td>10011</td><td>43</td><td></td><td>11011</td><td>51</td></tr><tr><td>00100</td><td>28</td><td></td><td>01100</td><td>36</td><td></td><td>10100</td><td>44</td><td></td><td>11100</td><td>52</td></tr><tr><td>00101</td><td>29</td><td></td><td>01101</td><td>37</td><td></td><td>10101</td><td>45</td><td></td><td>11101</td><td>53</td></tr><tr><td>00110</td><td>30</td><td></td><td>01110</td><td>38</td><td></td><td>10110</td><td>46</td><td></td><td>11110</td><td>54</td></tr><tr><td>00111</td><td>31</td><td></td><td>01111</td><td>39</td><td></td><td>10111</td><td>47</td><td></td><td>11111</td><td>55</td></tr></table> | VDIV 0 | Multiply Factor | | VDIV 0 | Multiply Factor | | VDIV 0 | Multiply Factor | | VDIV 0 | Multiply Factor | 00000 | 24 | | 01000 | 32 | | 10000 | 40 | | 11000 | 48 | 00001 | 25 | | 01001 | 33 | | 10001 | 41 | | 11001 | 49 | 00010 | 26 | | 01010 | 34 | | 10010 | 42 | | 11010 | 50 | 00011 | 27 | | 01011 | 35 | | 10011 | 43 | | 11011 | 51 | 00100 | 28 | | 01100 | 36 | | 10100 | 44 | | 11100 | 52 | 00101 | 29 | | 01101 | 37 | | 10101 | 45 | | 11101 | 53 | 00110 | 30 | | 01110 | 38 | | 10110 | 46 | | 11110 | 54 | 00111 | 31 | | 01111 | 39 | | 10111 | 47 | | 11111 | 55 |
| VDIV 0 | Multiply Factor | | VDIV 0 | Multiply Factor | | VDIV 0 | Multiply Factor | | VDIV 0 | Multiply Factor | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00000 | 24 | | 01000 | 32 | | 10000 | 40 | | 11000 | 48 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00001 | 25 | | 01001 | 33 | | 10001 | 41 | | 11001 | 49 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00010 | 26 | | 01010 | 34 | | 10010 | 42 | | 11010 | 50 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00011 | 27 | | 01011 | 35 | | 10011 | 43 | | 11011 | 51 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00100 | 28 | | 01100 | 36 | | 10100 | 44 | | 11100 | 52 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00101 | 29 | | 01101 | 37 | | 10101 | 45 | | 11101 | 53 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00110 | 30 | | 01110 | 38 | | 10110 | 46 | | 11110 | 54 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 00111 | 31 | | 01111 | 39 | | 10111 | 47 | | 11111 | 55 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

24.3.7 MCG Status Register (MCG_S)

Address: 4006_4000h base + 6h offset = 4006_4006h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|-------|-------|--------|-------|---|----------|-------|
| Read | LOLS0 | LOCK0 | PLLST | IREFST | CLKST | | OSCINIT0 | IRCST |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

MCG_S field descriptions

| Field | Description |
|-------------|---|
| 7 LOLS0 | <p>Loss of Lock Status</p> <p>This bit is a sticky bit indicating the lock status for the PLL. LOLS is set if after acquiring lock, the PLL output frequency has fallen outside the lock exit frequency tolerance, D_{unl}. LOLIE determines whether an interrupt request is made when LOLS is set. LOLRE determines whether a reset request is made when LOLS is set. This bit is cleared by reset or by writing a logic 1 to it when set. Writing a logic 0 to this bit has no effect.</p> <p>0 PLL has not lost lock since LOLS 0 was last cleared. 1 PLL has lost lock since LOLS 0 was last cleared.</p> |
| 6 LOCK0 | <p>Lock Status</p> <p>This bit indicates whether the PLL has acquired lock. Lock detection is only enabled when the PLL is enabled (either through clock mode selection or PLLCLKEN0=1 setting). While the PLL clock is locking to the desired frequency, the MCG PLL clock (MCGPLLCLK) will be gated off until the LOCK bit gets asserted. If the lock status bit is set, changing the value of the PRDIV0 [4:0] bits in the C5 register or the VDIV0[4:0] bits in the C6 register causes the lock status bit to clear and stay cleared until the PLL has reacquired lock. Loss of PLL reference clock will also cause the LOCK0 bit to clear until the PLL has reacquired lock. Entry into LLS, VLPS, or regular Stop with PLLSTEN=0 also causes the lock status bit to clear and stay cleared until the Stop mode is exited and the PLL has reacquired lock. Any time the PLL is enabled and the LOCK0 bit is cleared, the MCGPLLCLK will be gated off until the LOCK0 bit is asserted again.</p> <p>0 PLL is currently unlocked. 1 PLL is currently locked.</p> |
| 5 PLLST | <p>PLL Select Status</p> <p>This bit indicates the clock source selected by PLLS. The PLLST bit does not update immediately after a write to the PLLS bit due to internal synchronization between clock domains.</p> <p>0 Source of PLLS clock is FLL clock. 1 Source of PLLS clock is PLL output clock.</p> |
| 4 IREFST | <p>Internal Reference Status</p> <p>This bit indicates the current source for the FLL reference clock. The IREFST bit does not update immediately after a write to the IREFS bit due to internal synchronization between clock domains.</p> <p>0 Source of FLL reference clock is the external reference clock. 1 Source of FLL reference clock is the internal reference clock.</p> |

Table continues on the next page...

MCG_S field descriptions (continued)

| Field | Description |
|---------------|---|
| 3–2 CLKST | <p>Clock Mode Status</p> <p>These bits indicate the current clock mode. The CLKST bits do not update immediately after a write to the CLKS bits due to internal synchronization between clock domains.</p> <p>00 Encoding 0 — Output of the FLL is selected (reset default). 01 Encoding 1 — Internal reference clock is selected. 10 Encoding 2 — External reference clock is selected. 11 Encoding 3 — Output of the PLL is selected.</p> |
| 1 OSCINIT0 | <p>OSC Initialization</p> <p>This bit, which resets to 0, is set to 1 after the initialization cycles of the crystal oscillator clock have completed. After being set, the bit is cleared to 0 if the OSC is subsequently disabled. See the OSC module's detailed description for more information.</p> |
| 0 IRCST | <p>Internal Reference Clock Status</p> <p>The IRCST bit indicates the current source for the internal reference clock select clock (IRCSCCLK). The IRCST bit does not update immediately after a write to the IRCS bit due to internal synchronization between clock domains. The IRCST bit will only be updated if the internal reference clock is enabled, either by the MCG being in a mode that uses the IRC or by setting the C1[IRCLKEN] bit .</p> <p>0 Source of internal reference clock is the slow clock (32 kHz IRC). 1 Source of internal reference clock is the fast clock (4 MHz IRC).</p> |

24.3.8 MCG Status and Control Register (MCG_SC)

Address: 4006_4000h base + 8h offset = 4006_4008h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|------|------|----------|--------|---|---|-------|
| Read | ATME | ATMS | ATMF | FLTPRSRV | FCRDIV | | | LOCS0 |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

MCG_SC field descriptions

| Field | Description |
|-----------|--|
| 7 ATME | <p>Automatic Trim Machine Enable</p> <p>Enables the Auto Trim Machine to start automatically trimming the selected Internal Reference Clock.</p> <p>NOTE: ATME deasserts after the Auto Trim Machine has completed trimming all trim bits of the IRCS clock selected by the ATMS bit. Writing to C1, C3, C4, and SC registers or entering Stop mode aborts the auto trim operation and clears this bit.</p> <p>0 Auto Trim Machine disabled. 1 Auto Trim Machine enabled.</p> |

Table continues on the next page...

MCG_SC field descriptions (continued)

| Field | Description |
|---------------|--|
| 6 ATMS | <p>Automatic Trim Machine Select</p> <p>Selects the IRCS clock for Auto Trim Test.</p> <p>0 32 kHz Internal Reference Clock selected. 1 4 MHz Internal Reference Clock selected.</p> |
| 5 ATMF | <p>Automatic Trim Machine Fail Flag</p> <p>Fail flag for the Automatic Trim Machine (ATM). This bit asserts when the Automatic Trim Machine is enabled, ATME=1, and a write to the C1, C3, C4, and SC registers is detected or the MCG enters into any Stop mode. A write to ATMF clears the flag.</p> <p>0 Automatic Trim Machine completed normally. 1 Automatic Trim Machine failed.</p> |
| 4 FLTPRSRV | <p>FLL Filter Preserve Enable</p> <p>This bit will prevent the FLL filter values from resetting allowing the FLL output frequency to remain the same during clock mode changes where the FLL/DCO output is still valid. (Note: This requires that the FLL reference frequency to remain the same as what it was prior to the new clock mode switch. Otherwise FLL filter and frequency values will change.)</p> <p>0 FLL filter and FLL frequency will reset on changes to current clock mode. 1 FLL filter and FLL frequency retain their previous values during new clock mode change.</p> |
| 3–1 FCRDIV | <p>Fast Clock Internal Reference Divider</p> <p>Selects the amount to divide down the fast internal reference clock. The resulting frequency will be in the range 31.25 kHz to 4 MHz (Note: Changing the divider when the Fast IRC is enabled is not supported).</p> <p>000 Divide Factor is 1 001 Divide Factor is 2. 010 Divide Factor is 4. 011 Divide Factor is 8. 100 Divide Factor is 16 101 Divide Factor is 32 110 Divide Factor is 64 111 Divide Factor is 128.</p> |
| 0 LOCS0 | <p>OSC0 Loss of Clock Status</p> <p>The LOCS0 indicates when a loss of OSC0 reference clock has occurred. The LOCS0 bit only has an effect when CME0 is set. This bit is cleared by writing a logic 1 to it when set.</p> <p>0 Loss of OSC0 has not occurred. 1 Loss of OSC0 has occurred.</p> |

24.3.9 MCG Auto Trim Compare Value High Register (MCG_ATCVH)

Address: 4006_4000h base + Ah offset = 4006_400Ah

| | | | | | | | | |
|-------|-------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | ATCVH | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

MCG_ATCVH field descriptions

| Field | Description |
|--------------|--|
| 7–0 ATCVH | ATM Compare Value High Values are used by Auto Trim Machine to compare and adjust Internal Reference trim values during ATM SAR conversion. |

24.3.10 MCG Auto Trim Compare Value Low Register (MCG_ATCVL)

Address: 4006_4000h base + Bh offset = 4006_400Bh

| | | | | | | | | |
|-------|-------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | ATCVL | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

MCG_ATCVL field descriptions

| Field | Description |
|--------------|---|
| 7–0 ATCVL | ATM Compare Value Low Values are used by Auto Trim Machine to compare and adjust Internal Reference trim values during ATM SAR conversion. |

24.3.11 MCG Control 7 Register (MCG_C7)

Address: 4006_4000h base + Ch offset = 4006_400Ch

| | | | | | | | | |
|-------|---|---|---|---|---|---|--------|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | 0 | | | | 0 | OSCSEL | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

MCG_C7 field descriptions

| Field | Description |
|-----------------|--|
| 7–6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5–2 Reserved | Reserved This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 Reserved | Reserved This field is reserved. This read-only field is reserved and always has the value 0. |
| 0 OSCSEL | MCG OSC Clock Select Selects the MCG FLL external reference clock 0 Selects Oscillator (OSCCLK). 1 Selects 32 kHz RTC Oscillator. |

24.3.12 MCG Control 8 Register (MCG_C8)

Address: 4006_4000h base + Dh offset = 4006_400Dh

| | | | | | | | | |
|-------|--------|-------|------|---|---|---|---|-------|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | LOCRE1 | LOLRE | CME1 | 0 | | | | LOCS1 |
| Write | | | | | | | | |
| Reset | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

MCG_C8 field descriptions

| Field | Description |
|-------------|--|
| 7 LOCRE1 | Loss of Clock Reset Enable Determines if a interrupt or a reset request is made following a loss of RTC external reference clock. The LOCRE1 only has an affect when CME1 is set. 0 Interrupt request is generated on a loss of RTC external reference clock. 1 Generate a reset request on a loss of RTC external reference clock |
| 6 LOLRE | PLL Loss of Lock Reset Enable Determines if an interrupt or a reset request is made following a PLL loss of lock. 0 Interrupt request is generated on a PLL loss of lock indication. The PLL loss of lock interrupt enable bit must also be set to generate the interrupt request. 1 Generate a reset request on a PLL loss of lock indication. |
| 5 CME1 | Clock Monitor Enable1 Enables the loss of clock monitoring circuit for the output of the RTC external reference clock. The LOCRE1 bit will determine whether an interrupt or a reset request is generated following a loss of RTC clock indication. The CME1 bit should be set to a logic 1 when the MCG is in an operational mode that |

Table continues on the next page...

MCG_C8 field descriptions (continued)

| Field | Description |
|-----------------|---|
| | uses the RTC as its external reference clock or if the RTC is operational. CME1 bit must be set to a logic 0 before the MCG enters any Stop mode. Otherwise, a reset request may occur when in Stop mode. CME1 should also be set to a logic 0 before entering VLPR or VLPW power modes. 0 External clock monitor is disabled for RTC clock. 1 External clock monitor is enabled for RTC clock. |
| 4–1 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 0 LOCS1 | RTC Loss of Clock Status This bit indicates when a loss of clock has occurred. This bit is cleared by writing a logic 1 to it when set. 0 Loss of RTC has not occur. 1 Loss of RTC has occur |

24.3.13 MCG Control 10 Register (MCG_C10)

Address: 4006_4000h base + Fh offset = 4006_400Fh

| | | | | | | | | |
|-------|---|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | | | 0 | | | | 0 | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

MCG_C10 field descriptions

| Field | Description |
|-----------------|---|
| 7–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

24.4 Functional description

24.4.1 MCG mode state diagram

The nine states of the MCG are shown in the following figure and are described in [Table 24-17](#). The arrows indicate the permitted MCG mode transitions.

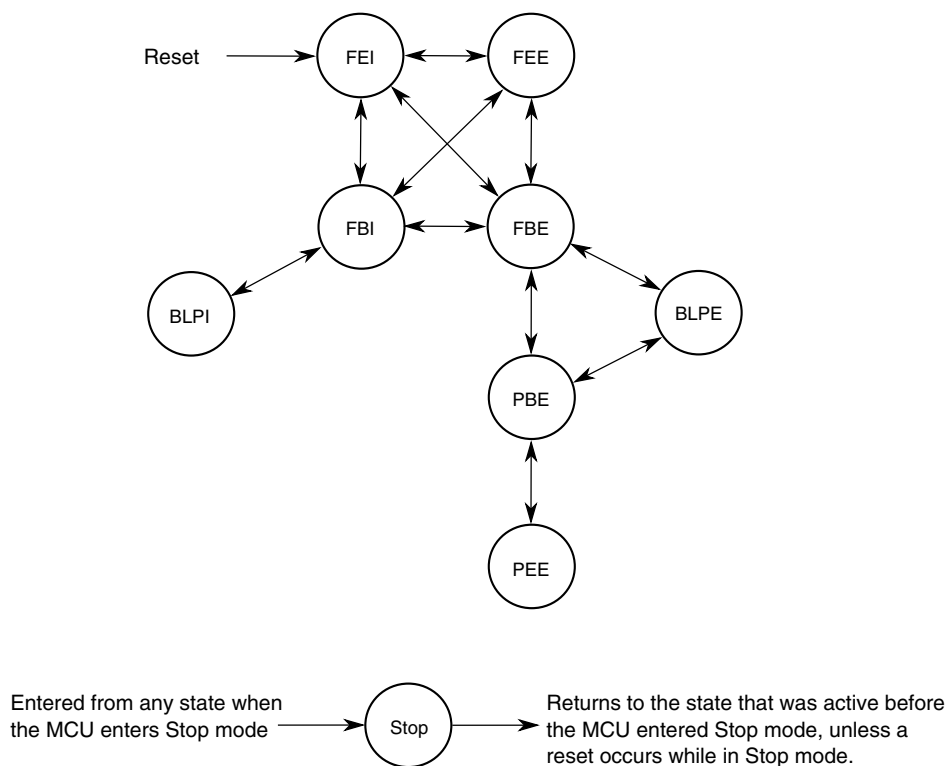


Figure 24-15. MCG mode state diagram

NOTE

- During exits from LLS or VLPS when the MCG is in PEE mode, the MCG will reset to PBE clock mode and the C1[CLKS] and S[CLKST] will automatically be set to 2'b10.
- If entering Normal Stop mode when the MCG is in PEE mode with PLLSTEN=0, the MCG will reset to PBE clock mode and C1[CLKS] and S[CLKST] will automatically be set to 2'b10.

24.4.1.1 MCG modes of operation

The MCG operates in one of the following modes.

Note

The MCG restricts transitions between modes. For the permitted transitions, see [Figure 24-15](#).

Table 24-17. MCG modes of operation

| Mode | Description |
|-----------------------------|---|
| FLL Engaged Internal (FEI) | <p>FLL engaged internal (FEI) is the default mode of operation and is entered when all the following conditions occur:</p> <ul style="list-style-type: none"> • 00 is written to C1[CLKS]. • 1 is written to C1[IREFS]. • 0 is written to C6[PLLS]. <p>In FEI mode, MCGOUTCLK is derived from the FLL clock (DCOCLK) that is controlled by the 32 kHz Internal Reference Clock (IRC). The FLL loop will lock the DCO frequency to the FLL factor, as selected by C4[DRST_DRS] and C4[DMX32] bits, times the internal reference frequency. See the C4[DMX32] bit description for more details. In FEI mode, disabled in a low-power state unless C5[PLLCLKEN] is set .</p> |
| FLL Engaged External (FEE) | <p>FLL engaged external (FEE) mode is entered when all the following conditions occur:</p> <ul style="list-style-type: none"> • 00 is written to C1[CLKS]. • 0 is written to C1[IREFS]. • C1[FRDIV] must be written to divide external reference clock to be within the range of 31.25 kHz to 39.0625 kHz • 0 is written to C6[PLLS]. <p>In FEE mode, MCGOUTCLK is derived from the FLL clock (DCOCLK) that is controlled by the external reference clock. The FLL loop will lock the DCO frequency to the FLL factor, as selected by C4[DRST_DRS] and C4[DMX32] bits, times the external reference frequency, as specified by C1[FRDIV] and C2[RANGE0]. See the C4[DMX32] bit description for more details. In FEE mode, disabled in a low-power state unless C5[PLLCLKEN] is set .</p> |
| FLL Bypassed Internal (FBI) | <p>FLL bypassed internal (FBI) mode is entered when all the following conditions occur:</p> <ul style="list-style-type: none"> • 01 is written to C1[CLKS]. • 1 is written to C1[IREFS]. • 0 is written to C6[PLLS] • 0 is written to C2[LP]. <p>In FBI mode, the MCGOUTCLK is derived either from the slow (32 kHz IRC) or fast (4 MHz IRC) internal reference clock, as selected by the C2[IRCS] bit. The FLL is operational but its output is not used. This mode is useful to allow the FLL to acquire its target frequency while the MCGOUTCLK is driven from the C2[IRCS] selected internal reference clock. The FLL clock (DCOCLK) is controlled by the slow internal reference clock, and the DCO clock frequency locks to a multiplication factor, as selected by C4[DRST_DRS] and C4[DMX32] bits, times the internal reference frequency. See the C4[DMX32] bit description for more details. In FBI mode, disabled in a low-power state unless C5[PLLCLKEN] is set .</p> |

Table continues on the next page...

Table 24-17. MCG modes of operation (continued)

| Mode | Description |
|-----------------------------|--|
| FLL Bypassed External (FBE) | <p>FLL bypassed external (FBE) mode is entered when all the following conditions occur:</p> <ul style="list-style-type: none"> • 10 is written to C1[CLKS]. • 0 is written to C1[IREFS]. • C1[FRDIV] must be written to divide external reference clock to be within the range of 31.25 kHz to 39.0625 kHz. • 0 is written to C6[PLLS]. • 0 is written to C2[LP]. <p>In FBE mode, the MCGOUTCLK is derived from the OSCSEL external reference clock. The FLL is operational but its output is not used. This mode is useful to allow the FLL to acquire its target frequency while the MCGOUTCLK is driven from the external reference clock. The FLL clock (DCOCLK) is controlled by the external reference clock, and the DCO clock frequency locks to a multiplication factor, as selected by C4[DRST_DRS] and C4[DMX32] bits, times the divided external reference frequency. See the C4[DMX32] bit description for more details. In FBE mode, disabled in a low-power state unless C5[PLLCLKEN] is set .</p> |
| PLL Engaged External (PEE) | <p>PLL Engaged External (PEE) mode is entered when all the following conditions occur:</p> <ul style="list-style-type: none"> • 00 is written to C1[CLKS]. • 0 is written to C1[IREFS]. • 1 is written to C6[PLLS]. <p>In PEE mode, the MCGOUTCLK is derived from the output of PLL controlled by a external reference clock. The PLL clock frequency locks to a multiplication factor, as specified by its corresponding VDIV, times the selected PLL reference frequency, as specified by its corresponding PRDIV. The PLL's programmable reference divider must be configured to produce a valid PLL reference clock. The FLL is disabled in a low-power state.</p> |
| PLL Bypassed External (PBE) | <p>PLL Bypassed External (PBE) mode is entered when all the following conditions occur:</p> <ul style="list-style-type: none"> • 10 is written to C1[CLKS]. • 0 is written to C1[IREFS]. • 1 is written to C6[PLLS]. • 0 is written to C2[LP]. <p>In PBE mode, MCGOUTCLK is derived from the OSCSEL external reference clock; the PLL is operational, but its output clock is not used. This mode is useful to allow the PLL to acquire its target frequency while MCGOUTCLK is driven from the external reference clock. The PLL clock frequency locks to a multiplication factor, as specified by its [VDIV], times the PLL reference frequency, as specified by its [PRDIV]. In preparation for transition to PEE, the PLL's programmable reference divider must be configured to produce a valid PLL reference clock. The FLL is disabled in a low-power state.</p> |

Table continues on the next page...

Table 24-17. MCG modes of operation (continued)

| Mode | Description |
|---|---|
| Bypassed Low Power Internal (BLPI) ¹ | <p>Bypassed Low Power Internal (BLPI) mode is entered when all the following conditions occur:</p> <ul style="list-style-type: none"> • 01 is written to C1[CLKS]. • 1 is written to C1[IREFS]. • 0 is written to C6[PLLS]. • 1 is written to C2[LP]. <p>In BLPI mode, MCGOUTCLK is derived from the internal reference clock. The FLL is disabled and PLL is disabled even if C5[PLLCLKEN] is set to 1.</p> |
| Bypassed Low Power External (BLPE) | <p>Bypassed Low Power External (BLPE) mode is entered when all the following conditions occur:</p> <ul style="list-style-type: none"> • 10 is written to C1[CLKS]. • 0 is written to C1[IREFS]. • 1 is written to C2[LP]. <p>In BLPE mode, MCGOUTCLK is derived from the OSCSEL external reference clock. The FLL is disabled and PLL is disabled even if the C5[PLLCLKEN] is set to 1.</p> |
| Stop | <p>Entered whenever the MCU enters a Stop state. The power modes are chip specific. For power mode assignments, see the chapter that describes how modules are configured and MCG behavior during Stop recovery. Entering Stop mode, the FLL is disabled, and all MCG clock signals are static except in the following case:</p> <p>MCGPLLCLK is active in Normal Stop mode when PLLSTEN=1</p> <p>MCGPLL1CLK is active in Normal Stop mode when PLLSTEN1=1</p> <p>MCGIRCLK is active in Normal Stop mode when all the following conditions become true:</p> <ul style="list-style-type: none"> • C1[IRCLKEN] = 1 • C1[IREFSTEN] = 1 <p>NOTE:</p> <ul style="list-style-type: none"> • When entering Low Power Stop modes (LLS or VLPS) from PEE mode, on exit the MCG clock mode is forced to PBE clock mode. C1[CLKS] and S[CLKST] will be configured to 2'b10 and S[LOCK] bit will be cleared without setting S[LOLS]. • When entering Normal Stop mode from PEE mode and if C5[PLLSTEN]=0, on exit the MCG clock mode is forced to PBE mode, the C1[CLKS] and S[CLKST] will be configured to 2'b10 and S[LOCK] bit will clear without setting S[LOLS]. If C5[PLLSTEN]=1, the S[LOCK] bit will not get cleared and on exit the MCG will continue to run in PEE mode. |

1. If entering VLPR mode, MCG has to be configured and enter BLPE mode or BLPI mode with the Fast IRC clock selected (C2[IRCS]=1). After it enters VLPR mode, writes to any of the MCG control registers that can cause an MCG clock mode switch to a non low power clock mode must be avoided.

NOTE

For the chip-specific modes of operation, see the power management chapter of this MCU.

24.4.1.2 MCG mode switching

C1[IREFS] can be changed at any time, but the actual switch to the newly selected reference clocks is shown by S[IREFST]. When switching between engaged internal and engaged external modes, the FLL will begin locking again after the switch is completed.

C1[CLKS] can also be changed at any time, but the actual switch to the newly selected clock is shown by S[CLKST]. If the newly selected clock is not available, the previous clock will remain selected.

The C4[DRST_DRS] write bits can be changed at any time except when C2[LP] bit is 1. If C4[DRST_DRS] write bits are changed while in FLL engaged internal (FEI) or FLL engaged external (FEE) mode, the MCGOUTCLK switches to the new selected DCO range within three clocks of the selected DCO clock. After switching to the new DCO (indicated by the updated C4[DRST_DRS] read bits), the FLL remains unlocked for several reference cycles. The FLL lock time is provided in the device data sheet as $t_{\text{fll_acquire}}$.

24.4.2 Low-power bit usage

C2[LP] is provided to allow the FLL or PLL to be disabled and thus conserve power when these systems are not being used. C4[DRST_DRS] can not be written while C2[LP] is 1. However, in some applications, it may be desirable to enable the FLL or PLL and allow it to lock for maximum accuracy before switching to an engaged mode. Do this by writing 0 to C2[LP].

24.4.3 MCG Internal Reference Clocks

This module supports two internal reference clocks with nominal frequencies of 32 kHz (slow IRC) and 4 MHz (fast IRC). The fast IRC frequency can be divided down by programming of the FCRDIV to produce a frequency range of 32 kHz to 4 MHz.

24.4.3.1 MCG Internal Reference Clock

The MCG Internal Reference Clock (MCGIRCLK) provides a clock source for other on-chip peripherals and is enabled when C1[IRCLKEN]=1. When enabled, MCGIRCLK is driven by either the fast internal reference clock (4 MHz IRC which can be divided down by the FRDIV factors) or the slow internal reference clock (32 kHz IRC). The IRCS clock frequency can be re-targeted by trimming the period of its IRCS selected internal reference clock. This can be done by writing a new trim value to the

C3[SCTRIM]:C4[SCFTRIM] bits when the slow IRC clock is selected or by writing a new trim value to C4[FCTRIM] when the fast IRC clock is selected. The internal reference clock period is proportional to the trim value written.

C3[SCTRIM]:C4[SCFTRIM] (if C2[IRCS]=0) and C4[FCTRIM] (if C2[IRCS]=1) bits affect the MCGOUTCLK frequency if the MCG is in FBI or BLPI modes.

C3[SCTRIM]:C4[SCFTRIM] (if C2[IRCS]=0) bits also affect the MCGOUTCLK frequency if the MCG is in FEI mode.

Additionally, this clock can be enabled in Stop mode by setting C1[IRCLKEN] and C1[IREFSTEN], otherwise this clock is disabled in Stop mode.

24.4.4 External Reference Clock

The MCG module can support an external reference clock in all modes. See the device datasheet for external reference frequency range. When C1[IREFS] is set, the external reference clock will not be used by the FLL or PLL. In these modes, the frequency can be equal to the maximum frequency the chip-level timing specifications will support.

If any of the CME bits are asserted the slow internal reference clock is enabled along with the enabled external clock monitor. For the case when C6[CME0]=1, a loss of clock is detected if the OSC0 external reference falls below a minimum frequency (f_{loc_high} or f_{loc_low} depending on C2[RANGE0]). For the case when C8[CME1]=1, a loss of clock is detected if the RTC external reference falls below a minimum frequency (f_{loc_low}).

NOTE

All clock monitors must be disabled before entering these low-power modes: Stop, VLPS, VLPR, VLPW, LLS, and VLLSx.

On detecting a loss-of-clock event, the MCU generates a system reset if the respective LOCRE bit is set. Otherwise the MCG sets the respective LOCS bit and the MCG generates a LOCS interrupt request. In the case where a OSC loss of clock is detected, the PLL LOCK status bit is cleared.

24.4.5 MCG Fixed Frequency Clock

The MCG Fixed Frequency Clock (MCGFFCLK) provides a fixed frequency clock source for other on-chip peripherals; see the block diagram. This clock is driven by either the slow clock from the internal reference clock generator or the external reference clock from the Crystal Oscillator, divided by the FLL reference clock divider. The source of MCGFFCLK is selected by C1[IREFS].

This clock is synchronized to the peripheral bus clock and is valid only when its frequency is not more than 1/8 of the MCGOUTCLK frequency. When it is not valid, it is disabled and held high. The MCGFFCLK is not available when the MCG is in BLPI mode. This clock is also disabled in Stop mode. The FLL reference clock must be set within the valid frequency range for the MCGFFCLK.

24.4.6 MCG PLL clock

The MCG PLL Clock (MCGPLLCLK) is available depending on the device's configuration of the MCG module. For more details, see the clock distribution chapter of this MCU. The MCGPLLCLK is prevented from coming out of the MCG until it is enabled and S[LOCK0] is set.

24.4.7 MCG Auto TRIM (ATM)

The MCG Auto Trim (ATM) is a MCG feature that when enabled, it configures the MCG hardware to automatically trim the MCG Internal Reference Clocks using an external clock as a reference. The selection between which MCG IRC clock gets tested and enabled is controlled by the ATC[ATMS] control bit (ATC[ATMS]=0 selects the 32 kHz IRC and ATC[ATMS]=1 selects the 4 MHz IRC). If 4 MHz IRC is selected for the ATM, a divide by 128 is enabled to divide down the 4 MHz IRC to a range of 31.250 kHz.

When MCG ATM is enabled by writing ATC[ATME] bit to 1, The ATM machine will start auto trimming the selected IRC clock. During the autotrim process, ATC[ATME] will remain asserted and will deassert after ATM is completed or an abort occurs. The MCG ATM is aborted if a write to any of the following control registers is detected : C1, C3, C4, or ATC or if Stop mode is entered. If an abort occurs, ATC[ATMF] fail flag is asserted.

The ATM machine uses the bus clock as the external reference clock to perform the IRC auto-trim. Therefore, it is required that the MCG is configured in a clock mode where the reference clock used to generate the system clock is the external reference clock such as FBE clock mode. The MCG must not be configured in a clock mode where selected IRC ATM clock is used to generate the system clock. The bus clock is also required to be running with in the range of 8–16 MHz.

To perform the ATM on the selected IRC, the ATM machine uses the successive approximation technique to adjust the IRC trim bits to generate the desired IRC trimmed frequency. The ATM SARs each of the ATM IRC trim bits starting with the MSB. For each trim bit test, the ATM uses a pulse that is generated by the ATM selected IRC clock to enable a counter that counts number of ATM external clocks. At end of each trim bit,

the ATM external counter value is compared to the ATCV[15:0] register value. Based on the comparison result, the ATM trim bit under test will get cleared or stay asserted. This is done until all trim bits have been tested by ATM SAR machine.

Before the ATM can be enabled, the ATM expected count needs to be derived and stored into the ATCV register. The ATCV expected count is derived based on the required target Internal Reference Clock (IRC) frequency, and the frequency of the external reference clock using the following formula:

$$\text{ATCV Expected Count Value} = 21 * (\text{Fe} / \text{Fr})$$

- Fr = Target Internal Reference Clock (IRC) Trimmed Frequency
- Fe = External Clock Frequency

If the auto trim is being performed on the 4 MHz IRC, the calculated expected count value must be multiplied by 128 before storing it in the ATCV register. Therefore, the ATCV Expected Count Value for trimming the 4 MHz IRC is calculated using the following formula.

$$\text{Expected Count Value} = (\text{Fe} / \text{Fr}) * 21 * (128)$$

24.5 Initialization / Application information

This section describes how to initialize and configure the MCG module in an application.

The following sections include examples on how to initialize the MCG and properly switch between the various available modes.

24.5.1 MCG module initialization sequence

The MCG comes out of reset configured for FEI mode.

The internal reference will stabilize in t_{irefstb} microseconds before the FLL can acquire lock. As soon as the internal reference is stable, the FLL will acquire lock in $t_{\text{fl_acquire}}$ milliseconds.

24.5.1.1 Initializing the MCG

Because the MCG comes out of reset in FEI mode, the only MCG modes that can be directly switched to upon reset are FEE, FBE, and FBI modes (see [Figure 24-15](#)). Reaching any of the other modes requires first configuring the MCG for one of these three intermediate modes. Care must be taken to check relevant status bits in the MCG status register reflecting all configuration changes within each mode.

To change from FEI mode to FEE or FBE modes, follow this procedure:

1. Enable the external clock source by setting the appropriate bits in C2 register.
2. Write to C1 register to select the clock mode.
 - If entering FEE mode, set C1[FRDIV] appropriately, clear C1[IREFS] bit to switch to the external reference, and leave C1[CLKS] at 2'b00 so that the output of the FLL is selected as the system clock source.
 - If entering FBE, clear C1[IREFS] to switch to the external reference and change C1[CLKS] to 2'b10 so that the external reference clock is selected as the system clock source. The C1[FRDIV] bits should also be set appropriately here according to the external reference frequency to keep the FLL reference clock in the range of 31.25 kHz to 39.0625 kHz. Although the FLL is bypassed, it is still on in FBE mode.
 - The internal reference can optionally be kept running by setting C1[IRCLKEN]. This is useful if the application will switch back and forth between internal and external modes. For minimum power consumption, leave the internal reference disabled while in an external clock mode.
3. Once the proper configuration bits have been set, wait for the affected bits in the MCG status register to be changed appropriately, reflecting that the MCG has moved into the proper mode.
 - If the MCG is in FEE, FBE, PEE, PBE, or BLPE mode, and C2[EREFS0] was also set in step 1, wait here for S[OSCINIT0] bit to become set indicating that the external clock source has finished its initialization cycles and stabilized.
 - If in FEE mode, check to make sure S[IREFST] is cleared before moving on.
 - If in FBE mode, check to make sure S[IREFST] is cleared and S[CLKST] bits have changed to 2'b10 indicating the external reference clock has been appropriately selected. Although the FLL is bypassed, it is still on in FBE mode.
4. Write to the C4 register to determine the DCO output (MCGFLLCLK) frequency range.

- By default, with C4[DMX32] cleared to 0, the FLL multiplier for the DCO output is 640. For greater flexibility, if a mid-low-range FLL multiplier of 1280 is desired instead, set C4[DRST_DRS] bits to 2'b01 for a DCO output frequency of 40 MHz. If a mid high-range FLL multiplier of 1920 is desired instead, set the C4[DRST_DRS] bits to 2'b10 for a DCO output frequency of 60 MHz. If a high-range FLL multiplier of 2560 is desired instead, set the C4[DRST_DRS] bits to 2'b11 for a DCO output frequency of 80 MHz.
 - When using a 32.768 kHz external reference, if the maximum low-range DCO frequency that can be achieved with a 32.768 kHz reference is desired, set C4[DRST_DRS] bits to 2'b00 and set C4[DMX32] bit to 1. The resulting DCO output (MCGOUTCLK) frequency with the new multiplier of 732 will be 24 MHz.
 - When using a 32.768 kHz external reference, if the maximum mid-range DCO frequency that can be achieved with a 32.768 kHz reference is desired, set C4[DRST_DRS] bits to 2'b01 and set C4[DMX32] bit to 1. The resulting DCO output (MCGOUTCLK) frequency with the new multiplier of 1464 will be 48 MHz.
 - When using a 32.768 kHz external reference, if the maximum mid high-range DCO frequency that can be achieved with a 32.768 kHz reference is desired, set C4[DRST_DRS] bits to 2'b10 and set C4[DMX32] bit to 1. The resulting DCO output (MCGOUTCLK) frequency with the new multiplier of 2197 will be 72 MHz.
 - When using a 32.768 kHz external reference, if the maximum high-range DCO frequency that can be achieved with a 32.768 kHz reference is desired, set C4[DRST_DRS] bits to 2'b11 and set C4[DMX32] bit to 1. The resulting DCO output (MCGOUTCLK) frequency with the new multiplier of 2929 will be 96 MHz.
5. Wait for the FLL lock time to guarantee FLL is running at new C4[DRST_DRS] and C4[DMX32] programmed frequency.

To change from FEI clock mode to FBI clock mode, follow this procedure:

1. Change C1[CLKS] bits in C1 register to 2'b01 so that the internal reference clock is selected as the system clock source.
2. Wait for S[CLKST] bits in the MCG status register to change to 2'b01, indicating that the internal reference clock has been appropriately selected.
3. Write to the C2 register to determine the IRCS output (IRCSCLK) frequency range.

- By default, with C2[IRCS] cleared to 0, the IRCS selected output clock is the slow internal reference clock (32 kHz IRC). If the faster IRC is desired, set C2[IRCS] to 1 for a IRCS clock derived from the 4 MHz IRC source.

24.5.2 Using a 32.768 kHz reference

In FEE and FBE modes, if using a 32.768 kHz external reference, at the default FLL multiplication factor of 640, the DCO output (MCGFLLCLK) frequency is 20.97 MHz at low-range.

If C4[DRST_DRS] bits are set to 2'b01, the multiplication factor is doubled to 1280, and the resulting DCO output frequency is 41.94 MHz at mid-low-range. If C4[DRST_DRS] bits are set to 2'b10, the multiplication factor is set to 1920, and the resulting DCO output frequency is 62.91 MHz at mid high-range. If C4[DRST_DRS] bits are set to 2'b11, the multiplication factor is set to 2560, and the resulting DCO output frequency is 83.89 MHz at high-range.

In FBI and FEI modes, setting C4[DMX32] bit is not recommended. If the internal reference is trimmed to a frequency above 32.768 kHz, the greater FLL multiplication factor could potentially push the microcontroller system clock out of specification and damage the part.

24.5.3 MCG mode switching

When switching between operational modes of the MCG, certain configuration bits must be changed in order to properly move from one mode to another.

Each time any of these bits are changed (C6[PLLS], C1[IREFS], C1[CLKS], C2[IRCS], or C2[EREFS0]), the corresponding bits in the MCG status register (PLLST, IREFST, CLKST, IRCST, or OSCINIT) must be checked before moving on in the application software.

Additionally, care must be taken to ensure that the reference clock divider (C1[FRDIV] and C5[PRDIV0]) is set properly for the mode being switched to. For instance, in PEE mode, if using a 4 MHz crystal, C5[PRDIV0] must be set to 5'b000 (divide-by-1) or 5'b001 (divide-by-2) to divide the external reference down to the required frequency between 2 and 4 MHz.

In FBE, FEE, FBI, and FEI modes, at any time, the application can switch the FLL multiplication factor between 640, 1280, 1920, and 2560 with C4[DRST_DRS] bits. Writes to C4[DRST_DRS] bits will be ignored if C2[LP]=1.

The table below shows MCGOUTCLK frequency calculations using C1[FRDIV], C5[PRDIV0], and C6[VDIV0] settings for each clock mode.

Table 24-18. MCGOUTCLK Frequency Calculation Options

| Clock Mode | $f_{\text{MCGOUTCLK}}^1$ | Note |
|------------------------------------|--|---|
| FEI (FLL engaged internal) | $(f_{\text{int}} * F)$ | Typical $f_{\text{MCGOUTCLK}} = 21 \text{ MHz}$ immediately after reset. |
| FEE (FLL engaged external) | $(f_{\text{ext}} / \text{FLL_R}) * F$ | $f_{\text{ext}} / \text{FLL_R}$ must be in the range of 31.25 kHz to 39.0625 kHz |
| FBE (FLL bypassed external) | OSCCLK | OSCCLK / FLL_R must be in the range of 31.25 kHz to 39.0625 kHz |
| FBI (FLL bypassed internal) | MCGIRCLK | Selectable between slow and fast IRC |
| PEE (PLL engaged external) | $(\text{OSCCLK} / \text{PLL_R}) * M$ | OSCCLK / PLL_R must be in the range of 2 – 4 MHz |
| PBE (PLL bypassed external) | OSCCLK | OSCCLK / PLL_R must be in the range of 2 – 4 MHz |
| BLPI (Bypassed low power internal) | MCGIRCLK | Selectable between slow and fast IRC |
| BLPE (Bypassed low power external) | OSCCLK | |

1. FLL_R is the reference divider selected by the C1[FRDIV] bits, PLL_R is the reference divider selected by C5[PRDIV0] bits, F is the FLL factor selected by C4[DRST_DRS] and C4[DMX32] bits, and M is the multiplier selected by C6[VDIV0] bits.

This section will include three mode switching examples using an 4 MHz external crystal. If using an external clock source less than 2 MHz, the MCG must not be configured for any of the PLL modes (PEE and PBE).

24.5.3.1 Example 1: Moving from FEI to PEE mode: External Crystal = 4 MHz, MCGOUTCLK frequency = 48 MHz

In this example, the MCG will move through the proper operational modes from FEI to PEE to achieve 48 MHz MCGOUTCLK frequency from 4 MHz external crystal reference. First, the code sequence will be described. Then there is a flowchart that illustrates the sequence.

1. First, FEI must transition to FBE mode:

- a. C2 = 0x2C

- C2[RANGE0] set to 2'b01 because the frequency of 4 MHz is within the high frequency range.

- C2[HGO0] set to 1 to configure the crystal oscillator for high gain operation.
 - C2[EREFS0] set to 1, because a crystal is being used.
- b. C1 = 0x90
- C1[CLKS] set to 2'b10 to select external reference clock as system clock source
 - C1[FRDIV] set to 3'b010, or divide-by-128 because $4 \text{ MHz} / 128 = 31.25 \text{ kHz}$ which is in the 31.25 kHz to 39.0625 kHz range required by the FLL
 - C1[IREFS] cleared to 0, selecting the external reference clock and enabling the external oscillator.
- c. Loop until S[OSCINIT0] is 1, indicating the crystal selected by C2[EREFS0] has been initialized.
- d. Loop until S[IREFST] is 0, indicating the external reference is the current source for the reference clock.
- e. Loop until S[CLKST] is 2'b10, indicating that the external reference clock is selected to feed MCGOUTCLK.
2. Then configure C5[PRDIV0] to generate correct PLL reference frequency.
- a. C5 = 0x01
- C5[PRDIV] set to 5'b00001, or divide-by-2 resulting in a pll reference frequency of $4\text{MHz}/2 = 2 \text{ MHz}$.
3. Then, FBE must transition either directly to PBE mode or first through BLPE mode and then to PBE mode:
- a. BLPE: If a transition through BLPE mode is desired, first set C2[LP] to 1.
- b. BLPE/PBE: C6 = 0x40
- C6[PLLS] set to 1, selects the PLL. At this time, with a C1[PRDIV] value of 2'b001, the PLL reference divider is 2 (see PLL External Reference Divide Factor table), resulting in a reference frequency of $4 \text{ MHz} / 2 = 2 \text{ MHz}$. In BLPE mode, changing the C6[PLLS] bit only prepares the MCG for PLL usage in PBE mode.
 - C6[VDIV] set to 5'b00000, or multiply-by-24 because $2 \text{ MHz reference} * 24 = 48 \text{ MHz}$. In BLPE mode, the configuration of the VDIV bits does not matter because the PLL is disabled. Changing them only sets up the multiply value for PLL usage in PBE mode.

- c. BLPE: If transitioning through BLPE mode, clear C2[LP] to 0 here to switch to PBE mode.
 - d. PBE: Loop until S[PLLST] is set, indicating that the current source for the PLLS clock is the PLL.
 - e. PBE: Then loop until S[LOCK0] is set, indicating that the PLL has acquired lock.
4. Lastly, PBE mode transitions into PEE mode:
- a. C1 = 0x10
 - C1[CLKS] set to 2'b00 to select the output of the PLL as the system clock source.
 - b. Loop until S[CLKST] are 2'b11, indicating that the PLL output is selected to feed MCGOUTCLK in the current clock mode.
 - Now, with PRDIV of divide-by-2, and C6[VDIV] of multiply-by-24, $MCGOUTCLK = [(4 \text{ MHz} / 2) * 24] = 48 \text{ MHz}$.

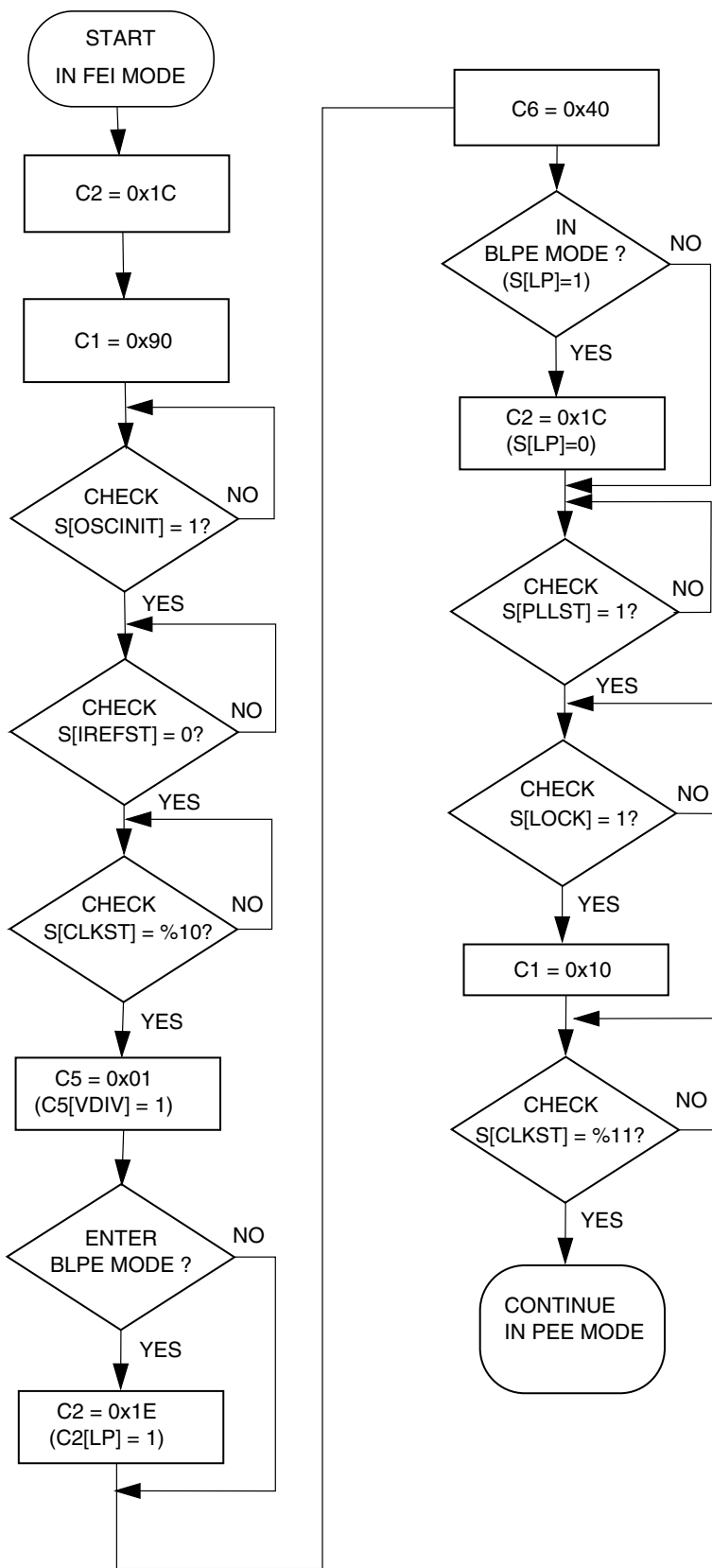


Figure 24-16. Flowchart of FEI to PEE mode transition using an 4 MHz crystal

24.5.3.2 Example 2: Moving from PEE to BLPI mode: MCGOUTCLK frequency =32 kHz

In this example, the MCG will move through the proper operational modes from PEE mode with a 4 MHz crystal configured for a 48 MHz MCGOUTCLK frequency (see previous example) to BLPI mode with a 32 kHz MCGOUTCLK frequency. First, the code sequence will be described. Then there is a flowchart that illustrates the sequence.

1. First, PEE must transition to PBE mode:
 - a. C1 = 0x90
 - C1[CLKS] set to 2'b10 to switch the system clock source to the external reference clock.
 - b. Loop until S[CLKST] are 2'b10, indicating that the external reference clock is selected to feed MCGOUTCLK.
2. Then, PBE must transition either directly to FBE mode or first through BLPE mode and then to FBE mode:
 - a. BLPE: If a transition through BLPE mode is desired, first set C2[LP] to 1.
 - b. BLPE/FBE: C6 = 0x00
 - C6[PLLS] clear to 0 to select the FLL. At this time, with C1[FRDIV] value of 3'b010, the FLL divider is set to 128, resulting in a reference frequency of $4 \text{ MHz} / 128 = 31.25 \text{ kHz}$. If C1[FRDIV] was not previously set to 3'b010 (necessary to achieve required 31.25–39.06 kHz FLL reference frequency with an 4 MHz external source frequency), it must be changed prior to clearing C6[PLLS] bit. In BLPE mode, changing this bit only prepares the MCG for FLL usage in FBE mode. With C6[PLLS] = 0, the C6[VDIV] value does not matter.
 - c. BLPE: If transitioning through BLPE mode, clear C2[LP] to 0 here to switch to FBE mode.
 - d. FBE: Loop until S[PLLST] is cleared, indicating that the current source for the PLLS clock is the FLL.
3. Next, FBE mode transitions into FBI mode:
 - a. C1 = 0x54
 - C1[CLKS] set to 2'b01 to switch the system clock to the internal reference clock.

- C1[IREFS] set to 1 to select the internal reference clock as the reference clock source.
 - C1[FRDIV] remain unchanged because the reference divider does not affect the internal reference.
- b. Loop until S[IREFST] is 1, indicating the internal reference clock has been selected as the reference clock source.
 - c. Loop until S[CLKST] are 2'b01, indicating that the internal reference clock is selected to feed MCGOUTCLK.
4. Lastly, FBI transitions into BLPI mode.
 - a. C2 = 0x02
 - C2[LP] is 1
 - C2[RANGE0], C2[HGO0], C2[EREFS0], C1[IRCLKEN], and C1[IREFSTEN] bits are ignored when the C1[IREFS] bit is set. They can remain set, or be cleared at this point.

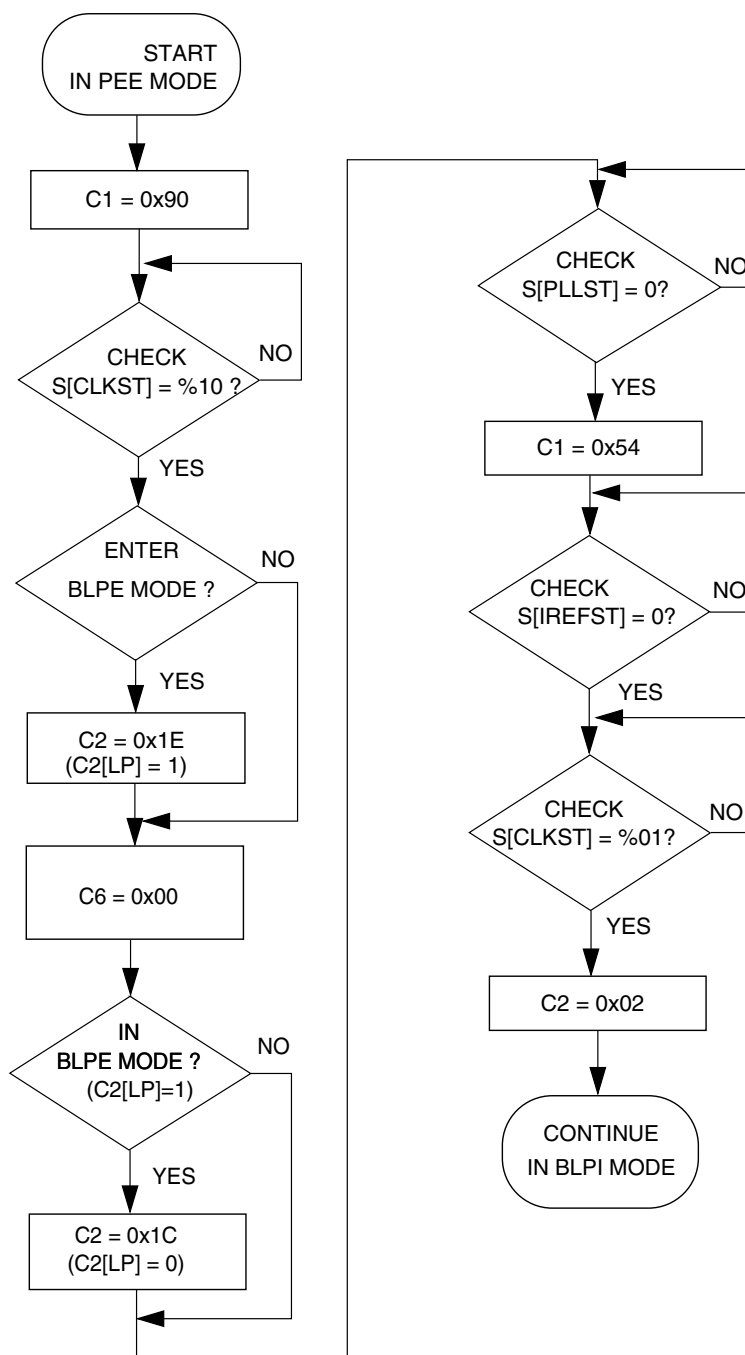


Figure 24-17. Flowchart of PEE to BLPI mode transition using an 4 MHz crystal

Chapter 25

Oscillator (OSC)

25.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The OSC module is a crystal oscillator. The module, in conjunction with an external crystal or resonator, generates a reference clock for the MCU.

25.2 Features and Modes

Key features of the module are listed here.

- Supports 32 kHz crystals (Low Range mode)
- Supports 3–8 MHz crystals and resonators (High Range mode)
- Automatic Gain Control (AGC) to optimize power consumption in high frequency ranges 3–8 MHz using low-power mode
- High gain option in frequency ranges: 32 kHz, 3–8 MHz
- Voltage and frequency filtering to guarantee clock frequency and stability
- Optionally external input bypass clock from EXTAL signal directly
- One clock for MCU clock system
- Two clocks for on-chip peripherals that can work in Stop modes

[Functional Description](#) describes the module's operation in more detail.

25.3 Block Diagram

The OSC module uses a crystal or resonator to generate three filtered oscillator clock signals. Three clocks are output from OSC module: OSCCLK for MCU system, OSCERCLK for on-chip peripherals, and OSC32KCLK. The OSCCLK can only work in run mode. OSCERCLK and OSC32KCLK can work in low power modes. For the clock source assignments, refer to the clock distribution information of this MCU.

Refer to the chip configuration details for the external reference clock source in this MCU.

The figure found here shows the block diagram of the OSC module.

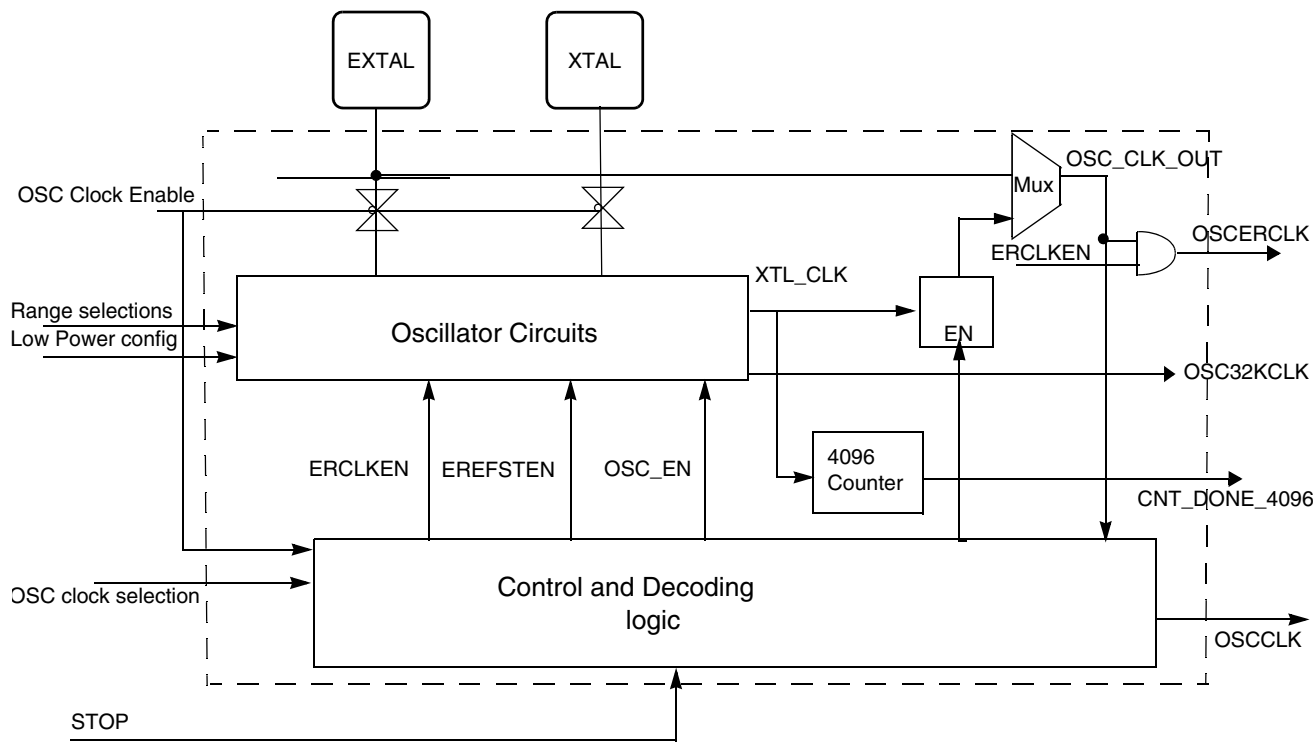


Figure 25-1. OSC Module Block Diagram

25.4 OSC Signal Descriptions

The table found here shows the user-accessible signals available for the OSC module.

Refer to signal multiplexing information for this MCU for more details.

Table 25-1. OSC Signal Descriptions

| Signal | Description | I/O |
|--------|---------------------------------|-----|
| EXTAL | External clock/Oscillator input | I |
| XTAL | Oscillator output | O |

25.5 External Crystal / Resonator Connections

The connections for a crystal/resonator frequency reference are shown in the figures found here.

When using low-frequency, low-power mode, the only external component is the crystal or ceramic resonator itself. In the other oscillator modes, load capacitors (C_x , C_y) and feedback resistor (R_F) are required. The following table shows all possible connections.

Table 25-2. External Crystal/Resonator Connections

| Oscillator Mode | Connections |
|--------------------------------------|--|
| Low-frequency (32 kHz), low-power | Connection 1 |
| Low-frequency (32 kHz), high-gain | Connection 2/Connection 3 ¹ |
| High-frequency (3~32 MHz), low-power | Connection 1/Connection 3 ^{2,2} |
| High-frequency (3~32 MHz), high-gain | Connection 2/Connection 3 ² |

1. When the load capacitors (C_x , C_y) are greater than 30 pF, use Connection 3.
2. With the low-power mode, the oscillator has the internal feedback resistor R_F . Therefore, the feedback resistor must not be externally with the Connection 3.

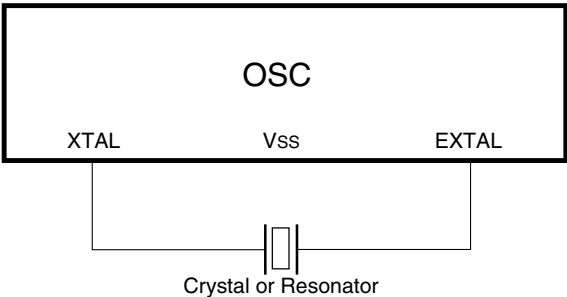


Figure 25-2. Crystal/Ceramic Resonator Connections - Connection 1

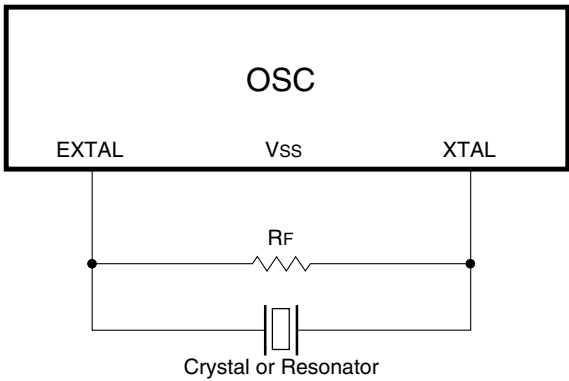


Figure 25-3. Crystal/Ceramic Resonator Connections - Connection 2

NOTE

Connection 1 and Connection 2 should use internal capacitors as the load of the oscillator by configuring the CR[SCxP] bits.

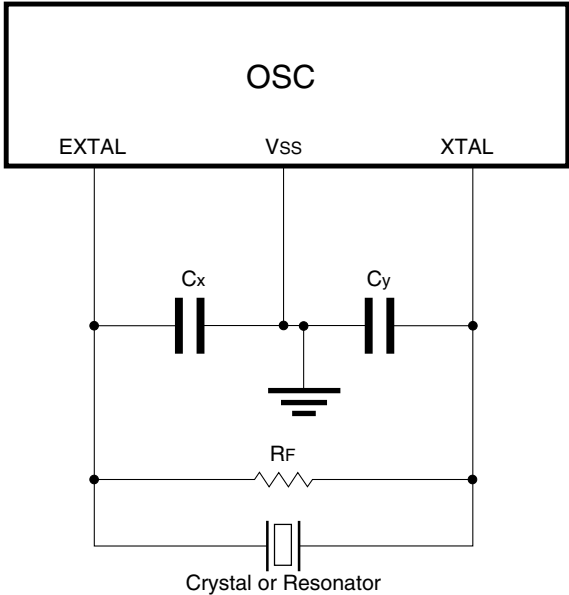


Figure 25-4. Crystal/Ceramic Resonator Connections - Connection 3

25.6 External Clock Connections

In external clock mode, the pins can be connected as shown in the figure found here.

NOTE

XTAL can be used as a GPIO when the GPIO alternate function is configured for it.

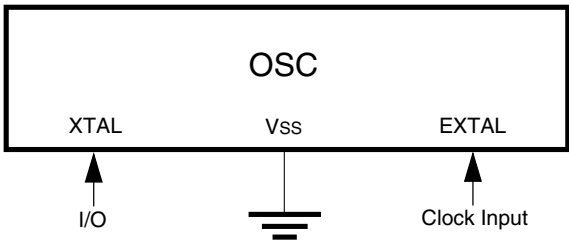


Figure 25-5. External Clock Connections

25.7 Memory Map/Register Definitions

Some oscillator module register bits are typically incorporated into other peripherals such as MCG or SIM.

25.7.1 OSC Memory Map/Register Definition

OSC memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|-------------------------------|-----------------|--------|-------------|-----------------------------|
| 4006_5000 | OSC Control Register (OSC_CR) | 8 | R/W | 00h | 25.71.1/485 |

25.71.1 OSC Control Register (OSC_CR)

NOTE

After OSC is enabled and starts generating the clocks, the configurations such as low power and frequency range, must not be changed.

Address: 4006_5000h base + 0h offset = 4006_5000h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---------|---|----------|---|------|------|------|-------|
| Read | ERCLKEN | 0 | EREFSTEN | 0 | SC2P | SC4P | SC8P | SC16P |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

OSC_CR field descriptions

| Field | Description |
|--------------|---|
| 7 ERCLKEN | External Reference Enable Enables external reference clock (OSCERCLK). |

Table continues on the next page...

OSC_CR field descriptions (continued)

| Field | Description |
|---------------|--|
| | 0 External reference clock is inactive. 1 External reference clock is enabled. |
| 6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5 EREFSTEN | External Reference Stop Enable Controls whether or not the external reference clock (OSCERCLK) remains enabled when MCU enters Stop mode. 0 External reference clock is disabled in Stop mode. 1 External reference clock stays enabled in Stop mode if ERCLKEN is set before entering Stop mode. |
| 4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3 SC2P | Oscillator 2 pF Capacitor Load Configure Configures the oscillator load. 0 Disable the selection. 1 Add 2 pF capacitor to the oscillator load. |
| 2 SC4P | Oscillator 4 pF Capacitor Load Configure Configures the oscillator load. 0 Disable the selection. 1 Add 4 pF capacitor to the oscillator load. |
| 1 SC8P | Oscillator 8 pF Capacitor Load Configure Configures the oscillator load. 0 Disable the selection. 1 Add 8 pF capacitor to the oscillator load. |
| 0 SC16P | Oscillator 16 pF Capacitor Load Configure Configures the oscillator load. 0 Disable the selection. 1 Add 16 pF capacitor to the oscillator load. |

25.8 Functional Description

Functional details of the module can be found [here](#).

25.8.1 OSC module states

The states of the OSC module are shown in the following figure. The states and their transitions between each other are described in this section.

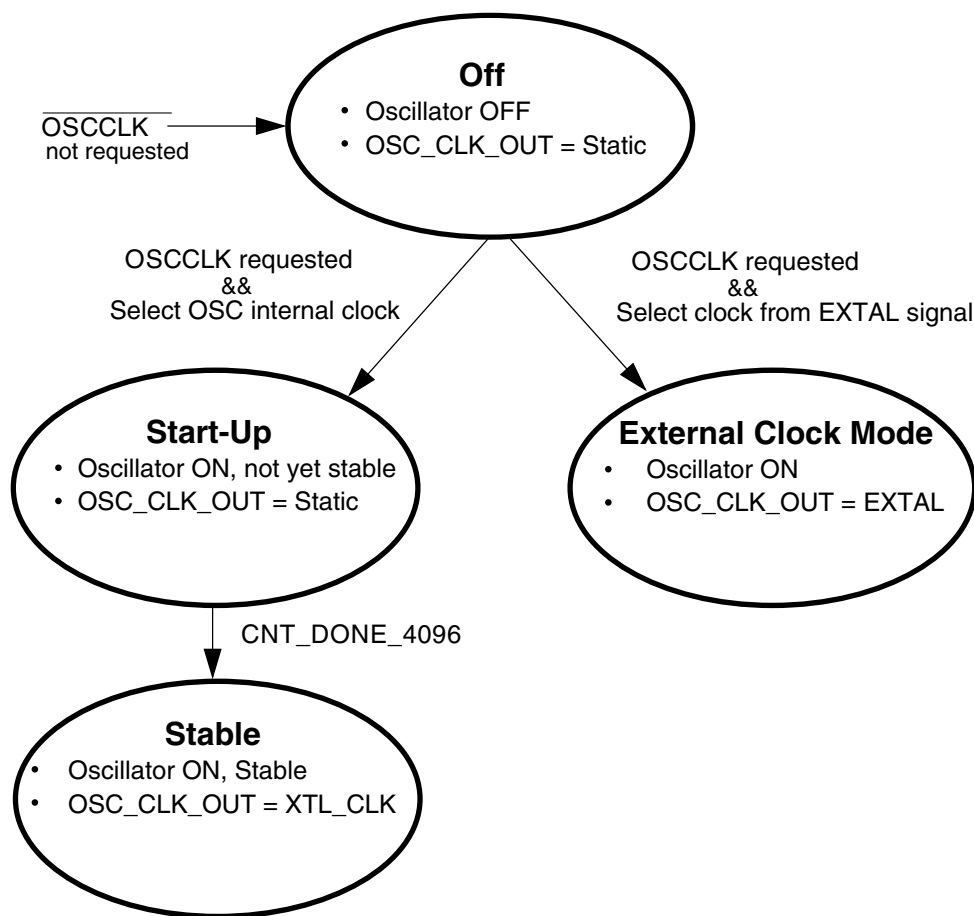


Figure 25-7. OSC Module state diagram

NOTE

XTL_CLK is the clock generated internally from OSC circuits.

25.8.1.1 Off

The OSC enters the Off state when the system does not require OSC clocks. Upon entering this state, XTL_CLK is static unless OSC is configured to select the clock from the EXTAL pad by clearing the external reference clock selection bit. For details regarding the external reference clock source in this MCU, refer to the chip configuration details. The EXTAL and XTAL pins are also decoupled from all other oscillator circuitry in this state. The OSC module circuitry is configured to draw minimal current.

25.8.1.2 Oscillator startup

The OSC enters startup state when it is configured to generate clocks (internally the OSC_EN transitions high) using the internal oscillator circuits by setting the external reference clock selection bit. In this state, the OSC module is enabled and oscillations are starting up, but have not yet stabilized. When the oscillation amplitude becomes large enough to pass through the input buffer, XTL_CLK begins clocking the counter. When the counter reaches 4096 cycles of XTL_CLK, the oscillator is considered stable and XTL_CLK is passed to the output clock OSC_CLK_OUT.

25.8.1.3 Oscillator Stable

The OSC enters stable state when it is configured to generate clocks (internally the OSC_EN transitions high) using the internal oscillator circuits by setting the external reference clock selection bit and the counter reaches 4096 cycles of XTL_CLK (when CNT_DONE_4096 is high). In this state, the OSC module is producing a stable output clock on OSC_CLK_OUT. Its frequency is determined by the external components being used.

25.8.1.4 External Clock mode

The OSC enters external clock state when it is enabled and external reference clock selection bit is cleared. For details regarding external reference clock source in this MCU, see the chip configuration details. In this state, the OSC module is set to buffer (with hysteresis) a clock from EXTAL onto the OSC_CLK_OUT. Its frequency is determined by the external clock being supplied.

25.8.2 OSC module modes

The OSC is a pierce-type oscillator that supports external crystals or resonators operating over the frequency ranges shown in [Table 25-5](#). These modes assume the following conditions: OSC is enabled to generate clocks (OSC_EN=1), configured to generate clocks internally (MCG_C2[EREFS] = 1), and some or one of the other peripherals (MCG, Timer, and so on) is configured to use the oscillator output clock (OSC_CLK_OUT).

Table 25-5. Oscillator modes

| Mode | Frequency Range |
|--------------------------|--|
| Low-frequency, high-gain | f_{osc_lo} (32.768 kHz) up to f_{osc_lo} (39.0625 kHz) |

Table continues on the next page...

Table 25-5. Oscillator modes (continued)

| Mode | Frequency Range |
|---------------------------------|--|
| High-frequency mode1, high-gain | $f_{osc_hi_1}$ (3 MHz) up to $f_{osc_hi_1}$ (8 MHz) |
| High-frequency mode1, low-power | |
| High-frequency mode2, high-gain | $f_{osc_hi_2}$ (8 MHz) up to $f_{osc_hi_2}$ (32 MHz) |
| High-frequency mode2, low-power | |

NOTE

For information about low power modes of operation used in this chip and their alignment with some OSC modes, see the chip's Power Management details.

25.8.2.1 Low-Frequency, High-Gain Mode

In Low-frequency, high-gain mode, the oscillator uses a simple inverter-style amplifier. The gain is set to achieve rail-to-rail oscillation amplitudes.

The oscillator input buffer in this mode is single-ended. It provides low pass frequency filtering as well as hysteresis for voltage filtering and converts the output to logic levels. In this mode, the internal capacitors could be used.

25.8.2.2 Low-Frequency, Low-Power Mode

In low-frequency, low-power mode, the oscillator uses a gain control loop to minimize power consumption. As the oscillation amplitude increases, the amplifier current is reduced. This continues until a desired amplitude is achieved at steady-state. This mode provides low pass frequency filtering as well as hysteresis for voltage filtering and converts the output to logic levels. In this mode, the internal capacitors could be used, the internal feedback resistor is connected, and no external resistor should be used.

In this mode, the amplifier inputs, gain-control input, and input buffer input are all capacitively coupled for leakage tolerance (not sensitive to the DC level of EXTAL).

Also in this mode, all external components except for the resonator itself are integrated, which includes the load capacitors and feedback resistor that biases EXTAL.

25.8.2.3 High-Frequency, High-Gain Mode

In high-frequency, high-gain mode, the oscillator uses a simple inverter-style amplifier. The gain is set to achieve rail-to-rail oscillation amplitudes. This mode provides low pass frequency filtering as well as hysteresis for voltage filtering and converts the output to logic levels. In this mode, the internal capacitors could be used.

25.8.2.4 High-Frequency, Low-Power Mode

In high-frequency, low-power mode, the oscillator uses a gain control loop to minimize power consumption. As the oscillation amplitude increases, the amplifier current is reduced. This continues until a desired amplitude is achieved at steady-state. In this mode, the internal capacitors could be used, the internal feedback resistor is connected, and no external resistor should be used.

The oscillator input buffer in this mode is differential. It provides low pass frequency filtering as well as hysteresis for voltage filtering and converts the output to logic levels.

25.8.3 Counter

The oscillator output clock (OSC_CLK_OUT) is gated off until the counter has detected 4096 cycles of its input clock (XTL_CLK). After 4096 cycles are completed, the counter passes XTL_CLK onto OSC_CLK_OUT. This counting timeout is used to guarantee output clock stability.

25.8.4 Reference clock pin requirements

The OSC module requires use of both the EXTAL and XTAL pins to generate an output clock in Oscillator mode, but requires only the EXTAL pin in External clock mode. The EXTAL and XTAL pins are available for I/O. For the implementation of these pins on this device, refer to the Signal Multiplexing chapter.

25.9 Reset

There is no reset state associated with the OSC module. The counter logic is reset when the OSC is not configured to generate clocks.

There are no sources of reset requests for the OSC module.

25.10 Low power modes operation

When the MCU enters Stop modes, the OSC is functional depending on CR[ERCLKEN] and CR[EREFSETN] bit settings. If both these bits are set, the OSC is in operation.

In Low Leakage Stop (LLS) modes, the OSC holds all register settings. If CR[ERCLKEN] and CR[EREFSTEN] are set before entry to Low Leakage Stop modes, the OSC is still functional in these modes. After waking up from Very Low Leakage Stop (VLLSx) modes, all OSC register bits are reset and initialization is required through software.

25.11 Interrupts

The OSC module does not generate any interrupts.



Chapter 26

RTC Oscillator (OSC32K)

26.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The RTC oscillator module provides the clock source for the RTC. The RTC oscillator module, in conjunction with an external crystal, generates a reference clock for the RTC.

26.1.1 Features and Modes

The key features of the RTC oscillator are as follows:

- Supports 32 kHz crystals with very low power
- Consists of internal feed back resistor
- Consists of internal programmable capacitors as the C_{load} of the oscillator
- Automatic Gain Control (AGC) to optimize power consumption

The RTC oscillator operations are described in detail in [Functional Description](#) .

26.1.2 Block Diagram

The following is the block diagram of the RTC oscillator.

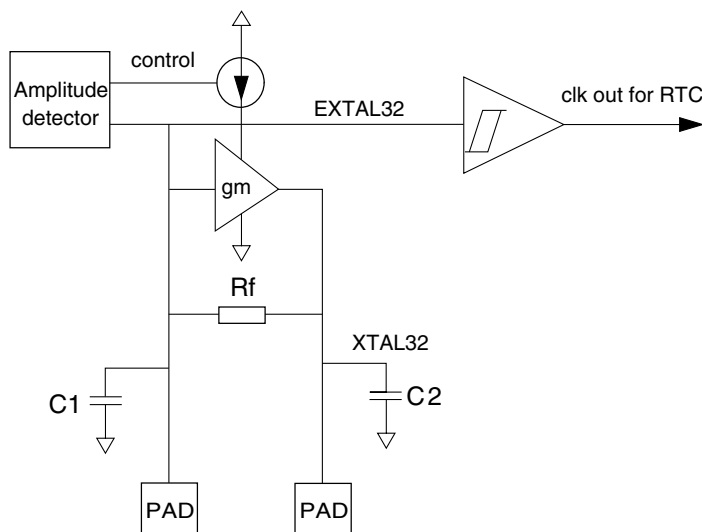


Figure 26-1. RTC Oscillator Block Diagram

26.2 RTC Signal Descriptions

The following table shows the user-accessible signals available for the RTC oscillator. See the chip-level specification to find out which signals are actually connected to the external pins.

Table 26-1. RTC Signal Descriptions

| Signal | Description | I/O |
|---------|-------------------|-----|
| EXTAL32 | Oscillator Input | I |
| XTAL32 | Oscillator Output | O |

26.2.1 EXTAL32 — Oscillator Input

This signal is the analog input of the RTC oscillator.

26.2.2 XTAL32 — Oscillator Output

This signal is the analog output of the RTC oscillator module.

26.3 External Crystal Connections

The connections with a crystal is shown in the following figure. External load capacitors and feedback resistor are not required.

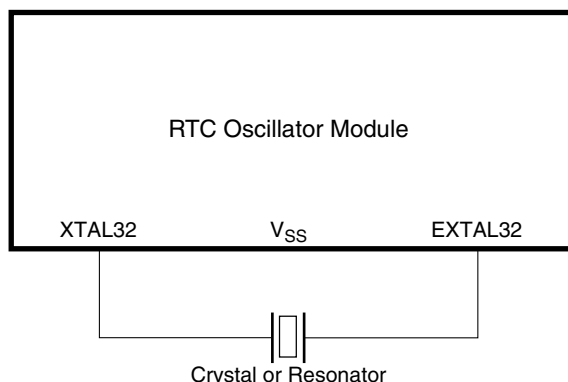


Figure 26-2. Crystal Connections

26.4 Memory Map/Register Descriptions

RTC oscillator control bits are part of the RTC registers. Refer to RTC Control register for more details.

26.5 Functional Description

As shown in [Figure 26-1](#), the module includes an amplifier which supplies the negative resistor for the RTC oscillator. The gain of the amplifier is controlled by the amplitude detector, which optimizes the power consumption. A schmitt trigger is used to translate the sine-wave generated by this oscillator to a pulse clock out, which is a reference clock for the RTC digital core.

The oscillator includes an internal feedback resistor of approximately 100 MΩ between EXTAL32 and XTAL32.

In addition, there are two programmable capacitors with this oscillator, which can be used as the Cload of the oscillator. The programmable range is from 0pF to 30pF.

26.6 Reset Overview

There is no reset state associated with the RTC oscillator.

26.7 Interrupts

The RTC oscillator does not generate any interrupts.

Chapter 27

Flash Memory Controller (FMC)

27.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The Flash Memory Controller (FMC) is a memory acceleration unit that provides:

- an interface between the device and the dual-bank nonvolatile memory. Bank 0 consists of program flash memory, and bank 1 consists of FlexNVM.
- buffers that can accelerate flash memory and FlexNVM data transfers.

27.1.1 Overview

The Flash Memory Controller manages the interface between the device and the dual-bank flash memory. The FMC receives status information detailing the configuration of the memory and uses this information to ensure a proper interface. The following table shows the supported read/write operations.

| Flash memory type | Read | Write |
|------------------------------------|---------------------------------|--|
| Program flash memory | 8-bit, 16-bit, and 32-bit reads | — ¹ A write operation to program flash memory causes a bus error. |
| FlexNVM used as Data flash memory | 8-bit, 16-bit, and 32-bit reads | — ¹ |
| FlexNVM and FlexRAM used as EEPROM | 8-bit, 16-bit, and 32-bit reads | 8-bit, 16-bit, and 32-bit writes |

1. A write operation to program flash memory or to FlexNVM used as data flash memory results in a bus error.

In addition, for bank 0 and bank 1, the FMC provides three separate mechanisms for accelerating the interface between the device and the flash memory. A 64-bit speculation buffer can prefetch the next 64-bit flash memory location, and both a 4-way, 2-set cache and a single-entry 64-bit buffer can store previously accessed flash memory or FlexNVM data for quick access times.

27.1.2 Features

The FMC's features include:

- Interface between the device and the dual-bank flash memory and FlexMemory:
 - 8-bit, 16-bit, and 32-bit read operations to program flash memory and FlexNVM used as data flash memory.
 - 8-bit, 16-bit, and 32-bit read and write operations to FlexNVM and FlexRAM used as EEPROM.
 - For bank 0 and bank 1: Read accesses to consecutive 32-bit spaces in memory return the second read data with no wait states. The memory returns 64 bits via the 32-bit bus access.
 - Crossbar master access protection for setting no access, read-only access, write-only access, or read/write access for each crossbar master.
- For bank 0 and bank 1: Acceleration of data transfer from program flash memory and FlexMemory to the device:
 - 64-bit prefetch speculation buffer with controls for instruction/data access per master and bank
 - 4-way, 2-set, 64-bit line size cache for a total of eight 64-bit entries with controls for replacement algorithm and lock per way for each bank
 - Single-entry buffer per bank
 - Invalidation control for the speculation buffer and the single-entry buffer

27.2 Modes of operation

The FMC only operates when a bus master accesses the flash memory or FlexMemory.

In terms of device power modes, the FMC only operates in run and wait modes, including VLPR and VLPW modes.

For any device power mode where the flash memory or FlexMemory cannot be accessed, the FMC is disabled.

27.3 External signal description

The FMC has no external signals.

27.4 Memory map and register descriptions

The programming model consists of the FMC control registers and the program visible cache (data and tag/valid entries).

NOTE

Program the registers only while the flash controller is idle (for example, execute from RAM). Changing configuration settings while a flash access is in progress can lead to non-deterministic behavior.

Table 27-2. FMC register access

| Registers | Read access | | Write access | |
|--|--|---------|--------------------------------------|---------|
| | Mode | Length | Mode | Length |
| Control registers: PFAPR, PFB0CR, PFB1CR | Supervisor (privileged) mode or user mode | 32 bits | Supervisor (privileged) mode only | 32 bits |
| Cache registers | Supervisor (privileged) mode or user mode | 32 bits | Supervisor (privileged) mode only | 32 bits |

NOTE

Accesses to unimplemented registers within the FMC's 4 KB address space return a bus error.

The cache entries, both data and tag/valid, can be read at any time.

NOTE

System software is required to maintain memory coherence when any segment of the flash cache is programmed. For example, all buffer data associated with the reprogrammed flash should be invalidated. Accordingly, cache program visible writes must occur after a programming or erase event is completed and before the new memory image is accessed.

The cache is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. The following table elaborates on the tag/valid and data entries.

Table 27-3. Program visible cache registers

| Cache storage | Based at offset | Contents of 32-bit read | Nomenclature | Nomenclature example |
|---------------|-----------------|---------------------------------|---|--|
| Tag | 100h | 13'h0, tag[18:4], 3'h0, valid | In TAGVDWxSy, x denotes the way and y denotes the set. | TAGVDW2S0 is the 15-bit tag and 1-bit valid for cache entry way 2, set 0. |
| Data | 200h | Upper or lower longword of data | In DATAWxSyU and DATAWxSyL, x denotes the way, y denotes the set, and U and L represent upper and lower word, respectively. | DATAW1S0U represents bits [63:32] of data entry way 1, set 0, and DATAW1S0L represents bits [31:0] of data entry way 1, set 0. |

FMC memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4001_F000 | Flash Access Protection Register (FMC_PFAPR) | 32 | R/W | 00F8_003Fh | 27.4.1/501 |
| 4001_F004 | Flash Bank 0 Control Register (FMC_PFB0CR) | 32 | R/W | 3002_001Fh | 27.4.2/504 |
| 4001_F008 | Flash Bank 1 Control Register (FMC_PFB1CR) | 32 | R/W | 3002_001Fh | 27.4.3/507 |
| 4001_F100 | Cache Tag Storage (FMC_TAGVDW0S0) | 32 | R/W | 0000_0000h | 27.4.4/509 |
| 4001_F104 | Cache Tag Storage (FMC_TAGVDW0S1) | 32 | R/W | 0000_0000h | 27.4.4/509 |
| 4001_F108 | Cache Tag Storage (FMC_TAGVDW1S0) | 32 | R/W | 0000_0000h | 27.4.5/510 |
| 4001_F10C | Cache Tag Storage (FMC_TAGVDW1S1) | 32 | R/W | 0000_0000h | 27.4.5/510 |
| 4001_F110 | Cache Tag Storage (FMC_TAGVDW2S0) | 32 | R/W | 0000_0000h | 27.4.6/511 |
| 4001_F114 | Cache Tag Storage (FMC_TAGVDW2S1) | 32 | R/W | 0000_0000h | 27.4.6/511 |
| 4001_F118 | Cache Tag Storage (FMC_TAGVDW3S0) | 32 | R/W | 0000_0000h | 27.4.7/512 |
| 4001_F11C | Cache Tag Storage (FMC_TAGVDW3S1) | 32 | R/W | 0000_0000h | 27.4.7/512 |
| 4001_F200 | Cache Data Storage (upper word) (FMC_DATAW0S0U) | 32 | R/W | 0000_0000h | 27.4.8/512 |
| 4001_F204 | Cache Data Storage (lower word) (FMC_DATAW0S0L) | 32 | R/W | 0000_0000h | 27.4.9/513 |
| 4001_F208 | Cache Data Storage (upper word) (FMC_DATAW0S1U) | 32 | R/W | 0000_0000h | 27.4.8/512 |
| 4001_F20C | Cache Data Storage (lower word) (FMC_DATAW0S1L) | 32 | R/W | 0000_0000h | 27.4.9/513 |
| 4001_F210 | Cache Data Storage (upper word) (FMC_DATAW1S0U) | 32 | R/W | 0000_0000h | 27.4.10/513 |
| 4001_F214 | Cache Data Storage (lower word) (FMC_DATAW1S0L) | 32 | R/W | 0000_0000h | 27.4.11/514 |
| 4001_F218 | Cache Data Storage (upper word) (FMC_DATAW1S1U) | 32 | R/W | 0000_0000h | 27.4.10/513 |
| 4001_F21C | Cache Data Storage (lower word) (FMC_DATAW1S1L) | 32 | R/W | 0000_0000h | 27.4.11/514 |
| 4001_F220 | Cache Data Storage (upper word) (FMC_DATAW2S0U) | 32 | R/W | 0000_0000h | 27.4.12/514 |

Table continues on the next page...

FMC memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|------------------------------|
| 4001_F224 | Cache Data Storage (lower word) (FMC_DATAW2S0L) | 32 | R/W | 0000_0000h | 27.4.13/ 515 |
| 4001_F228 | Cache Data Storage (upper word) (FMC_DATAW2S1U) | 32 | R/W | 0000_0000h | 27.4.12/ 514 |
| 4001_F22C | Cache Data Storage (lower word) (FMC_DATAW2S1L) | 32 | R/W | 0000_0000h | 27.4.13/ 515 |
| 4001_F230 | Cache Data Storage (upper word) (FMC_DATAW3S0U) | 32 | R/W | 0000_0000h | 27.4.14/ 515 |
| 4001_F234 | Cache Data Storage (lower word) (FMC_DATAW3S0L) | 32 | R/W | 0000_0000h | 27.4.15/ 516 |
| 4001_F238 | Cache Data Storage (upper word) (FMC_DATAW3S1U) | 32 | R/W | 0000_0000h | 27.4.14/ 515 |
| 4001_F23C | Cache Data Storage (lower word) (FMC_DATAW3S1L) | 32 | R/W | 0000_0000h | 27.4.15/ 516 |

27.4.1 Flash Access Protection Register (FMC_PFAPR)

Address: 4001_F000h base + 0h offset = 4001_F000h

| | | | | | | | | | | | | | | | | |
|-------|-----------|----|-----------|----|-----------|----|-----------|----|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | Reserved | | | | | | | | M7PFD | M6PFD | M5PFD | M4PFD | M3PFD | M2PFD | M1PFD | M0PFD |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | M7AP[1:0] | | M6AP[1:0] | | M5AP[1:0] | | M4AP[1:0] | | M3AP[1:0] | | M2AP[1:0] | | M1AP[1:0] | | M0AP[1:0] | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |

FMC_PFAPR field descriptions

| Field | Description |
|-------------------|---|
| 31–24 Reserved | This field is reserved. |
| 23 M7PFD | Master 7 Prefetch Disable These bits control whether prefetching is enabled based on the logical number of the requesting crossbar switch master. This field is further qualified by the PFBnCR[BxDPE,BxIPE] bits. |

Table continues on the next page...

FMC_PFAPR field descriptions (continued)

| Field | Description |
|-------------|--|
| | 0 Prefetching for this master is enabled. 1 Prefetching for this master is disabled. |
| 22 M6PFD | Master 6 Prefetch Disable These bits control whether prefetching is enabled based on the logical number of the requesting crossbar switch master. This field is further qualified by the PFBnCR[BxDPE,BxIPE] bits. 0 Prefetching for this master is enabled. 1 Prefetching for this master is disabled. |
| 21 M5PFD | Master 5 Prefetch Disable These bits control whether prefetching is enabled based on the logical number of the requesting crossbar switch master. This field is further qualified by the PFBnCR[BxDPE,BxIPE] bits. 0 Prefetching for this master is enabled. 1 Prefetching for this master is disabled. |
| 20 M4PFD | Master 4 Prefetch Disable These bits control whether prefetching is enabled based on the logical number of the requesting crossbar switch master. This field is further qualified by the PFBnCR[BxDPE,BxIPE] bits. 0 Prefetching for this master is enabled. 1 Prefetching for this master is disabled. |
| 19 M3PFD | Master 3 Prefetch Disable These bits control whether prefetching is enabled based on the logical number of the requesting crossbar switch master. This field is further qualified by the PFBnCR[BxDPE,BxIPE] bits. 0 Prefetching for this master is enabled. 1 Prefetching for this master is disabled. |
| 18 M2PFD | Master 2 Prefetch Disable These bits control whether prefetching is enabled based on the logical number of the requesting crossbar switch master. This field is further qualified by the PFBnCR[BxDPE,BxIPE] bits. 0 Prefetching for this master is enabled. 1 Prefetching for this master is disabled. |
| 17 M1PFD | Master 1 Prefetch Disable These bits control whether prefetching is enabled based on the logical number of the requesting crossbar switch master. This field is further qualified by the PFBnCR[BxDPE,BxIPE] bits. 0 Prefetching for this master is enabled. 1 Prefetching for this master is disabled. |
| 16 M0PFD | Master 0 Prefetch Disable These bits control whether prefetching is enabled based on the logical number of the requesting crossbar switch master. This field is further qualified by the PFBnCR[BxDPE,BxIPE] bits. 0 Prefetching for this master is enabled. 1 Prefetching for this master is disabled. |

Table continues on the next page...

FMC_PFAPR field descriptions (continued)

| Field | Description |
|--------------------|--|
| 15–14 M7AP[1:0] | <p>Master 7 Access Protection</p> <p>This field controls whether read and write access to the flash are allowed based on the logical master number of the requesting crossbar switch master.</p> <p>00 No access may be performed by this master. 01 Only read accesses may be performed by this master. 10 Only write accesses may be performed by this master. 11 Both read and write accesses may be performed by this master.</p> |
| 13–12 M6AP[1:0] | <p>Master 6 Access Protection</p> <p>This field controls whether read and write access to the flash are allowed based on the logical master number of the requesting crossbar switch master.</p> <p>00 No access may be performed by this master 01 Only read accesses may be performed by this master 10 Only write accesses may be performed by this master 11 Both read and write accesses may be performed by this master</p> |
| 11–10 M5AP[1:0] | <p>Master 5 Access Protection</p> <p>This field controls whether read and write access to the flash are allowed based on the logical master number of the requesting crossbar switch master.</p> <p>00 No access may be performed by this master 01 Only read accesses may be performed by this master 10 Only write accesses may be performed by this master 11 Both read and write accesses may be performed by this master</p> |
| 9–8 M4AP[1:0] | <p>Master 4 Access Protection</p> <p>This field controls whether read and write access to the flash are allowed based on the logical master number of the requesting crossbar switch master.</p> <p>00 No access may be performed by this master 01 Only read accesses may be performed by this master 10 Only write accesses may be performed by this master 11 Both read and write accesses may be performed by this master</p> |
| 7–6 M3AP[1:0] | <p>Master 3 Access Protection</p> <p>This field controls whether read and write access to the flash are allowed based on the logical master number of the requesting crossbar switch master.</p> <p>00 No access may be performed by this master 01 Only read accesses may be performed by this master 10 Only write accesses may be performed by this master 11 Both read and write accesses may be performed by this master</p> |
| 5–4 M2AP[1:0] | <p>Master 2 Access Protection</p> <p>This field controls whether read and write access to the flash are allowed based on the logical master number of the requesting crossbar switch master.</p> <p>00 No access may be performed by this master</p> |

Table continues on the next page...

FMC_PFAPR field descriptions (continued)

| Field | Description |
|------------------|---|
| | 01 Only read accesses may be performed by this master 10 Only write accesses may be performed by this master 11 Both read and write accesses may be performed by this master |
| 3–2 M1AP[1:0] | Master 1 Access Protection This field controls whether read and write access to the flash are allowed based on the logical master number of the requesting crossbar switch master. 00 No access may be performed by this master 01 Only read accesses may be performed by this master 10 Only write accesses may be performed by this master 11 Both read and write accesses may be performed by this master |
| 1–0 M0AP[1:0] | Master 0 Access Protection This field controls whether read and write access to the flash are allowed based on the logical master number of the requesting crossbar switch master. 00 No access may be performed by this master 01 Only read accesses may be performed by this master 10 Only write accesses may be performed by this master 11 Both read and write accesses may be performed by this master |

27.4.2 Flash Bank 0 Control Register (FMC_PFB0CR)

Address: 4001_F000h base + 4h offset = 4001_F004h

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|-------------|----|----|----|--------------|----|----|----|---------------|----|----|----|---------|-----------|----|----|
| R | B0RWSC[3:0] | | | | CLK_WAY[3:0] | | | | 0 | | | | 0 | B0MW[1:0] | | 0 |
| W | | | | | | | | | CINV_WAY[3:0] | | | | S_B_INV | | | |
| Reset | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|---|---|----------|---|---|-------|-------|-------|-------|--------|
| R | 0 | | | | | | | | CRC[2:0] | | | B0DCE | B0ICE | B0DPE | B0IPE | B0SEBE |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |

FMC_PFB0CR field descriptions

| Field | Description |
|------------------------|--|
| 31–28 BORWSC[3:0] | <p>Bank 0 Read Wait State Control</p> <p>This read-only field defines the number of wait states required to access the bank 0 flash memory.</p> <p>The relationship between the read access time of the flash array (expressed in system clock cycles) and RWSC is defined as:</p> $\text{Access time of flash array [system clocks]} = \text{RWSC} + 1$ <p>The FMC automatically calculates this value based on the ratio of the system clock speed to the flash clock speed. For example, when this ratio is 4:1, the field's value is 3h.</p> |
| 27–24 CLCK_WAY[3:0] | <p>Cache Lock Way x</p> <p>These bits determine if the given cache way is locked such that its contents will not be displaced by future misses.</p> <p>The bit setting definitions are for each bit in the field.</p> <p>0 Cache way is unlocked and may be displaced 1 Cache way is locked and its contents are not displaced</p> |
| 23–20 CINV_WAY[3:0] | <p>Cache Invalidate Way x</p> <p>These bits determine if the given cache way is to be invalidated (cleared). When a bit within this field is written, the corresponding cache way is immediately invalidated: the way's tag, data, and valid contents are cleared. This field always reads as zero.</p> <p>Cache invalidation takes precedence over locking. The cache is invalidated by system reset. System software is required to maintain memory coherency when any segment of the flash memory is programmed or erased. Accordingly, cache invalidations must occur after a programming or erase event is completed and before the new memory image is accessed.</p> <p>The bit setting definitions are for each bit in the field.</p> <p>0 No cache way invalidation for the corresponding cache 1 Invalidate cache way for the corresponding cache: clear the tag, data, and vld bits of ways selected</p> |
| 19 S_B_INV | <p>Invalidate Prefetch Speculation Buffer</p> <p>This bit determines if the FMC's prefetch speculation buffer and the single entry page buffer are to be invalidated (cleared). When this bit is written, the speculation buffer and single entry buffer are immediately cleared. This bit always reads as zero.</p> <p>0 Speculation buffer and single entry buffer are not affected. 1 Invalidate (clear) speculation buffer and single entry buffer.</p> |
| 18–17 BOMW[1:0] | <p>Bank 0 Memory Width</p> <p>This read-only field defines the width of the bank 0 memory.</p> <p>00 32 bits 01 64 bits 10 Reserved 11 Reserved</p> |
| 16 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 15–8 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |

Table continues on the next page...

FMC_PFB0CR field descriptions (continued)

| Field | Description |
|-----------------|---|
| 7–5 CRC[2:0] | <p>Cache Replacement Control</p> <p>This 3-bit field defines the replacement algorithm for accesses that are cached.</p> <p>000 LRU replacement algorithm per set across all four ways 001 Reserved 010 Independent LRU with ways [0-1] for ifetches, [2-3] for data 011 Independent LRU with ways [0-2] for ifetches, [3] for data 1xx Reserved</p> |
| 4 B0DCE | <p>Bank 0 Data Cache Enable</p> <p>This bit controls whether data references are loaded into the cache.</p> <p>0 Do not cache data references. 1 Cache data references.</p> |
| 3 B0ICE | <p>Bank 0 Instruction Cache Enable</p> <p>This bit controls whether instruction fetches are loaded into the cache.</p> <p>0 Do not cache instruction fetches. 1 Cache instruction fetches.</p> |
| 2 B0DPE | <p>Bank 0 Data Prefetch Enable</p> <p>This bit controls whether prefetches (or speculative accesses) are initiated in response to data references.</p> <p>0 Do not prefetch in response to data references. 1 Enable prefetches in response to data references.</p> |
| 1 B0IPE | <p>Bank 0 Instruction Prefetch Enable</p> <p>This bit controls whether prefetches (or speculative accesses) are initiated in response to instruction fetches.</p> <p>0 Do not prefetch in response to instruction fetches. 1 Enable prefetches in response to instruction fetches.</p> |
| 0 B0SEBE | <p>Bank 0 Single Entry Buffer Enable</p> <p>This bit controls whether the single entry page buffer is enabled in response to flash read accesses. Its operation is independent from bank 1's cache.</p> <p>A high-to-low transition of this enable forces the page buffer to be invalidated.</p> <p>0 Single entry buffer is disabled. 1 Single entry buffer is enabled.</p> |

27.4.3 Flash Bank 1 Control Register (FMC_PFB1CR)

This register has a format similar to that for PFB0CR, except it controls the operation of flash bank 1, and the "global" cache control fields are empty.

Address: 4001_F000h base + 8h offset = 4001_F008h

| | | | | | | | | | | | | | | | | | |
|-------|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|-----------|----|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | |
| R | B1RWSC[3:0] | | | | 0 | | | | | | | | | | B1MW[1:0] | | 0 |
| W | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | |

| | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|---|---|---|---|-------|-------|-------|-------|--------|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |
| R | 0 | | | | | | | | 0 | | | | | | | | |
| W | | | | | | | | | | | | | B1DCE | B1ICE | B1DPE | B1IPE | B1SEBE |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | |

FMC_PFB1CR field descriptions

| Field | Description |
|----------------------|--|
| 31–28 B1RWSC[3:0] | Bank 1 Read Wait State Control This read-only field defines the number of wait states required to access the bank 1 flash memory. The relationship between the read access time of the flash array (expressed in system clock cycles) and RWSC is defined as: Access time of flash array [system clocks] = RWSC + 1 The FMC automatically calculates this value based on the ratio of the system clock speed to the flash clock speed. For example, when this ratio is 4:1, the field's value is 3h. |
| 27–19 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 18–17 B1MW[1:0] | Bank 1 Memory Width This read-only field defines the width of the bank 1 memory. |

Table continues on the next page...

FMC_PFB1CR field descriptions (continued)

| Field | Description |
|------------------|---|
| | 00 32 bits 01 64 bits 10 Reserved 11 Reserved |
| 16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 B1DCE | Bank 1 Data Cache Enable This bit controls whether data references are loaded into the cache. 0 Do not cache data references. 1 Cache data references. |
| 3 B1ICE | Bank 1 Instruction Cache Enable This bit controls whether instruction fetches are loaded into the cache. 0 Do not cache instruction fetches. 1 Cache instruction fetches. |
| 2 B1DPE | Bank 1 Data Prefetch Enable This bit controls whether prefetches (or speculative accesses) are initiated in response to data references. 0 Do not prefetch in response to data references. 1 Enable prefetches in response to data references. |
| 1 B1IPE | Bank 1 Instruction Prefetch Enable This bit controls whether prefetches (or speculative accesses) are initiated in response to instruction fetches. 0 Do not prefetch in response to instruction fetches. 1 Enable prefetches in response to instruction fetches. |
| 0 B1SEBE | Bank 1 Single Entry Buffer Enable This bit controls whether the single entry buffer is enabled in response to flash read accesses. Its operation is independent from bank 0's cache. A high-to-low transition of this enable forces the page buffer to be invalidated. 0 Single entry buffer is disabled. 1 Single entry buffer is enabled. |

27.4.4 Cache Tag Storage (FMC_TAGVDW0Sn)

The cache is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In TAGVDWxSy, x denotes the way, and y denotes the set. This section represents tag/vld information for all sets in the indicated way.

Address: 4001_F000h base + 100h offset + (4d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | |
|-------|-----------|----|----|----|----|----|----|----|----|----|----|----|----|----|-----------|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | tag[18:4] | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | tag[18:4] | | | | | | | | | | | | 0 | | valid | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FMC_TAGVDW0Sn field descriptions

| Field | Description |
|-------------------|---|
| 31–19 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 18–4 tag[18:4] | 15-bit tag for cache entry |
| 3–1 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 0 valid | 1-bit valid for cache entry |

27.4.5 Cache Tag Storage (FMC_TAGVDW1Sn)

The cache is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In TAGVDWxSy, x denotes the way, and y denotes the set. This section represents tag/vld information for all sets in the indicated way.

Address: 4001_F000h base + 108h offset + (4d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | |
|-------|-----------|----|----|----|----|----|----|----|----|----|----|----|----|----|-----------|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | tag[18:4] | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | tag[18:4] | | | | | | | | | | | | 0 | | valid | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FMC_TAGVDW1Sn field descriptions

| Field | Description |
|-------------------|---|
| 31–19 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 18–4 tag[18:4] | 15-bit tag for cache entry |
| 3–1 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 0 valid | 1-bit valid for cache entry |

27.4.6 Cache Tag Storage (FMC_TAGVDW2Sn)

The cache is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In TAGVDWxSy, x denotes the way, and y denotes the set. This section represents tag/vld information for all sets in the indicated way.

Address: 4001_F000h base + 110h offset + (4d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | |
|-------|-----------|----|----|----|----|----|----|----|----|----|----|----|----|-----------|-------|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | tag[18:4] | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | tag[18:4] | | | | | | | | | | | | 0 | | valid | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FMC_TAGVDW2Sn field descriptions

| Field | Description |
|-------------------|---|
| 31–19 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 18–4 tag[18:4] | 15-bit tag for cache entry |
| 3–1 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 0 valid | 1-bit valid for cache entry |

27.4.7 Cache Tag Storage (FMC_TAGVDW3Sn)

The cache is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In TAGVDWxSy, x denotes the way, and y denotes the set. This section represents tag/vld information for all sets in the indicated way.

Address: 4001_F000h base + 118h offset + (4d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | |
|-------|-----------|----|----|----|----|----|----|----|----|----|----|----|----|-----------|-------|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | tag[18:4] | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | tag[18:4] | | | | | | | | | | | | 0 | | valid | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FMC_TAGVDW3Sn field descriptions

| Field | Description |
|-------------------|---|
| 31–19 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 18–4 tag[18:4] | 15-bit tag for cache entry |
| 3–1 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 0 valid | 1-bit valid for cache entry |

27.4.8 Cache Data Storage (upper word) (FMC_DATAW0SnU)

The cache of 64-bit entries is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In DATAWxSyU and DATAWxSyL, x denotes the way, y denotes the set, and U and L represent upper and lower word, respectively. This section represents data for the upper word (bits [63:32]) of all sets in the indicated way.

Address: 4001_F000h base + 200h offset + (8d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | data[63:32] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

FMC_DATAW0SnU field descriptions

| Field | Description |
|---------------------|----------------------------|
| 31–0 data[63:32] | Bits [63:32] of data entry |

27.4.9 Cache Data Storage (lower word) (FMC_DATAW0SnL)

The cache of 64-bit entries is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In DATAWxSyU and DATAWxSyL, x denotes the way, y denotes the set, and U and L represent upper and lower word, respectively. This section represents data for the lower word (bits [31:0]) of all sets in the indicated way.

Address: 4001_F000h base + 204h offset + (8d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | data[31:0] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FMC_DATAW0SnL field descriptions

| Field | Description |
|--------------------|---------------------------|
| 31–0 data[31:0] | Bits [31:0] of data entry |

27.4.10 Cache Data Storage (upper word) (FMC_DATAW1SnU)

The cache of 64-bit entries is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In DATAWxSyU and DATAWxSyL, x denotes the way, y denotes the set, and U and L represent upper and lower word, respectively. This section represents data for the upper word (bits [63:32]) of all sets in the indicated way.

Address: 4001_F000h base + 210h offset + (8d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | data[63:32] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

FMC_DATAW1SnU field descriptions

| Field | Description |
|---------------------|----------------------------|
| 31–0 data[63:32] | Bits [63:32] of data entry |

27.4.11 Cache Data Storage (lower word) (FMC_DATAW1SnL)

The cache of 64-bit entries is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In DATAWxSyU and DATAWxSyL, x denotes the way, y denotes the set, and U and L represent upper and lower word, respectively. This section represents data for the lower word (bits [31:0]) of all sets in the indicated way.

Address: 4001_F000h base + 214h offset + (8d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | data[31:0] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

FMC_DATAW1SnL field descriptions

| Field | Description |
|--------------------|---------------------------|
| 31–0 data[31:0] | Bits [31:0] of data entry |

27.4.12 Cache Data Storage (upper word) (FMC_DATAW2SnU)

The cache of 64-bit entries is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In DATAWxSyU and DATAWxSyL, x denotes the way, y denotes the set, and U and L represent upper and lower word, respectively. This section represents data for the upper word (bits [63:32]) of all sets in the indicated way.

Address: 4001_F000h base + 220h offset + (8d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | data[63:32] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

FMC_DATAW2SnU field descriptions

| Field | Description |
|---------------------|----------------------------|
| 31–0 data[63:32] | Bits [63:32] of data entry |

27.4.13 Cache Data Storage (lower word) (FMC_DATAW2SnL)

The cache of 64-bit entries is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In DATAWxSyU and DATAWxSyL, x denotes the way, y denotes the set, and U and L represent upper and lower word, respectively. This section represents data for the lower word (bits [31:0]) of all sets in the indicated way.

Address: 4001_F000h base + 224h offset + (8d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | data[31:0] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FMC_DATAW2SnL field descriptions

| Field | Description |
|--------------------|---------------------------|
| 31–0 data[31:0] | Bits [31:0] of data entry |

27.4.14 Cache Data Storage (upper word) (FMC_DATAW3SnU)

The cache of 64-bit entries is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In DATAWxSyU and DATAWxSyL, x denotes the way, y denotes the set, and U and L represent upper and lower word, respectively. This section represents data for the upper word (bits [63:32]) of all sets in the indicated way.

Address: 4001_F000h base + 230h offset + (8d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | data[63:32] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

FMC_DATAW3SnU field descriptions

| Field | Description |
|---------------------|----------------------------|
| 31–0 data[63:32] | Bits [63:32] of data entry |

27.4.15 Cache Data Storage (lower word) (FMC_DATAW3SnL)

The cache of 64-bit entries is a 4-way, set-associative cache with 2 sets. The ways are numbered 0-3 and the sets are numbered 0-1. In DATAWxSyU and DATAWxSyL, x denotes the way, y denotes the set, and U and L represent upper and lower word, respectively. This section represents data for the lower word (bits [31:0]) of all sets in the indicated way.

Address: 4001_F000h base + 234h offset + (8d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | data[31:0] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

FMC_DATAW3SnL field descriptions

| Field | Description |
|--------------------|---------------------------|
| 31–0 data[31:0] | Bits [31:0] of data entry |

27.5 Functional description

The FMC is a flash acceleration unit with flexible buffers for user configuration. Besides managing the interface between the device and the flash memory and FlexMemory, the FMC can be used to restrict access from crossbar switch masters and—for program flash only—to customize the cache and buffers to provide single-cycle system-clock data-access times. Whenever a hit occurs for the prefetch speculation buffer, the cache, or the single-entry buffer, the requested data is transferred within a single system clock.

27.5.1 Default configuration

Upon system reset, the FMC is configured to provide a significant level of buffering for transfers from the flash memory or FlexMemory:

- Crossbar masters 0, 1, 2 have read access to bank 0 and bank 1.

- These masters have write access to a portion of bank 1 when FlexNVM is used with FlexRAM as EEPROM.
- For bank 0 and bank 1:
 - Prefetch support for data and instructions is enabled for crossbar masters 0, 1, 2.
 - The cache is configured for least recently used (LRU) replacement for all four ways.
 - The cache is configured for data or instruction replacement.
 - The single-entry buffer is enabled.

27.5.2 Configuration options

Though the default configuration provides a high degree of flash acceleration, advanced users may desire to customize the FMC buffer configurations to maximize throughput for their use cases. When reconfiguring the FMC for custom use cases, do not program the FMC's control registers while the flash memory or FlexMemory is being accessed. Instead, change the control registers with a routine executing from RAM in supervisor mode.

The FMC's cache and buffering controls within PFB0CR and PFB1CR allow the tuning of resources to suit particular applications' needs. The cache and buffer are each controlled individually. The register controls enable buffering and prefetching per memory bank and access type (instruction fetch or data reference). The cache also supports 3 types of LRU replacement algorithms:

- LRU per set across all 4 ways,
- LRU with ways [0-1] for instruction fetches and ways [2-3] for data fetches, and
- LRU with ways [0-2] for instruction fetches and way [3] for data fetches.

As an application example: if both instruction fetches and data references are accessing flash memory, then control is available to send instruction fetches, data references, or both to the cache or the single-entry buffer. Likewise, speculation can be enabled or disabled for either type of access. If both instruction fetches and data references are cached, then the cache's way resources may be divided in several ways between the instruction fetches and data references.

In another application example, the cache can be configured for replacement from bank 0, while the single-entry buffer can be enabled for bank 1 only. This configuration is ideal for applications that use bank 0 for program space and bank 1 for data space.

27.5.3 Wait states

Because the core, crossbar switch, and bus masters can be clocked at a higher frequency than the flash clock, flash memory accesses that do not hit in the speculation buffer or cache usually require wait states. The number of wait states depends on both of the following:

1. the ratio of the core clock to the flash clock, and
2. the phase relationship of the core clock and flash clock at the time the read is requested.

The ratio of the core clock to the flash clock is equal to the value of PFB0CR[B0RWSC] + 1 for bank 0 and to the value of PFB1CR[B1RWSC] + 1 for bank 1.

For example, in a system with a 4:1 core-to-flash clock ratio, a read that does not hit in the speculation buffer or the cache can take between 4 and 7 core clock cycles to complete.

- The best-case scenario is a period of 4 core clock cycles because a read from the flash memory takes 1 flash clock, which translates to 4 core clocks.
- The worst-case scenario is a period of 7 core clock cycles, consisting of 4 cycles for the read operation and 3 cycles of delay to align the core and flash clocks.
 - A delay to align the core and flash clocks might occur because you can request a read cycle on any core clock edge, but that edge does not necessarily align with a flash clock edge where the read can start.
 - In this case, the read operation is delayed by a number of core clocks equal to the core-to-flash clock ratio minus one: $4 - 1 = 3$. That is, 3 additional core clock cycles are required to synchronize the clocks before the read operation can start.

All wait states and synchronization delays are handled automatically by the Flash Memory Controller. No direct user configuration is required or even allowed to set up the flash wait states.

27.5.4 Speculative reads

The FMC has a single buffer that reads ahead to the next word in the flash memory if there is an idle cycle. Speculative prefetching is programmable for each bank for instruction and/or data accesses using the B0DPE and B0IPE fields of PFB0CR and the B1DPE and B1IPE fields of PFB1CR. Because many code accesses are sequential, using the speculative prefetch buffer improves performance in most cases.

When speculative reads are enabled, the FMC immediately requests the next sequential address after a read completes. By requesting the next word immediately, speculative reads can help to reduce or even eliminate wait states when accessing sequential code and/or data.

For example, consider the following scenario:

- Assume a system with a 4:1 core-to-flash clock ratio and with speculative reads enabled.
- The core requests four sequential longwords in back-to-back requests, meaning there are no core cycle delays except for stalls waiting for flash memory data to be returned.
- None of the data is already stored in the cache or speculation buffer.

In this scenario, the sequence of events for accessing the four longwords is as follows:

1. The first longword read requires 4 to 7 core clocks. See [Wait states](#) for more information.
2. Due to the 64-bit data bus of the flash memory, the second longword read takes only 1 core clock because the data is already available inside the FMC. While the data for the second longword is being returned to the core, the FMC also starts reading the third and fourth longwords from the flash memory.
3. Accessing the third longword requires 3 core clock cycles. The flash memory read itself takes 4 clocks, but the first clock overlaps with the second longword read.
4. Reading the fourth longword, like the second longword, takes only 1 clock due to the 64-bit flash memory data bus.

27.6 Initialization and application information

The FMC does not require user initialization. Flash acceleration features are enabled by default.

The FMC has no visibility into flash memory erase and program cycles because the Flash Memory module manages them directly. As a result, if an application is executing flash memory commands, the FMC's cache might need to be disabled and/or flushed to prevent the possibility of returning stale data. Use the PFB0CR[CINV_WAY] field to invalidate the cache in this manner.



Chapter 28

Flash Memory Module (FTFL)

28.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The flash memory module includes the following accessible memory regions:

- Program flash memory for vector space and code store
- For FlexNVM devices: FlexNVM for data store and additional code store
- For FlexNVM devices: FlexRAM for high-endurance data store or traditional RAM
- For program flash only devices: Programming acceleration RAM to speed flash programming

Flash memory is ideal for single-supply applications, permitting in-the-field erase and reprogramming operations without the need for any external high voltage power sources.

The flash memory module includes a memory controller that executes commands to modify flash memory contents. An erased bit reads '1' and a programmed bit reads '0'. The programming operation is unidirectional; it can only move bits from the '1' state (erased) to the '0' state (programmed). Only the erase operation restores bits from '0' to '1'; bits cannot be programmed from a '0' to a '1'.

CAUTION

A flash memory location must be in the erased state before being programmed. Cumulative programming of bits (back-to-back program operations without an intervening erase) within a flash memory location is not allowed. Re-programming of existing 0s to 0 is not allowed as this overstresses the device.

The standard shipping condition for flash memory is erased with security disabled. Data loss over time may occur due to degradation of the erased ('1') states and/or programmed ('0') states. Therefore, it is recommended that each flash block or sector be re-erased immediately prior to factory programming to ensure that the full data retention capability is achieved.

28.1.1 Features

The flash memory module includes the following features.

NOTE

See the device's Chip Configuration details for the exact amount of flash memory available on your device.

28.1.1.1 Program Flash Memory Features

- Sector size of 2 KB
- Program flash protection scheme prevents accidental program or erase of stored data
- Automated, built-in, program and erase algorithms with verify
- Section programming for faster bulk programming times
- For devices containing only program flash memory: Read access to one logical program flash block is possible while programming or erasing data in the other logical program flash block
- For devices containing FlexNVM memory: Read access to program flash memory possible while programming or erasing data in the data flash memory or FlexRAM

28.1.1.2 FlexNVM Memory Features

When FlexNVM is partitioned for data flash memory (on devices that contain FlexNVM memory):

- Sector size of 2 KB
- Protection scheme prevents accidental program or erase of stored data
- Automated, built-in program and erase algorithms with verify

- Section programming for faster bulk programming times
- Read access to data flash memory possible while programming or erasing data in the program flash memory

28.1.1.3 Programming Acceleration RAM Features

- For devices with only program flash memory: RAM to support section programming

28.1.1.4 FlexRAM Features

For devices with FlexNVM memory:

- Memory that can be used as traditional RAM or as high-endurance EEPROM storage
- Up to 4 KB of FlexRAM configured for EEPROM or traditional RAM operations
- When configured for EEPROM:
 - Protection scheme prevents accidental program or erase of data written for EEPROM
 - Built-in hardware emulation scheme to automate EEPROM record maintenance functions
 - Programmable EEPROM data set size and FlexNVM partition code facilitating EEPROM memory endurance trade-offs
 - Supports FlexRAM aligned writes of 1, 2, or 4 bytes at a time
 - Read access to FlexRAM possible while programming or erasing data in the program or data flash memory
- When configured for traditional RAM:
 - Read and write access possible to the FlexRAM while programming or erasing data in the program or data flash memory

28.1.1.5 Other Flash Memory Module Features

- Internal high-voltage supply generator for flash memory program and erase operations

- Optional interrupt generation upon flash command completion
- Supports MCU security mechanisms which prevent unauthorized access to the flash memory contents

28.1.2 Block Diagram

The block diagram of the flash memory module is shown in the following figure.

For devices with FlexNVM feature:

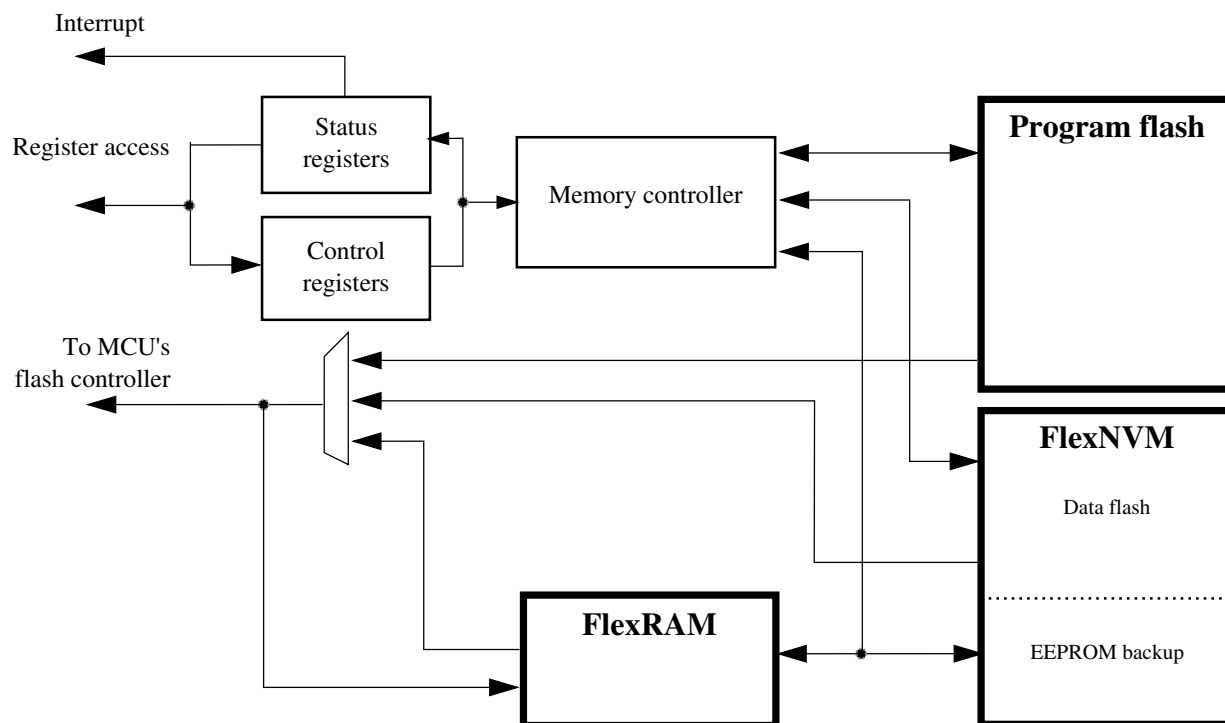


Figure 28-1. Flash Block Diagram

For devices that contain only program flash:

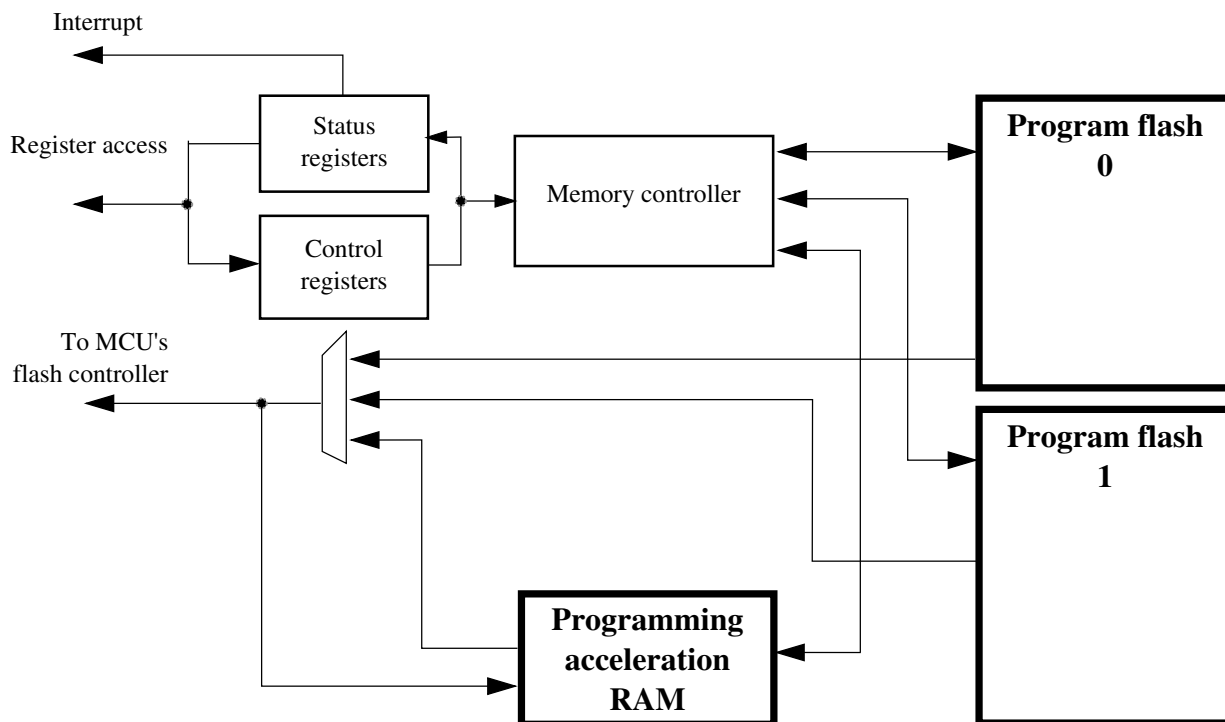


Figure 28-2. Flash Block Diagram

28.1.3 Glossary

Command write sequence — A series of MCU writes to the flash FCCOB register group that initiates and controls the execution of flash algorithms that are built into the flash memory module.

Data flash memory — Partitioned from the FlexNVM block, the data flash memory provides nonvolatile storage for user data, boot code, and additional code store.

Data flash sector — The data flash sector is the smallest portion of the data flash memory that can be erased.

EEPROM — Using a built-in filing system, the flash memory module emulates the characteristics of an EEPROM by effectively providing a high-endurance, byte-writeable (program and erase) NVM.

EEPROM backup data header — The EEPROM backup data header is comprised of a 32-bit field found in EEPROM backup data memory which contains information used by the EEPROM filing system to determine the status of a specific EEPROM backup flash sector.

EEPROM backup data record — The EEPROM backup data record is comprised of a 2-bit status field, a 14-bit address field, and a 16-bit data field found in EEPROM backup data memory which is used by the EEPROM filing system. If the status field indicates a record is valid, the data field is mirrored in the FlexRAM at a location determined by the address field.

EEPROM backup data memory — Partitioned from the FlexNVM block, EEPROM backup data memory provides nonvolatile storage for the EEPROM filing system representing data written to the FlexRAM requiring highest endurance.

EEPROM backup data sector — The EEPROM backup data sector contains one EEPROM backup data header and up to 255 EEPROM backup data records, which are used by the EEPROM filing system.

Endurance — The number of times that a flash memory location can be erased and reprogrammed.

FCCOB (Flash Common Command Object) — A group of flash registers that are used to pass command, address, data, and any associated parameters to the memory controller in the flash memory module.

Flash block — A macro within the flash memory module which provides the nonvolatile memory storage.

FlexMemory — Flash configuration that supports data flash, EEPROM, and FlexRAM.

FlexNVM Block — The FlexNVM block can be configured to be used as data flash memory, EEPROM backup flash memory, or a combination of both.

FlexRAM — The FlexRAM refers to a RAM, dedicated to the flash memory module, that can be configured to store EEPROM data or as traditional RAM. When configured for EEPROM, valid writes to the FlexRAM generate new EEPROM backup data records stored in the EEPROM backup flash memory.

Flash Memory Module — All flash blocks plus a flash management unit providing high-level control and an interface to MCU buses.

IFR — Nonvolatile information register found in each flash block, separate from the main memory array.

Longword — 32 bits of data with an aligned longword having byte-address[1:0] = 00.

NVM — Nonvolatile memory. A memory technology that maintains stored data during power-off. The flash array is an NVM using NOR-type flash memory technology.

NVM Normal Mode — An NVM mode that provides basic user access to flash memory module resources. The CPU or other bus masters initiate flash program and erase operations (or other flash commands) using writes to the FCCOB register group in the flash memory module.

NVM Special Mode — An NVM mode enabling external, off-chip access to the memory resources in the flash memory module. A reduced flash command set is available when the MCU is secured. See the Chip Configuration details for information on when this mode is used.

Phrase — 64 bits of data with an aligned phrase having byte-address[2:0] = 000.

Program flash — The program flash memory provides nonvolatile storage for vectors and code store.

Program flash Sector — The smallest portion of the program flash memory (consecutive addresses) that can be erased.

Retention — The length of time that data can be kept in the NVM without experiencing errors upon readout. Since erased (1) states are subject to degradation just like programmed (0) states, the data retention limit may be reached from the last erase operation (not from the programming time).

RWW— Read-While-Write. The ability to simultaneously read from one memory resource while commanded operations are active in another memory resource.

Section Program Buffer — Lower half of the programming acceleration RAM or FlexRAM allocated for storing large amounts of data for programming via the Program Section command.

Secure — An MCU state conveyed to the flash memory module as described in the Chip Configuration details for this device. In the secure state, reading and changing NVM contents is restricted.

Word — 16 bits of data with an aligned word having byte-address[0] = 0.

28.2 External Signal Description

The flash memory module contains no signals that connect off-chip.

28.3 Memory Map and Registers

This section describes the memory map and registers for the flash memory module.

Data read from unimplemented memory space in the flash memory module is undefined. Writes to unimplemented or reserved memory space (registers) in the flash memory module are ignored.

28.3.1 Flash Configuration Field Description

The program flash memory contains a 16-byte flash configuration field that stores default protection settings (loaded on reset) and security information that allows the MCU to restrict access to the flash memory module.

| Flash Configuration Field Byte Address | Size (Bytes) | Field Description |
|--|--------------|---|
| 0x0_0400–0x0_0407 | 8 | Backdoor Comparison Key. Refer to Verify Backdoor Access Key Command and Unsecuring the Chip Using Backdoor Key Access . |
| 0x0_0408–0x0_040B | 4 | Program flash protection bytes. Refer to the description of the Program Flash Protection Registers (FPROT0-3). |
| 0x0_040F | 1 | Program flash only devices: Reserved FlexNVM devices: Data flash protection byte. Refer to the description of the Data Flash Protection Register (FDPROT). |
| 0x0_040E | 1 | Program flash only devices: Reserved FlexNVM devices: EEPROM protection byte. Refer to the description of the EEPROM Protection Register (FEPROT). |
| 0x0_040D | 1 | Flash nonvolatile option byte. Refer to the description of the Flash Option Register (FOPT). |
| 0x0_040C | 1 | Flash security byte. Refer to the description of the Flash Security Register (FSEC). |

28.3.2 Program Flash IFR Map

The program flash IFR is nonvolatile information memory that can be read freely, but the user has no erase and limited program capabilities (see the Read Once, Program Once, and Read Resource commands in [Read Once Command](#), [Program Once Command](#) and [Read Resource Command](#)).

The contents of the program flash IFR are summarized in the table found here and further described in the subsequent paragraphs.

The program flash IFR is located within the program flash 0 memory block for devices that only contain program flash.

| Address Range | Size (Bytes) | Field Description |
|---------------|--------------|--------------------|
| 0x00 – 0xBF | 192 | Reserved |
| 0xC0 – 0xFF | 64 | Program Once Field |

28.3.2.1 Program Once Field

The Program Once Field in the program flash IFR provides 64 bytes of user data storage separate from the program flash main array. The user can program the Program Once Field one time only as there is no program flash IFR erase mechanism available to the user. The Program Once Field can be read any number of times. This section of the program flash IFR is accessed in 4-byte records using the Read Once and Program Once commands (see [Read Once Command](#) and [Program Once Command](#)).

28.3.3 Data Flash IFR Map

The following only applies to devices with FlexNVM.

The data flash IFR is a 256 byte nonvolatile information memory that can be read and erased, but the user has limited program capabilities in the data flash IFR (see the Program Partition command in [Program Partition Command](#), the Erase All Blocks command in [Erase All Blocks Command](#), and the Read Resource command in [Read Resource Command](#)). The contents of the data flash IFR are summarized in the following table and further described in the subsequent paragraphs.

| Address Range | Size (Bytes) | Field Description |
|--------------------------|--------------|------------------------|
| 0x00 – 0xFB, 0xFE – 0xFF | 254 | Reserved |
| 0xFD | 1 | EEPROM data set size |
| 0xFC | 1 | FlexNVM partition code |

28.3.3.1 EEPROM Data Set Size

The EEPROM data set size byte in the data flash IFR supplies information which determines the amount of FlexRAM used in each of the available EEPROM subsystems. To program the EEESPLIT and EEESIZE values, see the Program Partition command described in [Program Partition Command](#).

Table 28-1. EEPROM Data Set Size

| Data flash IFR: 0x00FD | | | | | | | |
|------------------------|-----------------------------|----------|---|---|---------|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 1 | 1 | EEESPLIT | | | EEESIZE | | |
| | = Unimplemented or Reserved | | | | | | |

Table 28-2. EEPROM Data Set Size Field Description

| Field | Description |
|-----------------|--|
| 7-6 Reserved | This read-only bitfield is reserved and must always be written as one. |
| 5-4 EESPLIT | EEPROM Split Factor — Determines the relative sizes of the two EEPROM subsystems. '00' = Subsystem A: EESIZE*1/8, subsystem B: EESIZE*7/8 '01' = Subsystem A: EESIZE*1/4, subsystem B: EESIZE*3/4 '10' = Subsystem A: EESIZE*1/2, subsystem B: EESIZE*1/2 '11' = Subsystem A: EESIZE*1/2, subsystem B: EESIZE*1/2 |
| 3-0 EESIZE | EEPROM Size — Encoding of the total available FlexRAM for EEPROM use. NOTE: EESIZE must be 0 bytes (1111b) when the FlexNVM partition code (FlexNVM Partition Code) is set to 'No EEPROM'. '0000' = Reserved '0001' = Reserved '0010' = 4,096 Bytes '0011' = 2,048 Bytes '0100' = 1,024 Bytes '0101' = 512 Bytes '0110' = 256 Bytes '0111' = 128 Bytes '1000' = 64 Bytes '1001' = 32 Bytes '1010' = Reserved '1011' = Reserved '1100' = Reserved '1101' = Reserved '1110' = Reserved '1111' = 0 Bytes |

28.3.3.2 FlexNVM Partition Code

The FlexNVM Partition Code byte in the data flash IFR supplies a code which specifies how to split the FlexNVM block between data flash memory and EEPROM backup memory supporting EEPROM functions. To program the DEPART value, see the Program Partition command described in [Program Partition Command](#).

Table 28-3. FlexNVM Partition Code

| Data Flash IFR: 0x00FC | | | | | | | |
|------------------------|-----------------------------|---|---|--------|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 1 | 1 | 1 | 1 | DEPART | | | |
| | = Unimplemented or Reserved | | | | | | |

Table 28-4. FlexNVM Partition Code Field Description

| Field | Description | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-----------------|--|--------------------------|-----------------|--------------------|------|----|---|------|----------|----------|------|----------|----------|------|----|----|------|---|----|------|----------|----------|------|----------|----------|------|----------|----------|------|---|----|------|----------|----------|------|----------|----------|------|----|----|------|----|---|------|----------|----------|------|----------|----------|------|---------------------------|--------------------------|
| 7-4 Reserved | This read-only bitfield is reserved and must always be written as one. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3-0 DEPART | <div><div>FlexNVM Partition Code — Encoding of the data flash / EEPROM backup split within the FlexNVM memory block. FlexNVM memory not partitioned for data flash will be used to store EEPROM records.</div><table><tr><th>DEPART</th><th>Data flash (KB)</th><th>EEPROM backup (KB)</th></tr><tr><td>0000</td><td>64</td><td>0</td></tr><tr><td>0001</td><td>Reserved</td><td>Reserved</td></tr><tr><td>0010</td><td>Reserved</td><td>Reserved</td></tr><tr><td>0011</td><td>32</td><td>32</td></tr><tr><td>0100</td><td>0</td><td>64</td></tr><tr><td>0101</td><td>Reserved</td><td>Reserved</td></tr><tr><td>0110</td><td>Reserved</td><td>Reserved</td></tr><tr><td>0111</td><td>Reserved</td><td>Reserved</td></tr><tr><td>1000</td><td>0</td><td>64</td></tr><tr><td>1001</td><td>Reserved</td><td>Reserved</td></tr><tr><td>1010</td><td>Reserved</td><td>Reserved</td></tr><tr><td>1011</td><td>32</td><td>32</td></tr><tr><td>1100</td><td>64</td><td>0</td></tr><tr><td>1101</td><td>Reserved</td><td>Reserved</td></tr><tr><td>1110</td><td>Reserved</td><td>Reserved</td></tr><tr><td>1111</td><td>Reserved (defaults to 64)</td><td>Reserved (defaults to 0)</td></tr></table></div> | DEPART | Data flash (KB) | EEPROM backup (KB) | 0000 | 64 | 0 | 0001 | Reserved | Reserved | 0010 | Reserved | Reserved | 0011 | 32 | 32 | 0100 | 0 | 64 | 0101 | Reserved | Reserved | 0110 | Reserved | Reserved | 0111 | Reserved | Reserved | 1000 | 0 | 64 | 1001 | Reserved | Reserved | 1010 | Reserved | Reserved | 1011 | 32 | 32 | 1100 | 64 | 0 | 1101 | Reserved | Reserved | 1110 | Reserved | Reserved | 1111 | Reserved (defaults to 64) | Reserved (defaults to 0) |
| DEPART | Data flash (KB) | EEPROM backup (KB) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0000 | 64 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0001 | Reserved | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0010 | Reserved | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0011 | 32 | 32 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0100 | 0 | 64 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0101 | Reserved | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0110 | Reserved | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0111 | Reserved | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1000 | 0 | 64 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1001 | Reserved | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1010 | Reserved | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1011 | 32 | 32 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1100 | 64 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1101 | Reserved | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1110 | Reserved | Reserved | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1111 | Reserved (defaults to 64) | Reserved (defaults to 0) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

28.3.4 Register Descriptions

The flash memory module contains a set of memory-mapped control and status registers.

NOTE

While a command is running (FSTAT[CCIF]=0), register writes are not accepted to any register except FCNFG and FSTAT. The no-write rule is relaxed during the start-up reset sequence, prior to the initial rise of CCIF. During this initialization period the user may write any register. All register writes are also disabled (except for registers FCNFG and FSTAT) whenever an erase suspend request is active (FCNFG[ERSSUSP]=1).

FTFL memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|---|-----------------|--------|-----------------------------|-----------------------------|
| 4002_0000 | Flash Status Register (FTFL_FSTAT) | 8 | R/W | 00h | 28.34.1/533 |
| 4002_0001 | Flash Configuration Register (FTFL_FCNFG) | 8 | R/W | See section | 28.34.2/534 |
| 4002_0002 | Flash Security Register (FTFL_FSEC) | 8 | R | Undefined | 28.34.3/536 |
| 4002_0003 | Flash Option Register (FTFL_FOPT) | 8 | R | Undefined | 28.34.4/538 |
| 4002_0004 | Flash Common Command Object Registers (FTFL_FCCOB3) | 8 | R/W | 00h | 28.34.5/539 |
| 4002_0005 | Flash Common Command Object Registers (FTFL_FCCOB2) | 8 | R/W | 00h | 28.34.5/539 |
| 4002_0006 | Flash Common Command Object Registers (FTFL_FCCOB1) | 8 | R/W | 00h | 28.34.5/539 |
| 4002_0007 | Flash Common Command Object Registers (FTFL_FCCOB0) | 8 | R/W | 00h | 28.34.5/539 |
| 4002_0008 | Flash Common Command Object Registers (FTFL_FCCOB7) | 8 | R/W | 00h | 28.34.5/539 |
| 4002_0009 | Flash Common Command Object Registers (FTFL_FCCOB6) | 8 | R/W | 00h | 28.34.5/539 |
| 4002_000A | Flash Common Command Object Registers (FTFL_FCCOB5) | 8 | R/W | 00h | 28.34.5/539 |
| 4002_000B | Flash Common Command Object Registers (FTFL_FCCOB4) | 8 | R/W | 00h | 28.34.5/539 |
| 4002_000C | Flash Common Command Object Registers (FTFL_FCCOBB) | 8 | R/W | 00h | 28.34.5/539 |
| 4002_000D | Flash Common Command Object Registers (FTFL_FCCOBA) | 8 | R/W | 00h | 28.34.5/539 |

Table continues on the next page...

FTFL memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4002_000E | Flash Common Command Object Registers (FTFL_FCCOB9) | 8 | R/W | 00h | 28.34.5/539 |
| 4002_000F | Flash Common Command Object Registers (FTFL_FCCOB8) | 8 | R/W | 00h | 28.34.5/539 |
| 4002_0010 | Program Flash Protection Registers (FTFL_FPROT3) | 8 | R/W | Undefined | 28.34.6/540 |
| 4002_0011 | Program Flash Protection Registers (FTFL_FPROT2) | 8 | R/W | Undefined | 28.34.6/540 |
| 4002_0012 | Program Flash Protection Registers (FTFL_FPROT1) | 8 | R/W | Undefined | 28.34.6/540 |
| 4002_0013 | Program Flash Protection Registers (FTFL_FPROT0) | 8 | R/W | Undefined | 28.34.6/540 |
| 4002_0016 | EEPROM Protection Register (FTFL_FEPROT) | 8 | R/W | Undefined | 28.34.7/541 |
| 4002_0017 | Data Flash Protection Register (FTFL_FDPROT) | 8 | R/W | Undefined | 28.34.8/543 |

28.34.1 Flash Status Register (FTFL_FSTAT)

The FSTAT register reports the operational status of the flash memory module.

The CCIF, RDCOLERR, ACCERR, and FPVIOL bits are readable and writable. The MGSTAT0 bit is read only. The unassigned bits read 0 and are not writable.

NOTE

When set, the Access Error (ACCERR) and Flash Protection Violation (FPVIOL) bits in this register prevent the launch of any more commands or writes to the FlexRAM (when EEERDY is set) until the flag is cleared (by writing a one to it).

Address: 4002_0000h base + 0h offset = 4002_0000h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|----------|--------|--------|---|---|---|---------|
| Read | CCIF | RDCOLERR | ACCERR | FPVIOL | 0 | | | MGSTAT0 |
| Write | w1c | w1c | w1c | w1c | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTFL_FSTAT field descriptions

| Field | Description |
|-----------|--|
| 7 CCIF | Command Complete Interrupt Flag Indicates that a flash command or EEPROM file system operation has completed. The CCIF flag is cleared by writing a 1 to CCIF to launch a command, and CCIF stays low until command completion or |

Table continues on the next page...

FTFL_FSTAT field descriptions (continued)

| Field | Description |
|-----------------|--|
| | <p>command violation. The CCIF flag is also cleared by a successful write to FlexRAM while enabled for EEE, and CCIF stays low until the EEPROM file system has created the associated EEPROM data record.</p> <p>CCIF is reset to 0 but is set to 1 by the memory controller at the end of the reset initialization sequence. Depending on how quickly the read occurs after reset release, the user may or may not see the 0 hardware reset value.</p> <p>0 Flash command or EEPROM file system operation in progress 1 Flash command or EEPROM file system operation has completed</p> |
| 6 RDCOLERR | <p>Flash Read Collision Error Flag</p> <p>Indicates that the MCU attempted a read from a flash memory resource that was being manipulated by a flash command (CCIF=0). Any simultaneous access is detected as a collision error by the block arbitration logic. The read data in this case cannot be guaranteed. The RDCOLERR bit is cleared by writing a 1 to it. Writing a 0 to RDCOLERR has no effect.</p> <p>0 No collision error detected 1 Collision error detected</p> |
| 5 ACCERR | <p>Flash Access Error Flag</p> <p>Indicates an illegal access has occurred to a flash memory resource caused by a violation of the command write sequence or issuing an illegal flash command. While ACCERR is set, the CCIF flag cannot be cleared to launch a command. The ACCERR bit is cleared by writing a 1 to it. Writing a 0 to the ACCERR bit has no effect.</p> <p>0 No access error detected 1 Access error detected</p> |
| 4 FPVIOL | <p>Flash Protection Violation Flag</p> <p>Indicates an attempt was made to program or erase an address in a protected area of program flash or data flash memory during a command write sequence or a write was attempted to a protected area of the FlexRAM while enabled for EEPROM. While FPVIOL is set, the CCIF flag cannot be cleared to launch a command. The FPVIOL bit is cleared by writing a 1 to it. Writing a 0 to the FPVIOL bit has no effect.</p> <p>0 No protection violation detected 1 Protection violation detected</p> |
| 3–1 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 0 MGSTAT0 | <p>Memory Controller Command Completion Status Flag</p> <p>The MGSTAT0 status flag is set if an error is detected during execution of a flash command or during the flash reset sequence. As a status flag, this field cannot (and need not) be cleared by the user like the other error flags in this register.</p> <p>The value of the MGSTAT0 bit for "command-N" is valid only at the end of the "command-N" execution when CCIF=1 and before the next command has been launched. At some point during the execution of "command-N+1," the previous result is discarded and any previous error is cleared.</p> |

28.34.2 Flash Configuration Register (FTFL_FCNFG)

This register provides information on the current functional state of the flash memory module.

The erase control bits (ERSAREQ and ERSSUSP) have write restrictions. SWAP, PFLSH, RAMRDY, and EEERDY are read-only status bits. The unassigned bits read as noted and are not writable. The reset values for the SWAP, PFLASH, RAMRDY, and EEERDY bits are determined during the reset sequence.

Address: 4002_0000h base + 1h offset = 4002_0001h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|----------|---------|---------|------|-------|--------|--------|
| Read | CCIE | RDCOLLIE | ERSAREQ | ERSSUSP | SWAP | PFLSH | RAMRDY | EEERDY |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | * | * | * | * |

- * Notes:
- SWAP field: Device specific value
 - PFLSH field: Device specific value
 - RAMRDY field: Device specific value
 - EEERDY field: Device specific value

FTFL_FCNFG field descriptions

| Field | Description |
|---------------|--|
| 7 CCIE | <p>Command Complete Interrupt Enable</p> <p>Controls interrupt generation when a flash command completes.</p> <p>0 Command complete interrupt disabled</p> <p>1 Command complete interrupt enabled. An interrupt request is generated whenever the FSTAT[CCIF] flag is set.</p> |
| 6 RDCOLLIE | <p>Read Collision Error Interrupt Enable</p> <p>Controls interrupt generation when a flash memory read collision error occurs.</p> <p>0 Read collision error interrupt disabled</p> <p>1 Read collision error interrupt enabled. An interrupt request is generated whenever a flash memory read collision error is detected (see the description of FSTAT[RDCOLERR]).</p> |
| 5 ERSAREQ | <p>Erase All Request</p> <p>Issues a request to the memory controller to execute the Erase All Blocks command and release security. ERSAREQ is not directly writable but is under indirect user control. Refer to the device's Chip Configuration details on how to request this command.</p> <p>ERSAREQ sets when an erase all request is triggered external to the flash memory module and CCIF is set (no command is currently being executed). ERSAREQ is cleared by the flash memory module when the operation completes.</p> <p>0 No request or request complete</p> <p>1 Request to:</p> <ol style="list-style-type: none"> 1. run the Erase All Blocks command, 2. verify the erased state, 3. program the security byte in the Flash Configuration Field to the unsecure state, and 4. release MCU security by setting the FSEC[SEC] field to the unsecure state. |
| 4 ERSSUSP | <p>Erase Suspend</p> <p>Allows the user to suspend (interrupt) the Erase Flash Sector command while it is executing.</p> |

Table continues on the next page...

FTFL_FCNFG field descriptions (continued)

| Field | Description |
|-------------|--|
| | <p>0 No suspend requested</p> <p>1 Suspend the current Erase Flash Sector command execution.</p> |
| 3 SWAP | <p>Swap</p> <p>For program flash only configurations, the SWAP flag indicates which physical program flash block is located at relative address 0x0000. The state of the SWAP flag is set by the flash memory module during the reset sequence. See the Swap Control command section for information on swap management.</p> <p>0 Physical program flash 0 is located at relative address 0x0000</p> <p>1 If the PFLSH flag is set, physical program flash 1 is located at relative address 0x0000. If the PFLSH flag is not set, physical program flash 0 is located at relative address 0x0000</p> |
| 2 PFLSH | <p>Flash memory configuration</p> <p>0 For devices with FlexNVM: Flash memory module configured for FlexMemory that supports data flash and/or EEPROM. For devices with program flash only: Reserved</p> <p>1 For devices with FlexNVM: Reserved. For devices with program flash only: Flash memory module configured for program flash only, without support for data flash and/or EEPROM</p> |
| 1 RAMRDY | <p>RAM Ready</p> <p>This flag indicates the current status of the FlexRAM/programming acceleration RAM.</p> <p>For devices with FlexNVM: The state of the RAMRDY flag is normally controlled by the Set FlexRAM Function command. During the reset sequence, the RAMRDY flag is cleared if the FlexNVM block is partitioned for EEPROM and is set if the FlexNVM block is not partitioned for EEPROM. The RAMRDY flag is cleared if the Program Partition command is run to partition the FlexNVM block for EEPROM. The RAMRDY flag sets after completion of the Erase All Blocks command or execution of the erase-all operation triggered external to the flash memory module.</p> <p>For devices without FlexNVM: This bit should always be set.</p> <p>0 For devices with FlexNVM: FlexRAM is not available for traditional RAM access. For devices without FlexNVM: Programming acceleration RAM is not available.</p> <p>1 For devices with FlexNVM: FlexRAM is available as traditional RAM only; writes to the FlexRAM do not trigger EEPROM operations. For devices without FlexNVM: Programming acceleration RAM is available.</p> |
| 0 EEERDY | <p>For devices with FlexNVM: This flag indicates if the EEPROM backup data has been copied to the FlexRAM and is therefore available for read access. During the reset sequence, the EEERDY flag will remain cleared while CCIF is clear and will only set if the FlexNVM block is partitioned for EEPROM.</p> <p>For devices without FlexNVM: This field is reserved.</p> <p>0 For devices with FlexNVM: FlexRAM is not available for EEPROM operation.</p> <p>1 For devices with FlexNVM: FlexRAM is available for EEPROM operations where:</p> <ul style="list-style-type: none"> reads from the FlexRAM return data previously written to the FlexRAM in EEPROM mode and writes to the FlexRAM clear EEERDY and launch an EEPROM operation to store the written data in the FlexRAM and EEPROM backup. |

28.34.3 Flash Security Register (FTFL_FSEC)

This read-only register holds all bits associated with the security of the MCU and flash memory module.

During the reset sequence, the register is loaded with the contents of the flash security byte in the Flash Configuration Field located in program flash memory. The flash basis for the values is signified by X in the reset value.

Address: 4002_0000h base + 2h offset = 4002_0002h

| | | | | | | | | |
|-------|-------|----|------|----|--------|----|-----|----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | KEYEN | | MEEN | | FSLACC | | SEC | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

FTFL_FSEC field descriptions

| Field | Description |
|---------------|---|
| 7–6 KEYEN | <p>Backdoor Key Security Enable</p> <p>Enables or disables backdoor key access to the flash memory module.</p> <p>00 Backdoor key access disabled</p> <p>01 Backdoor key access disabled (preferred KEYEN state to disable backdoor key access)</p> <p>10 Backdoor key access enabled</p> <p>11 Backdoor key access disabled</p> |
| 5–4 MEEN | <p>Mass Erase Enable Bits</p> <p>Enables and disables mass erase capability of the flash memory module. The state of this field is relevant only when SEC is set to secure outside of NVM Normal Mode. When SEC is set to unsecure, the MEEN setting does not matter.</p> <p>00 Mass erase is enabled</p> <p>01 Mass erase is enabled</p> <p>10 Mass erase is disabled</p> <p>11 Mass erase is enabled</p> |
| 3–2 FSLACC | <p>Freescall Failure Analysis Access Code</p> <p>Enables or disables access to the flash memory contents during returned part failure analysis at Freescale. When SEC is secure and FSLACC is denied, access to the program flash contents is denied and any failure analysis performed by Freescale factory test must begin with a full erase to unsecure the part.</p> <p>When access is granted (SEC is unsecure, or SEC is secure and FSLACC is granted), Freescale factory testing has visibility of the current flash contents. The state of the FSLACC bits is only relevant when SEC is set to secure. When SEC is set to unsecure, the FSLACC setting does not matter.</p> <p>00 Freescale factory access granted</p> <p>01 Freescale factory access denied</p> <p>10 Freescale factory access denied</p> <p>11 Freescale factory access granted</p> |
| 1–0 SEC | Flash Security |

Table continues on the next page...

FTFL_FSEC field descriptions (continued)

| Field | Description |
|-------|---|
| | Defines the security state of the MCU. In the secure state, the MCU limits access to flash memory module resources. The limitations are defined per device and are detailed in the Chip Configuration details. If the flash memory module is unsecured using backdoor key access, SEC is forced to 10b. |
| 00 | MCU security status is secure. |
| 01 | MCU security status is secure. |
| 10 | MCU security status is unsecure. (The standard shipping condition of the flash memory module is unsecure.) |
| 11 | MCU security status is secure. |

28.34.4 Flash Option Register (FTFL_FOPT)

The flash option register allows the MCU to customize its operations by examining the state of these read-only bits, which are loaded from NVM at reset. The function of the bits is defined in the device's Chip Configuration details.

All bits in the register are read-only .

During the reset sequence, the register is loaded from the flash nonvolatile option byte in the Flash Configuration Field located in program flash memory. The flash basis for the values is signified by X in the reset value.

Address: 4002_0000h base + 3h offset = 4002_0003h

| | | | | | | | | |
|-------|-----|----|----|----|----|----|----|----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | OPT | | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

- * Notes:
- x = Undefined at reset.

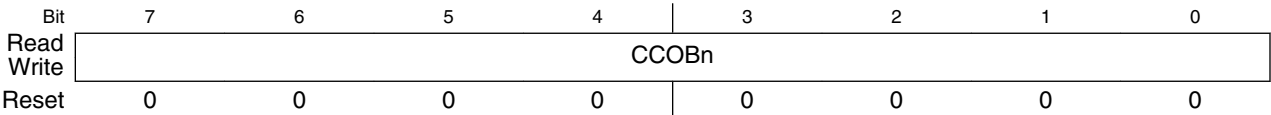
FTFL_FOPT field descriptions

| Field | Description |
|------------|--|
| 7–0 OPT | Nonvolatile Option These bits are loaded from flash to this register at reset. Refer to the device's Chip Configuration details for the definition and use of these bits. |

28.34.5 Flash Common Command Object Registers (FTFL_FCCOBn)

The FCCOB register group provides 12 bytes for command codes and parameters. The individual bytes within the set append a 0-B hex identifier to the FCCOB register name: FCCOB0, FCCOB1, ..., FCCOBB.

Address: 4002_0000h base + 4h offset + (1d × i), where i=0d to 11d



FTFL_FCCOBn field descriptions

| Field | Description | | | | | | | | | | | | | | | | | | | | | | |
|--------------|---|--------------|--|---|--|---|-----------------------|---|----------------------|---|---------------------|---|-------------|---|-------------|---|-------------|---|-------------|---|-------------|---|-------------|
| 7-0 CCOBn | <p>The FCCOB register provides a command code and relevant parameters to the memory controller. The individual registers that compose the FCCOB data set can be written in any order, but you must provide all needed values, which vary from command to command. First, set up all required FCCOB fields and then initiate the command's execution by writing a 1 to the FSTAT[CCIF] bit. This clears the CCIF bit, which locks all FCCOB parameter fields and they cannot be changed by the user until the command completes (CCIF returns to 1). No command buffering or queueing is provided; the next command can be loaded only after the current command completes.</p> <p>Some commands return information to the FCCOB registers. Any values returned to FCCOB are available for reading after the FSTAT[CCIF] flag returns to 1 by the memory controller.</p> <p>The following table shows a generic flash command format. The first FCCOB register, FCCOB0, always contains the command code. This 8-bit value defines the command to be executed. The command code is followed by the parameters required for this specific flash command, typically an address and/or data values.</p> <p>NOTE: The command parameter table is written in terms of FCCOB Number (which is equivalent to the byte number). This number is a reference to the FCCOB register name and is not the register address.</p> <table border="1"> <tr> <th>FCCOB Number</th><th>Typical Command Parameter Contents [7:0]</th></tr> <tr> <td>0</td><td>FCMD (a code that defines the flash command)</td></tr> <tr> <td>1</td><td>Flash address [23:16]</td></tr> <tr> <td>2</td><td>Flash address [15:8]</td></tr> <tr> <td>3</td><td>Flash address [7:0]</td></tr> <tr> <td>4</td><td>Data Byte 0</td></tr> <tr> <td>5</td><td>Data Byte 1</td></tr> <tr> <td>6</td><td>Data Byte 2</td></tr> <tr> <td>7</td><td>Data Byte 3</td></tr> <tr> <td>8</td><td>Data Byte 4</td></tr> <tr> <td>9</td><td>Data Byte 5</td></tr> </table> | FCCOB Number | Typical Command Parameter Contents [7:0] | 0 | FCMD (a code that defines the flash command) | 1 | Flash address [23:16] | 2 | Flash address [15:8] | 3 | Flash address [7:0] | 4 | Data Byte 0 | 5 | Data Byte 1 | 6 | Data Byte 2 | 7 | Data Byte 3 | 8 | Data Byte 4 | 9 | Data Byte 5 |
| FCCOB Number | Typical Command Parameter Contents [7:0] | | | | | | | | | | | | | | | | | | | | | | |
| 0 | FCMD (a code that defines the flash command) | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Flash address [23:16] | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Flash address [15:8] | | | | | | | | | | | | | | | | | | | | | | |
| 3 | Flash address [7:0] | | | | | | | | | | | | | | | | | | | | | | |
| 4 | Data Byte 0 | | | | | | | | | | | | | | | | | | | | | | |
| 5 | Data Byte 1 | | | | | | | | | | | | | | | | | | | | | | |
| 6 | Data Byte 2 | | | | | | | | | | | | | | | | | | | | | | |
| 7 | Data Byte 3 | | | | | | | | | | | | | | | | | | | | | | |
| 8 | Data Byte 4 | | | | | | | | | | | | | | | | | | | | | | |
| 9 | Data Byte 5 | | | | | | | | | | | | | | | | | | | | | | |

FTFL_FCCOB n field descriptions (continued)

| Field | Description | |
|-------|--|--|
| | FCCOB Number | Typical Command Parameter Contents [7:0] |
| | A | Data Byte 6 |
| | B | Data Byte 7 |
| | FCCOB Endianness and Multi-Byte Access : The FCCOB register group uses a big endian addressing convention. For all command parameter fields larger than 1 byte, the most significant data resides in the lowest FCCOB register number. The FCCOB register group may be read and written as individual bytes, aligned words (2 bytes) or aligned longwords (4 bytes). | |

28.34.6 Program Flash Protection Registers (FTFL_FPROT n)

The FPROT registers define which program flash regions are protected from program and erase operations. Protected flash regions cannot have their content changed; that is, these regions cannot be programmed and cannot be erased by any flash command. Unprotected regions can be changed by program and erase operations.

The four FPROT registers allow 32 protectable regions. Each bit protects a 1/32 region of the program flash memory . The bitfields are defined in each register as follows:

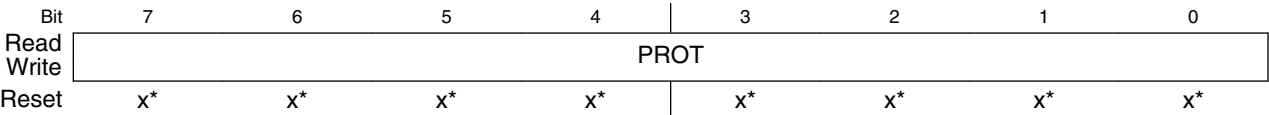
| Program flash protection register | Program flash protection bits |
|-----------------------------------|-------------------------------|
| FPROT0 | PROT[31:24] |
| FPROT1 | PROT[23:16] |
| FPROT2 | PROT[15:8] |
| FPROT3 | PROT[7:0] |

During the reset sequence, the FPROT registers are loaded with the contents of the program flash protection bytes in the Flash Configuration Field as indicated in the following table.

| Program flash protection register | Flash Configuration Field offset address |
|-----------------------------------|--|
| FPROT0 | 0x000B |
| FPROT1 | 0x000A |
| FPROT2 | 0x0009 |
| FPROT3 | 0x0008 |

To change the program flash protection that is loaded during the reset sequence, unprotect the sector of program flash memory that contains the Flash Configuration Field. Then, reprogram the program flash protection byte.

Address: 4002_0000h base + 10h offset + (1d × i), where i=0d to 3d



- * Notes:
- x = Undefined at reset.

FTFL_FPROTn field descriptions

| Field | Description |
|-------------|---|
| 7–0 PROT | <p>Program Flash Region Protect</p> <p>Each program flash region can be protected from program and erase operations by setting the associated PROT bit.</p> <p>In NVM Normal mode: The protection can only be increased, meaning that currently unprotected memory can be protected, but currently protected memory cannot be unprotected. Since unprotected regions are marked with a 1 and protected regions use a 0, only writes changing 1s to 0s are accepted. This 1-to-0 transition check is performed on a bit-by-bit basis. Those FPROT bits with 1-to-0 transitions are accepted while all bits with 0-to-1 transitions are ignored.</p> <p>In NVM Special mode: All bits of FPROT are writable without restriction. Unprotected areas can be protected and protected areas can be unprotected.</p> <p>Restriction: The user must never write to any FPROT register while a command is running (CCIF=0). Trying to alter data in any protected area in the program flash memory results in a protection violation error and sets the FSTAT[FPVIOL] bit. A full block erase of a program flash block is not possible if it contains any protected region.</p> <p>Each bit in the 32-bit protection register represents 1/32 of the total program flash.</p> <p>0 Program flash region is protected. 1 Program flash region is not protected</p> |

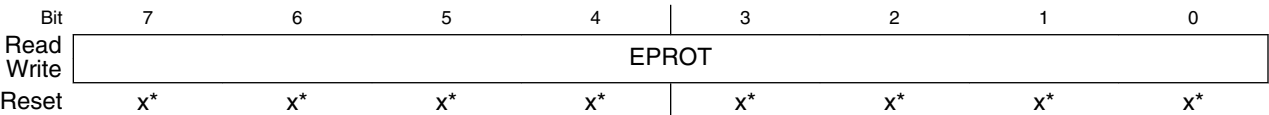
28.34.7 EEPROM Protection Register (FTFL_FEPROT)

For devices with FlexNVM: The FEPROT register defines which EEPROM regions of the FlexRAM are protected against program and erase operations. Protected EEPROM regions cannot have their content changed by writing to it. Unprotected regions can be changed by writing to the FlexRAM.

For devices with program flash only: This register is reserved and not used.

memory Map and Registers

Address: 4002_0000h base + 16h offset = 4002_0016h



- * Notes:
- x = Undefined at reset.

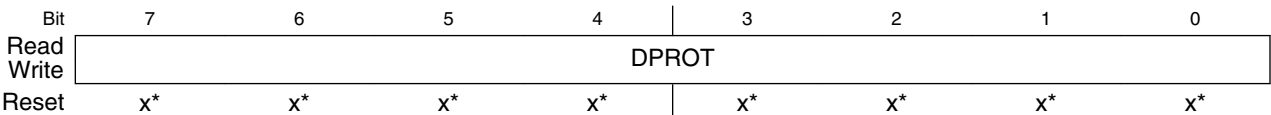
FTFL_FEPROT field descriptions

| Field | Description |
|--------------|--|
| 7-0 EPROT | <p>EEPROM Region Protect</p> <p>For devices with program flash only: Reserved</p> <p>For devices with FlexNVM:</p> <p>Individual EEPROM regions can be protected from alteration by setting the associated EPROT bit. The EPROT bits are not used when the FlexNVM Partition Code is set to data flash only. When the FlexNVM Partition Code is set to data flash and EEPROM or EEPROM only, each EPROT bit covers one-eighth of the configured EEPROM data (see the EEPROM Data Set Size parameter description).</p> <p>In NVM Normal mode: The protection can only be increased. This means that currently-unprotected memory can be protected, but currently-protected memory cannot be unprotected. Since unprotected regions are marked with a 1 and protected regions use a 0, only writes changing 1s to 0s are accepted. This 1-to-0 transition check is performed on a bit-by-bit basis. Those FEPROT bits with 1-to-0 transitions are accepted while all bits with 0-to-1 transitions are ignored.</p> <p>In NVM Special mode : All bits of the FEPROT register are writable without restriction. Unprotected areas can be protected and protected areas can be unprotected.</p> <p>Restriction: Never write to the FEPROT register while a command is running (CCIF=0).</p> <p>Reset: During the reset sequence, the FEPROT register is loaded with the contents of the FlexRAM protection byte in the Flash Configuration Field located in program flash. The flash basis for the reset values is signified by X in the register diagram. To change the EEPROM protection that will be loaded during the reset sequence, the sector of program flash that contains the Flash Configuration Field must be unprotected; then the EEPROM protection byte must be erased and reprogrammed.</p> <p>Trying to alter data by writing to any protected area in the EEPROM results in a protection violation error and sets the FPVIOL bit in the FSTAT register.</p> <p>0 For devices with program flash only: Reserved. For devices with FlexNVM: EEPROM region is protected</p> <p>1 For devices with program flash only: Reserved. For devices with FlexNVM: EEPROM region is not protected</p> |

28.34.8 Data Flash Protection Register (FTFL_FDPROT)

The FDPROT register defines which data flash regions are protected against program and erase operations. Protected Flash regions cannot have their content changed; that is, these regions cannot be programmed and cannot be erased by any flash command. Unprotected regions can be changed by both program and erase operations.

Address: 4002_0000h base + 17h offset = 4002_0017h



- * Notes:
- x = Undefined at reset.

FTFL_FDPROT field descriptions

| Field | Description |
|--------------|--|
| 7–0 DPROT | <p>Data Flash Region Protect</p> <p>For devices with program flash only: Reserved.</p> <p>For devices with FlexNVM: Individual data flash regions can be protected from program and erase operations by setting the associated DPROT bit. Each DPROT bit protects one-eighth of the partitioned data flash memory space. The granularity of data flash protection cannot be less than the data flash sector size. If an unused DPROT bit is set, the Erase all Blocks command does not execute and the FSTAT[FPVIOL] flag is set.</p> <p>In NVM Normal mode: The protection can only be increased, meaning that currently unprotected memory can be protected but currently protected memory cannot be unprotected. Since unprotected regions are marked with a 1 and protected regions use a 0, only writes changing 1s to 0s are accepted. This 1-to-0 transition check is performed on a bit-by-bit basis. Those FDPROT bits with 1-to-0 transitions are accepted while all bits with 0-to-1 transitions are ignored.</p> <p>In NVM Special mode: All bits of the FDPROT register are writable without restriction. Unprotected areas can be protected and protected areas can be unprotected.</p> <p>Restriction: The user must never write to the FDPROT register while a command is running (CCIF=0).</p> <p>Reset: During the reset sequence, the FDPROT register is loaded with the contents of the data flash protection byte in the Flash Configuration Field located in program flash memory. The flash basis for the reset values is signified by X in the register diagram. To change the data flash protection that will be loaded during the reset sequence, unprotect the sector of program flash that contains the Flash Configuration Field. Then, erase and reprogram the data flash protection byte.</p> <p>Trying to alter data with the program and erase commands in any protected area in the data flash memory results in a protection violation error and sets the FSTAT[FPVIOL] bit. A full block erase of the data flash memory (see the Erase Flash Block command description) is not possible if the data flash memory contains any protected region or if the FlexNVM block has been partitioned for EEPROM.</p> <p>0 Data Flash region is protected 1 Data Flash region is not protected</p> |

28.4 Functional Description

The information found here describes functional details of the flash memory module.

28.4.1 Program Flash Memory Swap

For devices that only contain program flash memory: The user can configure the logical memory map of the program flash space such that either of the two physical program flash blocks can exist at relative address 0x0000. This swap feature enables the lower half of the logical program flash space to be operational while the upper half is being updated for future use.

The Swap Control command handles swapping the two logical P-Flash memory blocks within the memory map. See [Swap Control Command](#) for details.

28.4.2 Flash Protection

Individual regions within the flash memory can be protected from program and erase operations.

Protection is controlled by the following registers:

- $FPROT_n$ —
 - For 2^n program flash sizes, four registers typically protect 32 regions of the program flash memory as shown in the following figure

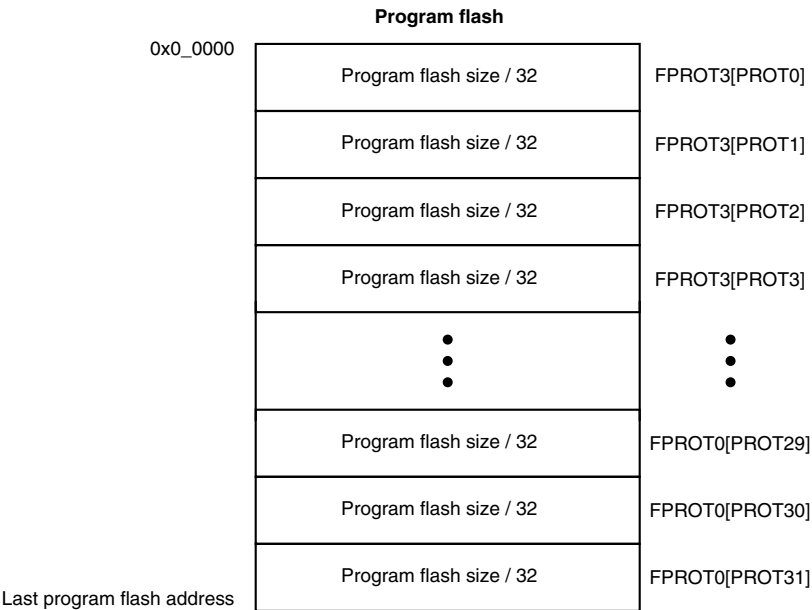


Figure 28-27. Program flash protection

- FDPROT —
 - protects eight regions of the data flash memory as shown in the following figure

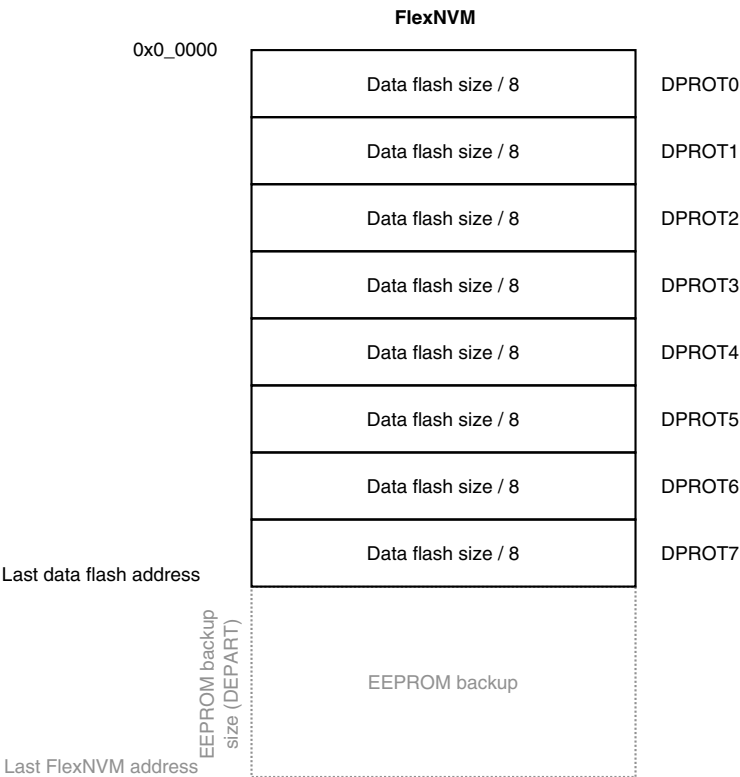


Figure 28-28. Data flash protection

- FEPROT — Protects eight regions of the EEPROM memory as shown in the following figure

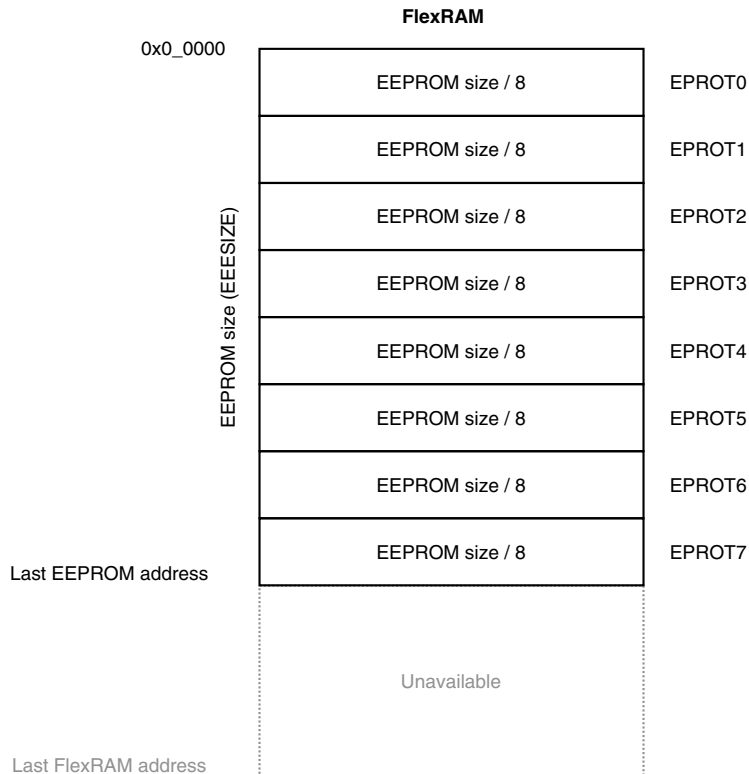


Figure 28-29. EEPROM protection

NOTE

Flash protection features are discussed further in [AN4507: Using the Kinetis Security and Flash Protection Features](#) . Not all features described in the application note are available on this device.

28.4.3 FlexNVM Description

This section describes the FlexNVM memory. This section does not apply for devices that contain only program flash memory.

28.4.3.1 FlexNVM Block Partitioning for FlexRAM

The user can configure the FlexNVM block as either:

- Basic data flash,
- EEPROM flash records to support the built-in EEPROM feature, or
- A combination of both.

The user's FlexNVM configuration choice is specified using the Program Partition command described in [Program Partition Command](#).

CAUTION

While different partitions of the FlexNVM block are available, the intention is that a single partition choice is used throughout the entire lifetime of a given application. The FlexNVM partition code choices affect the endurance and data retention characteristics of the device.

28.4.3.2 EEPROM User Perspective

The EEPROM system is shown in the following figure.

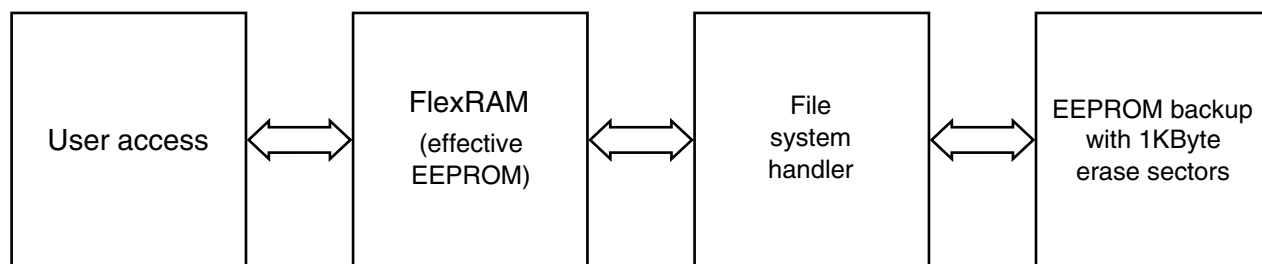


Figure 28-30. Top Level EEPROM Architecture

To handle varying customer requirements, the FlexRAM and FlexNVM blocks can be split into partitions as shown in the figure below.

1. **EEPROM partition** (EESIZE) — The amount of FlexRAM used for EEPROM can be set from 0 Bytes (no EEPROM) to the maximum FlexRAM size (see [Table 28-2](#)). The remainder of the FlexRAM is not accessible while the FlexRAM is configured for EEPROM (see [Set FlexRAM Function Command](#)). The EEPROM partition grows upward from the bottom of the FlexRAM address space.
2. **Data flash partition** (DEPART) — The amount of FlexNVM memory used for data flash can be programmed from 0 bytes (all of the FlexNVM block is available for EEPROM backup) to the maximum size of the FlexNVM block (see [Table 28-4](#)).
3. **FlexNVM EEPROM partition** — The amount of FlexNVM memory used for EEPROM backup, which is equal to the FlexNVM block size minus the data flash memory partition size. The EEPROM backup size must be at least 16 times the EEPROM partition size in FlexRAM.
4. **EEPROM split factor** (EESPLIT) — The FlexRAM partitioned for EEPROM can be divided into two subsystems, each backed by half of the partitioned EEPROM backup. One subsystem (A) is 1/8, 1/4, or 1/2 of the partitioned FlexRAM with the remainder belonging to the other subsystem (B).

The partition information (EEESIZE, DEPART, EEESPLIT) is stored in the data flash IFR and is programmed using the Program Partition command (see [Program Partition Command](#)). Typically, the Program Partition command is executed only once in the lifetime of the device.

Data flash memory is useful for applications that need to quickly store large amounts of data or store data that is static. The EEPROM partition in FlexRAM is useful for storing smaller amounts of data that will be changed often. The EEPROM partition in FlexRAM can be further sub-divided to provide subsystems, each backed by the same amount of EEPROM backup with subsystem A having higher endurance if the split factor is 1/8 or 1/4.

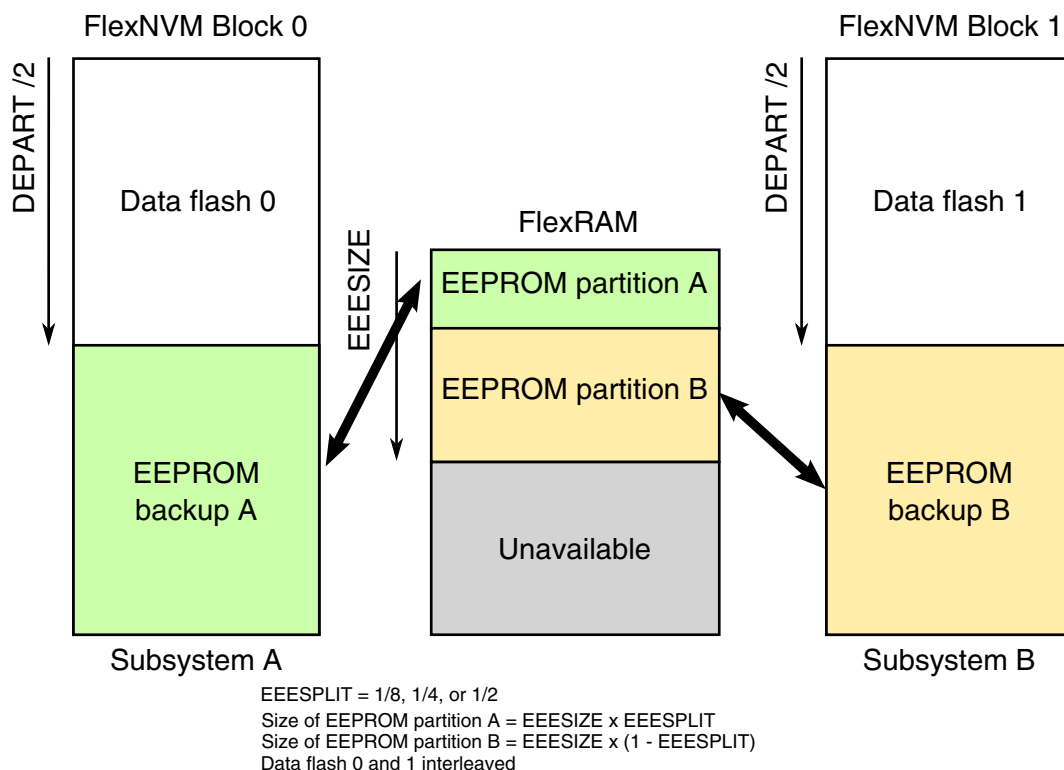


Figure 28-31. FlexRAM to FlexNVM Memory Mapping with 2 Sub-systems

28.4.3.3 EEPROM Implementation Overview

Out of reset with the FSTAT[CCIF] bit clear, the partition settings (EEESIZE, DEPART, EEESPLIT) are read from the data flash IFR and the EEPROM file system is initialized accordingly. The EEPROM file system locates all valid EEPROM data records in EEPROM backup and copies the newest data to FlexRAM. The FSTAT[CCIF] and FCNFG[EEERDY] bits are set after data from all valid EEPROM data records is copied to the FlexRAM. After the CCIF bit is set, the FlexRAM is available for read or write access.

When configured for EEPROM use, writes to an unprotected location in FlexRAM invokes the EEPROM file system to program a new EEPROM data record in the EEPROM backup memory in a round-robin fashion. As needed, the EEPROM file system identifies the EEPROM backup sector that is being erased for future use and partially erases that EEPROM backup sector. After a write to the FlexRAM, the FlexRAM is not accessible until the FSTAT[CCIF] bit is set. The FCNFG[EEERDY] bit will also be set. If enabled, the interrupt associated with the FSTAT[CCIF] bit can be used to determine when the FlexRAM is available for read or write access.

After a sector in EEPROM backup is full of EEPROM data records, EEPROM data records from the sector holding the oldest data are gradually copied over to a previously-erased EEPROM backup sector. When the sector copy completes, the EEPROM backup sector holding the oldest data is tagged for erase.

28.4.3.4 Write endurance to FlexRAM for EEPROM

When the FlexNVM partition code is not set to full data flash, the EEPROM data set size can be set to any of several non-zero values.

The bytes not assigned to data flash via the FlexNVM partition code are used by the flash memory module to obtain an effective endurance increase for the EEPROM data. The built-in EEPROM record management system raises the number of program/erase cycles that can be attained prior to device wear-out by cycling the EEPROM data through a larger EEPROM NVM storage space.

While different partitions of the FlexNVM are available, the intention is that a single choice for the FlexNVM partition code and EEPROM data set size is used throughout the entire lifetime of a given application. The EEPROM endurance equation and graph shown below assume that only one configuration is ever used.

$$\text{Writes_subsystem} = \frac{\text{EEPROM} - 2 \times \text{EESPLIT} \times \text{EESIZE}}{\text{EESPLIT} \times \text{EESIZE}} \times \text{Write_efficiency} \times n_{\text{nvmcycd}}$$

where

- Writes_subsystem — minimum number of writes to each FlexRAM location for subsystem (each subsystem can have different endurance)
- EEPROM — allocated FlexNVM for each EEPROM subsystem based on DEPART; entered with the Program Partition command
- EESPLIT — FlexRAM split factor for subsystem; entered with the Program Partition command
- EESIZE — allocated FlexRAM based on DEPART; entered with the Program Partition command

Functional Description

- Write_efficiency —
 - 0.25 for 8-bit writes to FlexRAM
 - 0.50 for 16-bit or 32-bit writes to FlexRAM
- n_{nvmcyed} — data flash cycling endurance (the following graph assumes 10,000 cycles)

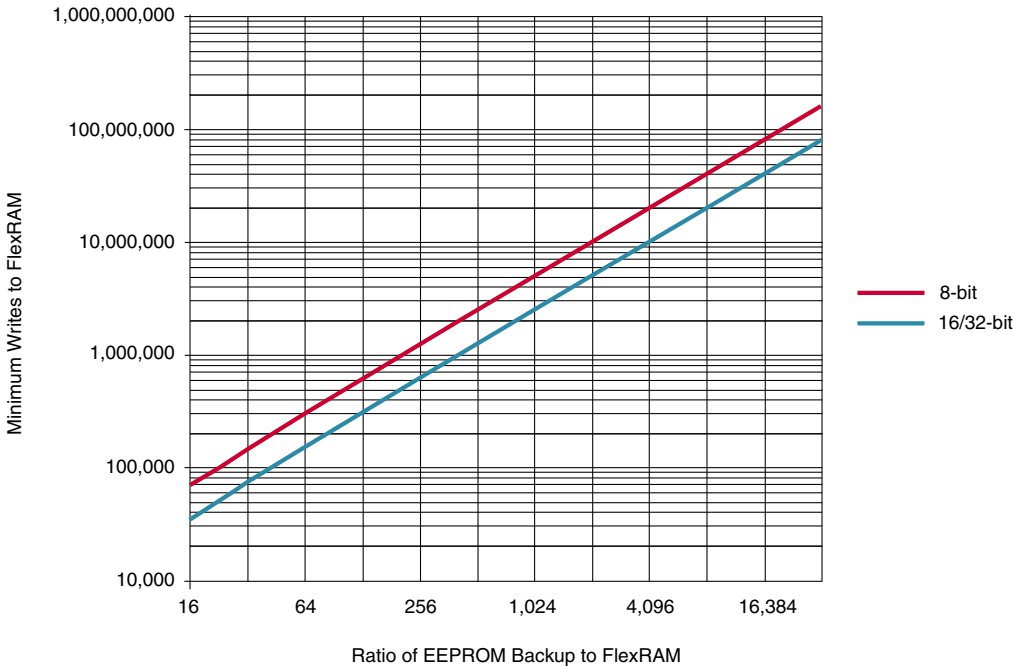


Figure 28-32. EEPROM backup writes to FlexRAM

28.4.4 Interrupts

The flash memory module can generate interrupt requests to the MCU upon the occurrence of various flash events.

These interrupt events and their associated status and control bits are shown in the following table.

Table 28-30. Flash Interrupt Sources

| Flash Event | Readable Status Bit | Interrupt Enable Bit |
|----------------------------|---------------------|----------------------|
| Flash Command Complete | FSTAT[CCIF] | FCNFG[CCIE] |
| Flash Read Collision Error | FSTAT[RDCOLERR] | FCNFG[RDCOLLIE] |

Note

Vector addresses and their relative interrupt priority are determined at the MCU level.

Some devices also generate a bus error response as a result of a Read Collision Error event. See the chip configuration information to determine if a bus error response is also supported.

28.4.5 Flash Operation in Low-Power Modes

28.4.5.1 Wait Mode

When the MCU enters wait mode, the flash memory module is not affected. The flash memory module can recover the MCU from wait via the command complete interrupt (see [Interrupts](#)).

28.4.5.2 Stop Mode

When the MCU requests stop mode, if a flash command is active (CCIF = 0) the command execution completes before the MCU is allowed to enter stop mode.

CAUTION

The MCU should never enter stop mode while any flash command is running (CCIF = 0).

NOTE

While the MCU is in very-low-power modes (VLPR, VLPW, VLPS), the flash memory module does not accept flash commands.

28.4.6 Functional Modes of Operation

The flash memory module has two operating modes: NVM Normal and NVM Special.

The operating mode affects the command set availability (see [Table 28-31](#)). Refer to the Chip Configuration details of this device for how to activate each mode.

28.4.7 Flash Reads and Ignored Writes

The flash memory module requires only the flash address to execute a flash memory read.

The MCU must not read from the flash memory while commands are running (as evidenced by CCIF=0) on that block. Read data cannot be guaranteed from a flash block while any command is processing within that block. The block arbitration logic detects any simultaneous access and reports this as a read collision error (see the FSTAT[RDCOLERR] bit).

28.4.8 Read While Write (RWW)

The following simultaneous accesses are allowed for devices with FlexNVM:

- The user may read from the program flash memory while commands (typically program and erase operations) are active in the data flash and FlexRAM memory space.
- The MCU can fetch instructions from program flash during both data flash program and erase operations and while EEPROM backup data is maintained by the EEPROM commands.
- Conversely, the user may read from data flash and FlexRAM while program and erase commands are executing on the program flash.
- When configured as traditional RAM, writes to the FlexRAM are allowed during program and data flash operations.

Simultaneous data flash operations and FlexRAM writes, when FlexRAM is used for EEPROM, are not possible.

The following simultaneous accesses are allowed for devices with program flash only:

- The user may read from one logical program flash memory space while flash commands are active in the other logical program flash memory space.

Simultaneous operations are further discussed in [Allowed Simultaneous Flash Operations](#).

28.4.9 Flash Program and Erase

All flash functions except read require the user to setup and launch a flash command through a series of peripheral bus writes.

The user cannot initiate any further flash commands until notified that the current command has completed. The flash command structure and operation are detailed in [Flash Command Operations](#).

28.4.10 Flash Command Operations

Flash command operations are typically used to modify flash memory contents.

The next sections describe:

- The command write sequence used to set flash command parameters and launch execution
- A description of all flash commands available

28.4.10.1 Command Write Sequence

Flash commands are specified using a command write sequence illustrated in [Figure 28-33](#). The flash memory module performs various checks on the command (FCCOB) content and continues with command execution if all requirements are fulfilled.

Before launching a command, the ACCERR and FPVIOL bits in the FSTAT register must be zero and the CCIF flag must read 1 to verify that any previous command has completed. If CCIF is zero, the previous command execution is still active, a new command write sequence cannot be started, and all writes to the FCCOB registers are ignored.

Attempts to launch a flash command in VLP mode will be ignored.

28.4.10.1.1 Load the FCCOB Registers

The user must load the FCCOB registers with all parameters required by the desired flash command. The individual registers that make up the FCCOB data set can be written in any order.

28.4.10.1.2 Launch the Command by Clearing CCIF

Once all relevant command parameters have been loaded, the user launches the command by clearing FSTAT[CCIF] by writing a '1' to it. FSTAT[CCIF] remains 0 until the flash command completes.

The FSTAT register contains a blocking mechanism that prevents a new command from launching (can't clear FSTAT[CCIF]) if the previous command resulted in an access error (FSTAT[ACCERR]=1) or a protection violation (FSTAT[FPVIOL]=1). In error scenarios, two writes to FSTAT are required to initiate the next command: the first write clears the error flags, the second write clears CCIF.

28.4.10.1.3 Command Execution and Error Reporting

The command processing has several steps:

1. The flash memory module reads the command code and performs a series of parameter checks and protection checks, if applicable, which are unique to each command.

If the parameter check fails, the FSTAT[ACCERR] (access error) flag is set. FSTAT[ACCERR] reports invalid instruction codes and out-of bounds addresses. Usually, access errors suggest that the command was not set-up with valid parameters in the FCCOB register group.

Program and erase commands also check the address to determine if the operation is requested to execute on protected areas. If the protection check fails, FSTAT[FPVIOL] (protection error) flag is set.

Command processing never proceeds to execution when the parameter or protection step fails. Instead, command processing is terminated after setting FSTAT[CCIF].

2. If the parameter and protection checks pass, the command proceeds to execution. Run-time errors, such as failure to erase verify, may occur during the execution phase. Run-time errors are reported in FSTAT[MGSTAT0]. A command may have access errors, protection errors, and run-time errors, but the run-time errors are not seen until all access and protection errors have been corrected.
3. Command execution results, if applicable, are reported back to the user via the FCCOB and FSTAT registers.
4. The flash memory module sets FSTAT[CCIF] signifying that the command has completed.

The flow for a generic command write sequence is illustrated in the following figure.

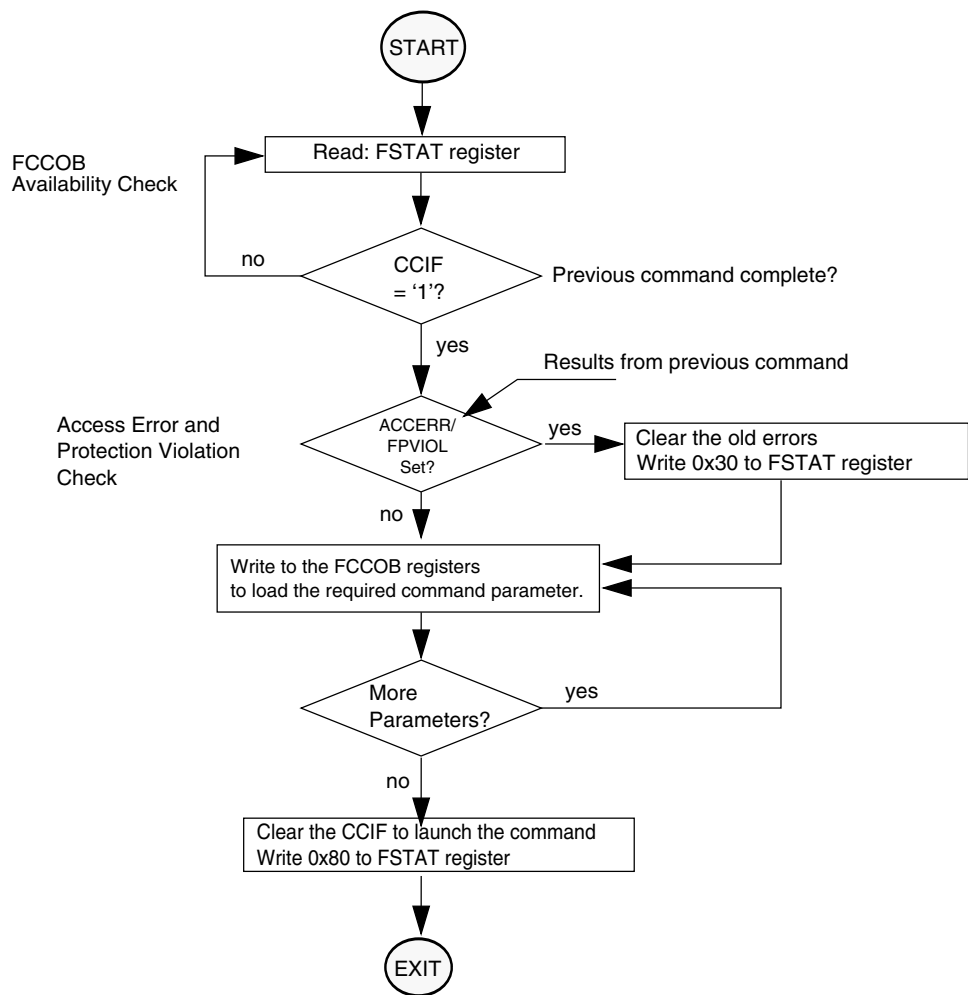


Figure 28-33. Generic flash command write sequence flowchart

28.4.10.2 Flash Commands

The following table summarizes the function of all flash commands. If the program flash, data flash, or FlexRAM column is marked with an 'X', the flash command is relevant to that particular memory resource.

Functional Description

| FCMD | Command | Program flash 0 | Program flash 1 (Devices with only program flash) | Data flash (Devices with FlexNVM) | FlexRAM (Devices with FlexNVM) | Function |
|------|--------------------|-----------------|--|--------------------------------------|-----------------------------------|---|
| 0x00 | Read 1s Block | x | x | x | | Verify that a program flash or data flash block is erased. FlexNVM block must not be partitioned for EEPROM. |
| 0x01 | Read 1s Section | x | x | x | | Verify that a given number of program flash or data flash locations from a starting address are erased. |
| 0x02 | Program Check | x | x | x | | Tests previously-programmed locations at margin read levels. |
| 0x03 | Read Resource | IFR, ID | IFR | IFR | | Read 4 bytes from program flash IFR, data flash IFR, or version ID. |
| 0x06 | Program Longword | x | x | x | | Program 4 bytes in a program flash block or a data flash block. |
| 0x08 | Erase Flash Block | x | x | x | | Erase a program flash block or data flash block. An erase of any flash block is only possible when unprotected. FlexNVM block must not be partitioned for EEPROM. |
| 0x09 | Erase Flash Sector | x | x | x | | Erase all bytes in a program flash or data flash sector. |

Table continues on the next page...

| FCMD | Command | Program flash 0 | Program flash 1 (Devices with only program flash) | Data flash (Devices with FlexNVM) | FlexRAM (Devices with FlexNVM) | Function |
|------|--------------------|-----------------|--|--------------------------------------|-----------------------------------|--|
| 0x0B | Program Section | x | x | x | x | Program data from the Section Program Buffer to a program flash or data flash block. |
| 0x40 | Read 1s All Blocks | x | x | x | | Verify that all program flash, data flash blocks, EEPROM backup data records, and data flash IFR are erased then release MCU security. |
| 0x41 | Read Once | IFR | | | | Read 4 bytes of a dedicated 64 byte field in the program flash 0 IFR. |
| 0x43 | Program Once | IFR | | | | One-time program of 4 bytes of a dedicated 64-byte field in the program flash 0 IFR. |

Table continues on the next page...

Functional Description

| FCMD | Command | Program flash 0 | Program flash 1 (Devices with only program flash) | Data flash (Devices with FlexNVM) | FlexRAM (Devices with FlexNVM) | Function |
|------|----------------------------|-----------------|--|--------------------------------------|-----------------------------------|--|
| 0x44 | Erase All Blocks | x | x | x | x | Erase all program flash blocks, program flash swap IFR, data flash blocks, FlexRAM, EEPROM backup data records, and data flash IFR. Then, verify-erase and release MCU security. NOTE: An erase is only possible when all memory locations are unprotected. |
| 0x45 | Verify Backdoor Access Key | x | x | | | Release MCU security after comparing a set of user-supplied security keys to those stored in the program flash. |
| 0x46 | Swap Control | x | x | | | Handles swap-related activities |
| 0x80 | Program Partition | | | IFR | x | Program the FlexNVM Partition Code and EEPROM Data Set Size into the data flash IFR. Format all EEPROM backup data sectors allocated for EEPROM. Initialize the FlexRAM. |

Table continues on the next page...

| FCMD | Command | Program flash 0 | Program flash 1 (Devices with only program flash) | Data flash (Devices with FlexNVM) | FlexRAM (Devices with FlexNVM) | Function |
|------|----------------------|-----------------|--|--------------------------------------|-----------------------------------|---|
| 0x81 | Set FlexRAM Function | | | x | x | Switches FlexRAM function between RAM and EEPROM. When switching to EEPROM, FlexNVM is not available while valid data records are being copied from EEPROM backup to FlexRAM. |

NOTE

FlexRAM, or Programming Acceleration RAM, is used during PGMSEC command.

28.4.10.3 Flash Commands by Mode

The following table shows the flash commands that can be executed in each flash operating mode.

Table 28-31. Flash Commands by Mode

| FCMD | Command | NVM Normal | | | NVM Special | | |
|------|--------------------|------------|--------|---------|-------------|--------|---------|
| | | Unsecure | Secure | MEEN=10 | Unsecure | Secure | MEEN=10 |
| 0x00 | Read 1s Block | x | x | x | x | — | — |
| 0x01 | Read 1s Section | x | x | x | x | — | — |
| 0x02 | Program Check | x | x | x | x | — | — |
| 0x03 | Read Resource | x | x | x | x | — | — |
| 0x06 | Program Longword | x | x | x | x | — | — |
| 0x08 | Erase Flash Block | x | x | x | x | — | — |
| 0x09 | Erase Flash Sector | x | x | x | x | — | — |
| 0x0B | Program Section | x | x | x | x | — | — |
| 0x40 | Read 1s All Blocks | x | x | x | x | x | — |
| 0x41 | Read Once | x | x | x | x | — | — |
| 0x43 | Program Once | x | x | x | x | — | — |

Table continues on the next page...

Table 28-31. Flash Commands by Mode (continued)

| FCMD | Command | NVM Normal | | | NVM Special | | |
|------|----------------------------|------------|--------|---------|-------------|--------|---------|
| | | Unsecure | Secure | MEEN=10 | Unsecure | Secure | MEEN=10 |
| 0x44 | Erase All Blocks | × | × | × | × | × | — |
| 0x45 | Verify Backdoor Access Key | × | × | × | × | — | — |
| 0x46 | Swap Control | × | × | × | × | — | — |
| 0x80 | Program Partition | × | × | × | × | — | — |
| 0x81 | Set FlexRAM Function | × | × | × | × | — | — |

28.4.10.4 Allowed Simultaneous Flash Operations

Only the operations marked 'OK' in the following table are permitted to run simultaneously on the program flash, data flash, and FlexRAM memories. Some operations cannot be executed simultaneously because certain hardware resources are shared by the memories. The priority has been placed on permitting program flash reads while program and erase operations execute on the FlexNVM and FlexRAM. This provides read (program flash) while write (FlexNVM, FlexRAM) functionality.

For devices containing FlexNVM:

Table 28-32. Allowed Simultaneous Memory Operations

| | | Program Flash | | | Data Flash | | | FlexRAM | | |
|---------------|----------------------|---------------|---------|--------------|------------|---------|--------------|---------|----------------------|----------------------|
| | | Read | Program | Sector Erase | Read | Program | Sector Erase | Read | E-Write ¹ | R-Write ² |
| Program flash | Read | — | | | | OK | OK | | OK | |
| | Program | | — | | OK | | | OK | | OK ³ |
| | Sector Erase | | | — | OK | | | OK | | OK |
| Data flash | Read | | OK | OK | — | | | | | |
| | Program | OK | | | | — | | OK | | OK |
| | Sector Erase | OK | | | | | — | OK | | OK |
| FlexRAM | Read | | OK | OK | | OK | OK | — | | |
| | E-Write ¹ | OK | | | | | | | — | |
| | R-Write ² | | OK | OK | | OK | OK | | | — |

1. When FlexRAM configured for EEPROM (writes are effectively multi-cycle operations).

2. When FlexRAM configured as traditional RAM (writes are single-cycle operations).

3. When FlexRAM configured as traditional RAM, writes to the RAM are ignored while the Program Section command is active (CCIF = 0).

For devices containing program flash only:

Table 28-33. Allowed Simultaneous Memory Operations

| | | Program Flash 0 | | | Program Flash 1 | | |
|-----------------|--------------|-----------------|---------|--------------|-----------------|---------|--------------|
| | | Read | Program | Sector Erase | Read | Program | Sector Erase |
| Program flash 0 | Read | — | | | | OK | OK |
| | Program | | — | | OK | | |
| | Sector Erase | | | — | OK | | |
| Program flash 1 | Read | | OK | OK | — | | |
| | Program | OK | | | | — | |
| | Sector Erase | OK | | | | | — |

28.4.11 Margin Read Commands

The Read-1s commands (Read 1s All Blocks, Read 1s Block, and Read 1s Section) and the Program Check command have a margin choice parameter that allows the user to apply non-standard read reference levels to the program flash and data flash array reads performed by these commands.

Using the preset 'user' and 'factory' margin levels, these commands perform their associated read operations at tighter tolerances than a 'normal' read. These non-standard read levels are applied only during the command execution. All simple (uncommanded) flash array reads to the MCU always use the standard, un-margined, read reference level.

Only the 'normal' read level should be employed during normal flash usage. The non-standard, 'user' and 'factory' margin levels should be employed only in special cases. They can be used during special diagnostic routines to gain confidence that the device is not suffering from the end-of-life data loss customary of flash memory devices.

Erased ('1') and programmed ('0') bit states can degrade due to elapsed time and data cycling (number of times a bit is erased and re-programmed). The lifetime of the erased states is relative to the last erase operation. The lifetime of the programmed states is measured from the last program time.

The 'user' and 'factory' levels become, in effect, a minimum safety margin; i.e. if the reads pass at the tighter tolerances of the 'user' and 'factory' margins, then the 'normal' reads have at least this much safety margin before they experience data loss.

The 'user' margin is a small delta to the normal read reference level. 'User' margin levels can be employed to check that flash memory contents have adequate margin for normal level read operations. If unexpected read results are encountered when checking flash memory contents at the 'user' margin levels, loss of information might soon occur during 'normal' readout.

The 'factory' margin is a bigger deviation from the norm, a more stringent read criteria that should only be attempted immediately (or very soon) after completion of an erase or program command, early in the cycling life. 'Factory' margin levels can be used to check that flash memory contents have adequate margin for long-term data retention at the normal level setting. If unexpected results are encountered when checking flash memory contents at 'factory' margin levels, the flash memory contents should be erased and reprogrammed.

CAUTION

Factory margin levels must only be used during verify of the initial factory programming.

28.4.12 Flash Command Description

This section describes all flash commands that can be launched by a command write sequence.

The flash memory module sets the FSTAT[ACCERR] bit and aborts the command execution if any of the following illegal conditions occur:

- There is an unrecognized command code in the FCCOB FCMD field.
- There is an error in a FCCOB field for the specific commands. Refer to the error handling table provided for each command.

Ensure that FSTAT[ACCERR] and FSTAT[FPVIOL] are cleared prior to starting the command write sequence. As described in [Launch the Command by Clearing CCIF](#), a new command cannot be launched while these error flags are set.

Do not attempt to read a flash block while the flash memory module is running a command (FSTAT[CCIF] = 0) on that same block. The flash memory module may return invalid data to the MCU with the collision error flag (FSTAT[RDCOLERR]) set.

When required by the command, address bit 23 selects between:

- program flash (=0)
- data flash (=1)

CAUTION

Flash data must be in the erased state before being programmed. Cumulative programming of bits (adding more zeros) is not allowed.

28.4.12.1 Read 1s Block Command

The Read 1s Block command checks to see if an entire program flash or data flash block has been erased to the specified margin level. The FCCOB flash address bits determine which flash block is erase-verified.

Table 28-34. Read 1s Block Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|--|
| 0 | 0x00 (RD1BLK) |
| 1 | Flash address [23:16] in the flash block to be verified |
| 2 | Flash address [15:8] in the flash block to be verified |
| 3 | Flash address [7:0] ¹ in the flash block to be verified |
| 4 | Read-1 Margin Choice |

1. Must be longword aligned (Flash address [1:0] = 00).

After clearing CCIF to launch the Read 1s Block command, the flash memory module sets the read margin for 1s according to [Table 28-35](#) and then reads all locations within the selected program flash or data flash block.

When the data flash is targeted, DEPART must be set for no EEPROM, else the Read 1s Block command aborts setting the FSTAT[ACCERR] bit. If the flash memory module fails to read all 1s (i.e. the flash block is not fully erased), the FSTAT[MGSTAT0] bit is set. The CCIF flag sets after the Read 1s Block operation has completed.

Table 28-35. Margin Level Choices for Read 1s Block

| Read Margin Choice | Margin Level Description |
|--------------------|---|
| 0x00 | Use the 'normal' read level for 1s |
| 0x01 | Apply the 'User' margin to the normal read-1 level |
| 0x02 | Apply the 'Factory' margin to the normal read-1 level |

Table 28-36. Read 1s Block Command Error Handling

| Error Condition | Error Bit |
|---|----------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| An invalid margin choice is specified | FSTAT[ACCERR] |
| Program flash is selected and the address is out of program flash range | FSTAT[ACCERR] |
| Data flash is selected and the address is out of data flash range | FSTAT[ACCERR] |
| Data flash is selected with EEPROM enabled | FSTAT[ACCERR] |
| Flash address is not longword aligned | FSTAT[ACCERR] |
| Read-1s fails | FSTAT[MGSTAT0] |

28.4.12.2 Read 1s Section Command

The Read 1s Section command checks if a section of program flash or data flash memory is erased to the specified read margin level. The Read 1s Section command defines the starting address and the number of phrases to be verified.

Table 28-37. Read 1s Section Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|---|
| 0 | 0x01 (RD1SEC) |
| 1 | Flash address [23:16] of the first phrase to be verified |
| 2 | Flash address [15:8] of the first phrase to be verified |
| 3 | Flash address [7:0] ¹ of the first phrase to be verified |
| 4 | Number of phrases to be verified [15:8] |
| 5 | Number of phrases to be verified [7:0] |
| 6 | Read-1 Margin Choice |

1. Must be phrase aligned (Flash address [2:0] = 000).

Upon clearing CCIF to launch the Read 1s Section command, the flash memory module sets the read margin for 1s according to [Table 28-38](#) and then reads all locations within the specified section of flash memory. If the flash memory module fails to read all 1s (that is, the flash section is not erased), FSTAT[MGSTAT0] is set. FSTAT[CCIF] sets after the Read 1s Section operation completes.

Table 28-38. Margin Level Choices for Read 1s Section

| Read Margin Choice | Margin Level Description |
|--------------------|---|
| 0x00 | Use the 'normal' read level for 1s |
| 0x01 | Apply the 'User' margin to the normal read-1 level |
| 0x02 | Apply the 'Factory' margin to the normal read-1 level |

Table 28-39. Read 1s Section Command Error Handling

| Error condition | Error bit |
|---|----------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| An invalid margin code is supplied. | FSTAT[ACCERR] |
| An invalid flash address is supplied. | FSTAT[ACCERR] |
| Flash address is not phrase aligned. | FSTAT[ACCERR] |
| The requested section crosses a Flash block boundary. | FSTAT[ACCERR] |
| The requested number of phrases is 0. | FSTAT[ACCERR] |
| Read-1s fails. | FSTAT[MGSTAT0] |

28.4.12.3 Program Check Command

The Program Check command tests a previously programmed program flash or data flash longword to see if it reads correctly at the specified margin level.

Table 28-40. Program Check Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|----------------------------------|
| 0 | 0x02 (PGMCHK) |
| 1 | Flash address [23:16] |
| 2 | Flash address [15:8] |
| 3 | Flash address [7:0] ¹ |
| 4 | Margin Choice |
| 8 | Byte 0 expected data |
| 9 | Byte 1 expected data |
| A | Byte 2 expected data |
| B | Byte 3 expected data |

1. Must be longword aligned (Flash address [1:0] = 00).

Upon clearing CCIF to launch the Program Check command, the flash memory module sets the read margin for 1s according to [Table 28-41](#), reads the specified longword, and compares the actual read data to the expected data provided by the FCCOB. If the comparison at margin-1 fails, FSTAT[MGSTAT0] is set.

The flash memory module then sets the read margin for 0s, re-reads, and compares again. If the comparison at margin-0 fails, FSTAT[MGSTAT0] is set. FSTAT[CCIF] is set after the Program Check operation completes.

The supplied address must be longword aligned (the lowest two bits of the byte address must be 00):

- Byte 3 data is written to the supplied byte address ('start'),
- Byte 2 data is programmed to byte address start+0b01,
- Byte 1 data is programmed to byte address start+0b10,
- Byte 0 data is programmed to byte address start+0b11.

NOTE

See the description of margin reads, [Margin Read Commands](#)

Table 28-41. Margin Level Choices for Program Check

| Read Margin Choice | Margin Level Description |
|--------------------|---|
| 0x01 | Read at 'User' margin-1 and 'User' margin-0 |
| 0x02 | Read at 'Factory' margin-1 and 'Factory' margin-0 |

Table 28-42. Program Check Command Error Handling

| Error Condition | Error Bit |
|---|----------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| An invalid flash address is supplied | FSTAT[ACCERR] |
| Flash address is not longword aligned | FSTAT[ACCERR] |
| An invalid margin choice is supplied | FSTAT[ACCERR] |
| Either of the margin reads does not match the expected data | FSTAT[MGSTAT0] |

28.4.12.4 Read Resource Command

The Read Resource command allows the user to read data from special-purpose memory resources located within the flash memory module. The special-purpose memory resources available include program flash IFR space, data flash IFR space, and the Version ID field. Each resource is assigned a select code as shown in [Table 28-44](#).

Table 28-43. Read Resource Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|----------------------|---|
| 0 | 0x03 (RDRSRC) |
| 1 | Flash address [23:16] |
| 2 | Flash address [15:8] |
| 3 | Flash address [7:0] ¹ |
| Returned Values | |
| 4 | Read Data [31:24] |
| 5 | Read Data [23:16] |
| 6 | Read Data [15:8] |
| 7 | Read Data [7:0] |
| User-provided values | |
| 8 | Resource Select Code (see Table 28-44) |

1. Must be longword aligned (Flash address [1:0] = 00).

Table 28-44. Read Resource Select Codes

| Resource Select Code | Description | Resource Size | Local Address Range |
|----------------------|---------------------|---------------|---------------------|
| 0x00 | Program Flash 0 IFR | 256 Bytes | 0x00_0000–0x00_00FF |

Table continues on the next page...

Table 28-44. Read Resource Select Codes (continued)

| Resource Select Code | Description | Resource Size | Local Address Range |
|----------------------|-------------------------------------|---------------|--|
| 0x00 | Program Flash Swap IFR ¹ | 256 Bytes | 0x02_0000 - 0x02_00FF (512 KB of program flash) 0x01_0000 - 0x01_00FF (256 KB of program flash) 0x00_8000 - 0x00_80FF (128 KB of program flash) |
| 0x00 | Data Flash 0 IFR ² | 256 Bytes | 0x80_0000 - 0x80_00FF |
| 0x01 ³ | Version ID | 8 Bytes | 0x00_0000–0x00_0007 |

1. This is for devices with program flash only.
2. This is for devices with FlexNVM.
3. Located in program flash 0 reserved space.

After clearing CCIF to launch the Read Resource command, four consecutive bytes are read from the selected resource at the provided relative address and stored in the FCCOB register. The CCIF flag sets after the Read Resource operation completes. The Read Resource command exits with an access error if an invalid resource code is provided or if the address for the applicable area is out-of-range.

Table 28-45. Read Resource Command Error Handling

| Error Condition | Error Bit |
|--|---------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| An invalid resource code is entered | FSTAT[ACCERR] |
| Flash address is out-of-range for the targeted resource. | FSTAT[ACCERR] |
| Flash address is not longword aligned | FSTAT[ACCERR] |

28.4.12.5 Program Longword Command

The Program Longword command programs four previously-erased bytes in the program flash memory or in the data flash memory using an embedded algorithm.

CAUTION

A flash memory location must be in the erased state before being programmed. Cumulative programming of bits (back-to-back program operations without an intervening erase) within a flash memory location is not allowed. Re-programming of existing 0s to 0 is not allowed as this overstresses the device.

Table 28-46. Program Longword Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|----------------------------------|
| 0 | 0x06 (PGM4) |
| 1 | Flash address [23:16] |
| 2 | Flash address [15:8] |
| 3 | Flash address [7:0] ¹ |
| 4 | Byte 0 program value |
| 5 | Byte 1 program value |
| 6 | Byte 2 program value |
| 7 | Byte 3 program value |

1. Must be longword aligned (Flash address [1:0] = 00).

Upon clearing CCIF to launch the Program Longword command, the flash memory module programs the data bytes into the flash using the supplied address. The swap indicator address in each program flash block is implicitly protected from programming. The targeted flash locations must be currently unprotected (see the description of the FPROT and FDPROT registers) to permit execution of the Program Longword operation.

The programming operation is unidirectional. It can only move NVM bits from the erased state ('1') to the programmed state ('0'). Erased bits that fail to program to the '0' state are flagged as errors in FSTAT[MGSTAT0]. The CCIF flag is set after the Program Longword operation completes.

The supplied address must be longword aligned (flash address [1:0] = 00):

- Byte 3 data is written to the supplied byte address ('start'),
- Byte 2 data is programmed to byte address start+0b01,
- Byte 1 data is programmed to byte address start+0b10, and
- Byte 0 data is programmed to byte address start+0b11.

Table 28-47. Program Longword Command Error Handling

| Error Condition | Error Bit |
|--|----------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| An invalid flash address is supplied | FSTAT[ACCERR] |
| Flash address is not longword aligned | FSTAT[ACCERR] |
| Flash address points to a protected area | FSTAT[FPVIOL] |
| Any errors have been encountered during the verify operation | FSTAT[MGSTAT0] |

28.4.12.6 Erase Flash Block Command

The Erase Flash Block operation erases all addresses in a single program flash or data flash block.

Table 28-48. Erase Flash Block Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|--|
| 0 | 0x08 (ERSBLK) |
| 1 | Flash address [23:16] in the flash block to be erased |
| 2 | Flash address [15:8] in the flash block to be erased |
| 3 | Flash address [7:0] ¹ in the flash block to be erased |

1. Must be longword aligned (Flash address [1:0] = 00).

Upon clearing CCIF to launch the Erase Flash Block command, the flash memory module erases the main array of the selected flash block and verifies that it is erased. When the data flash is targeted, DEPART must be set for no EEPROM (see [Table 28-4](#)) else the Erase Flash Block command aborts setting the FSTAT[ACCERR] bit. The Erase Flash Block command aborts and sets the FSTAT[FPVIOL] bit if any region within the block is protected (see the description of the FPROT and FDPROT registers). The swap indicator address in each program flash block is implicitly protected from block erase unless the swap system is in the UPDATE or UPDATE-ERASED state and the program flash block being erased is the non-active block. If the erase verify fails, FSTAT[MGSTAT0] is set. The CCIF flag will set after the Erase Flash Block operation has completed.

Table 28-49. Erase Flash Block Command Error Handling

| Error Condition | Error Bit |
|---|----------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| Program flash is selected and the address is out of program flash range | FSTAT[ACCERR] |
| Data flash is selected and the address is out of data flash range | FSTAT[ACCERR] |
| Data flash is selected with EEPROM enabled | FSTAT[ACCERR] |
| Flash address is not longword aligned | FSTAT[ACCERR] |
| Any area of the selected flash block is protected | FSTAT[FPVIOL] |
| Any errors have been encountered during the verify operation ¹ | FSTAT[MGSTAT0] |

1. User margin read may be run using the Read 1s Block command to verify all bits are erased.

28.4.12.7 Erase Flash Sector Command

The Erase Flash Sector operation erases all addresses in a flash sector.

Table 28-50. Erase Flash Sector Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|---|
| 0 | 0x09 (ERSSCR) |
| 1 | Flash address [23:16] in the flash sector to be erased |
| 2 | Flash address [15:8] in the flash sector to be erased |
| 3 | Flash address [7:0] ¹ in the flash sector to be erased |

1. Must be phrase aligned (flash address [2:0] = 000).

After clearing CCIF to launch the Erase Flash Sector command, the flash memory module erases the selected program flash or data flash sector and then verifies that it is erased. The Erase Flash Sector command aborts if the selected sector is protected (see the description of the FPROT and FDPROT registers). The swap indicator address in each program flash block is implicitly protected from sector erase unless the swap system is in the UPDATE or UPDATE-ERASED state and the program flash sector containing the swap indicator address being erased is the non-active block. If the erase-verify fails the FSTAT[MGSTAT0] bit is set. The CCIF flag is set after the Erase Flash Sector operation completes. The Erase Flash Sector command is suspendable (see the FCNFG[ERSSUSP] bit and [Figure 28-34](#)).

Table 28-51. Erase Flash Sector Command Error Handling

| Error Condition | Error Bit |
|---|----------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| An invalid Flash address is supplied | FSTAT[ACCERR] |
| Flash address is not phrase aligned | FSTAT[ACCERR] |
| The selected program flash or data flash sector is protected | FSTAT[FPVIOL] |
| Any errors have been encountered during the verify operation ¹ | FSTAT[MGSTAT0] |

1. User margin read may be run using the Read 1s Section command to verify all bits are erased.

28.4.12.7.1 Suspending an Erase Flash Sector Operation

To suspend an Erase Flash Sector operation set the FCNFG[ERSSUSP] bit (see [Flash Configuration Field Description](#)) when CCIF is clear and the CCOB command field holds the code for the Erase Flash Sector command. During the Erase Flash Sector operation (see [Erase Flash Sector Command](#)), the flash memory module samples the state of the ERSSUSP bit at convenient points. If the flash memory module detects that the ERSSUSP bit is set, the Erase Flash Sector operation is suspended and the flash memory module sets CCIF. While ERSSUSP is set, all writes to flash registers are ignored except for writes to the FSTAT and FCNFG registers.

If an Erase Flash Sector operation effectively completes before the flash memory module detects that a suspend request has been made, the flash memory module clears the ERSSUSP bit prior to setting CCIF. When an Erase Flash Sector operation has been successfully suspended, the flash memory module sets CCIF and leaves the ERSSUSP bit set. While CCIF is set, the ERSSUSP bit can only be cleared to prevent the withdrawal of a suspend request before the flash memory module has acknowledged it.

28.4.12.7.2 Resuming a Suspended Erase Flash Sector Operation

If the ERSSUSP bit is still set when CCIF is cleared to launch the next command, the previous Erase Flash Sector operation resumes. The flash memory module acknowledges the request to resume a suspended operation by clearing the ERSSUSP bit. A new suspend request can then be made by setting ERSSUSP. A single Erase Flash Sector operation can be suspended and resumed multiple times.

There is a minimum elapsed time limit between the request to resume the Erase Flash Sector operation (CCIF is cleared) and the request to suspend the operation again (ERSSUSP is set). This minimum time period is required to ensure that the Erase Flash Sector operation will eventually complete. If the minimum period is continually violated, i.e. the suspend requests come repeatedly and too quickly, no forward progress is made by the Erase Flash Sector algorithm. The resume/suspend sequence runs indefinitely without completing the erase.

28.4.12.7.3 Aborting a Suspended Erase Flash Sector Operation

The user may choose to abort a suspended Erase Flash Sector operation by clearing the ERSSUSP bit prior to clearing CCIF for the next command launch. When a suspended operation is aborted, the flash memory module starts the new command using the new FCCOB contents.

While FCNFG[ERSSUSP] is set, a write to the FlexRAM while FCNFG[EEERDY] is set clears ERSSUSP and aborts the suspended operation. The FlexRAM write operation is executed by the flash memory module.

Note

Aborting the erase leaves the bitcells in an indeterminate, partially-erased state. Data in this sector is not reliable until a new erase command fully completes.

The following figure shows how to suspend and resume the Erase Flash Sector operation.

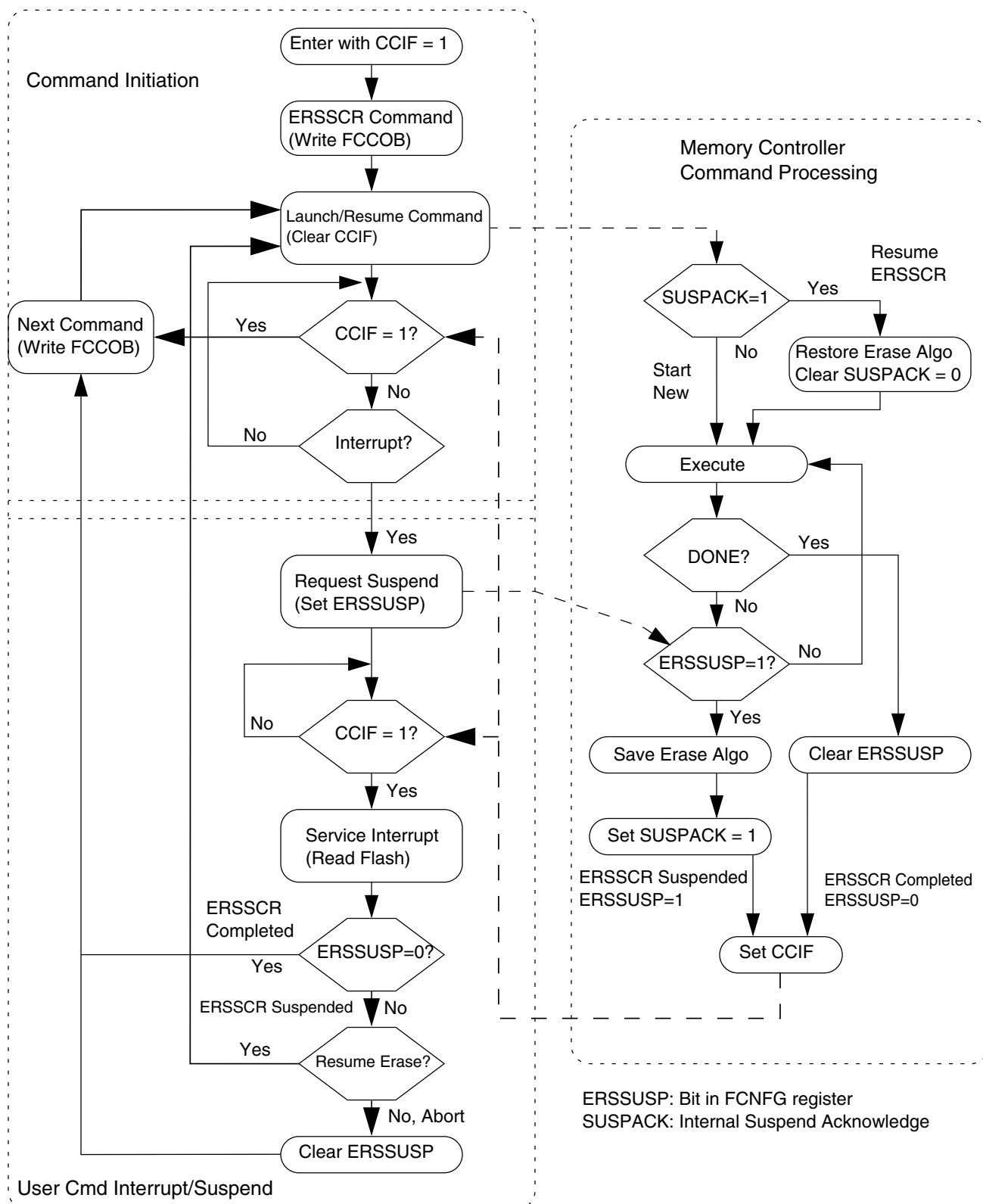


Figure 28-34. Suspend and Resume of Erase Flash Sector Operation

28.4.12.8 Program Section Command

The Program Section operation programs the data found in the section program buffer to previously erased locations in the flash memory using an embedded algorithm. Data is preloaded into the section program buffer by writing to the FlexRAM while it is set to function as traditional RAM or the programming acceleration RAM (see [Flash Sector Programming](#)).

The section program buffer is limited to the lower half of the RAM. Data written to the upper half of the RAM is ignored and may be overwritten during Program Section command execution.

CAUTION

A flash memory location must be in the erased state before being programmed. Cumulative programming of bits (back-to-back program operations without an intervening erase) within a flash memory location is not allowed. Re-programming of existing 0s to 0 is not allowed as this overstresses the device.

Table 28-52. Program Section Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|-------------------------------------|
| 0 | 0x0B (PGMSEC) |
| 1 | Flash address [23:16] |
| 2 | Flash address [15:8] |
| 3 | Flash address [7:0] ¹ |
| 4 | Number of phrases to program [15:8] |
| 5 | Number of phrases to program [7:0] |

1. Must be phrase aligned (Flash address [2:0] = 000).

After clearing CCIF to launch the Program Section command, the flash memory module blocks access to the programming acceleration RAM (program flash only devices) or FlexRAM (FlexNVM devices) and programs the data residing in the section program buffer into the flash memory starting at the flash address provided.

The starting address must be unprotected (see the description of the FPROT and FDPROT registers) to permit execution of the Program Section operation. The swap indicator address in each program flash block is implicitly protected from programming. If the swap indicator address is encountered during the Program Section operation, it is bypassed without setting FPVIOL and the contents are not programmed. Programming, which is not allowed to cross a flash sector boundary, continues until all requested phrases have been programmed. The Program Section command also verifies that after programming, all bits requested to be programmed are programmed.

After the Program Section operation completes, the CCIF flag is set and normal access to the RAM is restored. The contents of the section program buffer may be changed by the Program Section operation.

Table 28-53. Program Section Command Error Handling

| Error Condition | Error Bit |
|---|----------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| An invalid flash address is supplied | FSTAT[ACCERR] |
| Flash address is not phrase aligned | FSTAT[ACCERR] |
| The requested section crosses a program flash sector boundary | FSTAT[ACCERR] |
| The requested number of phrases is zero | FSTAT[ACCERR] |
| The space required to store data for the requested number of phrases is more than half the size of the programming acceleration RAM (program flash only devices) or FlexRAM (FlexNVM devices) | FSTAT[ACCERR] |
| The FlexRAM is not set to function as a traditional RAM, i.e. set if RAMRDY=0 | FSTAT[ACCERR] |
| The flash address falls in a protected area | FSTAT[FPVIOL] |
| Any errors have been encountered during the verify operation | FSTAT[MGSTAT0] |

28.4.12.8.1 Flash Sector Programming

The process of programming an entire flash sector using the Program Section command is as follows:

1. If required, for FlexNVM devices, execute the Set FlexRAM Function command to make the FlexRAM available as traditional RAM and initialize the FlexRAM to all ones.
2. Launch the Erase Flash Sector command to erase the flash sector to be programmed.
3. Beginning with the starting address of the programming acceleration RAM (program flash only devices) or FlexRAM (FlexNVM devices), sequentially write enough data to the RAM to fill an entire flash sector. This area of the RAM serves as the section program buffer.

NOTE

In step 1, the section program buffer was initialized to all ones, the erased state of the flash memory.

The section program buffer can be written to while the operation launched in step 2 is executing, i.e. while CCIF = 0.

4. Execute the Program Section command to program the contents of the section program buffer into the selected flash sector.
5. If a flash sector is larger than half the RAM, repeat steps 3 and 4 until the sector is completely programmed.
6. To program additional flash sectors, repeat steps 2 through 4.

7. To restore EEPROM functionality for FlexNVM devices, execute the Set FlexRAM Function command to make the FlexRAM available as EEPROM.

28.4.12.9 Read 1s All Blocks Command

The Read 1s All Blocks command checks if the program flash blocks, data flash blocks, EEPROM backup records, and data flash IFR have been erased to the specified read margin level, if applicable, and releases security if the readout passes, i.e. all data reads as '1'.

Table 28-54. Read 1s All Blocks Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|----------------------|
| 0 | 0x40 (RD1ALL) |
| 1 | Read-1 Margin Choice |

After clearing CCIF to launch the Read 1s All Blocks command, the flash memory module :

- sets the read margin for 1s according to [Table 28-55](#),
- checks the contents of the program flash, data flash, EEPROM backup records, and data flash IFR are in the erased state.

If the flash memory module confirms that these memory resources are erased, security is released by setting the FSEC[SEC] field to the unsecure state. The security byte in the flash configuration field (see [Flash Configuration Field Description](#)) remains unaffected by the Read 1s All Blocks command. If the read fails, i.e. all memory resources are not in the fully erased state, the FSTAT[MGSTAT0] bit is set.

The EEERDY and RAMRDY bits are clear during the Read 1s All Blocks operation and are restored at the end of the Read 1s All Blocks operation.

The CCIF flag sets after the Read 1s All Blocks operation has completed.

Table 28-55. Margin Level Choices for Read 1s All Blocks

| Read Margin Choice | Margin Level Description |
|--------------------|---|
| 0x00 | Use the 'normal' read level for 1s |
| 0x01 | Apply the 'User' margin to the normal read-1 level |
| 0x02 | Apply the 'Factory' margin to the normal read-1 level |

Table 28-56. Read 1s All Blocks Command Error Handling

| Error Condition | Error Bit |
|---------------------------------------|----------------|
| An invalid margin choice is specified | FSTAT[ACCERR] |
| Read-1s fails | FSTAT[MGSTAT0] |

28.4.12.10 Read Once Command

The Read Once command provides read access to special 64-byte fields located in the program flash 0 IFR (see [Program Flash IFR Map](#) and [Program Once Field](#)). Access to the Program Once field is via 16 records (index values 0x00 - 0x0F), each 4 bytes long. These fields are programmed using the Program Once command described in [Program Once Command](#).

Table 28-57. Read Once Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|-----------------|---|
| 0 | 0x41 (RDONCE) |
| 1 | Program Once record index (0x00 - 0x0F) |
| 2 | Not used |
| 3 | Not used |
| Returned Values | |
| 4 | Program Once byte 0 value |
| 5 | Program Once byte 1 value |
| 6 | Program Once byte 2 value |
| 7 | Program Once byte 3 value |

After clearing CCIF to launch the Read Once command, a 4-byte Program Once record is read and stored in the FCCOB register. The CCIF flag is set after the Read Once operation completes. Valid record index values for the Read Once command range from 0x00 - 0x0F. During execution of the Read Once command, any attempt to read addresses within the program flash block containing the selected record index returns invalid data. The Read Once command can be executed any number of times.

Table 28-58. Read Once Command Error Handling

| Error Condition | Error Bit |
|--|---------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| An invalid record index is supplied | FSTAT[ACCERR] |

28.4.12.11 Program Once Command

The Program Once command enables programming to special 64-byte fields in the program flash 0 IFR (see [Program Flash IFR Map](#) and [Program Once Field](#)). Access to the Program Once field is via 16 records (index values 0x00 - 0x0F), each 4 bytes long. These records can be read using the Read Once command (see [Read Once Command](#)) or using the Read Resource command (see [Read Resource Command](#)). These records can be programmed only once since the program flash 0 IFR cannot be erased.

Table 28-59. Program Once Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|---|
| 0 | 0x43 (PGMONCE) |
| 1 | Program Once record index (0x00 - 0x0F) |
| 2 | Not Used |
| 3 | Not Used |
| 4 | Program Once byte 0 value |
| 5 | Program Once byte 1 value |
| 6 | Program Once byte 2 value |
| 7 | Program Once byte 3 value |

After clearing CCIF to launch the Program Once command, the flash memory module first verifies that the selected record is erased. If erased, then the selected record is programmed using the values provided. The Program Once command also verifies that the programmed values read back correctly. The CCIF flag is set after the Program Once operation has completed.

Any attempt to program one of these records when the existing value is not Fs (erased) is not allowed. Valid record index values for the Program Once command range from 0x00 - 0x0F. During execution of the Program Once command, any attempt to read addresses within the program flash block containing the selected record index returns invalid data.

Table 28-60. Program Once Command Error Handling

| Error Condition | Error Bit |
|---|----------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| An invalid record index is supplied | FSTAT[ACCERR] |
| The requested record has already been programmed to a non-FFFF value ¹ | FSTAT[ACCERR] |
| Any errors have been encountered during the verify operation | FSTAT[MGSTAT0] |

1. If a Program Once record is initially programmed to 0xFFFF_FFFF, the Program Once command is allowed to execute again on that same record.

28.4.12.12 Erase All Blocks Command

The Erase All Blocks operation erases all flash memory, initializes the FlexRAM, verifies all memory contents, and releases MCU security.

Table 28-61. Erase All Blocks Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|----------------------|
| 0 | 0x44 (ERSALL) |

After clearing CCIF to launch the Erase All Blocks command, the flash memory module erases all program flash memory, program flash swap IFR space, data flash memory, data flash IFR space, EEPROM backup memory, and FlexRAM, then verifies that all are erased.

If the flash memory module verifies that all flash memories and the FlexRAM were properly erased, security is released by setting the FSEC[SEC] field to the unsecure state and the FCNFG[RAMRDY] bit is set. The Erase All Blocks command aborts if any flash or FlexRAM region is protected. The swap indicator address in each program flash block is not implicitly protected from the Erase All Blocks operation. The security byte and all other contents of the flash configuration field (see [Flash Configuration Field Description](#)) are erased by the Erase All Blocks command. If the erase-verify fails, the FSTAT[MGSTAT0] bit is set. The CCIF flag is set after the Erase All Blocks operation completes.

Table 28-62. Erase All Blocks Command Error Handling

| Error Condition | Error Bit |
|--|----------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| Any region of the program flash memory, data flash memory, or FlexRAM is protected | FSTAT[FPVIOL] |
| Any errors have been encountered during the verify operation ¹ | FSTAT[MGSTAT0] |

1. User margin read may be run using the Read 1s All Blocks command to verify all bits are erased.

28.4.12.12.1 Triggering an Erase All External to the Flash Memory Module

The functionality of the Erase All BlocksErase All Blocks Unsecure command is also available in an uncommanded fashion outside of the flash memory. Refer to the device's Chip Configuration details for information on this functionality.

Before invoking the external erase all function, the FSTAT[ACCERR and PVIOL] flags must be cleared and the FCCOB0 register must not contain 0x44. When invoked, the erase-all function erases all program flash memory, program flash swap IFR space, data flash memory, data flash IFR space, EEPROM backup, and FlexRAM regardless of the protection settings or if the swap system has been initialized. If the post-erase verify

passes, the routine then releases security by setting the FSEC[SEC] field register to the unsecure state and the FCNFG[RAMRDY] bit sets. The security byte in the Flash Configuration Field is also programmed to the unsecure state. The status of the erase-all request is reflected in the FCNFG[ERSAREQ] bit. The FCNFG[ERSAREQ] bit is cleared once the operation completes and the normal FSTAT error reporting is available as described in [Erase All Blocks Command](#).

CAUTION

Since the IFR Swap Field in the program flash swap IFR containing the swap indicator address is erased during the Erase All Blocks command operation, the swap system becomes uninitialized. The Swap Control command must be run with the initialization code to set the swap indicator address and initialize the swap system.

28.4.12.13 Verify Backdoor Access Key Command

The Verify Backdoor Access Key command only executes if the mode and security conditions are satisfied (see [Flash Commands by Mode](#)). Execution of the Verify Backdoor Access Key command is further qualified by the FSEC[KEYEN] bits. The Verify Backdoor Access Key command releases security if user-supplied keys in the FCCOB match those stored in the Backdoor Comparison Key bytes of the Flash Configuration Field (see [Flash Configuration Field Description](#)). The column labelled Flash Configuration Field offset address shows the location of the matching byte in the Flash Configuration Field.

Table 28-63. Verify Backdoor Access Key Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] | Flash Configuration Field Offset Address |
|--------------|----------------------|--|
| 0 | 0x45 (VFYKEY) | |
| 1-3 | Not Used | |
| 4 | Key Byte 0 | 0x0_0000 |
| 5 | Key Byte 1 | 0x0_0001 |
| 6 | Key Byte 2 | 0x0_0002 |
| 7 | Key Byte 3 | 0x0_0003 |
| 8 | Key Byte 4 | 0x0_0004 |
| 9 | Key Byte 5 | 0x0_0005 |
| A | Key Byte 6 | 0x0_0006 |
| B | Key Byte 7 | 0x0_0007 |

Functional Description

After clearing CCIF to launch the Verify Backdoor Access Key command, the flash memory module checks the FSEC[KEYEN] bits to verify that this command is enabled. If not enabled, the flash memory module sets the FSTAT[ACCERR] bit and terminates. If the command is enabled, the flash memory module compares the key provided in FCCOB to the backdoor comparison key in the Flash Configuration Field. If the backdoor keys match, the FSEC[SEC] field is changed to the unsecure state and security is released. If the backdoor keys do not match, security is not released and all future attempts to execute the Verify Backdoor Access Key command are immediately aborted and the FSTAT[ACCERR] bit is (again) set to 1 until a reset of the flash memory module occurs. If the entire 8-byte key is all zeros or all ones, the Verify Backdoor Access Key command fails with an access error. The CCIF flag is set after the Verify Backdoor Access Key operation completes.

Table 28-64. Verify Backdoor Access Key Command Error Handling

| Error Condition | Error Bit |
|--|---------------|
| The supplied key is all-0s or all-Fs | FSTAT[ACCERR] |
| An incorrect backdoor key is supplied | FSTAT[ACCERR] |
| Backdoor key access has not been enabled (see the description of the FSEC register) | FSTAT[ACCERR] |
| This command is launched and the backdoor key has mismatched since the last power down reset | FSTAT[ACCERR] |

28.4.12.14 Swap Control Command

The Swap Control command handles specific activities associated with swapping the two logical program flash memory blocks within the memory map.

Table 28-65. Swap Control Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|-----------------|--|
| 0 | 0x46 (SWAP) |
| 1 | Flash address [23:16] |
| 2 | Flash address [15:8] |
| 3 | Flash address [7:0] ¹ |
| 4 | Swap Control Code: 0x01 - Initialize Swap System 0x02 - Set Swap in Update State 0x04 - Set Swap in Complete State 0x08 - Report Swap Status |
| Returned values | |

Table continues on the next page...

Table 28-65. Swap Control Command FCCOB Requirements (continued)

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|---|
| 5 | Current Swap State: 0x00 - Uninitialized 0x01 - Ready 0x02 - Update 0x03 - Update-Erased 0x04 - Complete |
| 6 | Current Swap Block Status: 0x00 - Program flash block 0 at 0x0_0000 0x01 - Program flash block 1 at 0x0_0000 |
| 7 | Next Swap Block Status (after any reset): 0x00 - Program flash block 0 at 0x0_0000 0x01 - Program flash block 1 at 0x0_0000 |

1. Must be phrase-aligned (Flash address [2:0] = 000).

Upon clearing CCIF to launch the Swap Control command, the flash memory module will handle swap-related activities based on the swap control code provided in FCCOB4 as follows:

- 0x01 (Initialize Swap System to UPDATE-ERASED State) - After verifying that the current swap state is UNINITIALIZED and that the flash address provided is in Program flash block 0 but not in the Flash Configuration Field, the flash address (shifted with bits[2:0] removed) will be programmed into the IFR Swap Field found in program flash swap IFR. After the swap indicator address has been programmed into the IFR Swap Field, the swap enable word will be programmed to 0x0000. After the swap enable word has been programmed, the swap indicator, located within the Program flash block 0 address provided, will be programmed to 0xFF00.
- 0x02 (Progress Swap to UPDATE State) - After verifying that the current swap state is READY and that the flash address provided matches the one stored in the IFR Swap Field, the swap indicator located within bits [15:0] of the flash address in the currently active program flash block will be programmed to 0xFF00.
- 0x04 (Progress Swap to COMPLETE State) - After verifying that the current swap state is UPDATE-ERASED and that the flash address provided matches the one stored in the IFR Swap Field, the swap indicator located within bits [15:0] of the flash address in the currently active program flash block will be programmed to 0x0000. Before executing with this swap control code, the user must erase the non-active swap indicator using the Erase Flash Block or Erase Flash Sector commands and update the application code or data as needed. The non-active swap indicator will

be checked at the erase verify level and if the check fails, the current swap state will be changed to UPDATE with FSTAT[ACCERR] set.

- 0x08 (Report Swap System Status) - After verifying that the flash address provided matches the one stored in the IFR Swap Field, the status of the swap system will be reported as follows:
 - FCCOB5 (Current Swap State) - indicates the current swap state based on the status of the swap enable word and the swap indicators. If the FSTAT[MGSTAT0] flag is set after command completion, the swap state returned was not successfully transitioned from and the appropriate swap command code must be attempted again. If the current swap state is UPDATE and the non-active swap indicator is 0xFFFF, the current swap state is changed to UPDATE-ERASED.
 - FCCOB6 (Current Swap Block Status) - indicates which program flash block is currently located at relative flash address 0x0_0000.
 - FCCOB7 (Next Swap Block Status) - indicates which program flash block will be located at relative flash address 0x0_0000 after the next reset of the flash memory module.

NOTE

It is recommended that the user execute the Swap Control command to report swap status (code 0x08) after any reset to determine if issues with the swap system were detected during the swap state determination procedure.

NOTE

It is recommended that the user write 0xFF to FCCOB5, FCCOB6, and FCCOB7 since the Swap Control command will not always return the swap state and status fields when an access error is detected.

The swap indicators are implicitly protected from being programmed during Program Longword or Program Section command operations and are implicitly unprotected during Swap Control command operations. The swap indicators are implicitly protected from being erased during Erase Flash Block and Erase Flash Sector command operations unless the swap indicator being erased is in the non-active program flash block and the swap system is in the UPDATE or UPDATE-ERASED state. Once the swap system has been initialized, the Erase All Blocks command can be used to uninitialized the swap system.

Table 28-66. Swap Control Command Error Handling

| Error Condition | Swap Control Code | Error Bit |
|--|-------------------|----------------|
| Command not available in current mode/security ¹ | All | FSTAT[ACCERR] |
| Flash address is not in program flash block 0 | All | FSTAT[ACCERR] |
| Flash address is in the Flash Configuration Field | All | FSTAT[ACCERR] |
| Flash address is not phrase aligned | All | FSTAT[ACCERR] |
| Flash address does not match the swap indicator address in the IFR | 2, 4 | FSTAT[ACCERR] |
| Swap initialize requested when swap system is not in the uninitialized state | 1 | FSTAT[ACCERR] |
| Swap update requested when swap system is not in the ready state | 2 | FSTAT[ACCERR] |
| Swap complete requested when swap system is not in the update-erased state | 4 | FSTAT[ACCERR] |
| An undefined swap control code is provided | - | FSTAT[ACCERR] |
| Any errors have been encountered during the swap determination and program-verify operations | 1, 2, 4 | FSTAT[MGSTAT0] |
| Any brownouts were detected during the swap determination procedure | 8 | FSTAT[MGSTAT0] |

1. Returned fields will not be updated, i.e. no swap state or status reporting

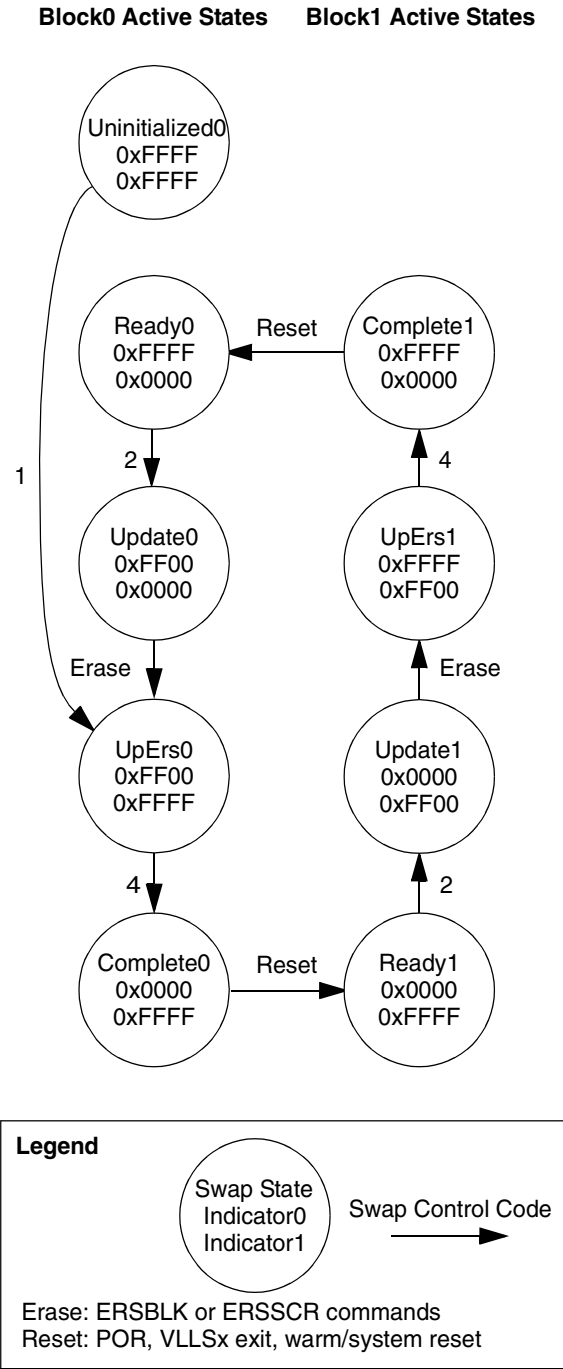


Figure 28-35. Valid Swap State Sequencing

Table 28-67. Swap State Report Mapping

| Case | Swap Enable Field ¹ | Swap Indicator 0 ¹ | Swap Indicator 1 ¹ | Swap State ² | State Code | MGST AT0 | Active Block |
|-----------------|--------------------------------|-------------------------------|-------------------------------|-------------------------|------------|----------|--------------|
| 1 | 0xFFFF | - | - | Uninitialized | 0 | 0 | 0 |
| 2 | 0x0000 | 0xFF00 | 0x0000 | Update | 2 | 0 | 0 |
| 3 | 0x0000 | 0xFF00- | 0xFFFF | Update-Erased | 3 | 0 | 0 |
| 4 | 0x0000 | 0x0000 | 0xFFFF ³ | Complete ⁴ | 4 | 0 | 0 |
| 5 | 0x0000 | 0x0000 | 0xFFFF | Ready ⁵ | 1 | 0 | 1 |
| 6 | 0x0000 | 0x0000 | 0xFF00 | Update | 2 | 0 | 1 |
| 7 | 0x0000 | 0xFFFF | 0xFF00 | Update-Erased | 3 | 0 | 1 |
| 8 | 0x0000 | 0xFFFF ³ | 0x0000 | Complete ⁴ | 4 | 0 | 1 |
| 9 | 0x0000 | 0xFFFF | 0x0000 | Ready ⁵ | 1 | 0 | 0 |
| 10 | 0XXXXX | - | - | Uninitialized | 0 | 1 | 0 |
| 11 | 0x0000 | 0xFFFF | 0xFFFF | Uninitialized | 0 | 1 | 0 |
| 12 | 0x0000 | 0xFFXX | 0xFFFF | Ready | 1 | 1 | 0 |
| 13 | 0x0000 | 0xFFXX | 0x0000 | Ready | 1 | 1 | 0 |
| 14 ⁶ | 0x0000 | 0XXXXX | 0x0000 | Ready | 1 | 1 | 0 |
| 15 ⁶ | 0x0000 | 0xFFFF | 0xFFXX | Ready | 1 | 1 | 1 |
| 16 | 0x0000 | 0x0000 | 0xFFXX | Ready | 1 | 1 | 1 |
| 17 ⁶ | 0x0000 | 0x0000 | 0XXXXX | Ready | 1 | 1 | 1 |
| 18 | 0x0000 | 0xFF00 | 0xFFFF ⁷ | Update | 2 | 1 | 0 |
| 19 | 0x0000 | 0xFF00 | 0XXXXX | Update | 2 | 1 | 0 |
| 20 | 0x0000 | 0xFF(00) | 0xFFXX | Update | 2 | 1 | 0 |
| 21 ⁶ | 0x0000 | 0x0000 | 0x0000 | Update | 2 | 1 | 0 |
| 22 ⁶ | 0x0000 | 0XXXXX | 0XXXXX | Update | 2 | 1 | 0 |
| 23 | 0x0000 | 0xFFFF ⁷ | 0xFF00 | Update | 2 | 1 | 1 |
| 24 | 0x0000 | 0XXXXX | 0xFF00 | Update | 2 | 1 | 1 |
| 25 | 0x0000 | 0xFFXX | 0xFF(00) | Update | 2 | 1 | 1 |
| 26 | 0x0000 | 0XX00 | 0xFFFF | Update-Erased | 3 | 1 | 0 |
| 27 | 0x0000 | 0XXXXX | 0xFFFF | Update-Erased | 3 | 1 | 0 |
| 28 | 0x0000 | 0xFFFF | 0XX00 | Update-Erased | 3 | 1 | 1 |
| 29 | 0x0000 | 0xFFFF | 0XXXXX | Update-Erased | 3 | 1 | 1 |

1. 0XXXXX, 0xFFXX, 0XX00 indicates a non-valid value was read; 0xFF(00) indicates more 0's than other indicator (if same number of 0's, then swap system defaults to block 0 active)
2. Cases 10-29 due to brownout (abort) detected during program or erase steps related to swap
3. Must read 0xFFFF with erase verify level before transition to Complete allowed
4. No reset since successful Swap Complete execution
5. Reset after successful Swap Complete execution
6. Not a valid case
7. Fails to read 0xFFFF at erase verify level

28.4.12.14.1 Swap State Determination

During the reset sequence, the state of the swap system is determined by evaluating the IFR Swap Field in the program flash swap IFR and the swap indicators located in each of the program flash blocks at the swap indicator address stored in the IFR Swap Field.

Table 28-68. Program Flash Swap IFR Fields

| Address Range | Size (Bytes) | Field Description |
|---------------|--------------|------------------------|
| 0x00 – 0x01 | 2 | Swap Indicator Address |
| 0x02 – 0x03 | 2 | Swap Enable Word |
| 0x04 – 0xFF | 252 | Reserved |

28.4.12.15 Program Partition Command

The Program Partition command prepares the FlexNVM block for use as data flash, EEPROM backup, or a combination of both and initializes the FlexRAM. The Program Partition command must not be launched from flash memory, since flash memory resources are not accessible during Program Partition command execution.

CAUTION

While different partitions of the FlexNVM are available, the intention is that a single partition choice is used throughout the entire lifetime of a given application. The FlexNVM Partition Code choices affect the endurance and data retention characteristics of the device.

Table 28-69. Program Partition Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|--|
| 0 | 0x80 (PGMPART) |
| 1 | Not Used |
| 2 | Not Used |
| 3 | Not Used |
| 4 | EEPROM Data Set Size Code ¹ |
| 5 | FlexNVM Partition Code ² |

1. See [Table 28-70](#) and [EEPROM Data Set Size](#)

2. See [Table 28-71](#)

Table 28-70. Valid EEPROM Data Set Size Codes

| EEPROM Data Set Size Code (FCCOB4) ¹ | | EEPROM Data Set Size (Bytes) Subsystem A + B |
|---|-----------------|---|
| FCCOB4[EEESPLIT] | FCCOB4[EEESIZE] | |
| 11 | 0xF | 0 ² |
| 00 | 0x9 | 4 + 28 |
| 01 | 0x9 | 8 + 24 |
| 10 | 0x9 | 16 + 16 |
| 11 | 0x9 | 16 + 16 |
| 00 | 0x8 | 8 + 56 |
| 01 | 0x8 | 16 + 48 |
| 10 | 0x8 | 32 + 32 |
| 11 | 0x8 | 32 + 32 |
| 00 | 0x7 | 16 + 112 |
| 01 | 0x7 | 32 + 96 |
| 10 | 0x7 | 64 + 64 |
| 11 | 0x7 | 64 + 64 |
| 00 | 0x6 | 32 + 224 |
| 01 | 0x6 | 64 + 192 |
| 10 | 0x6 | 128 + 128 |
| 11 | 0x6 | 128 + 128 |
| 00 | 0x5 | 64 + 448 |
| 01 | 0x5 | 128 + 384 |
| 10 | 0x5 | 256 + 256 |
| 11 | 0x5 | 256 + 256 |
| 00 | 0x4 | 128 + 896 |
| 01 | 0x4 | 256 + 768 |
| 10 | 0x4 | 512 + 512 |
| 11 | 0x4 | 512 + 512 |
| 00 | 0x3 | 256 + 1,792 |
| 01 | 0x3 | 512 + 1,536 |
| 10 | 0x3 | 1,024 + 1,024 |
| 11 | 0x3 | 1,024 + 1,024 |
| 00 | 0x2 | 512 + 3,584 |
| 01 | 0x2 | 1,024 + 3,072 |
| 10 | 0x2 | 2,048 + 2,048 |
| 11 | 0x2 | 2,048 + 2,048 |

1. FCCOB4[7:6] = 00

2. EEPROM Data Set Size must be set to 0 bytes when the FlexNVM Partition Code is set for no EEPROM.

Table 28-71. Valid FlexNVM Partition Codes

| FlexNVM Partition Code (FCCOB5[DEPART]) ¹ | Data flash Size (KB) | EEPROM backup Size (KB) |
|--|----------------------|-------------------------|
| 0000 | 64 | 0 |
| 0011 | 32 | 32 |
| 0100 | 0 | 64 |
| 1000 | 0 | 64 |
| 1011 | 32 | 32 |
| 1100 | 64 | 0 |

1. FCCOB5[7:4] = 0000

After clearing CCIF to launch the Program Partition command, the flash memory module first verifies that the EEPROM Data Set Size Code and FlexNVM Partition Code in the data flash IFR are erased. If erased, the Program Partition command erases the contents of the FlexNVM memory. If the FlexNVM is to be partitioned for EEPROM backup, the allocated EEPROM backup sectors are formatted for EEPROM use. Finally, the partition codes are programmed into the data flash IFR using the values provided. The Program Partition command also verifies that the partition codes read back correctly after programming. If the FlexNVM is partitioned for EEPROM backup, the EEERDY flag will set with RAMRDY clear. If the FlexNVM is not partitioned for EEPROM backup, the RAMRDY flag will set with EEERDY clear. The CCIF flag is set after the Program Partition operation completes.

Prior to launching the Program Partition command, the data flash IFR must be in an erased state, which can be accomplished by executing the Erase All Blocks command or by an external request (see [Erase All Blocks Command](#)). The EEPROM Data Set Size Code and FlexNVM Partition Code are read using the Read Resource command (see [Read Resource Command](#)).

Table 28-72. Program Partition Command Error Handling

| Error Condition | Error Bit |
|---|----------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| The EEPROM data size and FlexNVM partition code bytes are not initially 0xFFFF | FSTAT[ACCERR] |
| Invalid EEPROM Data Set Size Code is entered (see Table 28-70 for valid codes) | FSTAT[ACCERR] |
| Invalid FlexNVM Partition Code is entered (see Table 28-71 for valid codes) | FSTAT[ACCERR] |
| FlexNVM Partition Code = full data flash (no EEPROM) and EEPROM Data Set Size Code allocates FlexRAM for EEPROM | FSTAT[ACCERR] |
| FlexNVM Partition Code allocates space for EEPROM backup, but EEPROM Data Set Size Code allocates no FlexRAM for EEPROM | FSTAT[ACCERR] |
| FCCOB4[7:6] != 00 | FSTAT[ACCERR] |
| FCCOB5[7:4] != 0000 | FSTAT[ACCERR] |
| Any errors have been encountered during the verify operation | FSTAT[MGSTAT0] |

28.4.12.16 Set FlexRAM Function Command

The Set FlexRAM Function command changes the function of the FlexRAM:

- When not partitioned for EEPROM, the FlexRAM is typically used as traditional RAM.
- When partitioned for EEPROM, the FlexRAM is typically used to store EEPROM data.

Table 28-73. Set FlexRAM Function Command FCCOB Requirements

| FCCOB Number | FCCOB Contents [7:0] |
|--------------|---|
| 0 | 0x81 (SETRAM) |
| 1 | FlexRAM Function Control Code (see Table 28-74) |

Table 28-74. FlexRAM Function Control

| FlexRAM Function Control Code | Action |
|-------------------------------|--|
| 0xFF | Make FlexRAM available as RAM: <ul style="list-style-type: none"> • Clear the FCNFG[EEERDY] and FCNFG[RAMRDY] flags • Write a background of ones to all FlexRAM locations • Set the FCNFG[RAMRDY] flag |
| 0x00 | Make FlexRAM available for EEPROM: <ul style="list-style-type: none"> • Clear the FCNFG[EEERDY] and FCNFG[RAMRDY] flags • Write a background of ones to all FlexRAM locations • Copy-down existing EEPROM data to FlexRAM • Set the FCNFG[EEERDY] flag |

After clearing CCIF to launch the Set FlexRAM Function command, the flash memory module sets the function of the FlexRAM based on the FlexRAM Function Control Code.

When making the FlexRAM available as traditional RAM, the flash memory module clears the FCNFG[EEERDY] and FCNFG[RAMRDY] flags, overwrites the contents of the entire FlexRAM with a background pattern of all ones, and sets the FCNFG[RAMRDY] flag. The state of the FEPROT register does not prevent the FlexRAM from being overwritten. When the FlexRAM is set to function as a RAM, normal read and write accesses to the FlexRAM are available. When large sections of flash memory need to be programmed, e.g. during factory programming, the FlexRAM can be used as the Section Program Buffer for the Program Section command (see [Program Section Command](#)).

When making the FlexRAM available for EEPROM, the flash memory module clears the FCNFG[EEERDY] and FCNFG[RAMRDY] flags, overwrites the contents of the FlexRAM allocated for EEPROM with a background pattern of all ones, and copies the existing EEPROM data from the EEPROM backup record space to the FlexRAM. After completion of the EEPROM copy-down, the FCNFG[EEERDY] flag is set. When the FlexRAM is set to function as EEPROM, normal read and write access to the FlexRAM is available, but writes to the FlexRAM also invoke EEPROM activity. The CCIF flag is set after the Set FlexRAM Function operation completes.

Table 28-75. Set FlexRAM Function Command Error Handling

| Error Condition | Error Bit |
|--|---------------|
| Command not available in current mode/security | FSTAT[ACCERR] |
| FlexRAM Function Control Code is not defined | FSTAT[ACCERR] |
| FlexRAM Function Control Code is set to make the FlexRAM available for EEPROM, but FlexNVM is not partitioned for EEPROM | FSTAT[ACCERR] |

28.4.13 Security

The flash memory module provides security information to the MCU based on contents of the FSEC security register.

The MCU then limits access to flash memory resources as defined in the device's Chip Configuration details. During reset, the flash memory module initializes the FSEC register using data read from the security byte of the Flash Configuration Field (see [Flash Configuration Field Description](#)).

The following fields are available in the FSEC register. The settings are described in the [Flash Security Register \(FTFL_FSEC\)](#) details.

Flash security features are discussed further in [AN4507: Using the Kinetis Security and Flash Protection Features](#) . Note that not all features described in the application note are available on this device.

Table 28-76. FSEC register fields

| FSEC field | Description |
|------------|--------------------------|
| KEYEN | Backdoor Key Access |
| MEEN | Mass Erase Capability |
| FSLACC | Freescale Factory Access |
| SEC | MCU security |

28.4.13.1 Flash Memory Access by Mode and Security

The following table summarizes how access to the flash memory module is affected by security and operating mode.

Table 28-77. Flash Memory Access Summary

| Operating Mode | Chip Security State | |
|----------------|---------------------|--|
| | Unsecure | Secure |
| NVM Normal | Full command set | |
| NVM Special | Full command set | Only the Erase All Blocks and Read 1s All Blocks commands. |

28.4.13.2 Changing the Security State

The security state out of reset can be permanently changed by programming the security byte of the flash configuration field. This assumes that you are starting from a mode where the necessary program flash erase and program commands are available and that the region of the program flash containing the flash configuration field is unprotected. If the flash security byte is successfully programmed, its new value takes affect after the next chip reset.

28.4.13.2.1 Unsecuring the Chip Using Backdoor Key Access

The chip can be unsecured by using the backdoor key access feature, which requires knowledge of the contents of the 8-byte backdoor key value stored in the Flash Configuration Field (see [Flash Configuration Field Description](#)). If the FSEC[KEYEN] bits are in the enabled state, the Verify Backdoor Access Key command (see [Verify Backdoor Access Key Command](#)) can be run; it allows the user to present prospective keys for comparison to the stored keys. If the keys match, the FSEC[SEC] bits are changed to unsecure the chip. The entire 8-byte key cannot be all 0s or all 1s; that is, 0000_0000_0000_0000h and FFFF_FFFF_FFFF_FFFFh are not accepted by the Verify Backdoor Access Key command as valid comparison values. While the Verify Backdoor Access Key command is active, program flash memory is not available for read access and returns invalid data.

The user code stored in the program flash memory must have a method of receiving the backdoor keys from an external stimulus. This external stimulus would typically be through one of the on-chip serial ports.

If the KEYEN bits are in the enabled state, the chip can be unsecured by the following backdoor key access sequence:

1. Follow the command sequence for the Verify Backdoor Access Key command as explained in [Verify Backdoor Access Key Command](#)
2. If the Verify Backdoor Access Key command is successful, the chip is unsecured and the FSEC[SEC] bits are forced to the unsecure state

An illegal key provided to the Verify Backdoor Access Key command prohibits further use of the Verify Backdoor Access Key command. A reset of the chip is the only method to re-enable the Verify Backdoor Access Key command when a comparison fails.

After the backdoor keys have been correctly matched, the chip is unsecured by changing the FSEC[SEC] bits. A successful execution of the Verify Backdoor Access Key command changes the security in the FSEC register only. It does not alter the security byte or the keys stored in the Flash Configuration Field ([Flash Configuration Field Description](#)). After the next reset of the chip, the security state of the flash memory module reverts back to the flash security byte in the Flash Configuration Field. The Verify Backdoor Access Key command sequence has no effect on the program and erase protections defined in the program flash protection registers.

If the backdoor keys successfully match, the unsecured chip has full control of the contents of the Flash Configuration Field. The chip may erase the sector containing the Flash Configuration Field and reprogram the flash security byte to the unsecure state and change the backdoor keys to any desired value.

28.4.14 Reset Sequence

On each system reset the flash memory module executes a sequence which establishes initial values for the flash block configuration parameters, FPROT, FDPROT, FEPROT, FOPT, and FSEC registers and the FCNFG[SWAP, PFLSH, RAMRDY, EEERDY] bits.

FSTAT[CCIF] is cleared throughout the reset sequence. The flash memory module holds off CPU access during the reset sequence. Flash reads are possible when the hold is removed. Completion of the reset sequence is marked by setting CCIF which enables flash user commands.

If a reset occurs while any flash command is in progress, that command is immediately aborted. The state of the word being programmed or the sector/block being erased is not guaranteed. Commands and operations do not automatically resume after exiting reset.

Chapter 29

EzPort

29.1 Overview

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The EzPort module is a serial flash programming interface that enables In-System Programming (ISP) of flash memory contents in a 32-bit general-purpose microcontroller. Memory contents can be read/erased/programmed from an external source, in a format that is compatible with many standalone flash memory chips, without requiring the removal of the microcontroller from the system board.

29.1.1 Block diagram

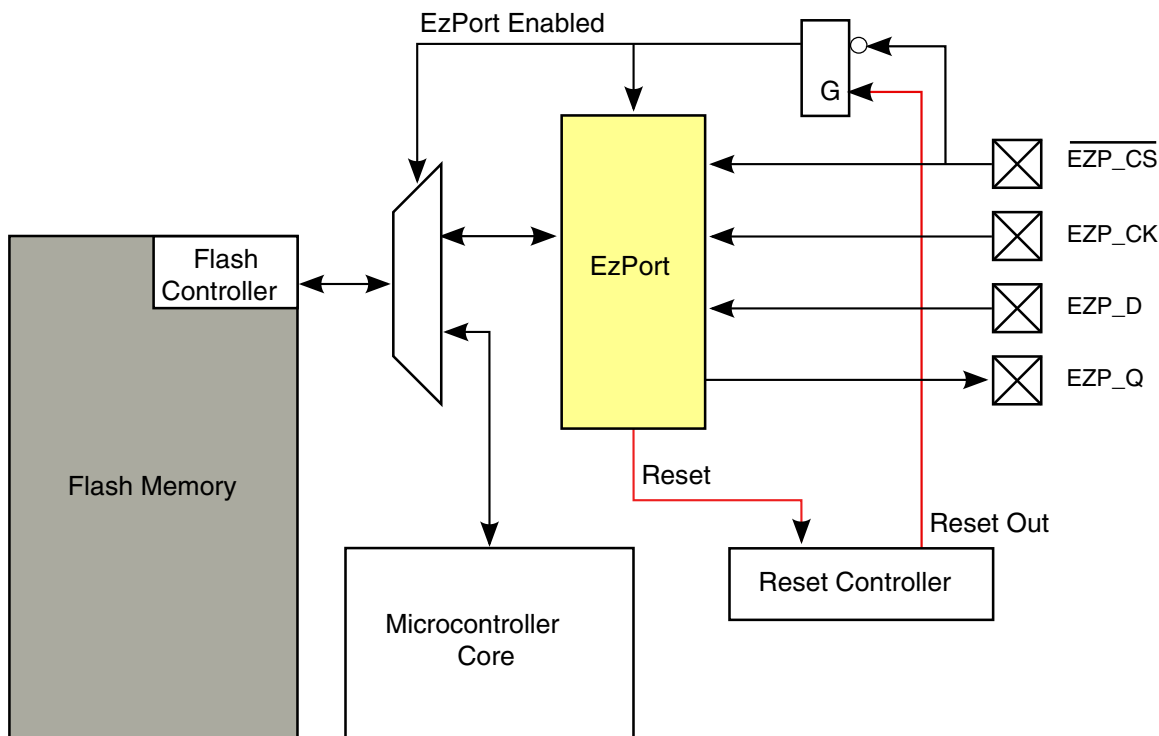


Figure 29-1. EzPort block diagram

29.1.2 Features

EzPort includes the following features:

- Serial interface that is compatible with a subset of the SPI format.
- Ability to read, erase, and program flash memory.
- Ability to reset the microcontroller, allowing it to boot from the flash memory after the memory has been configured.

29.1.3 Modes of operation

The EzPort can operate in one of two modes, enabled or disabled.

- Enabled — When enabled, the EzPort steals access to the flash memory, preventing access from other cores or peripherals. The rest of the microcontroller is disabled to avoid conflicts. The flash is configured for NVM Special mode.
- Disabled — When the EzPort is disabled, the rest of the microcontroller can access flash memory as normal.

The EzPort provides a simple interface to connect an external device to the flash memory on board a 32 bit microcontroller. The interface itself is compatible with the SPI interface, with the EzPort operating as a slave, running in either of the two following modes. The data is transmitted with the most significant bit first.

- CPOL = 0, CPHA = 0
- CPOL = 1, CPHA = 1

Commands are issued by the external device to erase, program, or read the contents of the flash memory. The serial data out from the EzPort is tri-stated unless data is being driven. This allows the signal to be shared among several different EzPort (or compatible) devices in parallel, as long as they have different chip-selects.

29.2 External signal descriptions

After the table of EzPort external signals, subsequent sections explain the signals in more detail.

Table 29-1. EzPort external signals

| JTAG (cJTAG) Signal | External Signal | Name | I/O |
|---------------------|-----------------|------------------------|--------|
| TCK (TCKC) | EZP_CK | EzPort Clock | Input |
| TMS (TMSC) | EZP_CS | EzPort Chip Select | Input |
| TDI (TDIC) | EZP_D | EzPort Serial Data In | Input |
| TDO (TDOC) | EZP_Q | EzPort Serial Data Out | Output |

29.2.1 EzPort Clock (EZP_CK)

EZP_CK is the serial clock for data transfers. The serial data in (EZP_D) and chip select (EZP_CS) are registered on the rising edge of EZP_CK, while serial data out (EZP_Q) is driven on the falling edge of EZP_CK.

The maximum frequency of the EzPort clock is half the system clock frequency for all commands, except when executing the Read Data or Read FlexRAM commands. When executing the Read Data or Read FlexRAM commands, the EzPort clock has a maximum frequency of 1/8 the system clock frequency.

29.2.2 EzPort Chip Select ($\overline{\text{EzP_CS}}$)

$\overline{\text{EzP_CS}}$ is the chip select for signaling the start and end of serial transfers. While $\overline{\text{EzP_CS}}$ is asserted, if the microcontroller's reset out signal is negated, then EzPort is enabled out of reset; otherwise EzPort is disabled. After EzPort is enabled, asserting $\overline{\text{EzP_CS}}$ starts a serial data transfer, which continues until $\overline{\text{EzP_CS}}$ is negated again. The negation of $\overline{\text{EzP_CS}}$ indicates that the current command has finished and resets the EzPort state machine, so that EzPort is ready to receive the next command.

29.2.3 EzPort Serial Data In (EzP_D)

EzP_D is the serial data in for data transfers. EzP_D is registered on the rising edge of EzP_CK . All commands, addresses, and data are shifted in most significant bit first. When the EzPort is driving output data on EzP_Q , the data shifted in EzP_D is ignored.

29.2.4 EzPort Serial Data Out (EzP_Q)

EzP_Q is the serial data out for data transfers. EzP_Q is driven on the falling edge of EzP_CK . It is tri-stated unless $\overline{\text{EzP_CS}}$ is asserted and the EzPort is driving data out. All data is shifted out most significant bit first.

29.3 Command definition

The EzPort receives commands from an external device and translates the commands into flash memory accesses. The following table lists the supported commands.

Table 29-2. EzPort commands

| Command | Description | Code | Address Bytes | Data Bytes | Accepted when secure? |
|---------|----------------------|------|---------------|------------|-----------------------|
| WREN | Write Enable | 0x06 | 0 | 0 | Yes |
| WRDI | Write Disable | 0x04 | 0 | 0 | Yes |
| RDSR | Read Status Register | 0x05 | 0 | 1 | Yes |

Table continues on the next page...

Table 29-2. EzPort commands (continued)

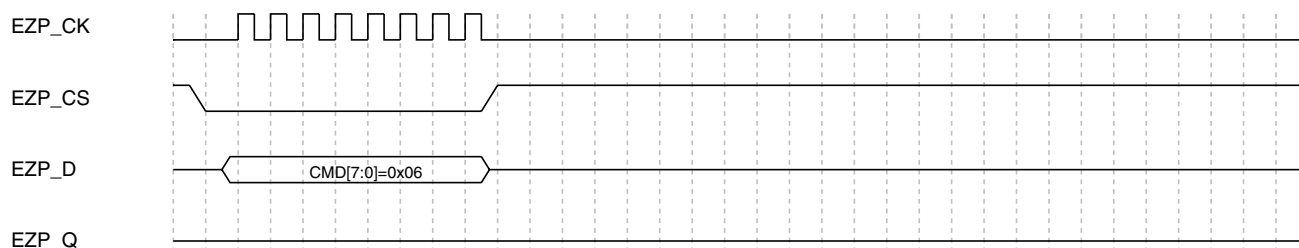
| Command | Description | Code | Address Bytes | Data Bytes | Accepted when secure? |
|-----------------|------------------------------------|------|----------------|---------------------------|-----------------------|
| READ | Flash Read Data | 0x03 | 3 ¹ | 1+ | No |
| FAST_READ | Flash Read Data at High Speed | 0x0B | 3 ¹ | 1+ ² | No |
| SP | Flash Section Program | 0x02 | 3 ³ | 48 - SECTION ⁴ | No |
| SE | Flash Sector Erase | 0xD8 | 3 ³ | 0 | No |
| BE | Flash Bulk Erase | 0xC7 | 0 | 0 | Yes ⁵ |
| RESET | Reset Chip | 0xB9 | 0 | 0 | Yes |
| WRFCCOB | Write FCCOB Registers | 0xBA | 0 | 12 | Yes ⁶ |
| FAST_RDFFCOB | Read FCCOB registers at high speed | 0xBB | 0 | 1 - 12 ² | No |
| WRFLEXRAM | Write FlexRAM | 0xBC | 3 ¹ | 4 | No |
| RDFFLEXRAM | Read FlexRAM | 0xBD | 3 ¹ | 1+ | No |
| FAST_RDFFLEXRAM | Read FlexRAM at high speed | 0xBE | 3 ¹ | 1+ ² | No |

1. Address must be 32-bit aligned (two LSBs must be zero).
2. One byte of dummy data must be shifted in before valid data is shifted out.
3. Address must be 32-bit aligned (two LSBs must be zero).64-bit aligned (three LSBs must be zero).
4. Please see the Flash Memory chapter for a definition of section size. Total number of data bytes programmed must be a multiple of 48.
5. Bulk Erase is accepted when security is set and only when the BEDIS status field is not set.
6. The flash will be in NVM Special mode, restricting the type of commands that can be executed through WRITE_FCCOB when security is enabled.

29.3.1 Command descriptions

This section describes the module commands.

29.3.1.1 Write Enable


Figure 29-2. Write Enable command sequence

Command definition

The Write Enable (WREN) command sets the write enable register field in the EzPort status register. The write enable field must be set for a write command (SP, SE, BE, WRFCCOB, or WRFLEXRAM) to be accepted. The write enable register field clears on reset, on a Write Disable command, and at the completion of write command. This command must not be used if a write is already in progress.

29.3.1.2 Write Disable

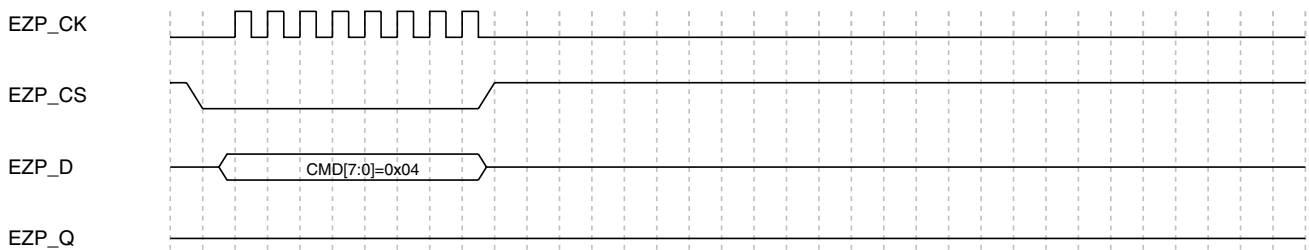


Figure 29-3. Write Disable command sequence

The Write Disable (WRDI) command clears the write enable register field in the status register. This command must not be used if a write is already in progress.

29.3.1.3 Read Status Register

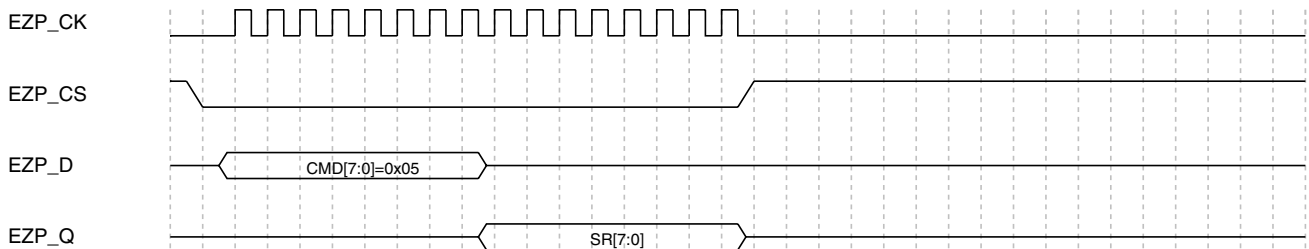


Figure 29-4. Read Status Register command sequence

The Read Status Register (RDSR) command returns the contents of the EzPort status register.

Table 29-3. EzPort status register

| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|----|-----|---|---|---------|-------|-----|-----|
| R | FS | WEF | | | FLEXRAM | BEDIS | WEN | WIP |

Table continues on the next page...

Table 29-3. EzPort status register (continued)

| W | | | | | | | | |
|--------|------------------|---|---|---|------------------|------------------|---|----------------|
| Reset: | 0/1 ¹ | 0 | 0 | 0 | 0/1 ² | 0/1 ³ | 0 | 1 ⁴ |

1. Reset value reflects the status of flash security out of reset.
2. Reset value reflects FlexNVM flash partitioning. If FlexNVM flash has been partitioned for EEPROM, this field is set immediately after reset. Note that FLEXRAM is cleared after the EzPort initialization sequence completes, as indicated by clearing of WIP.
3. Reset value reflects whether bulk erase is enabled or disabled out of reset.
4. Initial value of WIP is 1, but the value clears to 0 after EzPort initialization is complete.

Table 29-4. EzPort status register field description

| Field | Description |
|--------------|---|
| 0 WIP | Write in progress. Sets after a write command (SP, SE, BE, WRFCCOB, or WRFLEXRAM) is accepted and clears after the flash memory has completed all operations associated with the write command, as indicated by the Command Complete Interrupt Flag (CCIF) inside the flash. This field is also asserted on reset and cleared when EzPort initialization is complete. Only the Read Status Register (RDSR) command is accepted while a write is in progress. 0 = Write is not in progress. Accept any command. 1 = Write is in progress. Only accept RDSR command. |
| 1 WEN | Write enable Enables the write command that follows. It is a control field that must be set before a write command (SP, SE, BE, WRFCCOB, or WRFLEXRAM) is accepted. Is set by the Write Enable (WREN) command and cleared by reset or a Write Disable (WRDI) command. This field also clears when the flash memory has completed all operations associated with the command. 0 = Disables the following write command. 1 = Enables the following write command. |
| 2 BEDIS | Bulk erase disable Indicates whether bulk erase (BE) is disabled when flash is secure. 0 = BE is enabled. 1 = BE is disabled if FS is also set. Attempts to issue a BE command will result in the WEF flag being set. |
| 3 FLEXRAM | For devices with FlexRAM: FlexRAM mode Indicates the current mode of the FlexRAM. Valid only when WIP is cleared. 0 = FlexRAM is in RAM mode. RD/WRFLEXRAM command can be used to read/write data in FlexRAM. 1 = FlexRAM is in EEPROM mode. SP command is not accepted. RD/WRFLEXRAM command can be used to read/write data in the FlexRAM. |
| 6 WEF | Write error flag Indicates whether there has been an error while executing a write command (SP, SE, BE, WRFCCOB, or WRFLEXRAM). The WEF flag will set if Flash Access Error Flag (ACCERR), Flash Protection Violation (FPVIOL), or Memory Controller Command Completion Status (MGSTAT0) inside the flash memory is set at the completion of the write command. See the flash memory chapter for further description of these flags and their sources. The WEF flag clears after a Read Status Register (RDSR) command. 0 = No error on previous write command. 1 = Error on previous write command. |

Table continues on the next page...

Table 29-4. EzPort status register field description (continued)

| Field | Description |
|---------|---|
| 7 FS | Flash security Indicates whether the flash is secure. See Table 29-2 for the list of commands that will be accepted when flash is secure. Flash security can be disabled by performing a BE command. 0 = Flash is not secure. 1 = Flash is secure. |

29.3.1.4 Read Data

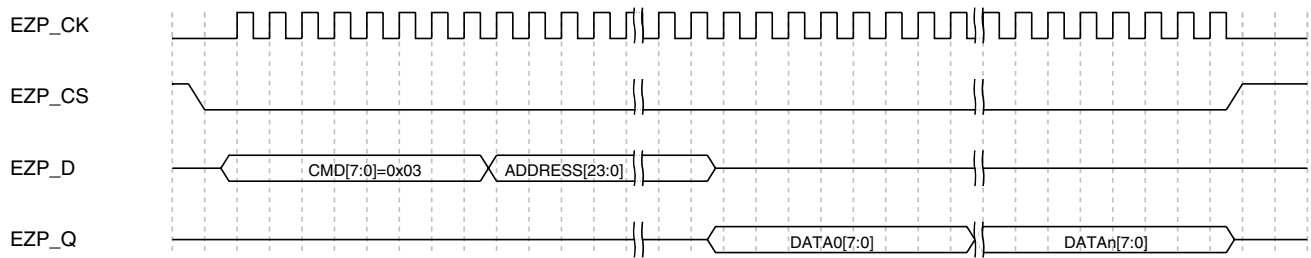


Figure 29-5. Read command sequence

The Read Data (READ) command returns data from the flash memory or FlexNVM, depending on the initial address specified in the command word. The initial address must be 32-bit aligned with the two LSBs being zero.

Data continues being returned for as long as the EzPort chip select ($\overline{\text{EZP_CS}}$) is asserted, with the address automatically incrementing. In this way, the entire contents of flash can be returned by one command. Attempts to read from an address which does not fall within the valid address range for the flash memory regions returns unknown data. See [Flash memory map for EzPort access](#).

For this command to return the correct data, the EzPort clock (EZP_CK) must run at the internal system clock divided by eight or slower. This command is not accepted if the WEF, WIP, or FS field in the EzPort status register is set.

29.3.1.5 Read Data at High Speed

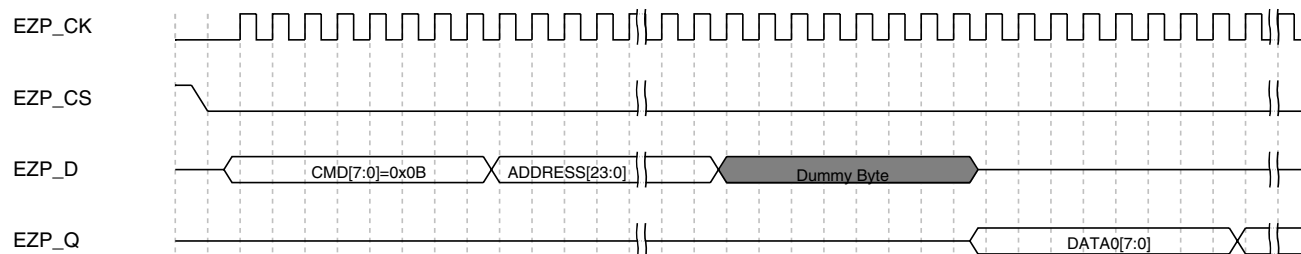


Figure 29-6. Read Data at High Speed command sequence

The Read Data at High Speed (FAST_READ) command is identical to the READ command, except for the inclusion of a dummy byte following the address bytes and before the first data byte is returned.

This command can be run with an EzPort clock (EZP_CK) frequency of half the internal system clock frequency of the microcontroller or slower. This command is not accepted if the WEF, WIP, or FS field in the EzPort status register is set.

29.3.1.6 Section Program

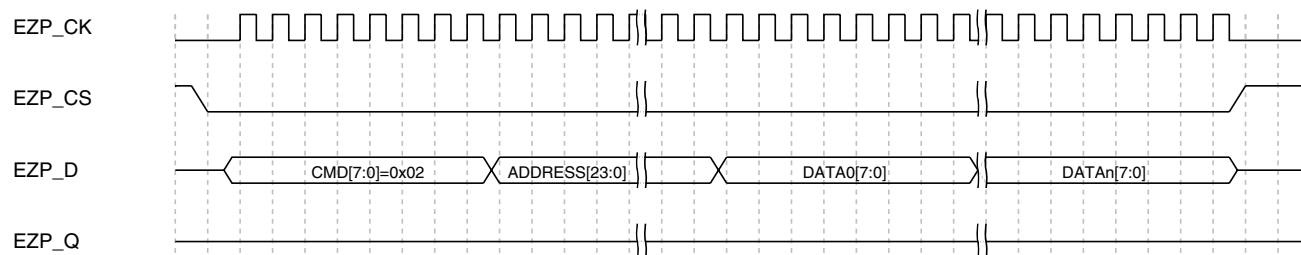


Figure 29-7. Section Program command sequence

The Section Program (SP) command programs up to one section of flash memory that has previously been erased. Please see the Flash Memory chapter for a definition of section size. The starting address of the memory to program is sent after the command word and must be a 32-bit aligned address with the two LSBs being zero. 64-bit aligned address with the three LSBs being zero.

As data is shifted in, the EzPort buffers the data in FlexRAMSystem RAM before executing an SP command within the flashsequentially moving the data into flash using the Program Longword command. For this reason, the number of bytes to be programmed must be a multiple of 48 and up to one flash section can be programmed at a time. For more details, see the Flash Memory Module.

Attempts to program more than one section, across a sector boundary or from an initial address which does not fall within the valid address range for the flash causes the WEF flag to set. See [Flash memory map for EzPort access](#).

For devices with FlexRAM: This command requires the FlexRAM to be configured for traditional RAM operation. By default, after entering EzPort mode, the FlexRAM is configured for traditional RAM operation. If the user reconfigures FlexRAM for EEPROM operation, then the user should use the WRFCCOB command to configure FlexRAM back to traditional RAM operation before issuing an SP command. See the Flash Memory chapter for details on how the FlexRAM function is modified.

This command is not accepted if the WEF, WIP, FLEXRAM, or FS field is set or if the WEN field is not set in the EzPort status register.

29.3.1.7 Sector Erase

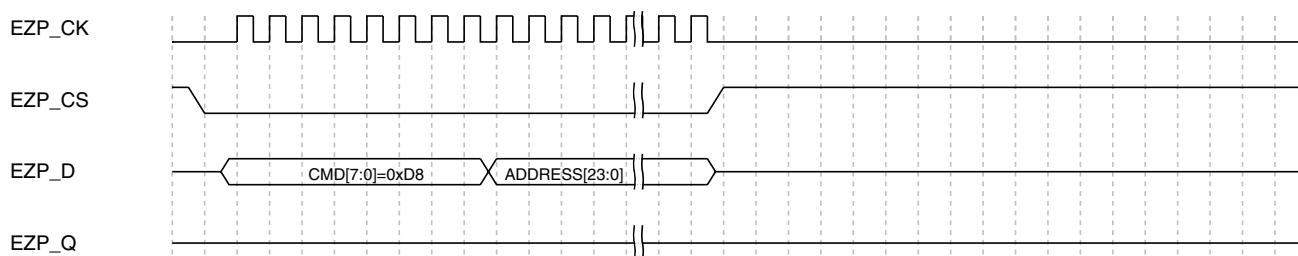


Figure 29-8. Sector Erase command sequence

The Sector Erase (SE) command erases the contents of one sector of flash memory. The three byte address sent after the command byte can be any address within the sector to erase, but must be a 64-bit aligned address (the three LSBs must be zero). Attempts to erase from an initial address which does not fall within the valid address range (see [Flash memory map for EzPort access](#)) for the flash results in the WEF flag being set.

This command is not accepted if the WEF, WIP or FS field is set or if the WEN field is not set in the EzPort status register.

29.3.1.8 Bulk Erase

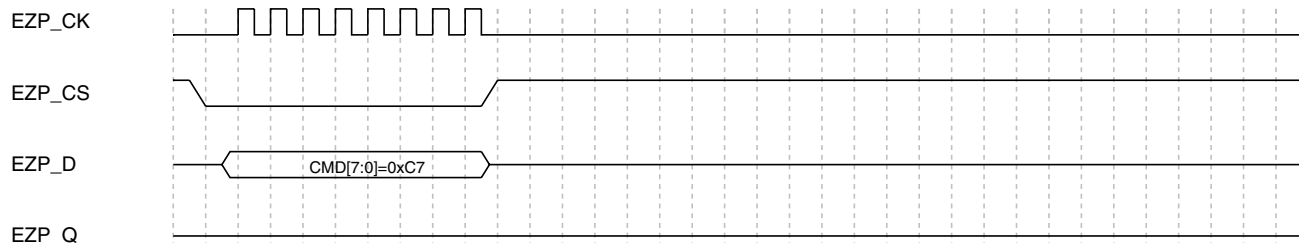


Figure 29-9. Bulk Erase command sequence

The Bulk Erase (BE) command erases the entire contents of flash memory, ignoring any protected sectors or flash security. Flash security is disabled upon successful completion of the BE command.

Attempts to issue a BE command while the BEDIS and FS fields are set results in the WEF flag being set in the EzPort status register. Also, this command is not accepted if the WEF or WIP field is set or if the WEN field is not set in the EzPort status register.

29.3.1.9 EzPort Reset Chip

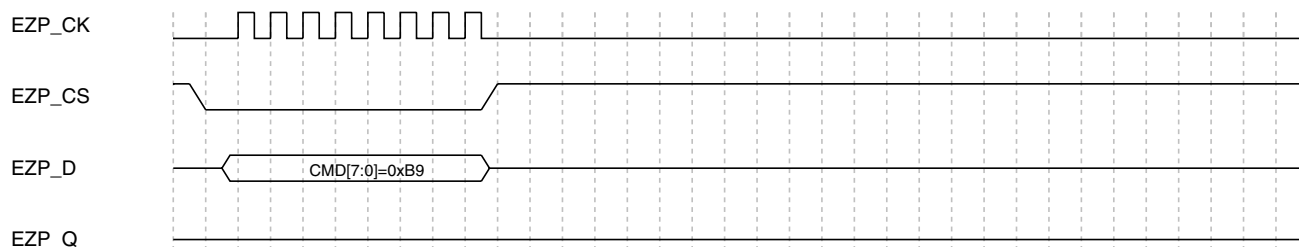


Figure 29-10. Reset Chip command sequence

The Reset Chip (RESET) command forces the chip into the reset state. If the EzPort chip select ($\overline{\text{EZP_CS}}$) pin is asserted at the end of the reset period, EzPort is enabled; otherwise, it is disabled. This command allows the chip to boot up from flash memory after being programmed by an external source.

This command is not accepted if the WIP field is set in the EzPort status register.

29.3.1.10 Write FCCOB Registers

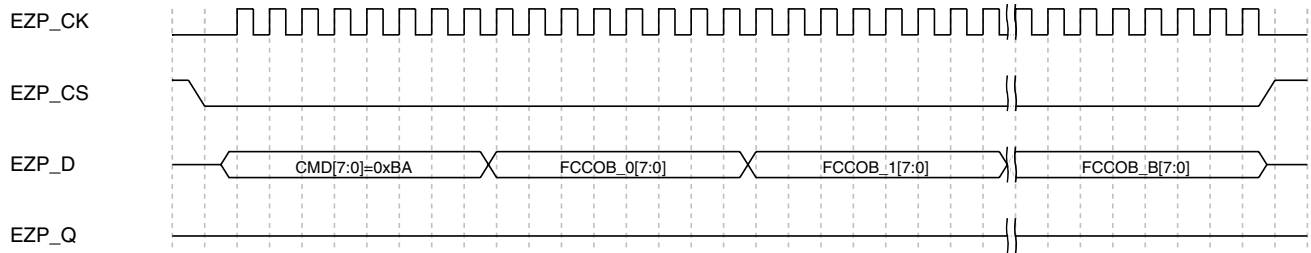


Figure 29-11. Write FCCOB Registers command sequence

The Write FCCOB Registers (WRFCCOB) command allows the user to write to the flash common command object registers and execute any command allowed by the flash.

NOTE

When security is enabled, the flash is configured in NVM Special mode, restricting the commands that can be executed by the flash.

After receiving 12 bytes of data, EzPort writes the data to the FCCOB 0-B registers in the flash and then automatically launches the command within the flash. If greater or less than 12 bytes of data is received, this command has unexpected results and may result in the WEF flag being set.

This command is not accepted if the WEF or WIP field is set or if the WEN field is not set in the EzPort status register.

29.3.1.11 Read FCCOB Registers at High Speed

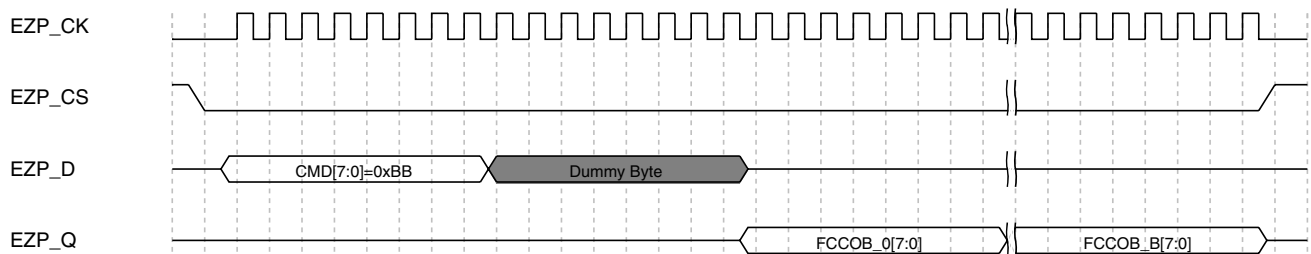


Figure 29-12. Read FCCOB Registers at High Speed command sequence

The Read FCCOB Registers at High Speed (FAST_RDFCCOB) command allows the user to read the contents of the flash common command object registers. After receiving the command, EzPort waits for one dummy byte of data before returning FCCOB register data starting at FCCOB 0 and ending with FCCOB B.

This command can be run with an EzPort clock (EZP_CK) frequency half the internal system clock frequency of the microcontroller or slower. Attempts to read greater than 12 bytes of data returns unknown data. This command is not accepted if the WEF, WIP, or FS fields in the EzPort status register are 1.

29.3.1.12 Write FlexRAM

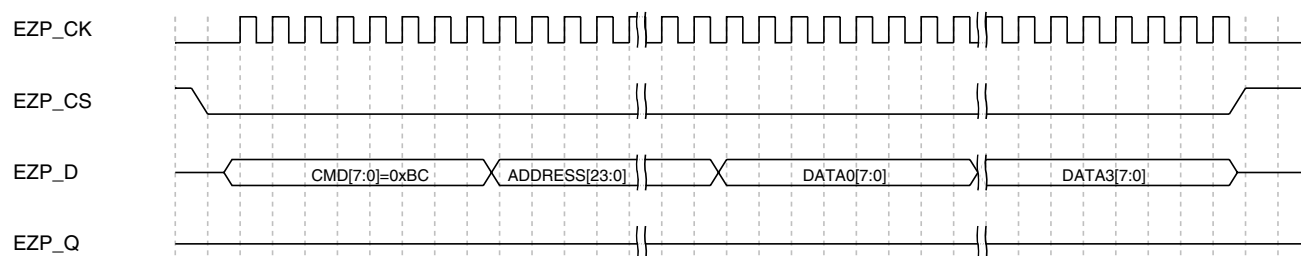


Figure 29-13. Write FlexRAM command sequence

This command is only applicable for devices with FlexRAM.

The Write FlexRAM (WRFLEXRAM) command allows the user to write four bytes of data to the FlexRAM. If the FlexRAM is configured for EEPROM operation, the WRFLEXRAM command can effectively be used to create data records in the EEPROM flash memory.

By default, after entering EzPort mode, the FlexRAM is configured for traditional RAM operation and functions as direct RAM. The user can alter the FlexRAM configuration by using WRFCCOB to execute a Set FlexRAM or Program Partition command within the flash.

The address of the FlexRAM location to be written is sent after the command word and must be a 32-bit aligned address (the two LSBs must be zero). Attempts to write an address which does not fall within the valid address range for the FlexRAM results in the value of the WEF flag being 1. See [Flash memory map for EzPort access](#) for more information.

After receiving four bytes of data, EzPort writes the data to the FlexRAM. If greater or less than four bytes of data is received, this command has unexpected results and may result in the value of the WEF flag being 1.

This command is not accepted if the WEF, WIP or FS fields are 1 or if the WEN field is 0 in the EzPort status register.

29.3.1.13 Read FlexRAM

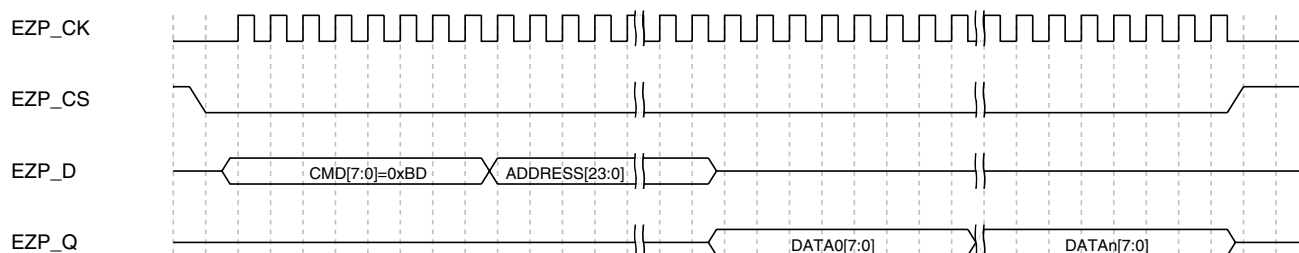


Figure 29-14. Read FlexRAM command sequence

This command is only applicable for devices with FlexRAM.

The Read FlexRAM (RDFLEXRAM) command returns data from the FlexRAM. If the FlexRAM is configured for EEPROM operation, the RDFLEXRAM command can effectively be used to read data from EEPROM flash memory.

Data continues being returned for as long as the EzPort chip select ($\overline{\text{EZP_CS}}$) is asserted, with the address automatically incrementing. In this way, the entire contents of FlexRAM can be returned by one command.

The initial address must be 32-bit aligned (the two LSBs must be zero). Attempts to read from an address which does not fall within the valid address range for the FlexRAM returns unknown data. See [Flash memory map for EzPort access](#) for more information.

For this command to return the correct data, the EzPort clock (EZP_CK) must run at the internal system clock divided by eight or slower. This command is not accepted if the WEF, WIP, or FS fields in the EzPort status register are set.

29.3.1.14 Read FlexRAM at High Speed

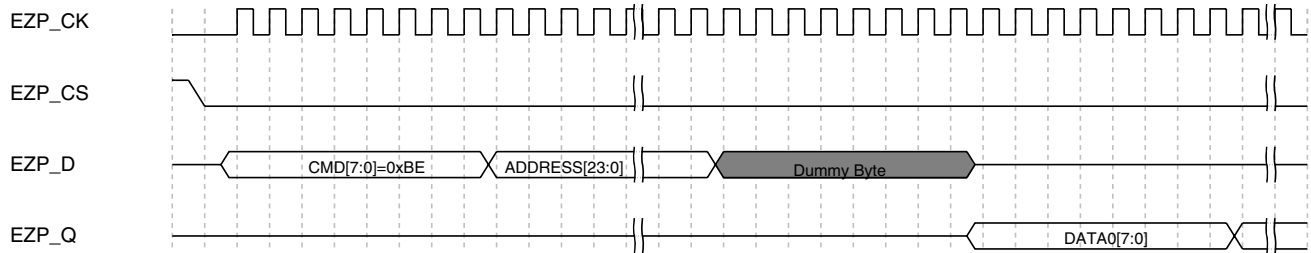


Figure 29-15. Read FlexRAM at High Speed command sequence

This command is only applicable for devices with FlexRAM.

The Read FlexRAM at High Speed (FAST_RDFLEXRAM) command is identical to the RDFLEXRAM command, except for the inclusion of a dummy byte following the address bytes and before the first data byte is returned.

This command can be run with an EzPort clock (E郑_CK) frequency up to and including half the internal system clock frequency of the microcontroller. This command is not accepted if the WEF, WIP, or FS fields in the EzPort status register are set.

29.4 Flash memory map for EzPort access

The following table shows the flash memory map for access through EzPort.

NOTE

The flash block address map for access through EzPort may not conform to the system memory map. Changes are made to allow the EzPort address width to remain 24 bits.

Table 29-5. Flash Memory Map for EzPort Access

| Valid start address | Size | Flash block | Valid commands |
|---------------------|---|-------------|--|
| 0x0000_0000 | See device's chip configuration details | Flash | READ, FAST_READ, SP, SE, BE |
| 0x0000_0000 | See device's chip configuration details | FlexRAM | RDFLEXRAM, FAST_RDFLEXRAM, WRFLEXRAM, BE |



Chapter 30

Cyclic Redundancy Check (CRC)

30.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The cyclic redundancy check (CRC) module generates 16/32-bit CRC code for error detection.

The CRC module provides a programmable polynomial, WAS, and other parameters required to implement a 16-bit or 32-bit CRC standard.

The 16/32-bit code is calculated for 32 bits of data at a time.

30.1.1 Features

Features of the CRC module include:

- Hardware CRC generator circuit using a 16-bit or 32-bit programmable shift register
- Programmable initial seed value and polynomial
- Option to transpose input data or output data (the CRC result) bitwise or byte-wise. This option is required for certain CRC standards. A byte-wise transpose operation is not possible when accessing the CRC data register via 8-bit accesses. In this case, the user's software must perform the byte-wise transpose function.
- Option for inversion of final CRC result
- 32-bit CPU register programming interface

30.1.2 Block diagram

The following is a block diagram of the CRC.

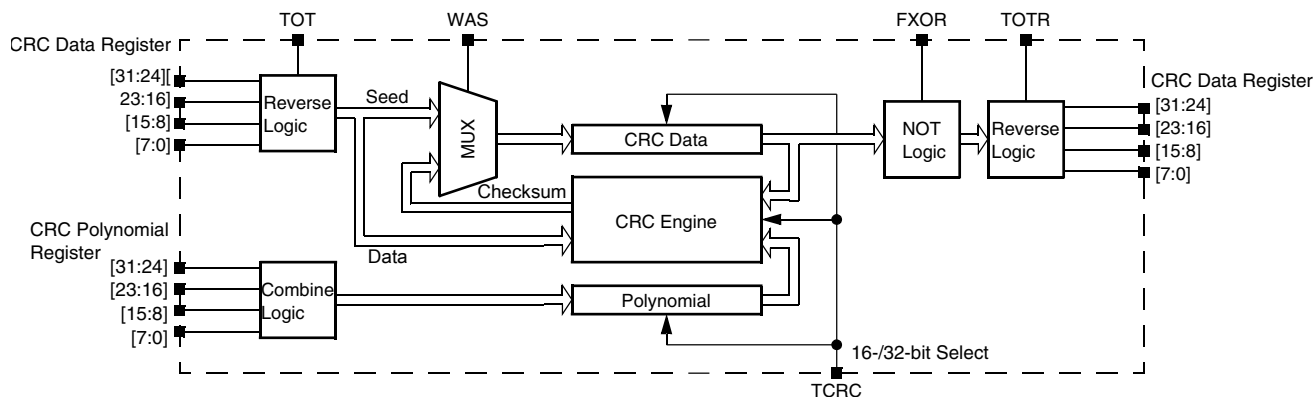


Figure 30-1. Programmable cyclic redundancy check (CRC) block diagram

30.1.3 Modes of operation

Various MCU modes affect the CRC module's functionality.

30.1.3.1 Run mode

This is the basic mode of operation.

30.1.3.2 Low-power modes (Wait or Stop)

Any CRC calculation in progress stops when the MCU enters a low-power mode that disables the module clock. It resumes after the clock is enabled or via the system reset for exiting the low-power mode. Clock gating for this module is dependent on the MCU.

30.2 Memory map and register descriptions

CRC memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|-------------------------------------|-----------------|--------|-------------|----------------------------|
| 4003_2000 | CRC Data register (CRC_DATA) | 32 | R/W | FFFF_FFFFh | 30.2.1/611 |
| 4003_2004 | CRC Polynomial register (CRC_GPOLY) | 32 | R/W | 0000_1021h | 30.2.2/612 |
| 4003_2008 | CRC Control register (CRC_CTRL) | 32 | R/W | 0000_0000h | 30.2.3/612 |

30.2.1 CRC Data register (CRC_DATA)

The CRC Data register contains the value of the seed, data, and checksum. When CTRL[WAS] is set, any write to the data register is regarded as the seed value. When CTRL[WAS] is cleared, any write to the data register is regarded as data for general CRC computation.

In 16-bit CRC mode, the HU and HL fields are not used for programming the seed value, and reads of these fields return an indeterminate value. In 32-bit CRC mode, all fields are used for programming the seed value.

When programming data values, the values can be written 8 bits, 16 bits, or 32 bits at a time, provided all bytes are contiguous; with MSB of data value written first.

After all data values are written, the CRC result can be read from this data register. In 16-bit CRC mode, the CRC result is available in the LU and LL fields. In 32-bit CRC mode, all fields contain the result. Reads of this register at any time return the intermediate CRC value, provided the CRC module is configured.

Address: 4003_2000h base + 0h offset = 4003_2000h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|----|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | HU | | | | | | | | HL | | | | | | | | LU | | | | | | | | LL | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |

CRC_DATA field descriptions

| Field | Description |
|-------------|---|
| 31–24 HU | CRC High Upper Byte In 16-bit CRC mode (CTRL[TCRC] is 0), this field is not used for programming a seed value. In 32-bit CRC mode (CTRL[TCRC] is 1), values written to this field are part of the seed value when CTRL[WAS] is 1. When CTRL[WAS] is 0, data written to this field is used for CRC checksum generation in both 16-bit and 32-bit CRC modes. |
| 23–16 HL | CRC High Lower Byte In 16-bit CRC mode (CTRL[TCRC] is 0), this field is not used for programming a seed value. In 32-bit CRC mode (CTRL[TCRC] is 1), values written to this field are part of the seed value when CTRL[WAS] is 1. When CTRL[WAS] is 0, data written to this field is used for CRC checksum generation in both 16-bit and 32-bit CRC modes. |
| 15–8 LU | CRC Low Upper Byte When CTRL[WAS] is 1, values written to this field are part of the seed value. When CTRL[WAS] is 0, data written to this field is used for CRC checksum generation. |
| 7–0 LL | CRC Low Lower Byte When CTRL[WAS] is 1, values written to this field are part of the seed value. When CTRL[WAS] is 0, data written to this field is used for CRC checksum generation. |

30.2.2 CRC Polynomial register (CRC_GPOLY)

This register contains the value of the polynomial for the CRC calculation. The HIGH field contains the upper 16 bits of the CRC polynomial, which are used only in 32-bit CRC mode. Writes to the HIGH field are ignored in 16-bit CRC mode. The LOW field contains the lower 16 bits of the CRC polynomial, which are used in both 16- and 32-bit CRC modes.

Address: 4003_2000h base + 4h offset = 4003_2004h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | HIGH | | | | | | | | | | | | | | | | LOW | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

CRC_GPOLY field descriptions

| Field | Description |
|---------------|---|
| 31–16 HIGH | High Polynomial Half-word Writable and readable in 32-bit CRC mode (CTRL[TCRC] is 1). This field is not writable in 16-bit CRC mode (CTRL[TCRC] is 0). |
| 15–0 LOW | Low Polynomial Half-word Writable and readable in both 32-bit and 16-bit CRC modes. |

30.2.3 CRC Control register (CRC_CTRL)

This register controls the configuration and working of the CRC module. Appropriate bits must be set before starting a new CRC calculation. A new CRC calculation is initialized by asserting CTRL[WAS] and then writing the seed into the CRC data register.

Address: 4003_2000h base + 8h offset = 4003_2008h

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|-----|----|------|----|----|------|-----|------|----|----|----|----|----|----|----|----|
| R | TOT | | TOTR | | 0 | FXOR | WAS | TCRC | 0 | | | | | | | |
| W | TOT | | TOTR | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CRC_CTRL field descriptions

| Field | Description |
|------------------|---|
| 31–30 TOT | <p>Type Of Transpose For Writes</p> <p>Defines the transpose configuration of the data written to the CRC data register. See the description of the transpose feature for the available transpose options.</p> <p>00 No transposition. 01 Bits in bytes are transposed; bytes are not transposed. 10 Both bits in bytes and bytes are transposed. 11 Only bytes are transposed; no bits in a byte are transposed.</p> |
| 29–28 TOTR | <p>Type Of Transpose For Read</p> <p>Identifies the transpose configuration of the value read from the CRC Data register. See the description of the transpose feature for the available transpose options.</p> <p>00 No transposition. 01 Bits in bytes are transposed; bytes are not transposed. 10 Both bits in bytes and bytes are transposed. 11 Only bytes are transposed; no bits in a byte are transposed.</p> |
| 27 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 26 FXOR | <p>Complement Read Of CRC Data Register</p> <p>Some CRC protocols require the final checksum to be XORed with 0xFFFFFFFF or 0xFFFF. Asserting this bit enables on the fly complementing of read data.</p> <p>0 No XOR on reading. 1 Invert or complement the read value of the CRC Data register.</p> |
| 25 WAS | <p>Write CRC Data Register As Seed</p> <p>When asserted, a value written to the CRC data register is considered a seed value. When deasserted, a value written to the CRC data register is taken as data for CRC computation.</p> <p>0 Writes to the CRC data register are data values. 1 Writes to the CRC data register are seed values.</p> |
| 24 TCRC | <p>Width of CRC protocol.</p> <p>0 16-bit CRC protocol. 1 32-bit CRC protocol.</p> |
| 23–0 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |

30.3 Functional description

30.3.1 CRC initialization/reinitialization

To enable the CRC calculation, the user must program CRC_CTRL[WAS], CRC_GPOLY, necessary parameters for transposition and CRC result inversion in the applicable registers. Asserting CRC_CTRL[WAS] enables the programming of the seed value into the CRC_DATA register.

After a completed CRC calculation, the module can be reinitialized for a new CRC computation by reasserting CRC_CTRL[WAS] and programming a new, or previously used, seed value. All other parameters must be set before programming the seed value and subsequent data values.

30.3.2 CRC calculations

In 16-bit and 32-bit CRC modes, data values can be programmed 8 bits, 16 bits, or 32 bits at a time, provided all bytes are contiguous. Noncontiguous bytes can lead to an incorrect CRC computation.

30.3.2.1 16-bit CRC

To compute a 16-bit CRC:

1. Clear CRC_CTRL[TCRC] to enable 16-bit CRC mode.
2. Program the transpose and complement options in the CTRL register as required for the CRC calculation. See [Transpose feature](#) and [CRC result complement](#) for details.
3. Write a 16-bit polynomial to the CRC_GPOLY[LOW] field. The CRC_GPOLY[HIGH] field is not usable in 16-bit CRC mode.
4. Set CRC_CTRL[WAS] to program the seed value.
5. Write a 16-bit seed to CRC_DATA[LU:LL]. CRC_DATA[HU:HL] are not used.
6. Clear CRC_CTRL[WAS] to start writing data values.
7. Write data values into CRC_DATA[HU:HL:LU:LL]. A CRC is computed on every data value write, and the intermediate CRC result is stored back into CRC_DATA[LU:LL].
8. When all values have been written, read the final CRC result from CRC_DATA[LU:LL].

Transpose and complement operations are performed on the fly while reading or writing values. See [Transpose feature](#) and [CRC result complement](#) for details.

30.3.2.2 32-bit CRC

To compute a 32-bit CRC:

1. Set CRC_CTRL[TCRC] to enable 32-bit CRC mode.
2. Program the transpose and complement options in the CTRL register as required for the CRC calculation. See [Transpose feature](#) and [CRC result complement](#) for details.
3. Write a 32-bit polynomial to CRC_GPOLY[HIGH:LOW].
4. Set CRC_CTRL[WAS] to program the seed value.
5. Write a 32-bit seed to CRC_DATA[HU:HL:LU:LL].
6. Clear CRC_CTRL[WAS] to start writing data values.
7. Write data values into CRC_DATA[HU:HL:LU:LL]. A CRC is computed on every data value write, and the intermediate CRC result is stored back into CRC_DATA[HU:HL:LU:LL].
8. When all values have been written, read the final CRC result from CRC_DATA[HU:HL:LU:LL]. The CRC is calculated byte-wise, and two clocks are required to complete one CRC calculation.

Transpose and complement operations are performed on the fly while reading or writing values. See [Transpose feature](#) and [CRC result complement](#) for details.

30.3.3 Transpose feature

By default, the transpose feature is not enabled. However, some CRC standards require the input data and/or the final checksum to be transposed. The user software has the option to configure each transpose operation separately, as desired by the CRC standard. The data is transposed on the fly while being read or written.

Some protocols use little endian format for the data stream to calculate a CRC. In this case, the transpose feature usefully flips the bits. This transpose option is one of the types supported by the CRC module.

30.3.3.1 Types of transpose

The CRC module provides several types of transpose functions to flip the bits and/or bytes, for both writing input data and reading the CRC result, separately using the CTRL[TOT] or CTRL[TOTR] fields, according to the CRC calculation being used.

The following types of transpose functions are available for writing to and reading from the CRC data register:

1. CTRL[TOT] or CTRL[TOTR] is 00.

No transposition occurs.

2. CTRL[TOT] or CTRL[TOTR] is 01

Bits in a byte are transposed, while bytes are not transposed.

reg[31:0] becomes {reg[24:31], reg[16:23], reg[8:15], reg[0:7]}

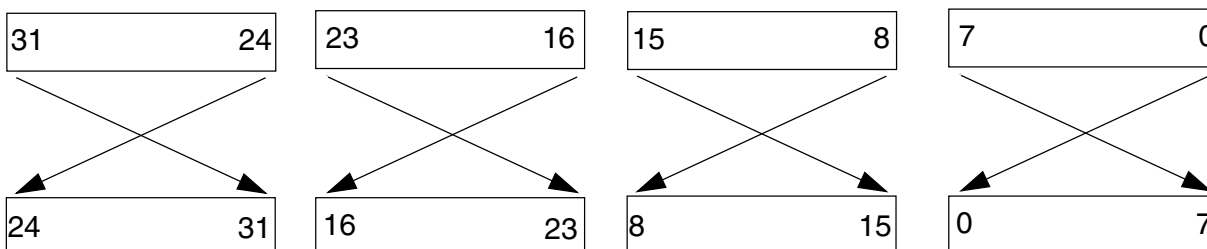


Figure 30-5. Transpose type 01

3. CTRL[TOT] or CTRL[TOTR] is 10.

Both bits in bytes and bytes are transposed.

reg[31:0] becomes = {reg[0:7], reg[8:15], reg[16:23], reg[24:31]}

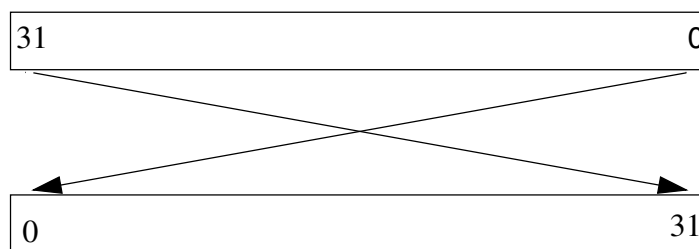


Figure 30-6. Transpose type 10

4. CTRL[TOT] or CTRL[TOTR] is 11.

Bytes are transposed, but bits are not transposed.

reg[31:0] becomes {reg[7:0], reg[15:8], reg[23:16], reg[31:24]}

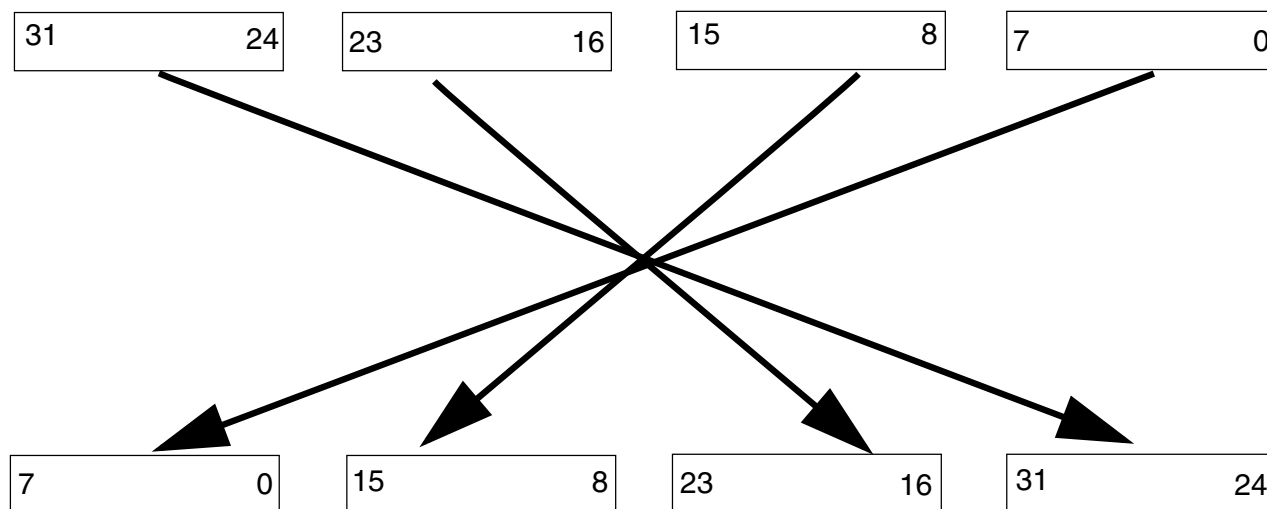


Figure 30-7. Transpose type 11

NOTE

For 8-bit and 16-bit write accesses to the CRC data register, the data is transposed with zeros on the unused byte or bytes (taking 32 bits as a whole), but the CRC is calculated on the valid byte(s) only. When reading the CRC data register for a 16-bit CRC result and using transpose options 10 and 11, the resulting value after transposition resides in the CRC[HU:HL] fields. The user software must account for this situation when reading the 16-bit CRC result, so reading 32 bits is preferred.

30.3.4 CRC result complement

When CTRL[FXOR] is set, the checksum is complemented. The CRC result complement function outputs the complement of the checksum value stored in the CRC data register every time the CRC data register is read. When CTRL[FXOR] is cleared, reading the CRC data register accesses the raw checksum value.



Chapter 31

Memory-Mapped Cryptographic Acceleration Unit (MMCAU)

31.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The Memory-Mapped Cryptographic Acceleration Unit (MMCAU) is a coprocessor that is connected to the processor's Private Peripheral Bus (PPB). It supports the hardware implementation of a set of specialized operations to improve the throughput of software-based security encryption/decryption operations and message digest functions.

The MMCAU supports acceleration of the DES, 3DES, AES, MD5, SHA-1, and SHA-256 algorithms. Freescale provides an optimized, callable C-function library that provides the appropriate software building blocks to implement higher-level security functions.

31.2 MMCAU Block Diagram

A simplified block diagram is given below that illustrates the MMCAU and a table to show its parts.

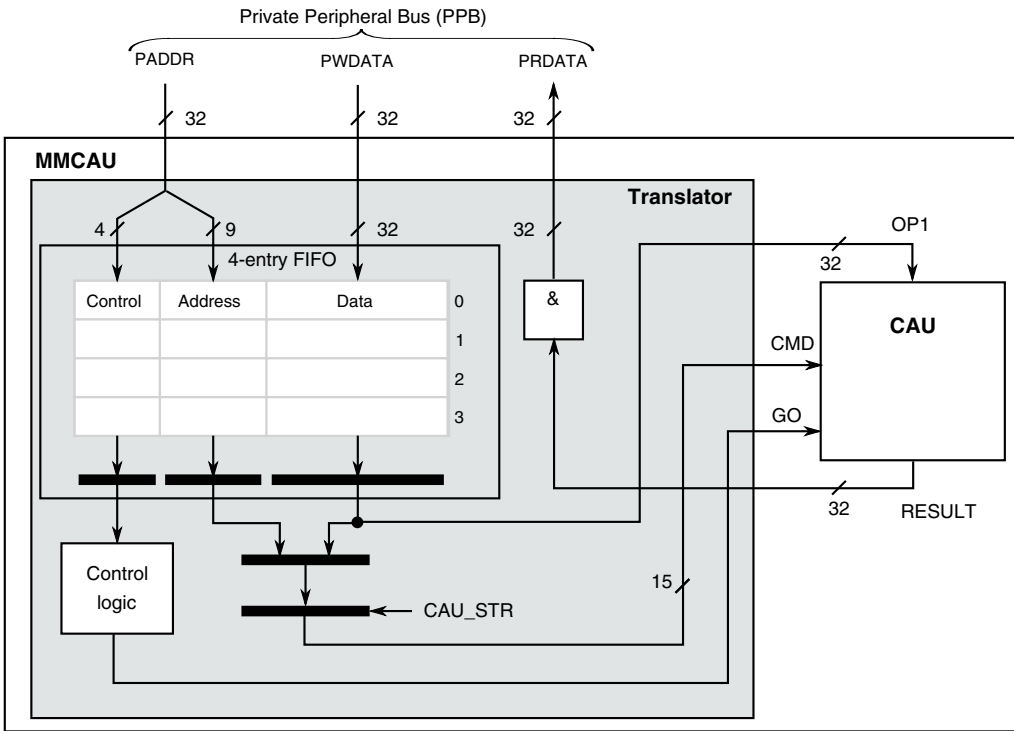


Figure 31-1. MMCAU block diagram

Table 31-1. MMCAU parts table

| Item | Description |
|----------------------|---|
| Translator submodule | Provides the bridge between the private APB interface and the CAU module. Passes memory-mapped commands and data on the APB to/from the CAU |
| 4-entry FIFO | Contains commands and input operands and the associated control captured from the PPB and sent to the CAU |
| CAU | 3-terminal block with a command and optional input operand and a result bus. More details in following figure. |

The following figure shows the CAU block in more detail.

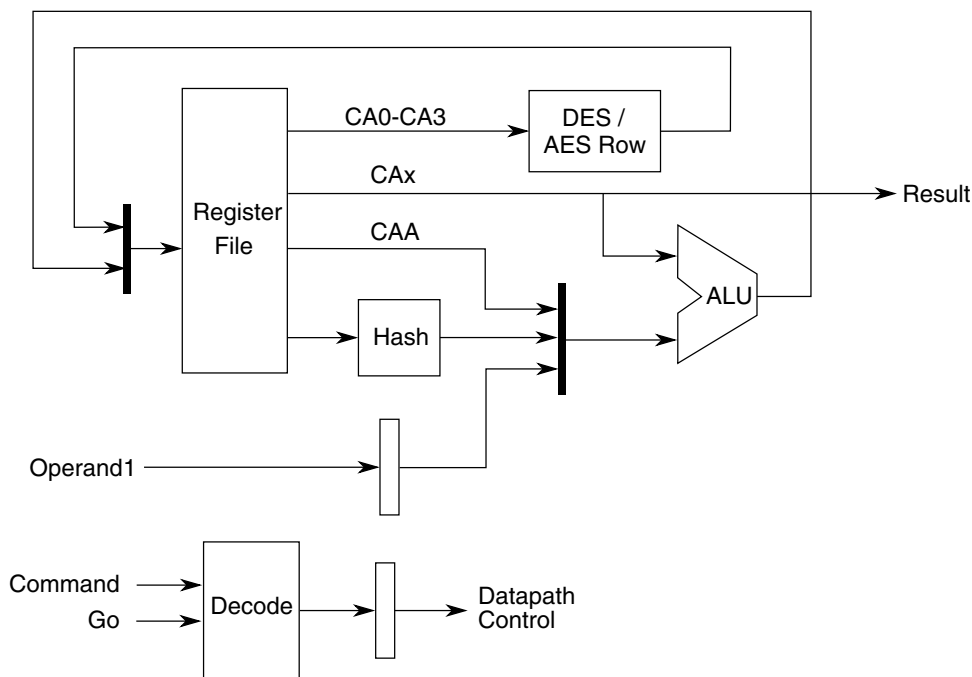


Figure 31-2. Top-level CAU block diagram

31.3 Overview

As the name suggests, the MMCAU provides a mechanism for memory-mapped register reads and writes to be transformed into specific commands and operands sent to the CAU coprocessor.

The MMCAU translator module performs the following functions:

- All the required functions affecting the transmission of commands to the CAU module.
- If needed, stalling the PPB transactions based on the state of the 4-entry command/data FIFO.
- Some basic integrity checks on PPB operations.

The set of implemented algorithms provides excellent support for network security standards, such as SSL and IPsec. Additionally, using the MMCAU efficiently permits the implementation of any higher level functions or modes of operation, such as HMAC, CBC, and so on based on the supported algorithms.

The cryptographic algorithms are implemented partially in software with only functions critical to increasing performance implemented in hardware. The MMCAU allows for efficient, fine-grained partitioning of functions between hardware and software:

- Implement the innermost security kernel functions using the coprocessor instructions.
- Implement higher level functions in software by using the standard processor instructions.

This partitioning of functions is key to minimizing size of the MMCAU while maintaining a high level of throughput. Using software for some functions also simplifies the MMCAU design. The CAU implements a set of coprocessor commands that operate on a register file of 32-bit registers.

31.4 Features

The MMCAU includes the following distinctive features:

- Supports DES, 3DES, AES, MD5, SHA-1, and SHA-256 algorithms
- Simple, flexible programming model
- Ability to send up to three commands in one data write operation

31.5 Memory map/Register definition

The CAU contains multiple registers used by each of the supported algorithms. The following table shows registers that are applicable to each supported algorithm and indicates the corresponding letter designations for each algorithm. For more information on these letter designations, see the algorithm specifications.

| Code | Register | DES | AES | MD5 | SHA-1 | SHA-256 |
|------|----------------------------------|-----|-----|-----|-------|---------|
| 0 | CAU Status Register (CASR) | — | — | — | — | — |
| 1 | CAU Accumulator (CAA) | — | — | a | T | T |
| 2 | General-Purpose Register 0 (CA0) | C | W0 | — | A | A |
| 3 | General-Purpose Register 1 (CA1) | D | W1 | b | B | B |

Table continues on the next page...

| Code | Register | DES | AES | MD5 | SHA-1 | SHA-256 |
|------|----------------------------------|-----|-----|-----|-------|------------------|
| 4 | General-Purpose Register 2 (CA2) | L | W2 | c | C | C |
| 5 | General-Purpose Register 3 (CA3) | R | W3 | d | D | D |
| 6 | General-Purpose Register 4 (CA4) | — | — | — | E | E |
| 7 | General-Purpose Register 5 (CA5) | — | — | — | W | F |
| 8 | General-Purpose Register 6 (CA6) | — | — | — | — | G |
| 9 | General-Purpose Register 7 (CA7) | — | — | — | — | H |
| 10 | General-Purpose Register 8 (CA8) | — | — | — | — | W/T ₁ |

The CAU supports only 32-bit operations and register accesses. All registers support read, write, and ALU operations. However, only bits 1–0 of the CASR are writeable. Bits 31–2 of the CASR must be written as 0 for compatibility with future versions of the CAU.

The codes listed in this section are used in the memory-mapped commands. For more details on this, see [MMCAU programming model](#).

NOTE

In the following table, the "address" or "offset" refers to the command code value for the CAU registers.

CAU memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|----------------------------|-----------------|--------|-------------|----------------------------|
| E008_1000 | Status Register (CAU_CASR) | 32 | R/W | 2000_0000h | 31.5.1/624 |
| E008_1001 | Accumulator (CAU_CAA) | 32 | R/W | 0000_0000h | 31.5.2/625 |

Table continues on the next page...

CAU memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|------------------------------------|-----------------|--------|-------------|----------------------------|
| E008_1002 | General Purpose Register (CAU_CA0) | 32 | R/W | 0000_0000h | 31.5.3/625 |
| E008_1003 | General Purpose Register (CAU_CA1) | 32 | R/W | 0000_0000h | 31.5.3/625 |
| E008_1004 | General Purpose Register (CAU_CA2) | 32 | R/W | 0000_0000h | 31.5.3/625 |
| E008_1005 | General Purpose Register (CAU_CA3) | 32 | R/W | 0000_0000h | 31.5.3/625 |
| E008_1006 | General Purpose Register (CAU_CA4) | 32 | R/W | 0000_0000h | 31.5.3/625 |
| E008_1007 | General Purpose Register (CAU_CA5) | 32 | R/W | 0000_0000h | 31.5.3/625 |
| E008_1008 | General Purpose Register (CAU_CA6) | 32 | R/W | 0000_0000h | 31.5.3/625 |
| E008_1009 | General Purpose Register (CAU_CA7) | 32 | R/W | 0000_0000h | 31.5.3/625 |
| E008_100A | General Purpose Register (CAU_CA8) | 32 | R/W | 0000_0000h | 31.5.3/625 |

31.5.1 Status Register (CAU_CASR)

CASR contains the status and configuration for the CAU.

Address: E008_1000h base + 0h offset = E008_1000h

| | | | | | | | | | | | | | | | | |
|-------|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | VER | | | | 0 | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | DPE | IC |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CAU_CASR field descriptions

| Field | Description |
|------------------|--|
| 31–28 VER | CAU Version Indicates CAU version. 0x1 Initial CAU version. 0x2 Second version, added support for SHA-256 algorithm (This is the value on this device). |
| 27–2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 DPE | DES Parity Error Indicates whether the DES parity error is detected. 0 No error detected. 1 DES key parity error detected. |

Table continues on the next page...

CAU_CASR field descriptions (continued)

| Field | Description |
|---------|--|
| 0 IC | Illegal Command Indicates an illegal instruction has been executed. 0 No illegal commands issued. 1 Illegal command issued. |

31.5.2 Accumulator (CAU_CAA)

Commands use the CAU accumulator for storage of results and as an operand for the cryptographic algorithms.

Address: E008_1000h base + 1h offset = E008_1001h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

CAU_CAA field descriptions

| Field | Description |
|-------------|--|
| 31–0 ACC | Accumulator Stores results of various CAU commands. |

31.5.3 General Purpose Register (CAU_CAn)

The General Purpose Register is used in the CAU commands for storage of results and as operands for various cryptographic algorithms.

Address: E008_1000h base + 2h offset + (1d × i), where i=0d to 8d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | CAn | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

CAU_CAn field descriptions

| Field | Description |
|-------------|--|
| 31–0 CAn | General Purpose Registers Used by the CAU commands. Some cryptographic operations work with specific registers. |

31.6 Functional description

This section discusses the programming model and operation of the MMCAU.

31.6.1 MMCAU programming model

The 4-entry FIFO is indirectly mapped into a 4-KB address space associated with the MMCAU located at byte addresses 0xE008_1000 – 0xE008_1FFF on this device. This address space is effectively split into two equal regions:

- one used to directly write commands for CAU load operations
- the other used to send commands and input operands for CAU loads

Data writes on the PPB are loaded into this FIFO and automatically converted into CAU load operands by the MMCAU translator. Data reads on the PPB are converted into CAU store register operations where the result is returned to the processor as the read data value.

The CAU requires a 15-bit command, and optionally, a 32-bit input operand, for each CAU load, PPB write. The 15-bit command includes the 9-bit opcode and other bits statically formed by the MMCAU translator logic controlling the CAU.

The following figure shows the 4-KB address space and the mapping of the CAU commands into this space.

NOTE

- Although the indirect store/load portion of the address space in the figure below shows only the indirect load/store commands, direct load commands can also be used in this space. However, it is more efficient to use the direct load portion of the address space.
- Accesses to the reserved space in the direct load space are terminated with an error, while accesses to the reserved space in the indirect load/store space are detected as an illegal CAU command. See [MMCAU integrity checks](#) for details.

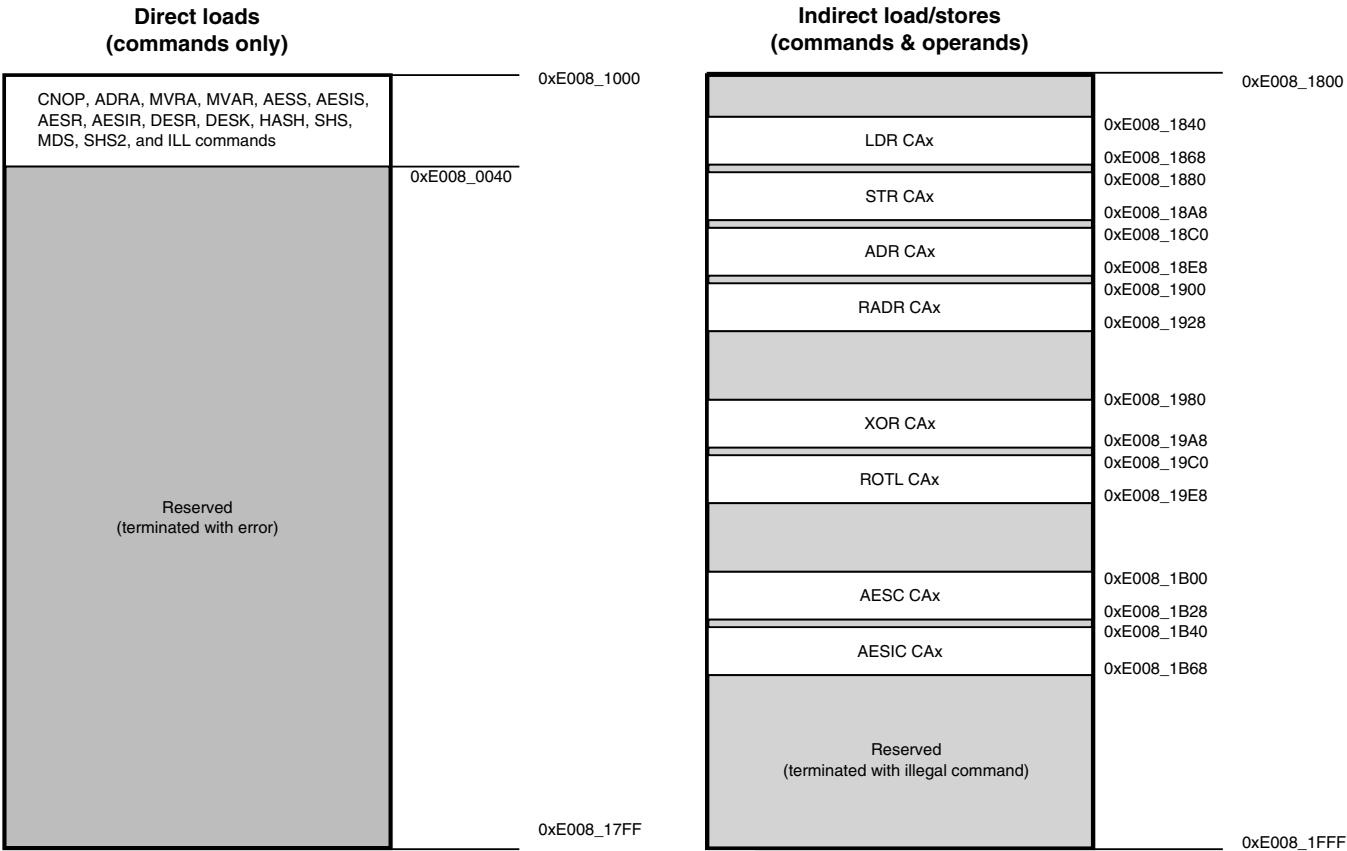


Figure 31-15. MMCAU memory map

31.6.1.1 Direct loads

The MMCAU supports writing multiple commands in each 32-bit direct write operation. Each 9-bit opcode also includes a valid bit. Therefore, one, two, or three commands can be transmitted in a single 32-bit PPB write. The following figure illustrates the accepted formats for the 32-bit MMCAU write data value:

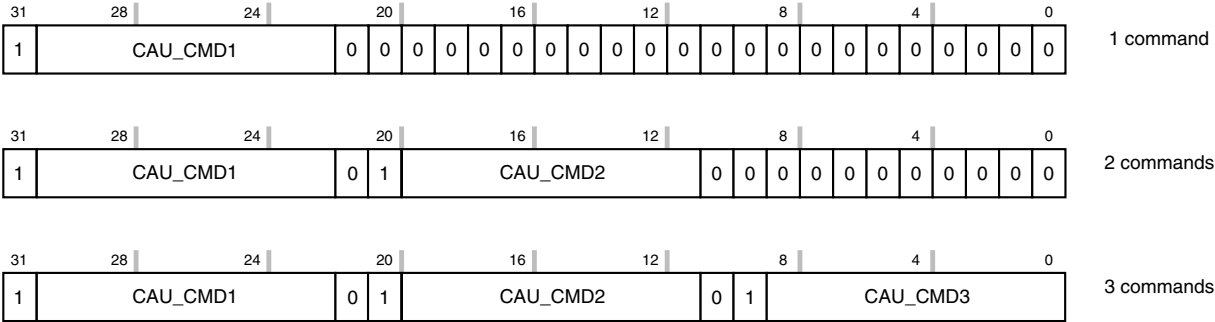


Figure 31-16. Direct loads

31.6.1.2 Indirect loads

For CAU load operations requiring a 32-bit input operand, the address contains the 9-bit opcode to be passed to the MMCAU while the data is the 32-bit operand. Specifically, the MMCAU address and data for these indirect writes is shown in the figure below.

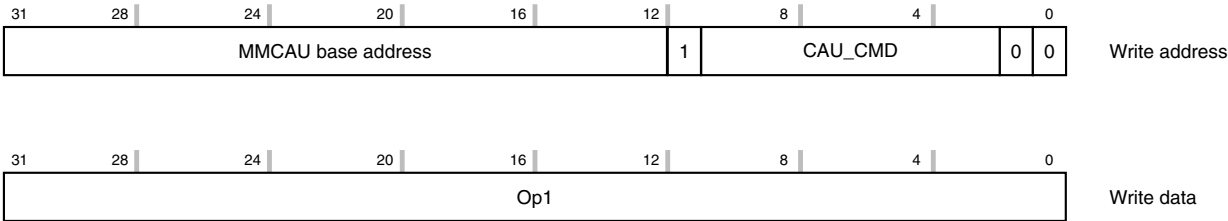


Figure 31-17. Indirect loads

31.6.1.3 Indirect stores

For CAU store operations, a PPB read is performed with the appropriate CAU store register opcode embedded in the address. This appears as another indirect command. The detail of Indirect stores is shown in the figure below.

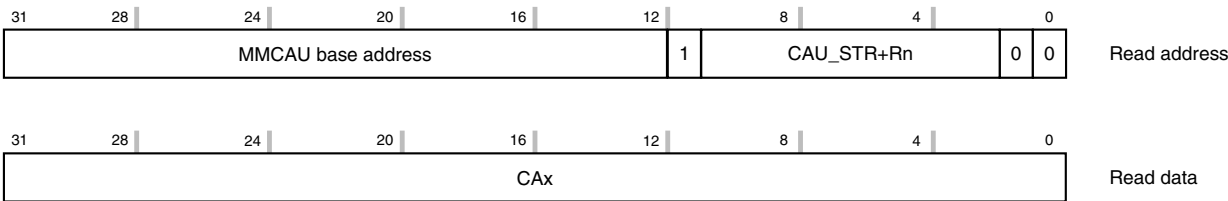


Figure 31-18. Indirect store

31.6.2 MMCAU integrity checks

If an illegal operation or access is attempted, the PPB bus cycle is terminated with an error response and the operation is aborted and not sent to the CAU.

The MMCAU performs a series of address and data integrity checks as described in the following sections. The results of these checks are logically summed together and, if appropriate, a PPB error termination is generated.

31.6.2.1 Address integrity checks

The MMCAU address checking includes the following. See [Figure 31-15](#) for the MMCAU memory map details.

- Any MMCAU reference using a non-0-modulo-4 byte address ($\text{addr}[1:0] \neq 00$) generates an error termination.
- For MMCAU writes:
 - Only the first 64 bytes of the 2-KB direct write address space can be referenced. Attempting to access regions beyond the first 64 bytes terminates with an error.
 - The second 2-KB space defines the indirect address-as-command region and any reference in this space is allowed by the MMCAU.

NOTE

The CAU contains error logic to detect any illegal command sent to it. Accordingly, there are address values in this upper 2-KB region of the address space that are passed to the CAU, and then detected as illegal commands. If the CAU detects an illegal command, it sets the CASR[IC] flag and performs no operation.

- For MMCAU reads:
 - Any attempted read from the first 2-KB region of the address space (an attempted direct read) is illegal and produces an error termination.
 - Within the second 2-KB region of the address space, i.e., $\text{addr}[11] = 1$, only a 64-byte space is treated as a legal CAU store operation. The allowable addresses are defined as:

$$\text{addr}[11:0] = 1000_10xx_xx_00$$

where the 4-bit xxxx value specifies the CAU register number. The CAU supports a subset of the allowable register numbers, 0x0 - 0xA. Attempting a store of a reserved register produces an undefined result.

31.6.2.2 Data integrity checks

Direct writes can send 1, 2, or 3 commands to the CAU in a single 32-bit transfer. As shown in [Figure 31-16](#), the commands include a valid bit located at bits 31, 20, and 9 of the write data where:

- Bit 31 is the valid bit for the first command
- Bit 20 is the valid bit for the second command
- Bit 9 is the valid bit for the third command

The direct write data check validates the combination of these three valid bits. The following table presents the three legal states associated with these bits:

functional description

| Value of bits 31, 20, and 9 | Number of commands included |
|-----------------------------|-----------------------------|
| 100 | 1 |
| 110 | 2 |
| 111 | 3 |

All other combinations of bits 31, 20, and 9 are illegal and generate an error termination.

31.6.3 CAU commands

The CAU supports the commands shown in the following table. All other encodings are reserved. The CASR[IC] bit is set if an undefined command is issued. A specific illegal command (ILL) is defined to allow software self-checking. Reserved commands must not be issued so as to ensure compatibility with future implementations.

The CMD field specifies the 9-bit CAU opcode for the operation command.

See [Assembler equate values](#) for a set of assembly constants used in the command descriptions here. If supported by the assembler, macros can also be created for each instruction. The value CAx should be interpreted as any CAU register (CASR, CAA, and CA_n).

Table 31-15. CAU commands

| Type | Command name | Description | CMD | | | | | | | | | Operation |
|----------------|--------------|-------------------|-------|---|---|---|-----|---|---|---|---|--|
| | | | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |
| Direct load | CNOP | No Operation | 0x000 | | | | | | | | | — |
| Indirect load | LDR | Load Reg | 0x01 | | | | CAx | | | | | Op1 → CAx |
| Indirect store | STR | Store Reg | 0x02 | | | | CAx | | | | | CAx → Result |
| Indirect load | ADR | Add | 0x03 | | | | CAx | | | | | CAx + Op1 → CAx |
| Indirect load | RADR | Reverse and Add | 0x04 | | | | CAx | | | | | CAx + ByteRev(Op1) → CAx |
| Direct load | ADRA | Add Reg to Acc | 0x05 | | | | CAx | | | | | CAx + CAA → CAA |
| Indirect load | XOR | Exclusive Or | 0x06 | | | | CAx | | | | | CAx ^ Op1 → CAx |
| Indirect load | ROTL | Rotate Left | 0x07 | | | | CAx | | | | | (CAx <<< (Op1 % 32)) (CAx >>> (32 - (Op1 % 32))) → CAx |
| Direct load | MVRA | Move Reg to Acc | 0x08 | | | | CAx | | | | | CAx → CAA |
| Direct load | MVAR | Move Acc to Reg | 0x09 | | | | CAx | | | | | CAA → CAx |
| Direct load | AESS | AES Sub Bytes | 0x0A | | | | CAx | | | | | SubBytes(CAx) → CAx |
| Direct load | AESIS | AES Inv Sub Bytes | 0x0B | | | | CAx | | | | | InvSubBytes(CAx) → CAx |
| Indirect load | AESC | AES Column Op | 0x0C | | | | CAx | | | | | MixColumns(CAx)^Op1 → CAx |
| Indirect load | AESIC | AES Inv Column Op | 0x0D | | | | CAx | | | | | InvMixColumns(CAx^Op1) → CAx |

Table continues on the next page...

Table 31-15. CAU commands (continued)

| Type | Command name | Description | CMD | | | | | | | | | Operation |
|-------------|--------------|----------------------|-------|---|---|---|----|---------|---------|----------------------------|---|---|
| | | | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |
| Direct load | AESR | AES Shift Rows | 0x0E0 | | | | | | | | | ShiftRows(CA0-CA3) → CA0-CA3 |
| Direct load | AESIR | AES Inv Shift Rows | 0x0F0 | | | | | | | | | InvShiftRows(CA0-CA3)→CA0-CA3 |
| Direct load | DESR | DES Round | 0x10 | | | | IP | FP | KS[1:0] | | DES Round(CA0-CA3) →CA0-CA3 | |
| Direct load | DESK | DES Key Setup | 0x11 | | | | 0 | 0 | CP | DC | DES Key Op(CA0-CA1)→CA0-CA1 Key Parity Error & CP →CASR[1] | |
| Direct load | HASH | Hash Function | 0x12 | | | | 0 | HF[2:0] | | Hash Func(CA1-CA3)+CAA→CAA | | |
| Direct load | SHS | Secure Hash Shift | 0x130 | | | | | | | | | CAA <<< 5→ CAA, CAA→CA0, CA0→CA1, CA1 <<< 30 → CA2, CA2→CA3, CA3→CA4 |
| Direct load | MDS | Message Digest Shift | 0x140 | | | | | | | | | CA3→CAA, CAA→CA1, CA1→CA2, CA2→CA3, |
| Direct load | SHS2 | Secure Hash Shift 2 | 0x150 | | | | | | | | | CAA→CA0, CA0→CA1, CA1 → CA2, CA2→CA3, CA3 + CA8 →CA4, CA4 → CA5, CA5 → CA6, CA6 → CA7 |
| Direct load | ILL | Illegal Command | 0x1F0 | | | | | | | | | 0x1→CASR[IC] |

31.6.3.1 Coprocessor No Operation (CNOP)

The CNOP command is the coprocessor no-op. It is issued by the MMCAU and consumes a location in the MMCAU FIFO, but has no effect on any CAU register.

31.6.3.2 Load Register (LDR)

The LDR command loads CAX with the source data specified by the write data.

31.6.3.3 Store Register (STR)

The STR command returns the value of CAX specified in the read address to the destination specified as read data.

31.6.3.4 Add to Register (ADR)

The ADR command adds the source operand specified by the write data to CAX and stores the result in CAX.

31.6.3.5 Reverse and Add to Register (RADR)

The RADR command performs a byte reverse on the source operand specified by the write data, adds that value to CAX, and stores the result in CAX. The table below shows an example.

Table 31-16. RADR command example

| Operand | CAX before | CAX after |
|-------------|-------------|-------------|
| 0x0102_0304 | 0xA0B0_C0D0 | 0xA4B3_C2D1 |

31.6.3.6 Add Register to Accumulator (ADRA)

The ADRA command adds CAX to CAA and stores the result in CAA.

31.6.3.7 Exclusive Or (XOR)

The XOR command performs an exclusive-or of the source operand specified by the write data with CAX and stores the result in CAX.

31.6.3.8 Rotate Left (ROTL)

ROTL rotates the CAX bits to the left with the result stored back to CAX. The number of bits to rotate is the value specified by the write data modulo 32.

31.6.3.9 Move Register to Accumulator (MVRA)

The MVRA command moves the value from the source register CAx to the destination register CAA.

31.6.3.10 Move Accumulator to Register (MVAR)

The MVAR command moves the value from source register CAA to the destination register CAx.

31.6.3.11 AES Substitution (AESS)

The AESS command performs the AES byte substitution operation on CAx and stores the result back to CAx.

31.6.3.12 AES Inverse Substitution (AESIS)

The AESIS command performs the AES inverse byte substitution operation on CAx and stores the result back to CAx.

31.6.3.13 AES Column Operation (AESC)

The AESC command performs the AES column operation on the contents of CAx. It then performs an exclusive-or of that result with the source operand specified by the write data and stores the result in CAx.

31.6.3.14 AES Inverse Column Operation (AESIC)

The AESIC command performs an exclusive-or operation of the source operand specified by the write data on the contents of CAx followed by the AES inverse mix column operation on that result and stores the result back in CAx.

31.6.3.15 AES Shift Rows (AESR)

The AESR command performs the AES shift rows operation on registers CA0, CA1, CA2, and CA3. The table below shows an example.

Table 31-17. AESR command example

| Register | Before | After |
|----------|-------------|-------------|
| CA0 | 0x0102_0304 | 0x0106_0B00 |
| CA1 | 0x0506_0708 | 0x050A_0F04 |
| CA2 | 0x090A_0B0C | 0x090E_0308 |
| CA3 | 0x0D0E_0F00 | 0x0D02_070C |

31.6.3.16 AES Inverse Shift Rows (AESIR)

The AESIR command performs the AES inverse shift rows operation on registers CA0, CA1, CA2, and CA3. The table below shows an example.

Table 31-18. AESIR command example

| Register | Before | After |
|----------|-------------|-------------|
| CA0 | 0x0106_0B00 | 0x0102_0304 |
| CA1 | 0x050A_0F04 | 0x0506_0708 |
| CA2 | 0x090E_0308 | 0x090A_0B0C |
| CA3 | 0x0D02_070C | 0x0D0E_0F00 |

31.6.3.17 DES Round (DESR)

The DESR command performs a round of the DES algorithm and a key schedule update with the following source and destination designations: CA0=C, CA1=D, CA2=L, CA3=R. If the IP bit is set, DES initial permutation performs on CA2 and CA3 before the round operation. If the FP bit is set, DES final permutation, that is, inverse initial permutation, performs on CA2 and CA3 after the round operation. The round operation uses the source values from registers CA0 and CA1 for the key addition operation. The KSx field specifies the shift for the key schedule operation to update the values in CA0 and CA1. The following table defines the specific shift function performed based on the KSx field.

Table 31-19. Key shift function codes

| KSx code | KSx define | Shift function |
|----------|------------|----------------|
| 0 | KSL1 | Left 1 |
| 1 | KSL2 | Left 2 |
| 2 | KSR1 | Right 1 |
| 3 | KSR2 | Right 2 |

31.6.3.18 DES Key setup (DESK)

The DESK command performs the initial key transformation, permuted choice 1, defined by the DES algorithm on CA0 and CA1 with CA0 containing bits 1–32 of the key and CA1 containing bits 33–64 of the key¹. If the DC bit is set, no shift operation performs and the values C₀ and D₀ store back to CA0 and CA1, respectively. The DC bit must be set for decrypt operations. If the DC bit is not set, a left shift by one also occurs and the values C₁ and D₁ store back to CA0 and CA1, respectively. The DC bit should be cleared for encrypt operations. If the CP bit is set and a key parity error is detected, CASR[DPE] bit is set; otherwise, it is cleared.

31.6.3.19 Hash Function (HASH)

The HASH command performs a hashing operation on a set of registers and adds that result to the value in CAA and stores the result in CAA. The specific hash function performed is based on the HFX field as defined in the table below.

This table uses the following terms:

- ROTRⁿ(CA_x): rotate CA_x register right *n* times
- SHRⁿ(CA_x): shift CA_x register right *n* times

Table 31-20. Hash Function codes

| HFX code | HFX define | Hash Function | Hash logic |
|----------|------------|-----------------------|---|
| 0 | HFF | MD5 F() | (CA1 & CA2) (CA1 & CA3) |
| 1 | HFG | MD5 G() | (CA1 & CA3) (CA2 & CA3) |
| 2 | HFH | MD5 H(), SHA Parity() | CA1 ^ CA2 ^ CA3 |
| 3 | HFI | MD5 I() | CA2 ^ (CA1 CA3) |
| 4 | HFC | SHA Ch() | (CA1 & CA2) ^ (CA1 & CA3) |
| 5 | HFM | SHA Maj() | (CA1 & CA2) ^ (CA1 & CA3) ^ (CA2 & CA3) |
| 6 | HF2C | SHA-256 Ch() | (CA4 & CA5) ^ (CA1 & CA6) |
| 7 | HF2M | SHA-256 Maj() | (CA0 & CA1) ^ (CA0 & CA2) ^ (CA1 & CA2) |
| 8 | HF2S | SHA-256 Sigma 0 | ROTR ² (CA0) ^ ROTR ¹³ (CA0) ^ ROTR ²² (CA0) |
| 9 | HF2T | SHA-256 Sigma 1 | ROTR ⁶ (CA4) ^ ROTR ¹¹ (CA4) ^ ROTR ²⁵ (CA4) |
| A | HF2U | SHA-256 Sigma 0 | ROTR ⁷ (CA8) ^ ROTR ¹⁸ (CA8) ^ SHR ³ (CA8) |
| B | HF2V | SHA-256 Sigma 1 | ROTR ¹⁷ (CA8) ^ ROTR ¹⁹ (CA8) ^ SHR ¹⁰ (CA8) |

1. The DES algorithm numbers the most significant bit of a block as bit 1 and the least significant as bit 64.

31.6.3.20 Secure Hash Shift (SHS)

The SHS command does a set of parallel register-to-register move and shift operations for implementing SHA-1. The following source and destination assignments are made:

| Register | Value prior to command | Value after command executes |
|----------|------------------------|------------------------------|
| CA4 | CA4 | CA3 |
| CA3 | CA3 | CA2 |
| CA2 | CA2 | CA1<<<30 |
| CA1 | CA1 | CA0 |
| CA0 | CA0 | CAA |
| CAA | CAA | CAA<<<5 |

31.6.3.21 Message Digest Shift (MDS)

The MDS command does a set of parallel register-to-register move operations for implementing MD5. The following source and destination assignments are made:

| Register | Value prior to command | Value after command executes |
|----------|------------------------|------------------------------|
| CA3 | CA3 | CA2 |
| CA2 | CA2 | CA1 |
| CA1 | CA1 | CAA |
| CAA | CAA | CA3 |

31.6.3.22 Secure Hash Shift 2 (SHS2)

The SHS2 command does an addition and a set of register to register moves in parallel for implementing SHA-256. The following source and destination assignments are made:

| Register | Value prior to command | Value after command executes |
|----------|------------------------|------------------------------|
| CA7 | CA7 | CA6 |
| CA6 | CA6 | CA5 |
| CA5 | CA5 | CA4 |
| CA4 | CA4 | CA3+CA8 |
| CA3 | CA3 | CA2 |
| CA2 | CA2 | CA1 |
| CA1 | CA1 | CA0 |
| CA0 | CA0 | CAA |

31.6.3.23 Illegal command (ILL)

The ILL command is a specific illegal command that sets CASR[IC]. All other illegal commands are reserved for use in future implementations.

31.7 Application/initialization information

This section discusses how to initialize and use the MMCAU.

31.7.1 Code example

A code fragment is shown below as an example of how the MMCAU is used. This example shows the round function of the AES algorithm. Core registers are defined as follows:

- R1 points to the key schedule
- R3 contains three direct MMCAU commands
- R8 contains two direct MMCAU commands
- R9 contains an indirect MMCAU command
- FP points to the MMCAU indirect command address space
- IP points to the MMCAU direct command space

```

movw    fp, #:lower16:MMCAU_PPB_INDIRECT      @ fp -> MMCAU_PPB_INDIRECT
movt    fp, #:upper16:MMCAU_PPB_INDIRECT
movw    ip, #:lower16:MMCAU_PPB_DIRECT        @ ip -> MMCAU_PPB_DIRECT
movt    ip, #:upper16:MMCAU_PPB_DIRECT

# r3 = mmcau_3_cmds(AESS+CA0,AESS+CA1,AESS+CA2)
movw    r3, #:lower16:(0x80100200+(AESS+CA0)<<22+(AESS+CA1)<<11+AESS+CA2)
movt    r3, #:upper16:(0x80100200+(AESS+CA0)<<22+(AESS+CA1)<<11+AESS+CA2)

# r8 = mmcau_2_cmds(AESS+CA3,AESR)
movw    r8, #:lower16:(0x80100000+(AESS+CA3)<<22+(AESR)<<11)
movt    r8, #:upper16:(0x80100000+(AESS+CA3)<<22+(AESR)<<11)

add     r9, fp, $((AESC+CA0)<<2)              @ r9 = mmcau_cmd(AESC+CA0)

str     r3, [ip]                             @ sub bytes w0, w1, w2
str     r8, [ip]                             @ sub bytes w3, shift rows
ldmia   r1!, {r4-r7}                         @ get next 4 keys; r1++
stmia   r9, {r4-r7}                         @ mix columns, add keys

```

31.7.2 Assembler equate values

The following equates ease programming of the MMCAU.

```
; CAU Registers (CAx)
```

Application/initialization information

```
.set CASR,0x0
.set CAA,0x1
.set CA0,0x2
.set CA1,0x3
.set CA2,0x4
.set CA3,0x5
.set CA4,0x6
.set CA5,0x7
.set CA6,0x8
.set CA7,0x9
.set CA8,0xA
; CAU Commands
.set CNOP,0x000
.set LDR,0x010
.set STR,0x020
.set ADR,0x030
.set RADR,0x040
.set ADRA,0x050
.set XOR,0x060
.set ROTL,0x070
.set MVRA,0x080
.set MVAR,0x090
.set AESS,0x0A0
.set AESIS,0x0B0
.set AESC,0x0C0
.set AESIC,0x0D0
.set AESR,0x0E0
.set AESIR,0x0F0
.set DESR,0x100
.set DESK,0x110
.set HASH,0x120
.set SHS,0x130
.set MDS,0x140
.set SHS2,0x150
.set ILL,0x1F0
; DESR Fields
.set IP,0x08      ; initial permutation
.set FP,0x04      ; final permutation
.set KSL1,0x00    ; key schedule left 1 bit
.set KSL2,0x01    ; key schedule left 2 bits
.set KSR1,0x02    ; key schedule right 1 bit
.set KSR2,0x03    ; key schedule right 2 bits
; DESK Field
.set DC,0x01      ; decrypt key schedule
.set CP,0x02      ; check parity
; HASH Functions Codes
.set HFF,0x0      ; MD5 F() CA1&CA2 | ~CA1&CA3
.set HFG,0x1      ; MD5 G() CA1&CA3 | CA2&~CA3
.set HFH,0x2      ; MD5 H(), SHA Parity() CA1^CA2^CA3
.set HFI,0x3      ; MD5 I() CA2^(CA1|~CA3)
.set HFC,0x4      ; SHA Ch() CA1&CA2 ^ ~CA1&CA3
.set HFM,0x5      ; SHA Maj() CA1&CA2 ^ CA1&CA3 ^ CA2&CA3
.set HF2C,0x6     ; SHA-256 Ch() CA4&CA5 ^ ~CA4&CA6
.set HF2M,0x7     ; SHA-256 Maj() CA0&CA1 ^ CA0&CA2 ^ CA1&CA2
.set HF2S,0x8     ; SHA-256 Sigma 0 ROTR2(CA0)^ROTR13(CA0)^ROTR22(CA0)
.set HF2T,0x9     ; SHA-256 Sigma 1 ROTR6(CA4)^ROTR11(CA4)^ROTR25(CA4)
.set HF2U,0xA     ; SHA-256 sigma 0 ROTR7(CA8)^ROTR18(CA8)^SHR3(CA8)
.set HF2V,0xB     ; SHA-256 sigma 1 ROTR17(CA8)^ROTR19(CA8)^SHR10(CA8)
```

Chapter 32

Random Number Generator Accelerator (RNGA)

32.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

This chapter describes the random-number-generator accelerator RNGA, including a programming model, functional description, and application information. Throughout this chapter, the terms "RNG" and "RNGA" are meant to be synonymous.

32.1.1 Overview

RNGA is a digital integrated circuit capable of generating 32-bit random numbers. The random bits are generated using shift registers with clocks derived from two free-running, independent ring oscillators. The configuration of the shift registers ensures statistically good data, that is, data that looks random. The oscillators, with their unknown frequencies and independent phases, provide the means of generating the required entropy needed to create random data. The random words generated by RNGA are loaded into an output register (OR). RNGA is designed to generate an error interrupt (if not masked), if OR is read and does not contain valid random data. OR contains valid random data if the LVL field in the status register (SR) is 1.

It is important to note there is no known cryptographic proof showing this is a secure method of generating random data. In fact, there may be an attack against this random number generator if its output is used directly in a cryptographic application. The attack is based on the linearity of the internal shift registers. Therefore, it is highly recommended that this random data produced by this module be used as an entropy source to provide an input seed to a NIST-approved pseudo-random-number generator based on DES or SHA-1 and defined in *NIST FIPS PUB 186-2 Appendix 3* and *NIST FIPS PUB SP 800-90*.

The requirement is to maximize the entropy of this input seed. In order to do this, when data is extracted from RNGA as quickly as the hardware allows, there are about one or two bits of added entropy per 32-bit word. Any single bit of that word contains that entropy. Therefore, when used as an entropy source, a random number should be generated for each bit of entropy required, and the least significant bit (any bit would be equivalent) of each word retained. The remainder of each random number should then be discarded. Used this way, even with full knowledge of the internal state of RNGA and all prior random numbers, an attacker is not able to predict the values of the extracted bits.

Other sources of entropy can be used along with RNGA to generate the seed to the pseudorandom algorithm. The more random sources combined to create the seed, the better. The following is a list of sources that can be easily combined with the output of this module:

- Current time using highest precision possible
- Real-time system inputs that can be characterized as "random"
- Other entropy supplied directly by the user

32.2 Modes of operation

RNGA supports the following modes of operation.

Table 32-1. Modes of operation supported by RNGA

| Mode | Description |
|--------|--|
| Normal | The ring-oscillator clocks are active; RNGA generates entropy (randomness) from the clocks and stores it in shift registers. |
| Sleep | The ring-oscillator clocks are inactive; RNGA does not generate entropy. |

32.2.1 Entering Normal mode

To enter Normal mode, write 0 to CR[SLP].

32.2.2 Entering Sleep mode

To enter Sleep mode, write 1 to CR[SLP].

32.3 Memory map and register definition

This section describes the RNGA registers.

RNG memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--------------------------------|-----------------|-----------------------|-------------|----------------------------|
| 4002_9000 | RNGA Control Register (RNG_CR) | 32 | R/W | 0000_0000h | 32.3.1/641 |
| 4002_9004 | RNGA Status Register (RNG_SR) | 32 | R | 0001_0000h | 32.3.2/643 |
| 4002_9008 | RNGA Entropy Register (RNG_ER) | 32 | W (always reads 0) | 0000_0000h | 32.3.3/645 |
| 4002_900C | RNGA Output Register (RNG_OR) | 32 | R | 0000_0000h | 32.3.4/645 |

32.3.1 RNGA Control Register (RNG_CR)

Controls the operation of RNGA.

Address: 4002_9000h base + 0h offset = 4002_9000h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|-----|------|------|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | 0 | | | |
| W | | | | | | | | | | | | | SLP | CLRI | INTM | HA |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

RNG_CR field descriptions

| Field | Description |
|------------------|--|
| 31–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 SLP | Sleep Specifies whether RNGA is in Sleep or Normal mode. NOTE: You can also enter Sleep mode by asserting the DOZE signal. 0 Normal mode 1 Sleep (low-power) mode |
| 3 CLRI | Clear Interrupt Clears the interrupt by resetting the error-interrupt indicator (SR[ERRI]). 0 Do not clear the interrupt. 1 Clear the interrupt. When you write 1 to this field, RNGA then resets the error-interrupt indicator (SR[ERRI]). This bit always reads as 0. |
| 2 INTM | Interrupt Mask Masks the triggering of an error interrupt to the interrupt controller when an OR underflow condition occurs. An OR underflow condition occurs when you read OR[RANDOUT] and SR[OREG_LVL]=0. See the Output Register (OR) description. 0 Not masked 1 Masked |
| 1 HA | High Assurance Enables notification of security violations (via SR[SECV]). A security violation occurs when you read OR[RANDOUT] and SR[OREG_LVL]=0. NOTE: This field is sticky. After enabling notification of security violations, you must reset RNGA to disable them again. 0 Disabled 1 Enabled |
| 0 GO | Go Specifies whether random-data generation and loading (into OR[RANDOUT]) is enabled. NOTE: This field is sticky. You must reset RNGA to stop RNGA from loading OR[RANDOUT] with data. 0 Disabled 1 Enabled |

32.3.2 RNGA Status Register (RNG_SR)

Indicates the status of RNGA. This register is read-only.

Address: 4002_9000h base + 4h offset = 4002_9004h

| | | | | | | | | | | | | | | | | |
|-------|----------|----|----|----|----|----|----|----|-----------|----|----|-----|------|-----|-----|------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | OREG_SIZE | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | OREG_LVL | | | | | | | | 0 | | | SLP | ERRI | ORU | LRS | SECV |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

RNG_SR field descriptions

| Field | Description |
|--------------------|---|
| 31–24 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 23–16 OREG_SIZE | Output Register Size Indicates the size of the Output (OR) register in terms of the number of 32-bit random-data words it can hold. 1 One word (this value is fixed) |
| 15–8 OREG_LVL | Output Register Level Indicates the number of random-data words that are in OR[RANDOUT], which indicates whether OR[RANDOUT] is valid. NOTE: If you read OR[RANDOUT] when SR[OREG_LVL] is not 0, then the contents of a random number contained in OR[RANDOUT] are returned, and RNGA writes 0 to both OR[RANDOUT] and SR[OREG_LVL]. 0 No words (empty) 1 One word (valid) |

Table continues on the next page...

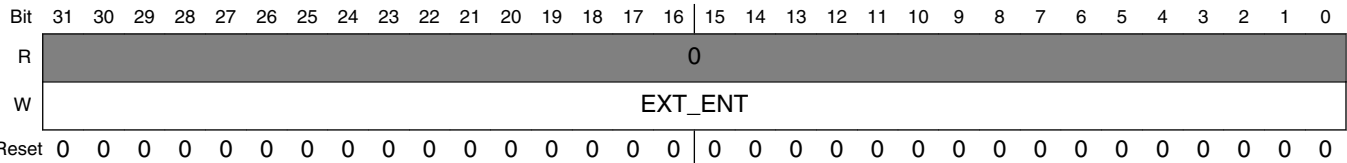
RNG_SR field descriptions (continued)

| Field | Description |
|-----------------|--|
| 7–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 SLP | Sleep Specifies whether RNGA is in Sleep or Normal mode. NOTE: You can also enter Sleep mode by asserting the DOZE signal. 0 Normal mode 1 Sleep (low-power) mode |
| 3 ERRI | Error Interrupt Indicates whether an OR underflow condition has occurred since you last cleared the error interrupt (CR[CLRI]) or RNGA was reset, regardless of whether the error interrupt is masked (CR[INTM]). An OR underflow condition occurs when you read OR[RANDOUT] and SR[OREG_LVL]=0. NOTE: After you reset the error-interrupt indicator (via CR[CLRI]), RNGA writes 0 to this field. 0 No underflow 1 Underflow |
| 2 ORU | Output Register Underflow Indicates whether an OR underflow condition has occurred since you last read this register (SR) or RNGA was reset, regardless of whether the error interrupt is masked (CR[INTM]). An OR underflow condition occurs when you read OR[RANDOUT] and SR[OREG_LVL]=0. NOTE: After you read this register, RNGA writes 0 to this field. 0 No underflow 1 Underflow |
| 1 LRS | Last Read Status Indicates whether the most recent read of OR[RANDOUT] caused an OR underflow condition, regardless of whether the error interrupt is masked (CR[INTM]). An OR underflow condition occurs when you read OR[RANDOUT] and SR[OREG_LVL]=0. NOTE: After you read this register, RNGA writes 0 to this field. 0 No underflow 1 Underflow |
| 0 SECV | Security Violation Used only when high assurance is enabled (CR[HA]). Indicates that a security violation has occurred. NOTE: This field is sticky. To clear SR[SECV], you must reset RNGA. 0 No security violation 1 Security violation |

32.3.3 RNGA Entropy Register (RNG_ER)

Specifies an entropy value that RNGA uses in addition to its ring oscillators to seed its pseudorandom algorithm. This is a write-only register; reads return all zeros.

Address: 4002_9000h base + 8h offset = 4002_9008h



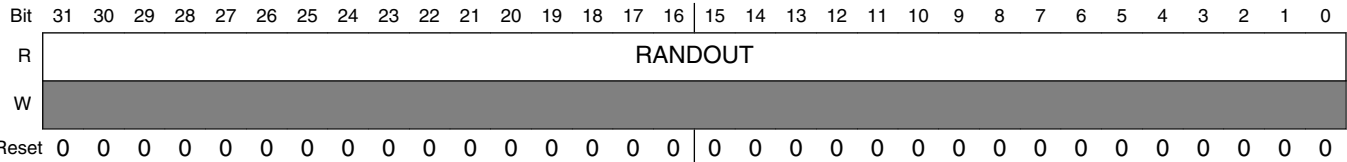
RNG_ER field descriptions

| Field | Description |
|-----------------|---|
| 31–0 EXT_ENT | <p>External Entropy</p> <p>Specifies an entropy value that RNGA uses in addition to its ring oscillators to seed its pseudorandom algorithm.</p> <p>NOTE: Specifying a value for this field is optional but recommended. You can write to this field at any time during operation.</p> |

32.3.4 RNGA Output Register (RNG_OR)

Stores a random-data word generated by RNGA.

Address: 4002_9000h base + Ch offset = 4002_900Ch



RNG_OR field descriptions

| Field | Description |
|-----------------|---|
| 31–0 RANDOUT | <p>Random Output</p> <p>Stores a random-data word generated by RNGA. This is a read-only field.</p> <p>NOTE: Before reading RANDOUT, be sure it is valid (SR[OREG_LVL]=1).</p> |

RNG_OR field descriptions (continued)

| Field | Description |
|------------------|--|
| 0 | Invalid data (if you read this field when it is 0 and SR[OREG_LVL] is 0, RNGA then writes 1 to SR[ERRI], SR[ORU], and SR[LRS]; when the error interrupt is not masked (CR[INTM]=0), RNGA also asserts an error interrupt request to the interrupt controller). |
| All other values | Valid data (if you read this field when SR[OREG_LVL] is not 0, RNGA returns RANDOUT, and then writes 0 to this field and to SR[OREG_LVL]). |

32.4 Functional description

This is a block diagram of RNGA.

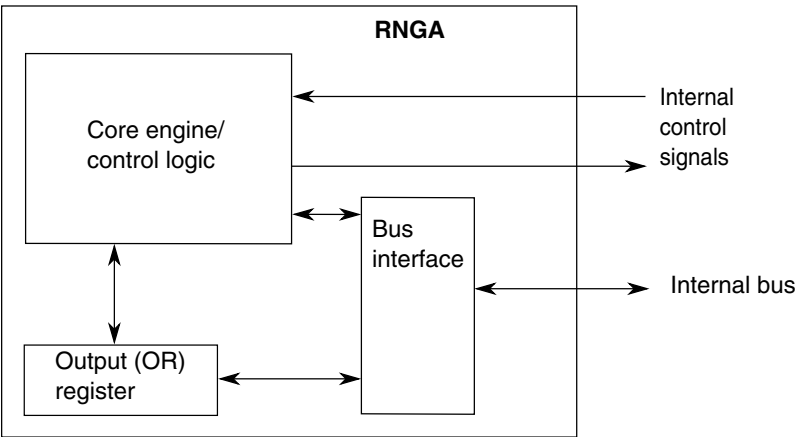


Figure 32-5. RNGA block diagram

32.4.1 Output (OR) register

The Output (OR) register provides temporary storage for random data generated by the core engine / control logic. The Status (SR) register allows the user to monitor the presence of valid random data in OR through SR[OREG_LVL].

If the OR is read while containing valid random data (as signaled by SR[OREG_LVL] = 1), the valid data is returned, then OR and SR[OREG_LVL] are both cleared. If the user reads from OR when it is empty, RNGA returns all zeros and, if the interrupt is enabled, RNGA drives a request to the interrupt controller. Polling SR[OREG_LVL] is very important to make sure random values are present before reading from OR.

32.4.2 Core engine / control logic

This block contains RNGA's control logic as well as its core engine used to generate random data.

32.4.2.1 Control logic

The control logic contains the address decoder, all addressable registers, and control state machines for RNGA. This block is responsible for communication with both the peripheral interface and the Output (OR) register interface. The block also controls the core engine to generate random data. The general functionality of the block is as follows:

After reset, RNGA operates in Normal mode as follows:

1. The core engine generates entropy and stores it in the shift registers.
2. After you enable random-data generation by loading CR[GO], every 256 clock cycles the core engine generates a new random-data word. If SR[OREG_LVL] = 0, then the control block loads the new random data into OR and set SR[OREG_LVL] = 1; else the new data is discarded.

32.4.2.2 Core engine

The core engine block contains the logic used to generate random data. The logic within the core engine contains the internal shift registers as well as the logic used to generate the two oscillator-based clocks. The control logic determines how the shift registers are configured as well as when the oscillator clocks are turned on.

32.5 Initialization/application information

The intended general operation of RNGA is as follows:

1. Reset/initialize.
2. Write 1 to CR[INTM], CR[HA], and CR[GO].
3. Poll SR[OREG_LVL] until it is not 0.
4. When SR[OREG_LVL] is not 0, read the available random data from OR[RANDOUT].
5. Repeat steps 3 and 4 as needed.



For application information, see [Overview](#).

Chapter 33

Analog-to-Digital Converter (ADC)

33.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The 16-bit analog-to-digital converter (ADC) is a successive approximation ADC designed for operation within an integrated microcontroller system-on-chip.

NOTE

For the chip specific modes of operation, see the power management information of the device.

33.1.1 Features

Following are the features of the ADC module.

- Linear successive approximation algorithm with up to 16-bit resolution
- Up to four pairs of differential and 24 single-ended external analog inputs
- Output modes:
 - differential 16-bit, 13-bit, 11-bit, and 9-bit modes
 - single-ended 16-bit, 12-bit, 10-bit, and 8-bit modes
- Output format in 2's complement 16-bit sign extended for differential modes
- Output in right-justified unsigned format for single-ended
- Single or continuous conversion, that is, automatic return to idle after single conversion

- Configurable sample time and conversion speed/power
- Conversion complete/hardware average complete flag and interrupt
- Input clock selectable from up to four sources
- Operation in low-power modes for lower noise
- Asynchronous clock source for lower noise operation with option to output the clock
- Selectable hardware conversion trigger with hardware channel select
- Automatic compare with interrupt for less-than, greater-than or equal-to, within range, or out-of-range, programmable value
- Temperature sensor
- Hardware average function
- Selectable voltage reference: external or alternate
- Self-Calibration mode

33.1.2 Block diagram

The following figure is the ADC module block diagram.

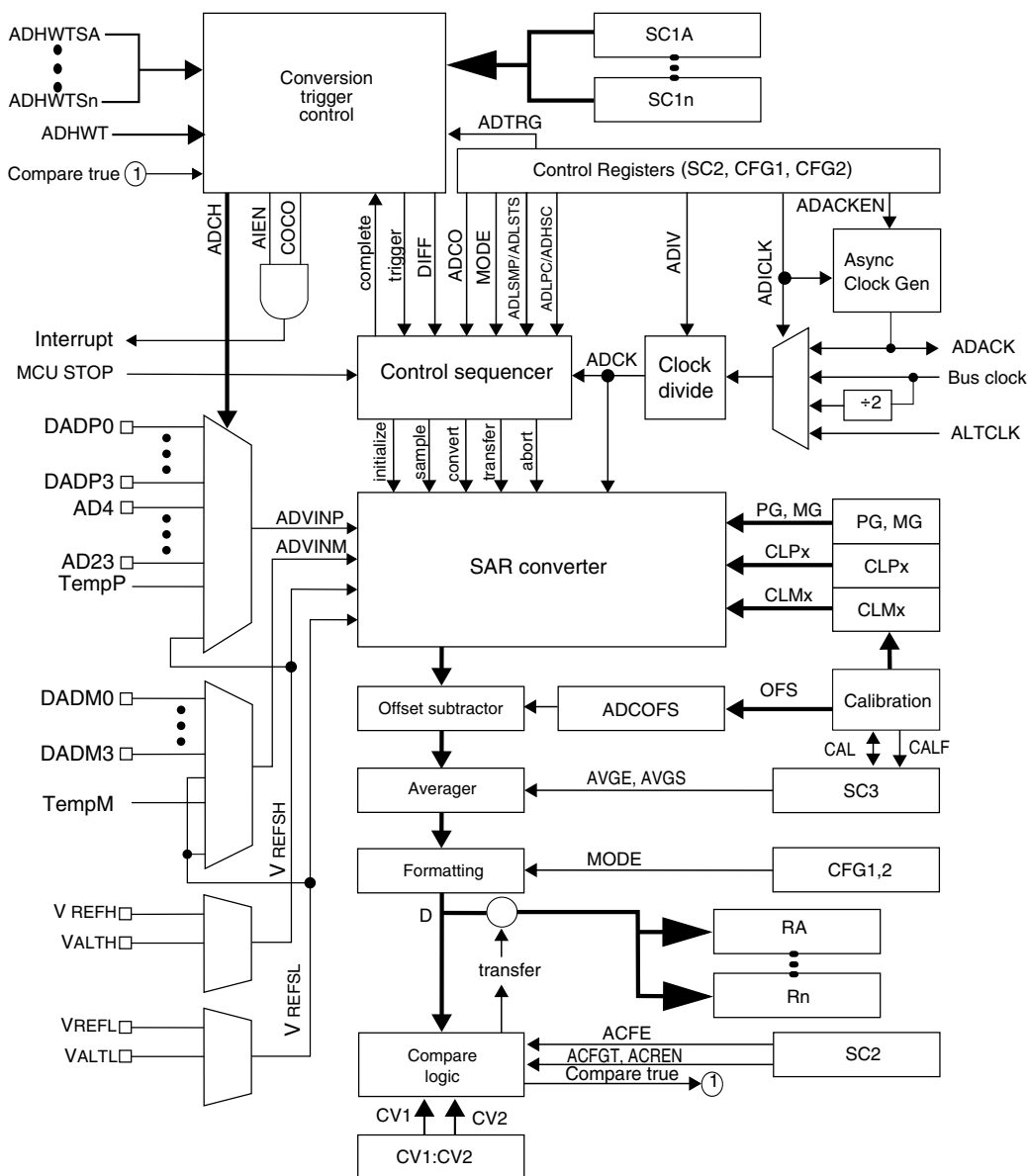


Figure 33-1. ADC block diagram

33.2 ADC signal descriptions

The ADC module supports up to 4 pairs of differential inputs and up to 24 single-ended inputs.

Each differential pair requires two inputs, DADPx and DADMx. The ADC also requires four supply/reference/ground connections.

NOTE

Refer to ADC configuration section in chip configuration chapter for the number of channels supported on this device.

Table 33-1. ADC signal descriptions

| Signal | Description | I/O |
|--------------------|------------------------------------|-----|
| DADP3–DADP0 | Differential Analog Channel Inputs | I |
| DADM3–DADM0 | Differential Analog Channel Inputs | I |
| AD _n | Single-Ended Analog Channel Inputs | I |
| V _{REFSH} | Voltage Reference Select High | I |
| V _{REFSL} | Voltage Reference Select Low | I |
| V _{DDA} | Analog Power Supply | I |
| V _{SSA} | Analog Ground | I |

33.2.1 Analog Power (V_{DDA})

The ADC analog portion uses V_{DDA} as its power connection. In some packages, V_{DDA} is connected internally to V_{DD}. If externally available, connect the V_{DDA} pin to the same voltage potential as V_{DD}. External filtering may be necessary to ensure clean V_{DDA} for good results.

33.2.2 Analog Ground (V_{SSA})

The ADC analog portion uses V_{SSA} as its ground connection. In some packages, V_{SSA} is connected internally to V_{SS}. If externally available, connect the V_{SSA} pin to the same voltage potential as V_{SS}.

33.2.3 Voltage Reference Select

V_{REFSH} and V_{REFSL} are the high and low reference voltages for the ADC module.

The ADC can be configured to accept one of two voltage reference pairs for V_{REFSH} and V_{REFSL}. Each pair contains a positive reference that must be between the minimum Ref Voltage High and V_{DDA}, and a ground reference that must be at the same potential as V_{SSA}. The two pairs are external (V_{REFH} and V_{REFL}) and alternate (V_{ALTH} and V_{ALTTL}). These voltage references are selected using SC2[REFSEL]. The alternate V_{ALTH} and V_{ALTTL} voltage reference pair may select additional external pins or internal sources depending on MCU configuration. See the chip configuration information on the Voltage References specific to this MCU.

In some packages, V_{REFH} is connected in the package to V_{DDA} and V_{REFL} to V_{SSA} . If externally available, the positive reference(s) may be connected to the same potential as V_{DDA} or may be driven by an external source to a level between the minimum Ref Voltage High and the V_{DDA} potential. V_{REFH} must never exceed V_{DDA} . Connect the ground references to the same voltage potential as V_{SSA} .

33.2.4 Analog Channel Inputs (ADx)

The ADC module supports up to 24 single-ended analog inputs. A single-ended input is selected for conversion through the $SC1[ADCH]$ channel select bits when $SC1n[DIFF]$ is low.

33.2.5 Differential Analog Channel Inputs (DADx)

The ADC module supports up to four differential analog channel inputs. Each differential analog input is a pair of external pins, $DADPx$ and $DADMx$, referenced to each other to provide the most accurate analog to digital readings. A differential input is selected for conversion through $SC1[ADCH]$ when $SC1n[DIFF]$ is high. All $DADPx$ inputs may be used as single-ended inputs if $SC1n[DIFF]$ is low. In certain MCU configurations, some $DADMx$ inputs may also be used as single-ended inputs if $SC1n[DIFF]$ is low. See the chip configuration chapter for ADC connections specific to this MCU.

33.3 Memory map and register definitions

This section describes the ADC registers.

ADC memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|--|-----------------|--------|-------------|----------------------------|
| 4003_B000 | ADC Status and Control Registers 1 (ADC0_SC1A) | 32 | R/W | 0000_001Fh | 33.3.1/654 |
| 4003_B004 | ADC Status and Control Registers 1 (ADC0_SC1B) | 32 | R/W | 0000_001Fh | 33.3.1/654 |
| 4003_B008 | ADC Configuration Register 1 (ADC0_CFG1) | 32 | R/W | 0000_0000h | 33.3.2/657 |
| 4003_B00C | ADC Configuration Register 2 (ADC0_CFG2) | 32 | R/W | 0000_0000h | 33.3.3/659 |
| 4003_B010 | ADC Data Result Register (ADC0_RA) | 32 | R | 0000_0000h | 33.3.4/660 |
| 4003_B014 | ADC Data Result Register (ADC0_RB) | 32 | R | 0000_0000h | 33.3.4/660 |
| 4003_B018 | Compare Value Registers (ADC0_CV1) | 32 | R/W | 0000_0000h | 33.3.5/661 |
| 4003_B01C | Compare Value Registers (ADC0_CV2) | 32 | R/W | 0000_0000h | 33.3.5/661 |

Table continues on the next page...

ADC memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4003_B020 | Status and Control Register 2 (ADC0_SC2) | 32 | R/W | 0000_0000h | 33.3.6/662 |
| 4003_B024 | Status and Control Register 3 (ADC0_SC3) | 32 | R/W | 0000_0000h | 33.3.7/664 |
| 4003_B028 | ADC Offset Correction Register (ADC0_OFS) | 32 | R/W | 0000_0004h | 33.3.8/666 |
| 4003_B02C | ADC Plus-Side Gain Register (ADC0_PG) | 32 | R/W | 0000_8200h | 33.3.9/666 |
| 4003_B030 | ADC Minus-Side Gain Register (ADC0_MG) | 32 | R/W | 0000_8200h | 33.3.10/667 |
| 4003_B034 | ADC Plus-Side General Calibration Value Register (ADC0_CLPD) | 32 | R/W | 0000_000Ah | 33.3.11/667 |
| 4003_B038 | ADC Plus-Side General Calibration Value Register (ADC0_CLPS) | 32 | R/W | 0000_0020h | 33.3.12/668 |
| 4003_B03C | ADC Plus-Side General Calibration Value Register (ADC0_CLP4) | 32 | R/W | 0000_0200h | 33.3.13/668 |
| 4003_B040 | ADC Plus-Side General Calibration Value Register (ADC0_CLP3) | 32 | R/W | 0000_0100h | 33.3.14/669 |
| 4003_B044 | ADC Plus-Side General Calibration Value Register (ADC0_CLP2) | 32 | R/W | 0000_0080h | 33.3.15/669 |
| 4003_B048 | ADC Plus-Side General Calibration Value Register (ADC0_CLP1) | 32 | R/W | 0000_0040h | 33.3.16/670 |
| 4003_B04C | ADC Plus-Side General Calibration Value Register (ADC0_CLP0) | 32 | R/W | 0000_0020h | 33.3.17/670 |
| 4003_B054 | ADC Minus-Side General Calibration Value Register (ADC0_CLMD) | 32 | R/W | 0000_000Ah | 33.3.18/671 |
| 4003_B058 | ADC Minus-Side General Calibration Value Register (ADC0_CLMS) | 32 | R/W | 0000_0020h | 33.3.19/671 |
| 4003_B05C | ADC Minus-Side General Calibration Value Register (ADC0_CLM4) | 32 | R/W | 0000_0200h | 33.3.20/672 |
| 4003_B060 | ADC Minus-Side General Calibration Value Register (ADC0_CLM3) | 32 | R/W | 0000_0100h | 33.3.21/672 |
| 4003_B064 | ADC Minus-Side General Calibration Value Register (ADC0_CLM2) | 32 | R/W | 0000_0080h | 33.3.22/673 |
| 4003_B068 | ADC Minus-Side General Calibration Value Register (ADC0_CLM1) | 32 | R/W | 0000_0040h | 33.3.23/673 |
| 4003_B06C | ADC Minus-Side General Calibration Value Register (ADC0_CLM0) | 32 | R/W | 0000_0020h | 33.3.24/674 |

33.3.1 ADC Status and Control Registers 1 (ADCx_SC1n)

SC1A is used for both software and hardware trigger modes of operation.

To allow sequential conversions of the ADC to be triggered by internal peripherals, the ADC can have more than one status and control register: one for each conversion. The SC1B–SC1n registers indicate potentially multiple SC1 registers for use only in hardware

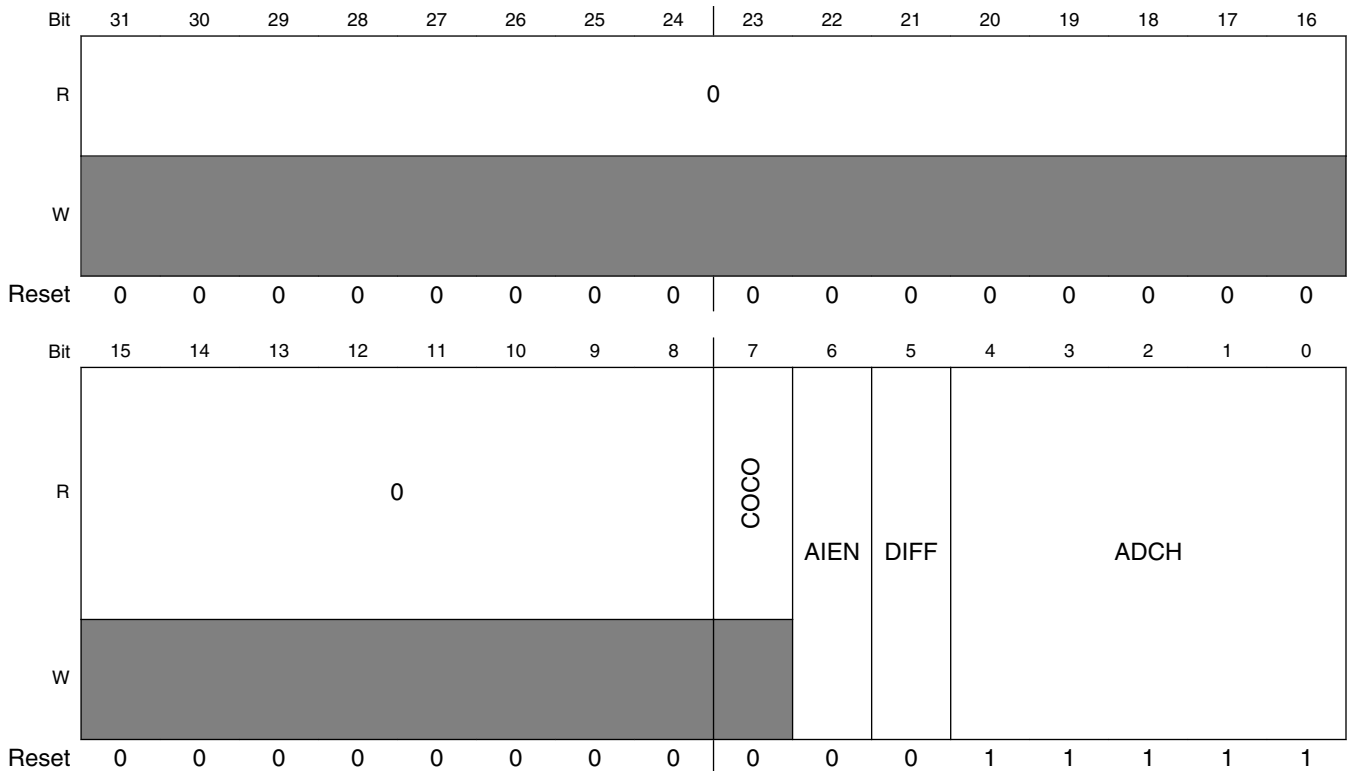
trigger mode. See the chip configuration information about the number of SC1n registers specific to this device. The SC1n registers have identical fields, and are used in a "ping-pong" approach to control ADC operation.

At any one point in time, only one of the SC1n registers is actively controlling ADC conversions. Updating SC1A while SC1n is actively controlling a conversion is allowed, and vice-versa for any of the SC1n registers specific to this MCU.

Writing SC1A while SC1A is actively controlling a conversion aborts the current conversion. In Software Trigger mode, when SC2[ADTRG]=0, writes to SC1A subsequently initiate a new conversion, if SC1[ADCH] contains a value other than all 1s.

Writing any of the SC1n registers while that specific SC1n register is actively controlling a conversion aborts the current conversion. None of the SC1B-SC1n registers are used for software trigger operation and therefore writes to the SC1B-SC1n registers do not initiate a new conversion.

Address: 4003_B000h base + 0h offset + (4d × i), where i=0d to 1d



ADCx_SC1n field descriptions

| Field | Description |
|------------------|---|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 COCO | Conversion Complete Flag |

Table continues on the next page...

ADCx_SC1n field descriptions (continued)

| Field | Description |
|-------------|---|
| | <p>This is a read-only field that is set each time a conversion is completed when the compare function is disabled, or SC2[ACFE]=0 and the hardware average function is disabled, or SC3[AVGE]=0. When the compare function is enabled, or SC2[ACFE]=1, COCO is set upon completion of a conversion only if the compare result is true. When the hardware average function is enabled, or SC3[AVGE]=1, COCO is set upon completion of the selected number of conversions (determined by AVGS). COCO in SC1A is also set at the completion of a calibration sequence. COCO is cleared when the respective SC1n register is written or when the respective Rn register is read.</p> <p>0 Conversion is not completed. 1 Conversion is completed.</p> |
| 6 AIEN | <p>Interrupt Enable</p> <p>Enables conversion complete interrupts. When COCO becomes set while the respective AIEN is high, an interrupt is asserted.</p> <p>0 Conversion complete interrupt is disabled. 1 Conversion complete interrupt is enabled.</p> |
| 5 DIFF | <p>Differential Mode Enable</p> <p>Configures the ADC to operate in differential mode. When enabled, this mode automatically selects from the differential channels, and changes the conversion algorithm and the number of cycles to complete a conversion.</p> <p>0 Single-ended conversions and input channels are selected. 1 Differential conversions and input channels are selected.</p> |
| 4–0 ADCH | <p>Input channel select</p> <p>Selects one of the input channels. The input channel decode depends on the value of DIFF. DAD0-DAD3 are associated with the input pin pairs DADPx and DADMx.</p> <p>NOTE: Some of the input channel options in the bitfield-setting descriptions might not be available for your device. For the actual ADC channel assignments for your device, see the Chip Configuration details.</p> <p>The successive approximation converter subsystem is turned off when the channel select bits are all set, that is, ADCH = 11111. This feature allows explicit disabling of the ADC and isolation of the input channel from all sources. Terminating continuous conversions this way prevents an additional single conversion from being performed. It is not necessary to set ADCH to all 1s to place the ADC in a low-power state when continuous conversions are not enabled because the module automatically enters a low-power state when a conversion completes.</p> <p>00000 When DIFF=0, DADP0 is selected as input; when DIFF=1, DAD0 is selected as input. 00001 When DIFF=0, DADP1 is selected as input; when DIFF=1, DAD1 is selected as input. 00010 When DIFF=0, DADP2 is selected as input; when DIFF=1, DAD2 is selected as input. 00011 When DIFF=0, DADP3 is selected as input; when DIFF=1, DAD3 is selected as input. 00100 When DIFF=0, AD4 is selected as input; when DIFF=1, it is reserved. 00101 When DIFF=0, AD5 is selected as input; when DIFF=1, it is reserved. 00110 When DIFF=0, AD6 is selected as input; when DIFF=1, it is reserved. 00111 When DIFF=0, AD7 is selected as input; when DIFF=1, it is reserved. 01000 When DIFF=0, AD8 is selected as input; when DIFF=1, it is reserved. 01001 When DIFF=0, AD9 is selected as input; when DIFF=1, it is reserved. 01010 When DIFF=0, AD10 is selected as input; when DIFF=1, it is reserved. 01011 When DIFF=0, AD11 is selected as input; when DIFF=1, it is reserved.</p> |

Table continues on the next page...

ADCx_SC1n field descriptions (continued)

| Field | Description |
|-------|--|
| 01100 | When DIFF=0, AD12 is selected as input; when DIFF=1, it is reserved. |
| 01101 | When DIFF=0, AD13 is selected as input; when DIFF=1, it is reserved. |
| 01110 | When DIFF=0, AD14 is selected as input; when DIFF=1, it is reserved. |
| 01111 | When DIFF=0, AD15 is selected as input; when DIFF=1, it is reserved. |
| 10000 | When DIFF=0, AD16 is selected as input; when DIFF=1, it is reserved. |
| 10001 | When DIFF=0, AD17 is selected as input; when DIFF=1, it is reserved. |
| 10010 | When DIFF=0, AD18 is selected as input; when DIFF=1, it is reserved. |
| 10011 | When DIFF=0, AD19 is selected as input; when DIFF=1, it is reserved. |
| 10100 | When DIFF=0, AD20 is selected as input; when DIFF=1, it is reserved. |
| 10101 | When DIFF=0, AD21 is selected as input; when DIFF=1, it is reserved. |
| 10110 | When DIFF=0, AD22 is selected as input; when DIFF=1, it is reserved. |
| 10111 | When DIFF=0, AD23 is selected as input; when DIFF=1, it is reserved. |
| 11000 | Reserved. |
| 11001 | Reserved. |
| 11010 | When DIFF=0, Temp Sensor (single-ended) is selected as input; when DIFF=1, Temp Sensor (differential) is selected as input. |
| 11011 | When DIFF=0, Bandgap (single-ended) is selected as input; when DIFF=1, Bandgap (differential) is selected as input. |
| 11100 | Reserved. |
| 11101 | When DIFF=0, V_{REFSH} is selected as input; when DIFF=1, $-V_{REFSH}$ (differential) is selected as input. Voltage reference selected is determined by SC2[REFSEL]. |
| 11110 | When DIFF=0, V_{REFSL} is selected as input; when DIFF=1, it is reserved. Voltage reference selected is determined by SC2[REFSEL]. |
| 11111 | Module is disabled. |

33.3.2 ADC Configuration Register 1 (ADCx_CFG1)

The configuration Register 1 (CFG1) selects the mode of operation, clock source, clock divide, and configuration for low power or long sample time.

Address: 4003_B000h base + 8h offset = 4003_B008h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|-------|------|----|--------|------|----|--------|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | ADLPC | ADIV | | ADLSMP | MODE | | ADICLK | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

ADCx_CFG1 field descriptions

| Field | Description |
|------------------|---|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 ADLPC | Low-Power Configuration Controls the power configuration of the successive approximation converter. This optimizes power consumption when higher sample rates are not required. 0 Normal power configuration. 1 Low-power configuration. The power is reduced at the expense of maximum clock speed. |
| 6–5 ADIV | Clock Divide Select Selects the divide ratio used by the ADC to generate the internal clock ADCK. 00 The divide ratio is 1 and the clock rate is input clock. 01 The divide ratio is 2 and the clock rate is (input clock)/2. 10 The divide ratio is 4 and the clock rate is (input clock)/4. 11 The divide ratio is 8 and the clock rate is (input clock)/8. |
| 4 ADLSMP | Sample Time Configuration Selects between different sample times based on the conversion mode selected. This field adjusts the sample period to allow higher impedance inputs to be accurately sampled or to maximize conversion speed for lower impedance inputs. Longer sample times can also be used to lower overall power consumption if continuous conversions are enabled and high conversion rates are not required. When ADLSMP=1, the long sample time select bits, (ADLSTS[1:0]), can select the extent of the long sample time. 0 Short sample time. 1 Long sample time. |
| 3–2 MODE | Conversion mode selection Selects the ADC resolution mode. 00 When DIFF=0:It is single-ended 8-bit conversion; when DIFF=1, it is differential 9-bit conversion with 2's complement output. 01 When DIFF=0:It is single-ended 12-bit conversion ; when DIFF=1, it is differential 13-bit conversion with 2's complement output. 10 When DIFF=0:It is single-ended 10-bit conversion. ; when DIFF=1, it is differential 11-bit conversion with 2's complement output 11 When DIFF=0:It is single-ended 16-bit conversion..; when DIFF=1, it is differential 16-bit conversion with 2's complement output |
| 1–0 ADICLK | Input Clock Select Selects the input clock source to generate the internal clock, ADCK. Note that when the ADACK clock source is selected, it is not required to be active prior to conversion start. When it is selected and it is not active prior to a conversion start, when CFG2[ADACKEN]=0, the asynchronous clock is activated at the start of a conversion and deactivated when conversions are terminated. In this case, there is an associated clock startup delay each time the clock source is re-activated. 00 Bus clock 01 Bus clock divided by 2(BUSCLK/DIV2) 10 Alternate clock (ALTCLK) 11 Asynchronous clock (ADACK) |

33.3.3 ADC Configuration Register 2 (ADCx_CFG2)

Configuration Register 2 (CFG2) selects the special high-speed configuration for very high speed conversions and selects the long sample time duration during long sample mode.

Address: 4003_B000h base + Ch offset = 4003_B00Ch

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|--------|---------|-------|--------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | 0 | | | | MUXSEL | ADACKEN | ADHSC | ADLSTS |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

ADCx_CFG2 field descriptions

| Field | Description |
|------------------|---|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 MUXSEL | ADC Mux Select Changes the ADC mux setting to select between alternate sets of ADC channels. 0 ADxxa channels are selected. 1 ADxxb channels are selected. |
| 3 ADACKEN | Asynchronous Clock Output Enable Enables the asynchronous clock source and the clock source output regardless of the conversion and status of CFG1[ADICLK]. Based on MCU configuration, the asynchronous clock may be used by other modules. See chip configuration information. Setting this field allows the clock to be used even while the ADC is idle or operating from a different clock source. Also, latency of initiating a single or first-continuous conversion with the asynchronous clock selected is reduced because the ADACK clock is already operational. 0 Asynchronous clock output disabled; Asynchronous clock is enabled only if selected by ADICLK and a conversion is active. 1 Asynchronous clock and clock output is enabled regardless of the state of the ADC. |
| 2 ADHSC | High-Speed Configuration |

Table continues on the next page...

ADCx_CFG2 field descriptions (continued)

| Field | Description |
|---------------|---|
| | Configures the ADC for very high-speed operation. The conversion sequence is altered with 2 ADCK cycles added to the conversion time to allow higher speed conversion clocks. 0 Normal conversion sequence selected. 1 High-speed conversion sequence selected with 2 additional ADCK cycles to total conversion time. |
| 1–0 ADLSTS | Long Sample Time Select Selects between the extended sample times when long sample time is selected, that is, when CFG1[ADLSMP]=1. This allows higher impedance inputs to be accurately sampled or to maximize conversion speed for lower impedance inputs. Longer sample times can also be used to lower overall power consumption when continuous conversions are enabled if high conversion rates are not required. 00 Default longest sample time; 20 extra ADCK cycles; 24 ADCK cycles total. 01 12 extra ADCK cycles; 16 ADCK cycles total sample time. 10 6 extra ADCK cycles; 10 ADCK cycles total sample time. 11 2 extra ADCK cycles; 6 ADCK cycles total sample time. |

33.3.4 ADC Data Result Register (ADCx_Rn)

The data result registers (Rn) contain the result of an ADC conversion of the channel selected by the corresponding status and channel control register (SC1A:SC1n). For every status and channel control register, there is a corresponding data result register.

Unused bits in Rn are cleared in unsigned right-aligned modes and carry the sign bit (MSB) in sign-extended 2's complement modes. For example, when configured for 10-bit single-ended mode, D[15:10] are cleared. When configured for 11-bit differential mode, D[15:10] carry the sign bit, that is, bit 10 extended through bit 15.

The following table describes the behavior of the data result registers in the different modes of operation.

Table 33-43. Data result register description

| Conversion mode | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Format |
|---------------------|-----|-----|-----|-----|-----|-----|----|----|----|----|----|----|----|----|----|----|------------------------------|
| 16-bit differential | S | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | Signed 2's complement |
| 16-bit single-ended | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | Unsigned right justified |
| 13-bit differential | S | S | S | S | D | D | D | D | D | D | D | D | D | D | D | D | Sign-extended 2's complement |
| 12-bit single-ended | 0 | 0 | 0 | 0 | D | D | D | D | D | D | D | D | D | D | D | D | Unsigned right-justified |
| 11-bit differential | S | S | S | S | S | S | D | D | D | D | D | D | D | D | D | D | Sign-extended 2's complement |

Table continues on the next page...

Table 33-43. Data result register description (continued)

| Conversion mode | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Format |
|---------------------|-----|-----|-----|-----|-----|-----|----|----|----|----|----|----|----|----|----|----|------------------------------|
| 10-bit single-ended | 0 | 0 | 0 | 0 | 0 | 0 | D | D | D | D | D | D | D | D | D | D | Unsigned right-justified |
| 9-bit differential | S | S | S | S | S | S | S | S | D | D | D | D | D | D | D | D | Sign-extended 2's complement |
| 8-bit single-ended | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | D | D | D | D | D | D | D | D | Unsigned right-justified |

NOTE

S: Sign bit or sign bit extension;

D: Data, which is 2's complement data if indicated

Address: 4003_B000h base + 10h offset + (4d × i), where i=0d to 1d

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | 0 | | | | | | | | | | | | | | | | D | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

ADCx_Rn field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 D | Data result |

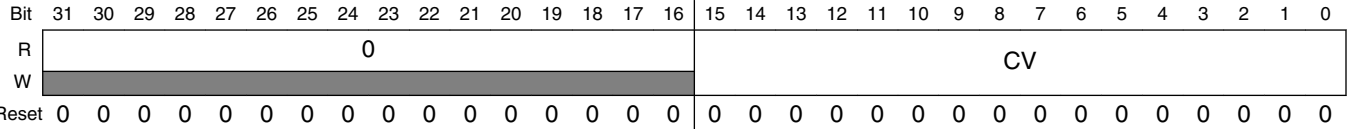
33.3.5 Compare Value Registers (ADCx_CVn)

The Compare Value Registers (CV1 and CV2) contain a compare value used to compare the conversion result when the compare function is enabled, that is, SC2[ACFE]=1. This register is formatted in the same way as the Rn registers in different modes of operation for both bit position definition and value format using unsigned or sign-extended 2's complement. Therefore, the compare function uses only the CVn fields that are related to the ADC mode of operation.

The compare value 2 register (CV2) is used only when the compare range function is enabled, that is, SC2[ACREN]=1.

memory map and register definitions

Address: 4003_B000h base + 18h offset + (4d × i), where i=0d to 1d



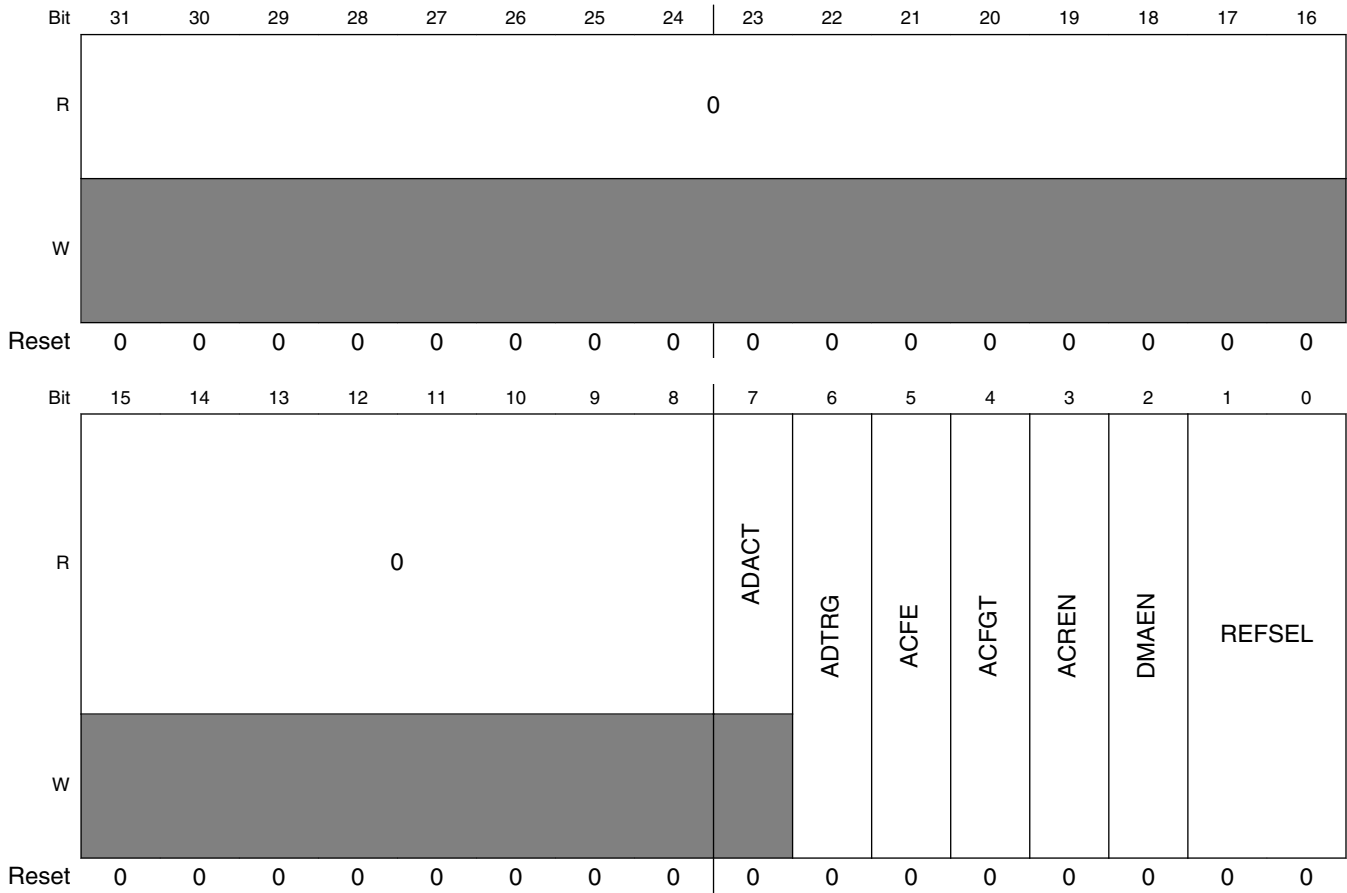
ADCx_CVn field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 CV | Compare Value. |

33.3.6 Status and Control Register 2 (ADCx_SC2)

The status and control register 2 (SC2) contains the conversion active, hardware/software trigger select, compare function, and voltage reference select of the ADC module.

Address: 4003_B000h base + 20h offset = 4003_B020h



ADCx_SC2 field descriptions

| Field | Description |
|------------------|--|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 ADACT | Conversion Active Indicates that a conversion or hardware averaging is in progress. ADACT is set when a conversion is initiated and cleared when a conversion is completed or aborted. 0 Conversion not in progress. 1 Conversion in progress. |
| 6 ADTRG | Conversion Trigger Select Selects the type of trigger used for initiating a conversion. Two types of trigger are selectable: <ul style="list-style-type: none"> Software trigger: When software trigger is selected, a conversion is initiated following a write to SC1A. Hardware trigger: When hardware trigger is selected, a conversion is initiated following the assertion of the ADHWT input after a pulse of the ADHWTSn input. 0 Software trigger selected. 1 Hardware trigger selected. |
| 5 ACFE | Compare Function Enable Enables the compare function. 0 Compare function disabled. 1 Compare function enabled. |
| 4 ACFGT | Compare Function Greater Than Enable Configures the compare function to check the conversion result relative to the CV1 and CV2 based upon the value of ACREN. ACFE must be set for ACFGT to have any effect. 0 Configures less than threshold, outside range not inclusive and inside range not inclusive; functionality based on the values placed in CV1 and CV2. 1 Configures greater than or equal to threshold, outside and inside ranges inclusive; functionality based on the values placed in CV1 and CV2. |
| 3 ACREN | Compare Function Range Enable Configures the compare function to check if the conversion result of the input being monitored is either between or outside the range formed by CV1 and CV2 determined by the value of ACFGT. ACFE must be set for ACFGT to have any effect. 0 Range function disabled. Only CV1 is compared. 1 Range function enabled. Both CV1 and CV2 are compared. |
| 2 DMAEN | DMA Enable 0 DMA is disabled. 1 DMA is enabled and will assert the ADC DMA request during an ADC conversion complete event noted when any of the SC1n[COCO] flags is asserted. |
| 1–0 REFSEL | Voltage Reference Selection Selects the voltage reference source used for conversions. 00 Default voltage reference pin pair, that is, external pins V_{REFH} and V_{REFL} |

Table continues on the next page...

ADCx_SC2 field descriptions (continued)

| Field | Description |
|-------|--|
| 01 | Alternate reference pair, that is, V_{ALTH} and V_{ALTL} . This pair may be additional external pins or internal sources depending on the MCU configuration. See the chip configuration information for details specific to this MCU |
| 10 | Reserved |
| 11 | Reserved |

33.3.7 Status and Control Register 3 (ADCx_SC3)

The Status and Control Register 3 (SC3) controls the calibration, continuous convert, and hardware averaging functions of the ADC module.

Address: 4003_B000h base + 24h offset = 4003_B024h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|-----|------|---|---|------|------|------|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | CAL | CALF | 0 | | ADCO | AVGE | AVGS | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

ADCx_SC3 field descriptions

| Field | Description |
|------------------|---|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

Table continues on the next page...

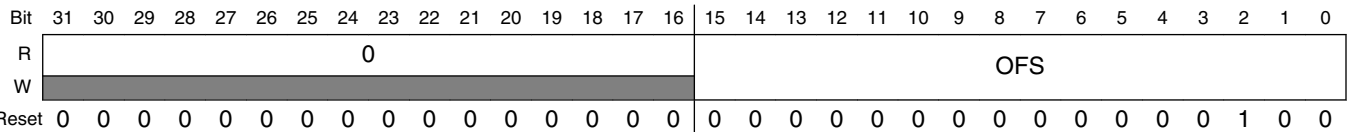
ADCx_SC3 field descriptions (continued)

| Field | Description |
|-----------------|--|
| 7 CAL | <p>Calibration</p> <p>Begins the calibration sequence when set. This field stays set while the calibration is in progress and is cleared when the calibration sequence is completed. CALF must be checked to determine the result of the calibration sequence. Once started, the calibration routine cannot be interrupted by writes to the ADC registers or the results will be invalid and CALF will set. Setting CAL will abort any current conversion.</p> |
| 6 CALF | <p>Calibration Failed Flag</p> <p>Displays the result of the calibration sequence. The calibration sequence will fail if SC2[ADTRG] = 1, any ADC register is written, or any stop mode is entered before the calibration sequence completes. Writing 1 to CALF clears it.</p> <p>0 Calibration completed normally. 1 Calibration failed. ADC accuracy specifications are not guaranteed.</p> |
| 5–4 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 3 ADCO | <p>Continuous Conversion Enable</p> <p>Enables continuous conversions.</p> <p>0 One conversion or one set of conversions if the hardware average function is enabled, that is, AVGE=1, after initiating a conversion. 1 Continuous conversions or sets of conversions if the hardware average function is enabled, that is, AVGE=1, after initiating a conversion.</p> |
| 2 AVGE | <p>Hardware Average Enable</p> <p>Enables the hardware average function of the ADC.</p> <p>0 Hardware average function disabled. 1 Hardware average function enabled.</p> |
| 1–0 AVGS | <p>Hardware Average Select</p> <p>Determines how many ADC conversions will be averaged to create the ADC average result.</p> <p>00 4 samples averaged. 01 8 samples averaged. 10 16 samples averaged. 11 32 samples averaged.</p> |

33.3.8 ADC Offset Correction Register (ADCx_OFS)

The ADC Offset Correction Register (OFS) contains the user-selected or calibration-generated offset error correction value. This register is a 2’s complement, left-justified, 16-bit value . The value in OFS is subtracted from the conversion and the result is transferred into the result registers, Rn. If the result is greater than the maximum or less than the minimum result value, it is forced to the appropriate limit for the current mode of operation.

Address: 4003_B000h base + 28h offset = 4003_B028h



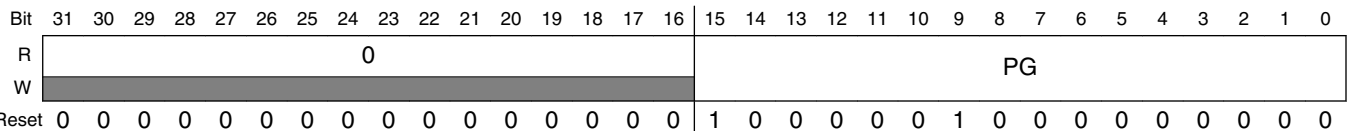
ADCx_OFS field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 OFS | Offset Error Correction Value |

33.3.9 ADC Plus-Side Gain Register (ADCx_PG)

The Plus-Side Gain Register (PG) contains the gain error correction for the plus-side input in differential mode or the overall conversion in single-ended mode. PG, a 16-bit real number in binary format, is the gain adjustment factor, with the radix point fixed between ADPG15 and ADPG14. This register must be written by the user with the value described in the calibration procedure. Otherwise, the gain error specifications may not be met.

Address: 4003_B000h base + 2Ch offset = 4003_B02Ch



ADCx_PG field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 PG | Plus-Side Gain |

33.3.10 ADC Minus-Side Gain Register (ADCx_MG)

The Minus-Side Gain Register (MG) contains the gain error correction for the minus-side input in differential mode. This register is ignored in single-ended mode. MG, a 16-bit real number in binary format, is the gain adjustment factor, with the radix point fixed between ADMG15 and ADMG14. This register must be written by the user with the value described in the calibration procedure. Otherwise, the gain error specifications may not be met.

Address: 4003_B000h base + 30h offset = 4003_B030h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | MG | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

ADCx_MG field descriptions

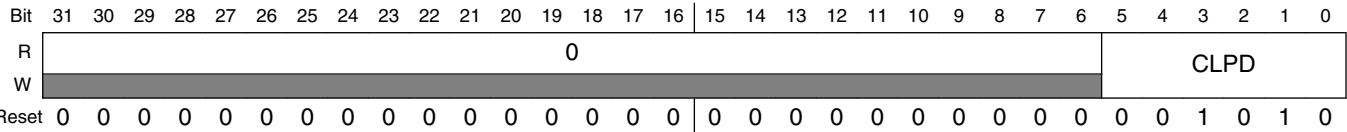
| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 MG | Minus-Side Gain |

33.3.11 ADC Plus-Side General Calibration Value Register (ADCx_CLPD)

The Plus-Side General Calibration Value Registers (CLPx) contain calibration information that is generated by the calibration function. These registers contain seven calibration values of varying widths: CLP0[5:0], CLP1[6:0], CLP2[7:0], CLP3[8:0], CLP4[9:0], CLPS[5:0], and CLPD[5:0]. CLPx are automatically set when the self-calibration sequence is done, that is, CAL is cleared. If these registers are written by the user after calibration, the linearity error specifications may not be met.

memory map and register definitions

Address: 4003_B000h base + 34h offset = 4003_B034h



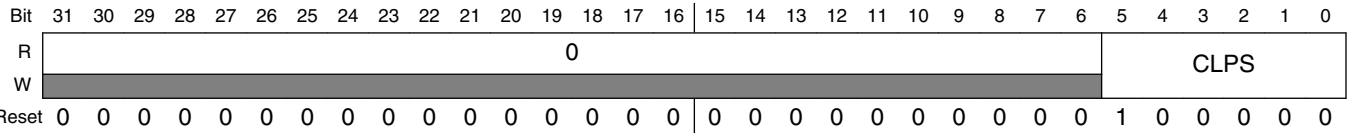
ADCx_CLPD field descriptions

| Field | Description |
|------------------|---|
| 31–6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5–0 CLPD | Calibration Value Calibration Value |

33.3.12 ADC Plus-Side General Calibration Value Register (ADCx_CLPS)

For more information, see CLPD register description.

Address: 4003_B000h base + 38h offset = 4003_B038h



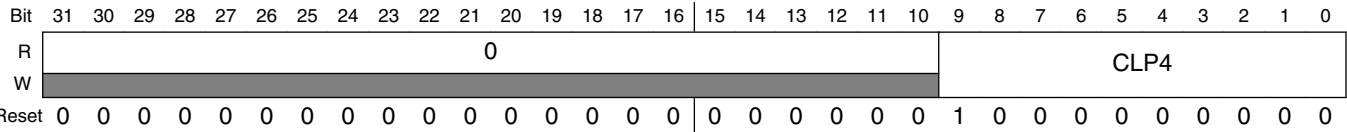
ADCx_CLPS field descriptions

| Field | Description |
|------------------|---|
| 31–6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5–0 CLPS | Calibration Value Calibration Value |

33.3.13 ADC Plus-Side General Calibration Value Register (ADCx_CLP4)

For more information, see CLPD register description.

Address: 4003_B000h base + 3Ch offset = 4003_B03Ch



ADCx_CLP4 field descriptions

| Field | Description |
|-------------------|---|
| 31–10 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 9–0 CLP4 | Calibration Value Calibration Value |

33.3.14 ADC Plus-Side General Calibration Value Register (ADCx_CLP3)

For more information, see CLPD register description.

Address: 4003_B000h base + 40h offset = 4003_B040h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | CLP3 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

ADCx_CLP3 field descriptions

| Field | Description |
|------------------|---|
| 31–9 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 8–0 CLP3 | Calibration Value Calibration Value |

33.3.15 ADC Plus-Side General Calibration Value Register (ADCx_CLP2)

For more information, see CLPD register description.

Address: 4003_B000h base + 44h offset = 4003_B044h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | CLP2 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

ADCx_CLP2 field descriptions

| Field | Description |
|------------------|---|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

Table continues on the next page...

ADCx_CLP2 field descriptions (continued)

| Field | Description |
|-------------|-------------------|
| 7–0 CLP2 | Calibration Value |
| | Calibration Value |

33.3.16 ADC Plus-Side General Calibration Value Register (ADCx_CLP1)

For more information, see CLPD register description.

Address: 4003_B000h base + 48h offset = 4003_B048h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | CLP1 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | CLP1 | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | |

ADCx_CLP1 field descriptions

| Field | Description |
|------------------|---|
| 31–7 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 6–0 CLP1 | Calibration Value |
| | Calibration Value |

33.3.17 ADC Plus-Side General Calibration Value Register (ADCx_CLP0)

For more information, see CLPD register description.

Address: 4003_B000h base + 4Ch offset = 4003_B04Ch

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | CLP0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | CLP0 | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | |

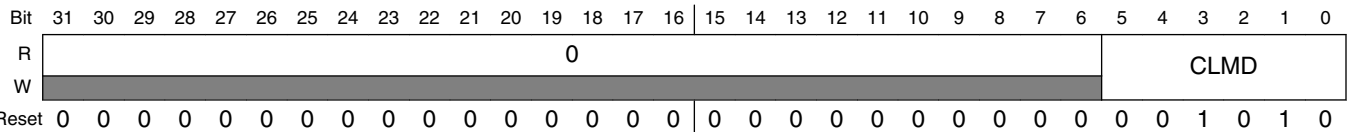
ADCx_CLP0 field descriptions

| Field | Description |
|------------------|---|
| 31–6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5–0 CLP0 | Calibration Value |
| | Calibration Value |

33.3.18 ADC Minus-Side General Calibration Value Register (ADCx_CLMD)

The Minus-Side General Calibration Value (CLMx) registers contain calibration information that is generated by the calibration function. These registers contain seven calibration values of varying widths: CLM0[5:0], CLM1[6:0], CLM2[7:0], CLM3[8:0], CLM4[9:0], CLMS[5:0], and CLMD[5:0]. CLMx are automatically set when the self-calibration sequence is done, that is, CAL is cleared. If these registers are written by the user after calibration, the linearity error specifications may not be met.

Address: 4003_B000h base + 54h offset = 4003_B054h



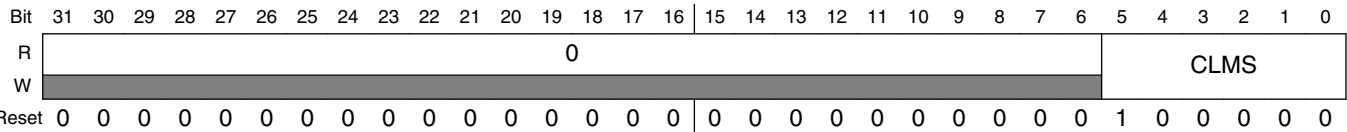
ADCx_CLMD field descriptions

| Field | Description |
|------------------|---|
| 31–6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5–0 CLMD | Calibration Value Calibration Value |

33.3.19 ADC Minus-Side General Calibration Value Register (ADCx_CLMS)

For more information, see CLMD register description.

Address: 4003_B000h base + 58h offset = 4003_B058h



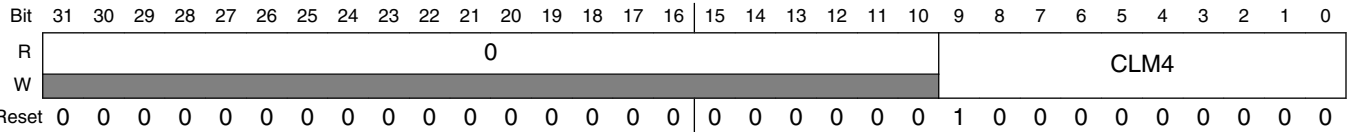
ADCx_CLMS field descriptions

| Field | Description |
|------------------|---|
| 31–6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5–0 CLMS | Calibration Value Calibration Value |

33.3.20 ADC Minus-Side General Calibration Value Register (ADCx_CLM4)

For more information, see CLMD register description.

Address: 4003_B000h base + 5Ch offset = 4003_B05Ch



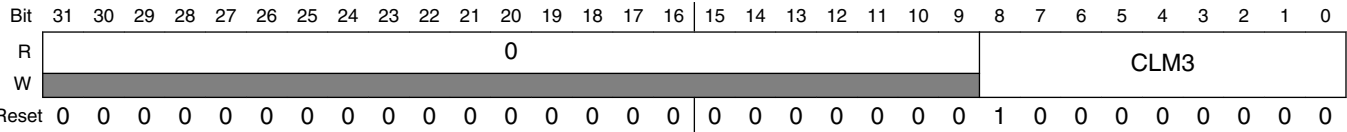
ADCx_CLM4 field descriptions

| Field | Description |
|-------------------|---|
| 31–10 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 9–0 CLM4 | Calibration Value Calibration Value |

33.3.21 ADC Minus-Side General Calibration Value Register (ADCx_CLM3)

For more information, see CLMD register description.

Address: 4003_B000h base + 60h offset = 4003_B060h



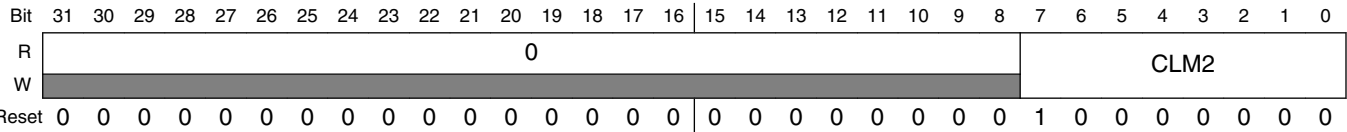
ADCx_CLM3 field descriptions

| Field | Description |
|------------------|---|
| 31–9 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 8–0 CLM3 | Calibration Value Calibration Value |

33.3.22 ADC Minus-Side General Calibration Value Register (ADCx_CLM2)

For more information, see CLMD register description.

Address: 4003_B000h base + 64h offset = 4003_B064h



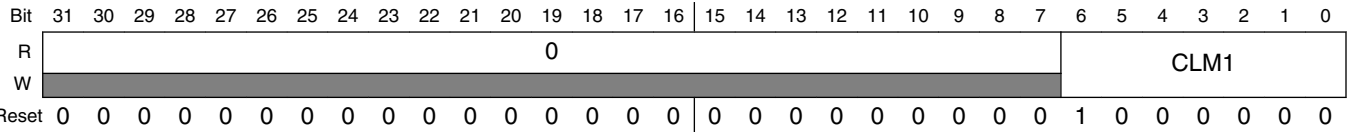
ADCx_CLM2 field descriptions

| Field | Description |
|------------------|---|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–0 CLM2 | Calibration Value Calibration Value |

33.3.23 ADC Minus-Side General Calibration Value Register (ADCx_CLM1)

For more information, see CLMD register description.

Address: 4003_B000h base + 68h offset = 4003_B068h



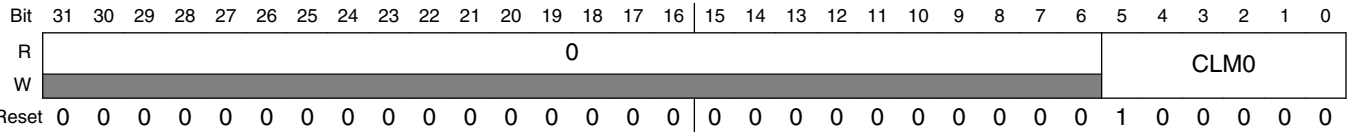
ADCx_CLM1 field descriptions

| Field | Description |
|------------------|---|
| 31–7 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 6–0 CLM1 | Calibration Value Calibration Value |

33.3.24 ADC Minus-Side General Calibration Value Register (ADCx_CLM0)

For more information, see CLMD register description.

Address: 4003_B000h base + 6Ch offset = 4003_B06Ch



ADCx_CLM0 field descriptions

| Field | Description |
|------------------|---|
| 31–6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5–0 CLM0 | Calibration Value Calibration Value |

33.4 Functional description

The ADC module is disabled during reset, in Low-Power Stop mode, or when SC1n[ADCH] are all high; see the power management information for details. The module is idle when a conversion has completed and another conversion has not been initiated. When it is idle and the asynchronous clock output enable is disabled, or CFG2[ADACKEN]= 0, the module is in its lowest power state. The ADC can perform an analog-to-digital conversion on any of the software selectable channels. All modes perform conversion by a successive approximation algorithm.

To meet accuracy specifications, the ADC module must be calibrated using the on-chip calibration function.

See [Calibration function](#) for details on how to perform calibration.

When the conversion is completed, the result is placed in the Rn data registers. The respective SC1n[COCO] is then set and an interrupt is generated if the respective conversion complete interrupt has been enabled, or, when SC1n[AIEN]=1.

The ADC module has the capability of automatically comparing the result of a conversion with the contents of the CV1 and CV2 registers. The compare function is enabled by setting SC2[ACFE] and operates in any of the conversion modes and configurations.

The ADC module has the capability of automatically averaging the result of multiple conversions. The hardware average function is enabled by setting SC3[AVGE] and operates in any of the conversion modes and configurations.

NOTE

For the chip specific modes of operation, see the power management information of this MCU.

33.4.1 Clock select and divide control

One of four clock sources can be selected as the clock source for the ADC module.

This clock source is then divided by a configurable value to generate the input clock ADCK, to the module. The clock is selected from one of the following sources by means of CFG1[ADICLK].

- Bus clock. This is the default selection following reset.
- Bus clock divided by two. For higher bus clock rates, this allows a maximum divide-by-16 of the bus clock using CFG1[ADIV].
- ALTCLK: As defined for this MCU. See the chip configuration information. Conversions are possible using ALTCLK as the input clock source while the MCU is in Normal Stop mode.
- Asynchronous clock (ADACK): This clock is generated from a clock source within the ADC module. When the ADACK clock source is selected, it is not required to be active prior to conversion start. When it is selected and it is not active prior to a conversion start CFG2[ADACKEN]=0, ADACK is activated at the start of a conversion and deactivated when conversions are terminated. In this case, there is an associated clock startup delay each time the clock source is re-activated. To avoid the conversion time variability and latency associated with the ADACK clock startup, set CFG2[ADACKEN]=1 and wait the worst-case startup time of 5 μ s prior to initiating any conversions using the ADACK clock source. Conversions are possible using ADACK as the input clock source while the MCU is in Normal Stop mode. See [Power Control](#) for more information.

Whichever clock is selected, its frequency must fall within the specified frequency range for ADCK. If the available clocks are too slow, the ADC may not perform according to specifications. If the available clocks are too fast, the clock must be divided to the appropriate frequency. This divider is specified by CFG1[ADIV] and can be divide-by 1, 2, 4, or 8.

33.4.2 Voltage reference selection

The ADC can be configured to accept one of the two voltage reference pairs as the reference voltage (V_{REFSH} and V_{REFSL}) used for conversions.

Each pair contains a positive reference that must be between the minimum Ref Voltage High and V_{DDA} , and a ground reference that must be at the same potential as V_{SSA} . The two pairs are external (V_{REFH} and V_{REFL}) and alternate (V_{ALTH} and V_{ALTL}). These voltage references are selected using $SC2[REFSEL]$. The alternate (V_{ALTH} and V_{ALTL}) voltage reference pair may select additional external pins or internal sources depending on MCU configuration. See the chip configuration information on the voltage references specific to this MCU.

33.4.3 Hardware trigger and channel selects

The ADC module has a selectable asynchronous hardware conversion trigger, ADHWT, that is enabled when $SC2[ADTRG]$ is set and a hardware trigger select event, ADHWTSn, has occurred.

This source is not available on all MCUs. See the Chip Configuration chapter for information on the ADHWT source and the ADHWTSn configurations specific to this MCU.

When an ADHWT source is available and hardware trigger is enabled, that is $SC2[ADTRG]=1$, a conversion is initiated on the rising-edge of ADHWT after a hardware trigger select event, that is, ADHWTSn, has occurred. If a conversion is in progress when a rising-edge of a trigger occurs, the rising-edge is ignored. In continuous convert configuration, only the initial rising-edge to launch continuous conversions is observed, and until conversion is aborted, the ADC continues to do conversions on the same SCn register that initiated the conversion. The hardware trigger function operates in conjunction with any of the conversion modes and configurations.

The hardware trigger select event, ADHWTSn, must be set prior to the receipt of the ADHWT signal. If these conditions are not met, the converter may ignore the trigger or use the incorrect configuration. If a hardware trigger select event is asserted during a conversion, it must stay asserted until the end of current conversion and remain set until the receipt of the ADHWT signal to trigger a new conversion. The channel and status fields selected for the conversion depend on the active trigger select signal:

- ADHWTSn active selects SC1A.
- ADHWTSn active selects SC1n.

Note

Asserting more than one hardware trigger select signal (ADHWTSn) at the same time results in unknown results. To avoid this, select only one hardware trigger select signal (ADHWTSn) prior to the next intended conversion.

When the conversion is completed, the result is placed in the Rn registers associated with the ADHWTSn received. For example:

- ADHWTSa active selects RA register
- ADHWTSn active selects Rn register

The conversion complete flag associated with the ADHWTSn received, that is, SC1n[COCO], is then set and an interrupt is generated if the respective conversion complete interrupt has been enabled, that is, SC1[AIEN]=1.

33.4.4 Conversion control

Conversions can be performed as determined by CFG1[MODE] and SC1n[DIFF] as shown in the description of CFG1[MODE].

Conversions can be initiated by a software or hardware trigger.

In addition, the ADC module can be configured for:

- Low-power operation
- Long sample time
- Continuous conversion
- Hardware average
- Automatic compare of the conversion result to a software determined compare value

33.4.4.1 Initiating conversions

A conversion is initiated:

- Following a write to SC1A, with SC1n[ADCH] not all 1's, if software triggered operation is selected, that is, when SC2[ADTRG]=0.
- Following a hardware trigger, or ADHWT event, if hardware triggered operation is selected, that is, SC2[ADTRG]=1, and a hardware trigger select event, ADHWTSn, has occurred. The channel and status fields selected depend on the active trigger select signal:
 - ADHWTSa active selects SC1A.

- ADHWTSn active selects SC1n.
- if neither is active, the off condition is selected

Note

Selecting more than one ADHWTSn prior to a conversion completion will result in unknown results. To avoid this, select only one ADHWTSn prior to a conversion completion.

- Following the transfer of the result to the data registers when continuous conversion is enabled, that is, when $SC3[ADCO] = 1$.

If continuous conversions are enabled, a new conversion is automatically initiated after the completion of the current conversion. In software triggered operation, that is, when $SC2[ADTRG] = 0$, continuous conversions begin after SC1A is written and continue until aborted. In hardware triggered operation, that is, when $SC2[ADTRG] = 1$ and one ADHWTSn event has occurred, continuous conversions begin after a hardware trigger event and continue until aborted.

If hardware averaging is enabled, a new conversion is automatically initiated after the completion of the current conversion until the correct number of conversions are completed. In software triggered operation, conversions begin after SC1A is written. In hardware triggered operation, conversions begin after a hardware trigger. If continuous conversions are also enabled, a new set of conversions to be averaged are initiated following the last of the selected number of conversions.

33.4.4.2 Completing conversions

A conversion is completed when the result of the conversion is transferred into the data result registers, Rn. If the compare functions are disabled, this is indicated by setting of $SC1n[COCO]$. If hardware averaging is enabled, the respective $SC1n[COCO]$ sets only if the last of the selected number of conversions is completed. If the compare function is enabled, the respective $SC1n[COCO]$ sets and conversion result data is transferred only if the compare condition is true. If both hardware averaging and compare functions are enabled, then the respective $SC1n[COCO]$ sets only if the last of the selected number of conversions is completed and the compare condition is true. An interrupt is generated if the respective $SC1n[AIEN]$ is high at the time that the respective $SC1n[COCO]$ is set.

33.4.4.3 Aborting conversions

Any conversion in progress is aborted when:

- Writing to SC1A while it is actively controlling a conversion, aborts the current conversion. In Software Trigger mode, when SC2[ADTRG]=0, a write to SC1A initiates a new conversion if SC1A[ADCH] is equal to a value other than all 1s. Writing to any of the SC1B–SC1n registers while that specific SC1B–SC1n register is actively controlling a conversion aborts the current conversion. The SC1(B-n) registers are not used for software trigger operation and therefore writes to the SC1(B-n) registers do not initiate a new conversion.
- A write to any ADC register besides the SC1A-SC1n registers occurs. This indicates that a change in mode of operation has occurred and the current conversion is therefore invalid.
- The MCU is reset or enters Low-Power Stop modes.
- The MCU enters Normal Stop mode with ADACK or Alternate Clock Sources not enabled.

When a conversion is aborted, the contents of the data registers, Rn, are not altered. The data registers continue to be the values transferred after the completion of the last successful conversion. If the conversion was aborted by a reset or Low-Power Stop modes, RA and Rn return to their reset states.

33.4.4.4 Power control

The ADC module remains in its idle state until a conversion is initiated. If ADACK is selected as the conversion clock source, but the asynchronous clock output is disabled, that is CFG2[ADACKEN]=0, the ADACK clock generator also remains in its idle state (disabled) until a conversion is initiated. If the asynchronous clock output is enabled, that is, CFG2[ADACKEN]=1, it remains active regardless of the state of the ADC or the MCU power mode.

Power consumption when the ADC is active can be reduced by setting CFG1[ADLPC]. This results in a lower maximum value for f_{ADCK} .

33.4.4.5 Sample time and total conversion time

For short sample, that is, when CFG1[ADLSMP]=0, there is a 2-cycle adder for first conversion over the base sample time of four ADCK cycles. For high-speed conversions, that is, when CFG2[ADHSC]=1, there is an additional 2-cycle adder on any conversion. The table below summarizes sample times for the possible ADC configurations.

| ADC configuration | | | Sample time (ADCK cycles) | |
|-------------------|--------------|-------------|---------------------------|------------|
| CFG1[ADLSMP] | CFG2[ADLSTS] | CFG2[ADHSC] | First or Single | Subsequent |
| 0 | X | 0 | 6 | 4 |
| 1 | 00 | 0 | 24 | |
| 1 | 01 | 0 | 16 | |
| 1 | 10 | 0 | 10 | |
| 1 | 11 | 0 | 6 | |
| 0 | X | 1 | 8 | 6 |
| 1 | 00 | 1 | 26 | |
| 1 | 01 | 1 | 18 | |
| 1 | 10 | 1 | 12 | |
| 1 | 11 | 1 | 8 | |

The total conversion time depends upon:

- The sample time as determined by CFG1[ADLSMP] and CFG2[ADLSTS]
- The MCU bus frequency
- The conversion mode, as determined by CFG1[MODE] and SC1n[DIFF]
- The high-speed configuration, that is, CFG2[ADHSC]
- The frequency of the conversion clock, that is, f_{ADCK} .

CFG2[ADHSC] is used to configure a higher clock input frequency. This will allow faster overall conversion times. To meet internal ADC timing requirements, CFG2[ADHSC] adds additional ADCK cycles. Conversions with CFG2[ADHSC]=1 take two more ADCK cycles. CFG2[ADHSC] must be used when the ADCLK exceeds the limit for CFG2[ADHSC]=0.

After the module becomes active, sampling of the input begins.

1. CFG1[ADLSMP] and CFG2[ADLSTS] select between sample times based on the conversion mode that is selected.
2. When sampling is completed, the converter is isolated from the input channel and a successive approximation algorithm is applied to determine the digital value of the analog signal.
3. The result of the conversion is transferred to Rn upon completion of the conversion algorithm.

If the bus frequency is less than f_{ADCK} , precise sample time for continuous conversions cannot be guaranteed when short sample is enabled, that is, when $CFG1[ADLSMP]=0$.

The maximum total conversion time is determined by the clock source chosen and the divide ratio selected. The clock source is selectable by $CFG1[ADICLK]$, and the divide ratio is specified by $CFG1[ADIV]$.

The maximum total conversion time for all configurations is summarized in the equation below. See the following tables for the variables referenced in the equation.

$$\text{ConversionTime} = \text{SFCAdder} + \text{AverageNum} \times (\text{BCT} + \text{LSTAdder} + \text{HSCAdder})$$

Figure 33-62. Conversion time equation

Table 33-70. Single or first continuous time adder (SFCAdder)

| CFG1[ADLSMP] | CFG2[ADACKEN] | CFG1[ADICLK] | Single or first continuous time adder (SFCAdder) |
|--------------|---------------|--------------|--|
| 1 | x | 0x, 10 | 3 ADCK cycles + 5 bus clock cycles |
| 1 | 1 | 11 | 3 ADCK cycles + 5 bus clock cycles ¹ |
| 1 | 0 | 11 | 5 μ s + 3 ADCK cycles + 5 bus clock cycles |
| 0 | x | 0x, 10 | 5 ADCK cycles + 5 bus clock cycles |
| 0 | 1 | 11 | 5 ADCK cycles + 5 bus clock cycles ¹ |
| 0 | 0 | 11 | 5 μ s + 5 ADCK cycles + 5 bus clock cycles |

1. To achieve this time, $CFG2[ADACKEN]$ must be 1 for at least 5 μ s prior to the conversion is initiated.

Table 33-71. Average number factor (AverageNum)

| SC3[AVGE] | SC3[AVGS] | Average number factor (AverageNum) |
|-----------|-----------|------------------------------------|
| 0 | xx | 1 |
| 1 | 00 | 4 |
| 1 | 01 | 8 |
| 1 | 10 | 16 |
| 1 | 11 | 32 |

Table 33-72. Base conversion time (BCT)

| Mode | Base conversion time (BCT) |
|------------------|----------------------------|
| 8b single-ended | 17 ADCK cycles |
| 9b differential | 27 ADCK cycles |
| 10b single-ended | 20 ADCK cycles |
| 11b differential | 30 ADCK cycles |
| 12b single-ended | 20 ADCK cycles |
| 13b differential | 30 ADCK cycles |

Table continues on the next page...

Table 33-72. Base conversion time (BCT) (continued)

| Mode | Base conversion time (BCT) |
|------------------|----------------------------|
| 16b single-ended | 25 ADCK cycles |
| 16b differential | 34 ADCK cycles |

Table 33-73. Long sample time adder (LSTAdder)

| CFG1[ADLSMP] | CFG2[ADLSTS] | Long sample time adder (LSTAdder) |
|--------------|--------------|-----------------------------------|
| 0 | xx | 0 ADCK cycles |
| 1 | 00 | 20 ADCK cycles |
| 1 | 01 | 12 ADCK cycles |
| 1 | 10 | 6 ADCK cycles |
| 1 | 11 | 2 ADCK cycles |

Table 33-74. High-speed conversion time adder (HSCAdder)

| CFG2[ADHSC] | High-speed conversion time adder (HSCAdder) |
|-------------|---|
| 0 | 0 ADCK cycles |
| 1 | 2 ADCK cycles |

Note

The ADCK frequency must be between f_{ADCK} minimum and f_{ADCK} maximum to meet ADC specifications.

33.4.4.6 Conversion time examples

The following examples use the [Figure 33-62](#), and the information provided in [Table 33-70](#) through [Table 33-74](#).

33.4.4.6.1 Typical conversion time configuration

A typical configuration for ADC conversion is:

- 10-bit mode, with the bus clock selected as the input clock source
- The input clock divide-by-1 ratio selected
- Bus frequency of 8 MHz
- Long sample time disabled
- High-speed conversion disabled

The conversion time for a single conversion is calculated by using the [Figure 33-62](#), and the information provided in [Table 33-70](#) through [Table 33-74](#). The table below lists the variables of [Figure 33-62](#).

Table 33-75. Typical conversion time

| Variable | Time |
|------------|------------------------------------|
| SFCAdder | 5 ADCK cycles + 5 bus clock cycles |
| AverageNum | 1 |
| BCT | 20 ADCK cycles |
| LSTAdder | 0 |
| HSCAdder | 0 |

The resulting conversion time is generated using the parameters listed in the preceding table. Therefore, for a bus clock and an ADCK frequency equal to 8 MHz, the resulting conversion time is 3.75 μ s.

33.4.4.6.2 Long conversion time configuration

A configuration for long ADC conversion is:

- 16-bit differential mode with the bus clock selected as the input clock source
- The input clock divide-by-8 ratio selected
- Bus frequency of 8 MHz
- Long sample time enabled
- Configured for longest adder
- High-speed conversion disabled
- Average enabled for 32 conversions

The conversion time for this conversion is calculated by using the [Figure 33-62](#), and the information provided in [Table 33-70](#) through [Table 33-74](#). The following table lists the variables of the [Figure 33-62](#).

Table 33-76. Typical conversion time

| Variable | Time |
|------------|------------------------------------|
| SFCAdder | 3 ADCK cycles + 5 bus clock cycles |
| AverageNum | 32 |
| BCT | 34 ADCK cycles |
| LSTAdder | 20 ADCK cycles |
| HSCAdder | 0 |

functional description

The resulting conversion time is generated using the parameters listed in the preceding table. Therefore, for bus clock equal to 8 MHz and ADCK equal to 1 MHz, the resulting conversion time is 57.625 μ s, that is, AverageNum. This results in a total conversion time of 1.844 ms.

33.4.4.6.3 Short conversion time configuration

A configuration for short ADC conversion is:

- 8-bit Single-Ended mode with the bus clock selected as the input clock source
- The input clock divide-by-1 ratio selected
- Bus frequency of 20 MHz
- Long sample time disabled
- High-speed conversion enabled

The conversion time for this conversion is calculated by using the [Figure 33-62](#), and the information provided in [Table 33-70](#) through [Table 33-74](#). The table below lists the variables of [Figure 33-62](#).

Table 33-77. Typical conversion time

| Variable | Time |
|------------|------------------------------------|
| SFCAdder | 5 ADCK cycles + 5 bus clock cycles |
| AverageNum | 1 |
| BCT | 17 ADCK cycles |
| LSTAdder | 0 ADCK cycles |
| HSCAdder | 2 |

The resulting conversion time is generated using the parameters listed in in the preceding table. Therefore, for bus clock and ADCK frequency equal to 20 MHz, the resulting conversion time is 1.45 μ s.

33.4.4.7 Hardware average function

The hardware average function can be enabled by setting SC3[AVGE]=1 to perform a hardware average of multiple conversions. The number of conversions is determined by the AVGS[1:0] bits, which can select 4, 8, 16, or 32 conversions to be averaged. While the hardware average function is in progress, SC2[ADACT] will be set.

After the selected input is sampled and converted, the result is placed in an accumulator from which an average is calculated once the selected number of conversions have been completed. When hardware averaging is selected, the completion of a single conversion will not set SC1n[COCO].

If the compare function is either disabled or evaluates true, after the selected number of conversions are completed, the average conversion result is transferred into the data result registers, Rn, and SC1n[COCO] is set. An ADC interrupt is generated upon the setting of SC1n[COCO] if the respective ADC interrupt is enabled, that is, SC1n[AIEN]=1.

Note

The hardware average function can perform conversions on a channel while the MCU is in Wait or Normal Stop modes. The ADC interrupt wakes the MCU when the hardware average is completed if SC1n[AIEN] is set.

33.4.5 Automatic compare function

The compare function can be configured to check whether the result is less than or greater-than-or-equal-to a single compare value, or, if the result falls within or outside a range determined by two compare values.

The compare mode is determined by SC2[ACFGT], SC2[ACREN], and the values in the compare value registers, CV1 and CV2. After the input is sampled and converted, the compare values in CV1 and CV2 are used as described in the following table. There are six Compare modes as shown in the following table.

Table 33-78. Compare modes

| SC2[ACFGT] | SC2[ACREN] | ADCCV1 relative to ADCCV2 | Function | Compare mode description |
|------------|------------|---------------------------|------------------------------------|--|
| 0 | 0 | — | Less than threshold | Compare true if the result is less than the CV1 registers. |
| 1 | 0 | — | Greater than or equal to threshold | Compare true if the result is greater than or equal to CV1 registers. |
| 0 | 1 | Less than or equal | Outside range, not inclusive | Compare true if the result is less than CV1 Or the result is greater than CV2. |
| 0 | 1 | Greater than | Inside range, not inclusive | Compare true if the result is less than CV1 And the result is greater than CV2. |
| 1 | 1 | Less than or equal | Inside range, inclusive | Compare true if the result is greater than or equal to CV1 And the result is less than or equal to CV2. |
| 1 | 1 | Greater than | Outside range, inclusive | Compare true if the result is greater than or equal to CV1 Or the result is less than or equal to CV2. |

With SC2[ACREN] =1, and if the value of CV1 is less than or equal to the value of CV2, then setting SC2[ACFGT] will select a trigger-if-inside-compare-range inclusive-of-endpoints function. Clearing SC2[ACFGT] will select a trigger-if-outside-compare-range, not-inclusive-of-endpoints function.

If CV1 is greater than CV2, setting SC2[ACFGT] will select a trigger-if-outside-compare-range, inclusive-of-endpoints function. Clearing SC2[ACFGT] will select a trigger-if-inside-compare-range, not-inclusive-of-endpoints function.

If the condition selected evaluates true, SC1n[COCO] is set.

Upon completion of a conversion while the compare function is enabled, if the compare condition is not true, SC1n[COCO] is not set and the conversion result data will not be transferred to the result register, Rn. If the hardware averaging function is enabled, the compare function compares the averaged result to the compare values. The same compare function definitions apply. An ADC interrupt is generated when SC1n[COCO] is set and the respective ADC interrupt is enabled, that is, SC1n[AIEN]=1.

Note

The compare function can monitor the voltage on a channel while the MCU is in Wait or Normal Stop modes. The ADC interrupt wakes the MCU when the compare condition is met.

33.4.6 Calibration function

>The ADC contains a self-calibration function that is required to achieve the specified accuracy.

Calibration must be run, or valid calibration values written, after any reset and before a conversion is initiated. The calibration function sets the offset calibration value, the minus-side calibration values, and the plus-side calibration values. The offset calibration value is automatically stored in the ADC offset correction register (OFS), and the plus-side and minus-side calibration values are automatically stored in the ADC plus-side and minus-side calibration registers, CLPx and CLMx. The user must configure the ADC correctly prior to calibration, and must generate the plus-side and minus-side gain calibration results and store them in the ADC plus-side gain register (PG) after the calibration function completes.

Prior to calibration, the user must configure the ADC's clock source and frequency, low power configuration, voltage reference selection, sample time, and high speed configuration according to the application's clock source availability and needs. If the

application uses the ADC in a wide variety of configurations, the configuration for which the highest accuracy is required should be selected, or multiple calibrations can be done for the different configurations. For best calibration results:

- Set hardware averaging to maximum, that is, SC3[AVGE]=1 and SC3[AVGS]=11 for an average of 32
- Set ADC clock frequency f_{ADCK} less than or equal to 4 MHz
- $V_{\text{REFH}}=V_{\text{DDA}}$
- Calibrate at nominal voltage and temperature

The input channel, conversion mode continuous function, compare function, resolution mode, and differential/single-ended mode are all ignored during the calibration function.

To initiate calibration, the user sets SC3[CAL] and the calibration will automatically begin if the SC2[ADTRG] is 0. If SC2[ADTRG] is 1, SC3[CAL] will not get set and SC3[CALF] will be set. While calibration is active, no ADC register can be written and no stop mode may be entered, or the calibration routine will be aborted causing SC3[CAL] to clear and SC3[CALF] to set. At the end of a calibration sequence, SC1n[COCO] will be set. SC1n[AIEN] can be used to allow an interrupt to occur at the end of a calibration sequence. At the end of the calibration routine, if SC3[CALF] is not set, the automatic calibration routine is completed successfully.

To complete calibration, the user must generate the gain calibration values using the following procedure:

1. Initialize or clear a 16-bit variable in RAM.
2. Add the plus-side calibration results CLP0, CLP1, CLP2, CLP3, CLP4, and CLPS to the variable.
3. Divide the variable by two.
4. Set the MSB of the variable.
5. The previous two steps can be achieved by setting the carry bit, rotating to the right through the carry bit on the high byte and again on the low byte.
6. Store the value in the plus-side gain calibration register PG.
7. Repeat the procedure for the minus-side gain calibration value.

When calibration is complete, the user may reconfigure and use the ADC as desired. A second calibration may also be performed, if desired, by clearing and again setting SC3[CAL].

Overall, the calibration routine may take as many as 14k ADCK cycles and 100 bus cycles, depending on the results and the clock source chosen. For an 8 MHz clock source, this length amounts to about 1.7 ms. To reduce this latency, the calibration values, which are offset, plus-side and minus-side gain, and plus-side and minus-side calibration values, may be stored in flash memory after an initial calibration and recovered prior to the first ADC conversion. This method can reduce the calibration latency to 20 register store operations on all subsequent power, reset, or Low-Power Stop mode recoveries.

Further information on the calibration procedure can be found in the Calibration section of [AN3949: ADC16 Calibration Procedure and Programmable Delay Block Synchronization](#).

33.4.7 User-defined offset function

OFS contains the user-selected or calibration-generated offset error correction value.

This register is a 2's complement, left-justified. The value in OFS is subtracted from the conversion and the result is transferred into the result registers, Rn. If the result is greater than the maximum or less than the minimum result value, it is forced to the appropriate limit for the current mode of operation.

The formatting of the OFS is different from the data result register, Rn, to preserve the resolution of the calibration value regardless of the conversion mode selected. Lower order bits are ignored in lower resolution modes. For example, in 8-bit single-ended mode, OFS[14:7] are subtracted from D[7:0]; OFS[15] indicates the sign (negative numbers are effectively added to the result) and OFS[6:0] are ignored. The same bits are used in 9-bit differential mode because OFS[15] indicates the sign bit, which maps to D[8]. For 16-bit differential mode, OFS[15:0] are directly subtracted from the conversion result data D[15:0]. In 16-bit single-ended mode, there is no field in the OFS corresponding to the least significant result D[0], so odd values, such as -1 or +1, cannot be subtracted from the result.

OFS is automatically set according to calibration requirements once the self-calibration sequence is done, that is, SC3[CAL] is cleared. The user may write to OFS to override the calibration result if desired. If the OFS is written by the user to a value that is different from the calibration value, the ADC error specifications may not be met. Storing the value generated by the calibration function in memory before overwriting with a user-specified value is recommended.

Note

There is an effective limit to the values of offset that can be set by the user. If the magnitude of the offset is too high, the results of the conversions will cap off at the limits.

The offset calibration function may be employed by the user to remove application offsets or DC bias values. OFS may be written with a number in 2's complement format and this offset will be subtracted from the result, or hardware averaged value. To add an offset, store the negative offset in 2's complement format and the effect will be an addition. An offset correction that results in an out-of-range value will be forced to the minimum or maximum value. The minimum value for single-ended conversions is 0x0000; for a differential conversion it is 0x8000.

To preserve accuracy, the calibrated offset value initially stored in OFS must be added to the user-defined offset. For applications that may change the offset repeatedly during operation, store the initial offset calibration value in flash so it can be recovered and added to any user offset adjustment value and the sum stored in OFS.

33.4.8 Temperature sensor

The ADC module includes a temperature sensor whose output is connected to one of the ADC analog channel inputs.

The following equation provides an approximate transfer function of the temperature sensor.

$$\text{Temp} = 25 - \left(\left(V_{\text{TEMP}} - V_{\text{TEMP25}} \right) \div m \right)$$

Figure 33-63. Approximate transfer function of the temperature sensor

where:

- V_{TEMP} is the voltage of the temperature sensor channel at the ambient temperature.
- V_{TEMP25} is the voltage of the temperature sensor channel at 25 °C.
- m is referred as temperature sensor slope in the device data sheet. It is the hot or cold voltage versus temperature slope in V/°C.

For temperature calculations, use the V_{TEMP25} and temperature sensor slope values from the ADC Electricals table.

In application code, the user reads the temperature sensor channel, calculates V_{TEMP} , and compares to V_{TEMP25} . If V_{TEMP} is greater than V_{TEMP25} the cold slope value is applied in the preceding equation. If V_{TEMP} is less than V_{TEMP25} , the hot slope value is applied in the preceding equation. ADC Electricals table may only specify one temperature sensor slope value. In that case, the user could use the same slope for the calculation across the operational temperature range.

For more information on using the temperature sensor, see the application note titled *Temperature Sensor for the HCS08 Microcontroller Family* (document AN3031).

33.4.9 MCU wait mode operation

Wait mode is a lower-power consumption Standby mode from which recovery is fast because the clock sources remain active.

If a conversion is in progress when the MCU enters Wait mode, it continues until completion. Conversions can be initiated while the MCU is in Wait mode by means of the hardware trigger or if continuous conversions are enabled.

The bus clock, bus clock divided by two; and ADACK are available as conversion clock sources while in Wait mode. The use of ALTCLK as the conversion clock source in Wait is dependent on the definition of ALTCLK for this MCU. See the Chip Configuration information on ALTCLK specific to this MCU.

If the compare and hardware averaging functions are disabled, a conversion complete event sets $SC1n[COCO]$ and generates an ADC interrupt to wake the MCU from Wait mode if the respective ADC interrupt is enabled, that is, when $SC1n[AIEN]=1$. If the hardware averaging function is enabled, $SC1n[COCO]$ will set, and generate an interrupt if enabled, when the selected number of conversions are completed. If the compare function is enabled, $SC1n[COCO]$ will set, and generate an interrupt if enabled, only if the compare conditions are met. If a single conversion is selected and the compare trigger is not met, the ADC will return to its idle state and cannot wake the MCU from Wait mode unless a new conversion is initiated by the hardware trigger.

33.4.10 MCU Normal Stop mode operation

Stop mode is a low-power consumption Standby mode during which most or all clock sources on the MCU are disabled.

33.4.10.1 Normal Stop mode with ADACK disabled

If the asynchronous clock, ADACK, is not selected as the conversion clock, executing a stop instruction aborts the current conversion and places the ADC in its Idle state. The contents of the ADC registers, including Rn, are unaffected by Normal Stop mode. After exiting from Normal Stop mode, a software or hardware trigger is required to resume conversions.

33.4.10.2 Normal Stop mode with ADACK enabled

If ADACK is selected as the conversion clock, the ADC continues operation during Normal Stop mode. See the chip configuration chapter for configuration information for this MCU.

If a conversion is in progress when the MCU enters Normal Stop mode, it continues until completion. Conversions can be initiated while the MCU is in Normal Stop mode by means of the hardware trigger or if continuous conversions are enabled.

If the compare and hardware averaging functions are disabled, a conversion complete event sets SC1n[COCO] and generates an ADC interrupt to wake the MCU from Normal Stop mode if the respective ADC interrupt is enabled, that is, when SC1n[AIEN]=1. The result register, Rn, will contain the data from the first completed conversion that occurred during Normal Stop mode. If the hardware averaging function is enabled, SC1n[COCO] will set, and generate an interrupt if enabled, when the selected number of conversions are completed. If the compare function is enabled, SC1n[COCO] will set, and generate an interrupt if enabled, only if the compare conditions are met. If a single conversion is selected and the compare is not true, the ADC will return to its Idle state and cannot wake the MCU from Normal Stop mode unless a new conversion is initiated by another hardware trigger.

33.4.11 MCU Low-Power Stop mode operation

The ADC module is automatically disabled when the MCU enters Low-Power Stop mode.

All module registers contain their reset values following exit from Low-Power Stop mode. Therefore, the module must be re-enabled and re-configured following exit from Low-Power Stop mode.

NOTE

For the chip specific modes of operation, see the power management information for the device.

33.5 Initialization information

This section gives an example that provides some basic direction on how to initialize and configure the ADC module.

The user can configure the module for 16-bit, 12-bit, 10-bit, or 8-bit single-ended resolution or 16-bit, 13-bit, 11-bit, or 9-bit differential resolution, single or continuous conversion, and a polled or interrupt approach, among many other options. For information used in this example, refer to [Table 33-73](#), [Table 33-74](#), and [Table 33-75](#).

Note

Hexadecimal values are designated by a preceding 0x, binary values designated by a preceding %, and decimal values have no preceding character.

33.5.1 ADC module initialization example

33.5.1.1 Initialization sequence

Before the ADC module can be used to complete conversions, an initialization procedure must be performed. A typical sequence is:

1. Calibrate the ADC by following the calibration instructions in [Calibration function](#).
2. Update CFG to select the input clock source and the divide ratio used to generate ADCK. This register is also used for selecting sample time and low-power configuration.
3. Update SC2 to select the conversion trigger, hardware or software, and compare function options, if enabled.
4. Update SC3 to select whether conversions will be continuous or completed only once (ADCO) and whether to perform hardware averaging.
5. Update SC1:SC1n registers to select whether conversions will be single-ended or differential and to enable or disable conversion complete interrupts. Also, select the input channel which can be used to perform conversions.

33.5.1.2 Pseudo-code example

In this example, the ADC module is set up with interrupts enabled to perform a single 10-bit conversion at low-power with a long sample time on input channel 1, where ADCK is derived from the bus clock divided by 1.

CFG1 = 0x98 (%10011000)

| | | | |
|---------|--------|----|---|
| Bit 7 | ADLPC | 1 | Configures for low power, lowers maximum clock speed. |
| Bit 6:5 | ADIV | 00 | Sets the ADCK to the input clock ÷ 1. |
| Bit 4 | ADLSMP | 1 | Configures for long sample time. |
| Bit 3:2 | MODE | 10 | Selects the single-ended 10-bit conversion, differential 11-bit conversion. |
| Bit 1:0 | ADICLK | 00 | Selects the bus clock. |

SC2 = 0x00 (%00000000)

| | | | |
|---------|--------|----|--|
| Bit 7 | ADACT | 0 | Flag indicates if a conversion is in progress. |
| Bit 6 | ADTRG | 0 | Software trigger selected. |
| Bit 5 | ACFE | 0 | Compare function disabled. |
| Bit 4 | ACFGT | 0 | Not used in this example. |
| Bit 3 | ACREN | 0 | Compare range disabled. |
| Bit 2 | DMAEN | 0 | DMA request disabled. |
| Bit 1:0 | REFSEL | 00 | Selects default voltage reference pin pair (External pins V_{REFH} and V_{REFL}). |

SC1A = 0x41 (%01000001)

| | | | |
|---------|------|-------|--|
| Bit 7 | COCO | 0 | Read-only flag which is set when a conversion completes. |
| Bit 6 | AIEN | 1 | Conversion complete interrupt enabled. |
| Bit 5 | DIFF | 0 | Single-ended conversion selected. |
| Bit 4:0 | ADCH | 00001 | Input channel 1 selected as ADC input channel. |

RA = 0xxx

Holds results of conversion.

CV = 0xxx

Holds compare value when compare function enabled.

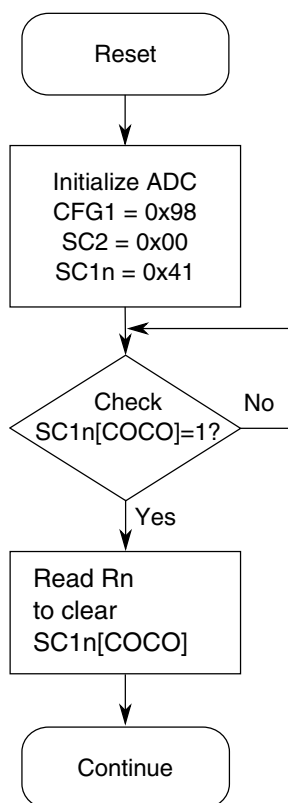


Figure 33-64. Initialization flowchart example

33.6 Application information

The ADC has been designed to be integrated into a microcontroller for use in embedded control applications requiring an ADC.

For guidance on selecting optimum external component values and converter parameters see [AN4373: Cookbook for SAR ADC Measurements](#).

33.6.1 External pins and routing

33.6.1.1 Analog supply pins

Depending on the device, the analog power and ground supplies, V_{DDA} and V_{SSA} , of the ADC module are available as:

- V_{DDA} and V_{SSA} available as separate pins—When available on a separate pin, both V_{DDA} and V_{SSA} must be connected to the same voltage potential as their corresponding MCU digital supply, V_{DD} and V_{SS} , and must be routed carefully for maximum noise immunity and bypass capacitors placed as near as possible to the package.
- V_{SSA} is shared on the same pin as the MCU digital V_{SS} .
- V_{SSA} and V_{DDA} are shared with the MCU digital supply pins—In these cases, there are separate pads for the analog supplies bonded to the same pin as the corresponding digital supply so that some degree of isolation between the supplies is maintained.

If separate power supplies are used for analog and digital power, the ground connection between these supplies must be at the V_{SSA} pin. This must be the only ground connection between these supplies, if possible. V_{SSA} makes a good single point ground location.

33.6.1.2 Analog voltage reference pins

In addition to the analog supplies, the ADC module has connections for two reference voltage inputs used by the converter:

- V_{REFSH} is the high reference voltage for the converter.
- V_{REFSL} is the low reference voltage for the converter.

The ADC can be configured to accept one of two voltage reference pairs for V_{REFSH} and V_{REFSL} . Each pair contains a positive reference and a ground reference. The two pairs are external, V_{REFH} and V_{REFL} and alternate, V_{ALTH} and V_{ALTL} . These voltage references are selected using $SC2[REFSEL]$. The alternate voltage reference pair, V_{ALTH} and V_{ALTL} , may select additional external pins or internal sources based on MCU configuration. See the chip configuration information on the voltage references specific to this MCU.

In some packages, the external or alternate pairs are connected in the package to V_{DDA} and V_{SSA} , respectively. One of these positive references may be shared on the same pin as V_{DDA} on some devices. One of these ground references may be shared on the same pin as V_{SSA} on some devices.

If externally available, the positive reference may be connected to the same potential as V_{DDA} or may be driven by an external source to a level between the minimum Ref Voltage High and the V_{DDA} potential. The positive reference must never exceed V_{DDA} . If externally available, the ground reference must be connected to the same voltage potential as V_{SSA} . The voltage reference pairs must be routed carefully for maximum noise immunity and bypass capacitors placed as near as possible to the package.

AC current in the form of current spikes required to supply charge to the capacitor array at each successive approximation step is drawn through the V_{REFH} and V_{REFL} loop. The best external component to meet this current demand is a 0.1 μF capacitor with good

high-frequency characteristics. This capacitor is connected between V_{REFH} and V_{REFL} and must be placed as near as possible to the package pins. Resistance in the path is not recommended because the current causes a voltage drop that could result in conversion errors. Inductance in this path must be minimum, that is, parasitic only.

33.6.1.3 Analog input pins

The external analog inputs are typically shared with digital I/O pins on MCU devices.

Empirical data shows that capacitors on the analog inputs improve performance in the presence of noise or when the source impedance is high. Use of 0.01 μF capacitors with good high-frequency characteristics is sufficient. These capacitors are not necessary in all cases, but when used, they must be placed as near as possible to the package pins and be referenced to V_{SSA} .

For proper conversion, the input voltage must fall between V_{REFH} and V_{REFL} . If the input is equal to or exceeds V_{REFH} , the converter circuit converts the signal to 0xFFF, which is full scale 12-bit representation, 0x3FF, which is full scale 10-bit representation, or 0xFF, which is full scale 8-bit representation. If the input is equal to or less than V_{REFL} , the converter circuit converts it to 0x000. Input voltages between V_{REFH} and V_{REFL} are straight-line linear conversions. There is a brief current associated with V_{REFL} when the sampling capacitor is charging.

For minimal loss of accuracy due to current injection, pins adjacent to the analog input pins must not be transitioning during conversions.

33.6.2 Sources of error

33.6.2.1 Sampling error

For proper conversions, the input must be sampled long enough to achieve the proper accuracy.

$$RAS + RADIN = SC / (FMAX * NUMTAU * CADIN)$$

Figure 33-65. Sampling equation

Where:

RAS = External analog source resistance

SC = Number of ADCK cycles used during sample window

CADIN = Internal ADC input capacitance

NUMTAU = $-\ln(\text{LSBERR} / 2^N)$

LSBERR = value of acceptable sampling error in LSBs

N = 8 in 8-bit mode, 10 in 10-bit mode, 12 in 12-bit mode or 16 in 16-bit mode

Higher source resistances or higher-accuracy sampling is possible by setting CFG1[ADLSMP] and changing CFG2[ADLSTS] to increase the sample window, or decreasing ADCK frequency to increase sample time.

33.6.2.2 Pin leakage error

Leakage on the I/O pins can cause conversion error if the external analog source resistance, R_{AS} , is high. If this error cannot be tolerated by the application, keep R_{AS} lower than $V_{REFH} / (4 \times I_{LEAK} \times 2^N)$ for less than 1/4 LSB leakage error, where N = 8 in 8-bit mode, 10 in 10-bit mode, 12 in 12-bit mode, or 16 in 16-bit mode.

33.6.2.3 Noise-induced errors

System noise that occurs during the sample or conversion process can affect the accuracy of the conversion. The ADC accuracy numbers are guaranteed as specified only if the following conditions are met:

- There is a 0.1 μF low-ESR capacitor from V_{REFH} to V_{REFL} .
- There is a 0.1 μF low-ESR capacitor from V_{DDA} to V_{SSA} .
- If inductive isolation is used from the primary supply, an additional 1 μF capacitor is placed from V_{DDA} to V_{SSA} .
- V_{SSA} , and V_{REFL} , if connected, is connected to V_{SS} at a quiet point in the ground plane.
- Operate the MCU in Wait or Normal Stop mode before initiating (hardware-triggered conversions) or immediately after initiating (hardware- or software-triggered conversions) the ADC conversion.

- For software triggered conversions, immediately follow the write to SC1 with a Wait instruction or Stop instruction.
- For Normal Stop mode operation, select ADACK as the clock source. Operation in Normal Stop reduces V_{DD} noise but increases effective conversion time due to stop recovery.
- There is no I/O switching, input or output, on the MCU during the conversion.

There are some situations where external system activity causes radiated or conducted noise emissions or excessive V_{DD} noise is coupled into the ADC. In these situations, or when the MCU cannot be placed in Wait or Normal Stop mode, or I/O activity cannot be halted, the following actions may reduce the effect of noise on the accuracy:

- Place a 0.01 μF capacitor (C_{AS}) on the selected input channel to V_{REFL} or V_{SSA} . This improves noise issues, but affects the sample rate based on the external analog source resistance.
- Average the result by converting the analog input many times in succession and dividing the sum of the results. Four samples are required to eliminate the effect of a 1 LSB, one-time error.
- Reduce the effect of synchronous noise by operating off the asynchronous clock, that is, ADACK, and averaging. Noise that is synchronous to ADCK cannot be averaged out.

33.6.2.4 Code width and quantization error

The ADC quantizes the ideal straight-line transfer function into 65536 steps in the 16-bit mode). Each step ideally has the same height, that is, 1 code, and width. The width is defined as the delta between the transition points to one code and the next. The ideal code width for an N-bit converter, where N can be 16, 12, 10, or 8, defined as 1 LSB, is:

$$1\text{LSB} = (V_{REFH}) / 2^N$$

Figure 33-66. Ideal code width for an N-bit converter

There is an inherent quantization error due to the digitization of the result. For 8-bit, 10-bit, or 12-bit conversions, the code transitions when the voltage is at the midpoint between the points where the straight line transfer function is exactly represented by the actual transfer function. Therefore, the quantization error will be $\pm 1/2$ LSB in 8-bit, 10-bit, or 12-bit modes. As a consequence, however, the code width of the first (0x000) conversion is only 1/2 LSB and the code width of the last (0xFF or 0x3FF) is 1.5 LSB.

For 16-bit conversions, the code transitions only after the full code width is present, so the quantization error is -1 LSB to 0 LSB and the code width of each step is 1 LSB.

33.6.2.5 Linearity errors

The ADC may also exhibit non-linearity of several forms. Every effort has been made to reduce these errors, but the system designers must be aware of these errors because they affect overall accuracy:

- Zero-scale error (E_{ZS}), sometimes called offset: This error is defined as the difference between the actual code width of the first conversion and the ideal code width. This is 1/2 LSB in 8-bit, 10-bit, or 12-bit modes and 1 LSB in 16-bit mode. If the first conversion is 0x001, the difference between the actual 0x001 code width and its ideal (1 LSB) is used.
- Full-scale error (E_{FS}): This error is defined as the difference between the actual code width of the last conversion and the ideal code width. This is 1.5 LSB in 8-bit, 10-bit, or 12-bit modes and 1 LSB in 16-bit mode. If the last conversion is 0x3FE, the difference between the actual 0x3FE code width and its ideal (1 LSB) is used.
- Differential non-linearity (DNL): This error is defined as the worst-case difference between the actual code width and the ideal code width for all conversions.
- Integral non-linearity (INL): This error is defined as the highest-value or absolute value that the running sum of DNL achieves. More simply, this is the worst-case difference of the actual transition voltage to a given code and its corresponding ideal transition voltage, for all codes.
- Total unadjusted error (TUE): This error is defined as the difference between the actual transfer function and the ideal straight-line transfer function and includes all forms of error.

33.6.2.6 Code jitter, non-monotonicity, and missing codes

Analog-to-digital converters are susceptible to three special forms of error:

- Code jitter: Code jitter is when, at certain points, a given input voltage converts to one of the two values when sampled repeatedly. Ideally, when the input voltage is infinitesimally smaller than the transition voltage, the converter yields the lower code, and vice-versa. However, even small amounts of system noise can cause the converter to be indeterminate, between two codes, for a range of input voltages around the transition voltage.

This error may be reduced by repeatedly sampling the input and averaging the result. Additionally, the techniques discussed in [Noise-induced errors](#) reduces this error.

- Non-monotonicity: Non-monotonicity is defined as when, except for code jitter, the converter converts to a lower code for a higher input voltage.
- Missing codes: Missing codes are those values never converted for any input value.

In 8-bit or 10-bit mode, the ADC is guaranteed to be monotonic and have no missing codes.

Chapter 34

Comparator (CMP)

34.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The comparator (CMP) module provides a circuit for comparing two analog input voltages. The comparator circuit is designed to operate across the full range of the supply voltage, known as rail-to-rail operation.

The Analog MUX (ANMUX) provides a circuit for selecting an analog input signal from eight channels. One signal is provided by the 6-bit digital-to-analog converter (DAC). The mux circuit is designed to operate across the full range of the supply voltage.

The 6-bit DAC is 64-tap resistor ladder network which provides a selectable voltage reference for applications where voltage reference is needed. The 64-tap resistor ladder network divides the supply reference V_{in} into 64 voltage levels. A 6-bit digital signal input selects the output voltage level, which varies from V_{in} to $V_{in}/64$. V_{in} can be selected from two voltage sources, V_{in1} and V_{in2} . The 6-bit DAC from a comparator is available as an on-chip internal signal only and is not available externally to a pin.

34.1.1 CMP features

The CMP has the following features:

- Operational over the entire supply range
- Inputs may range from rail to rail
- Programmable hysteresis control

- Selectable interrupt on rising-edge, falling-edge, or both rising or falling edges of the comparator output
- Selectable inversion on comparator output
- Capability to produce a wide range of outputs such as:
 - Sampled
 - Windowed, which is ideal for certain PWM zero-crossing-detection applications
 - Digitally filtered:
 - Filter can be bypassed
 - Can be clocked via external SAMPLE signal or scaled bus clock
- External hysteresis can be used at the same time that the output filter is used for internal functions
- Two software selectable performance levels:
 - Shorter propagation delay at the expense of higher power
 - Low power, with longer propagation delay
- DMA transfer support
 - A comparison event can be selected to trigger a DMA transfer
- Functional in all modes of operation
- The window and filter functions are not available in the following modes:
 - Stop
 - VLPS
 - LLS
 - VLLSx

34.1.2 6-bit DAC key features

- 6-bit resolution
- Selectable supply reference source
- Power Down mode to conserve power when not in use
- Option to route the output to internal comparator input

34.1.3 ANMUX key features

- Two 8-to-1 channel mux
- Operational over the entire supply range

34.1.4 CMP, DAC and ANMUX diagram

The following figure shows the block diagram for the High-Speed Comparator, DAC, and ANMUX modules.

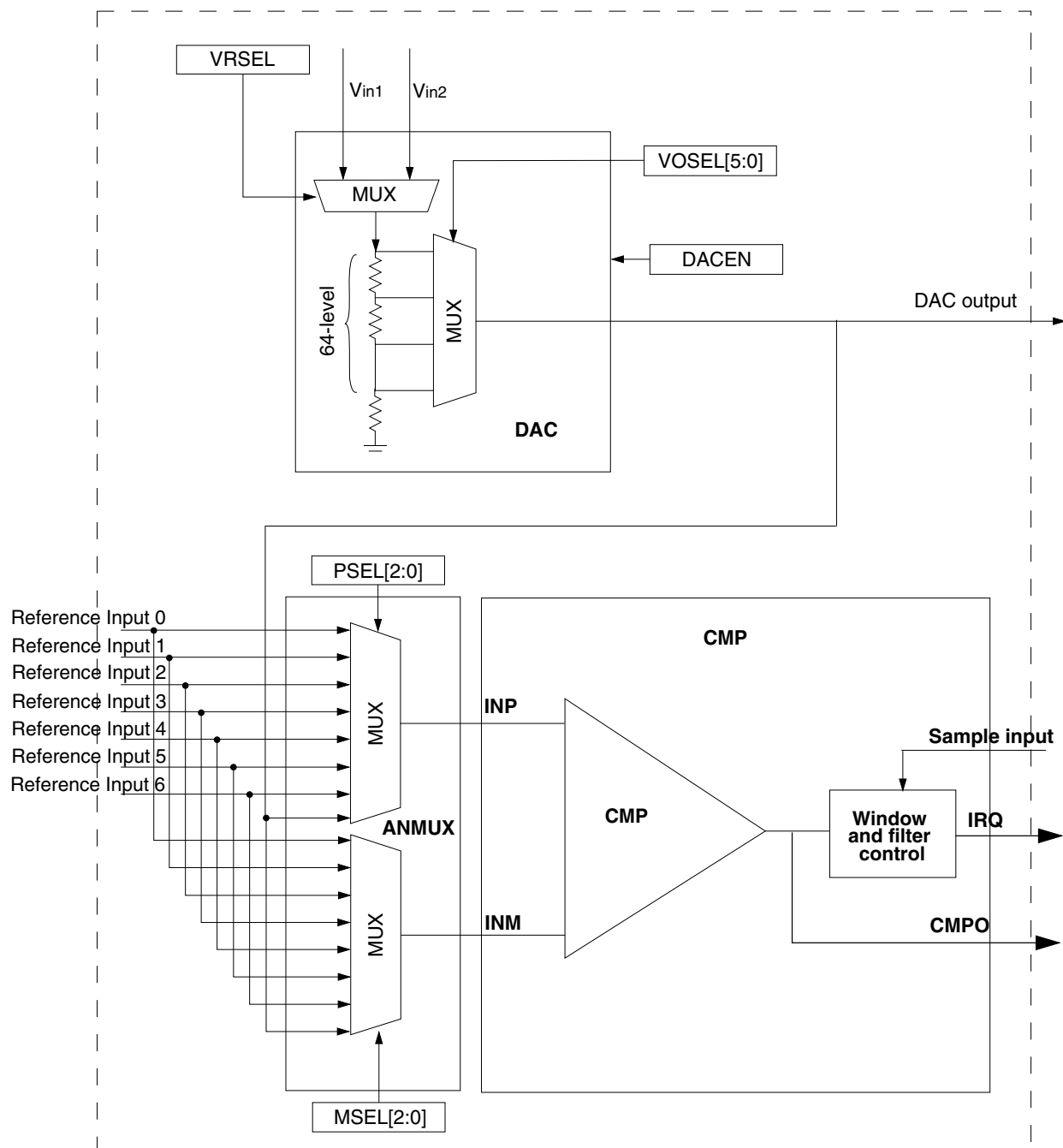


Figure 34-1. CMP, DAC and ANMUX block diagram

34.1.5 CMP block diagram

The following figure shows the block diagram for the CMP module.

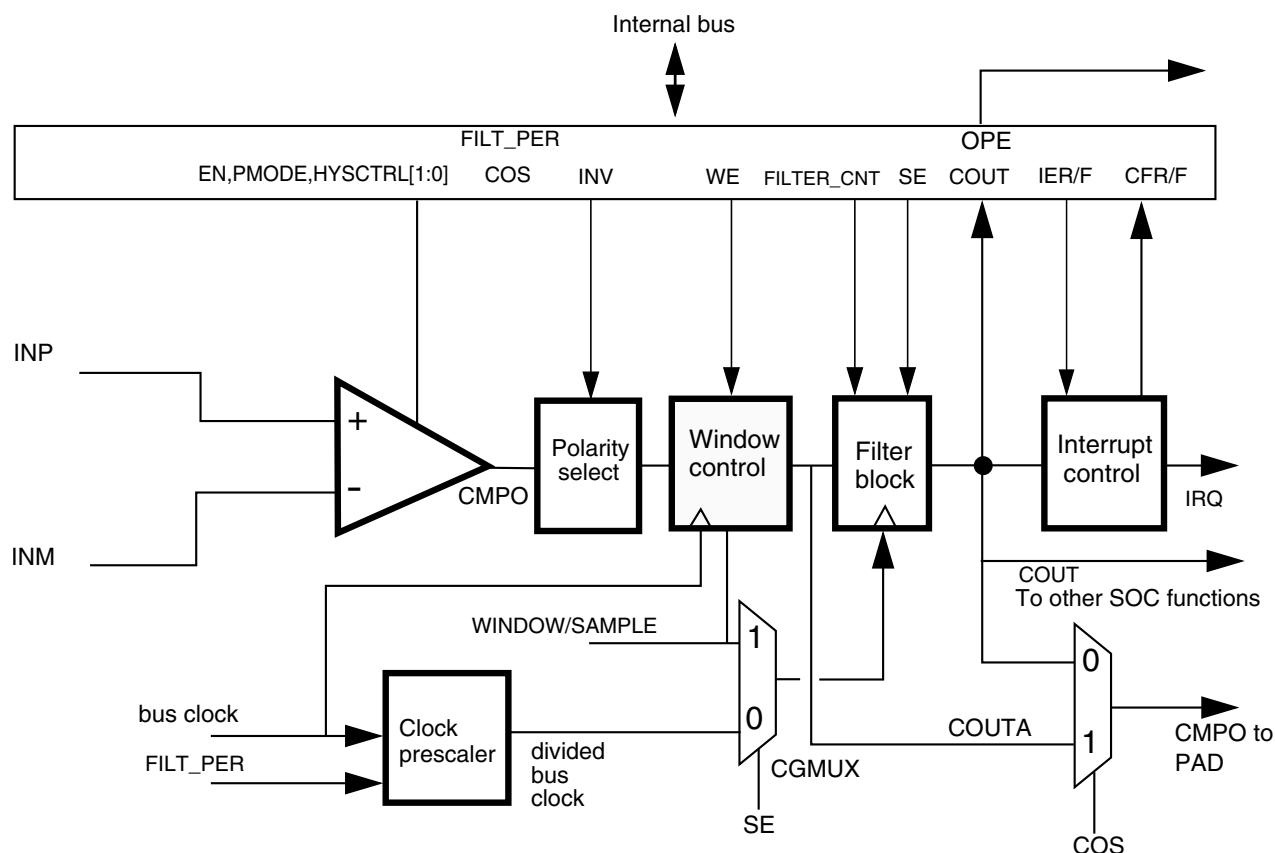


Figure 34-2. Comparator module block diagram

In the CMP block diagram:

- The Window Control block is bypassed when $CR1[WE] = 0$
- If $CR1[WE] = 1$, the comparator output will be sampled on every bus clock when $WINDOW=1$ to generate $COUTA$. Sampling does NOT occur when $WINDOW = 0$.
- The Filter block is bypassed when not in use.
- The Filter block acts as a simple sampler if the filter is bypassed and $CR0[FILTER_CNT]$ is set to $0x01$.
- The Filter block filters based on multiple samples when the filter is bypassed and $CR0[FILTER_CNT]$ is set greater than $0x01$.
 - If $CR1[SE] = 1$, the external $SAMPLE$ input is used as sampling clock
 - If $CR1[SE] = 0$, the divided bus clock is used as sampling clock

- If enabled, the Filter block will incur up to one bus clock additional latency penalty on COUT due to the fact that COUT, which is crossing clock domain boundaries, must be resynchronized to the bus clock.
- CR1[WE] and CR1[SE] are mutually exclusive.

34.2 Memory map/register definitions

CMP memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|----------------------------|
| 4007_3000 | CMP Control Register 0 (CMP0_CR0) | 8 | R/W | 00h | 34.2.1/706 |
| 4007_3001 | CMP Control Register 1 (CMP0_CR1) | 8 | R/W | 00h | 34.2.2/707 |
| 4007_3002 | CMP Filter Period Register (CMP0_FPR) | 8 | R/W | 00h | 34.2.3/709 |
| 4007_3003 | CMP Status and Control Register (CMP0_SCR) | 8 | R/W | 00h | 34.2.4/709 |
| 4007_3004 | DAC Control Register (CMP0_DACCR) | 8 | R/W | 00h | 34.2.5/710 |
| 4007_3005 | MUX Control Register (CMP0_MUXCR) | 8 | R/W | 00h | 34.2.6/711 |
| 4007_3008 | CMP Control Register 0 (CMP1_CR0) | 8 | R/W | 00h | 34.2.1/706 |
| 4007_3009 | CMP Control Register 1 (CMP1_CR1) | 8 | R/W | 00h | 34.2.2/707 |
| 4007_300A | CMP Filter Period Register (CMP1_FPR) | 8 | R/W | 00h | 34.2.3/709 |
| 4007_300B | CMP Status and Control Register (CMP1_SCR) | 8 | R/W | 00h | 34.2.4/709 |
| 4007_300C | DAC Control Register (CMP1_DACCR) | 8 | R/W | 00h | 34.2.5/710 |
| 4007_300D | MUX Control Register (CMP1_MUXCR) | 8 | R/W | 00h | 34.2.6/711 |

34.2.1 CMP Control Register 0 (CMPx_CR0)

Address: Base address + 0h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|---|------------|---|---|---|---|---------|---|
| Read | 0 | FILTER_CNT | | | 0 | 0 | HYSTCTR | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CMPx_CR0 field descriptions

| Field | Description |
|-------------------|---|
| 7 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 6–4 FILTER_CNT | Filter Sample Count |

Table continues on the next page...

CMPx_CR0 field descriptions (continued)

| Field | Description |
|----------------|---|
| | Represents the number of consecutive samples that must agree prior to the comparator output filter accepting a new output state. For information regarding filter programming and latency, see the Functional description . |
| | 000 Filter is disabled. If SE = 1, then COUT is a logic 0. This is not a legal state, and is not recommended. If SE = 0, COUT = COUTA. |
| | 001 One sample must agree. The comparator output is simply sampled. |
| | 010 2 consecutive samples must agree. |
| | 011 3 consecutive samples must agree. |
| | 100 4 consecutive samples must agree. |
| | 101 5 consecutive samples must agree. |
| | 110 6 consecutive samples must agree. |
| | 111 7 consecutive samples must agree. |
| 3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1–0 HYSTCTR | Comparator hard block hysteresis control Defines the programmable hysteresis level. The hysteresis values associated with each level are device-specific. See the Data Sheet of the device for the exact values. 00 Level 0 01 Level 1 10 Level 2 11 Level 3 |

34.2.2 CMP Control Register 1 (CMPx_CR1)

Address: Base address + 1h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|---|-------|-----|-----|-----|----|
| Read | SE | WE | 0 | PMODE | INV | COS | OPE | EN |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CMPx_CR1 field descriptions

| Field | Description |
|---------|--|
| 7 SE | Sample Enable At any given time, either SE or WE can be set. If a write to this register attempts to set both, then SE is set and WE is cleared. However, avoid writing 1s to both field locations because this "11" case is reserved and may change in future implementations. 0 Sampling mode is not selected. 1 Sampling mode is selected. |

Table continues on the next page...

CMPx_CR1 field descriptions (continued)

| Field | Description |
|---------------|--|
| 6 WE | <p>Windowing Enable</p> <p>At any given time, either SE or WE can be set. If a write to this register attempts to set both, then SE is set and WE is cleared. However, avoid writing 1s to both field locations because this "11" case is reserved and may change in future implementations.</p> <p>0 Windowing mode is not selected. 1 Windowing mode is selected.</p> |
| 5 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 4 PMODE | <p>Power Mode Select</p> <p>See the electrical specifications table in the device Data Sheet for details.</p> <p>0 Low-Speed (LS) Comparison mode selected. In this mode, CMP has slower output propagation delay and lower current consumption. 1 High-Speed (HS) Comparison mode selected. In this mode, CMP has faster output propagation delay and higher current consumption.</p> |
| 3 INV | <p>Comparator INVERT</p> <p>Allows selection of the polarity of the analog comparator function. It is also driven to the COUT output, on both the device pin and as SCR[COUT], when OPE=0.</p> <p>0 Does not invert the comparator output. 1 Inverts the comparator output.</p> |
| 2 COS | <p>Comparator Output Select</p> <p>0 Set the filtered comparator output (CMPO) to equal COUT. 1 Set the unfiltered comparator output (CMPO) to equal COUTA.</p> |
| 1 OPE | <p>Comparator Output Pin Enable</p> <p>0 CMPO is not available on the associated CMPO output pin. If the comparator does not own the pin, this field has no effect. 1 CMPO is available on the associated CMPO output pin.</p> <p>The comparator output (CMPO) is driven out on the associated CMPO output pin if the comparator owns the pin. If the comparator does not own the field, this bit has no effect.</p> |
| 0 EN | <p>Comparator Module Enable</p> <p>Enables the Analog Comparator module. When the module is not enabled, it remains in the off state, and consumes no power. When the user selects the same input from analog mux to the positive and negative port, the comparator is disabled automatically.</p> <p>0 Analog Comparator is disabled. 1 Analog Comparator is enabled.</p> |

34.2.3 CMP Filter Period Register (CMPx_FPR)

Address: Base address + 2h offset

| | | | | | | | | |
|-------|----------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | FILT_PER | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CMPx_FPR field descriptions

| Field | Description |
|-----------------|--|
| 7–0 FILT_PER | <p>Filter Sample Period</p> <p>Specifies the sampling period, in bus clock cycles, of the comparator output filter, when CR1[SE]=0. Setting FILT_PER to 0x0 disables the filter. Filter programming and latency details appear in the Functional description.</p> <p>This field has no effect when CR1[SE]=1. In that case, the external SAMPLE signal is used to determine the sampling period.</p> |

34.2.4 CMP Status and Control Register (CMPx_SCR)

Address: Base address + 3h offset

| | | | | | | | | |
|-------|---|-------|---|-----|-----|-----|-----|------|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | DMAEN | 0 | IER | IEF | CFR | CFF | COUT |
| Write | | | | | | w1c | w1c | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CMPx_SCR field descriptions

| Field | Description |
|---------------|--|
| 7 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 6 DMAEN | <p>DMA Enable Control</p> <p>Enables the DMA transfer triggered from the CMP module. When this field is set, a DMA request is asserted when CFR or CFF is set.</p> <p>0 DMA is disabled. 1 DMA is enabled.</p> |
| 5 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 4 IER | <p>Comparator Interrupt Enable Rising</p> <p>Enables the CFR interrupt from the CMP. When this field is set, an interrupt will be asserted when CFR is set.</p> |

Table continues on the next page...

CMPx_SCR field descriptions (continued)

| Field | Description |
|-----------|--|
| | 0 Interrupt is disabled. 1 Interrupt is enabled. |
| 3 IEF | Comparator Interrupt Enable Falling Enables the CFF interrupt from the CMP. When this field is set, an interrupt will be asserted when CFF is set. 0 Interrupt is disabled. 1 Interrupt is enabled. |
| 2 CFR | Analog Comparator Flag Rising Detects a rising-edge on COUT, when set, during normal operation. CFR is cleared by writing 1 to it. During Stop modes, CFR is level sensitive . 0 Rising-edge on COUT has not been detected. 1 Rising-edge on COUT has occurred. |
| 1 CFF | Analog Comparator Flag Falling Detects a falling-edge on COUT, when set, during normal operation. CFF is cleared by writing 1 to it. During Stop modes, CFF is level sensitive . 0 Falling-edge on COUT has not been detected. 1 Falling-edge on COUT has occurred. |
| 0 COUT | Analog Comparator Output Returns the current value of the Analog Comparator output, when read. The field is reset to 0 and will read as CR1[INV] when the Analog Comparator module is disabled, that is, when CR1[EN] = 0. Writes to this field are ignored. |

34.2.5 DAC Control Register (CMPx_DACCR)

Address: Base address + 4h offset

| | | | | | | | | |
|-------|-------|-------|-------|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | DACEN | VRSEL | VOSEL | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CMPx_DACCR field descriptions

| Field | Description |
|------------|---|
| 7 DACEN | DAC Enable Enables the DAC. When the DAC is disabled, it is powered down to conserve power. 0 DAC is disabled. 1 DAC is enabled. |
| 6 VRSEL | Supply Voltage Reference Source Select |

Table continues on the next page...

CMPx_DACCR field descriptions (continued)

| Field | Description |
|--------------|---|
| | 0 V_{in1} is selected as resistor ladder network supply reference. 1 V_{in2} is selected as resistor ladder network supply reference. |
| 5–0 VOSEL | DAC Output Voltage Select Selects an output voltage from one of 64 distinct levels. $DACO = (V_{in} / 64) * (VOSEL[5:0] + 1)$, so the DACO range is from $V_{in} / 64$ to V_{in} . |

34.2.6 MUX Control Register (CMPx_MUXCR)

Address: Base address + 5h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|---|---|------|---|---|------|---|
| Read | PSTM | 0 | | PSEL | | | MSEL | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CMPx_MUXCR field descriptions

| Field | Description |
|---------------|--|
| 7 PSTM | Pass Through Mode Enable This bit is used to enable to MUX pass through mode. Pass through mode is always available but for some devices this feature must be always disabled due to the lack of package pins. 0 Pass Through Mode is disabled. 1 Pass Through Mode is enabled. |
| 6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5–3 PSEL | Plus Input Mux Control Determines which input is selected for the plus input of the comparator. For INx inputs, see CMP, DAC, and ANMUX block diagrams. NOTE: When an inappropriate operation selects the same input for both muxes, the comparator automatically shuts down to prevent itself from becoming a noise generator. 000 IN0 001 IN1 010 IN2 011 IN3 100 IN4 101 IN5 110 IN6 111 IN7 |
| 2–0 MSEL | Minus Input Mux Control Determines which input is selected for the minus input of the comparator. For INx inputs, see CMP, DAC, and ANMUX block diagrams. |

Table continues on the next page...

CMPx_MUXCR field descriptions (continued)

| Field | Description |
|-------|--|
| | NOTE: When an inappropriate operation selects the same input for both muxes, the comparator automatically shuts down to prevent itself from becoming a noise generator. |
| 000 | IN0 |
| 001 | IN1 |
| 010 | IN2 |
| 011 | IN3 |
| 100 | IN4 |
| 101 | IN5 |
| 110 | IN6 |
| 111 | IN7 |

34.3 Functional description

The CMP module can be used to compare two analog input voltages applied to INP and INM.

CMPO is high when the non-inverting input is greater than the inverting input, and is low when the non-inverting input is less than the inverting input. This signal can be selectively inverted by setting CR1[INV] = 1.

SCR[IER] and SCR[IEF] are used to select the condition which will cause the CMP module to assert an interrupt to the processor. SCR[CFF] is set on a falling-edge and SCR[CFR] is set on rising-edge of the comparator output. The optionally filtered CMPO can be read directly through SCR[COUT].

34.3.1 CMP functional modes

There are the following main sub-blocks to the CMP module:

- The comparator itself
- The window function
- The filter function

The filter, CR0[FILTER_CNT], can be clocked from an internal or external clock source. The filter is programmable with respect to the number of samples that must agree before a change in the output is registered. In the simplest case, only one sample must agree. In this case, the filter acts as a simple sampler.

The external sample input is enabled using CR1[SE]. When set, the output of the comparator is sampled only on rising edges of the sample input.

The "windowing mode" is enabled by setting CR1[WE]. When set, the comparator output is sampled only when WINDOW=1. This feature can be used to ignore the comparator output during time periods in which the input voltages are not valid. This is especially useful when implementing zero-crossing-detection for certain PWM applications.

The comparator filter and sampling features can be combined as shown in the following table. Individual modes are discussed below.

Table 34-22. Comparator sample/filter controls

| Mode # | CR1[EN] | CR1[WE] | CR1[SE] | CR0[FILTER_CNT] | FPR[FILT_PER] | Operation |
|--|---------|---------|---------|-----------------|---------------|---|
| 1 | 0 | X | X | X | X | Disabled See the Disabled mode (# 1) . |
| 2A | 1 | 0 | 0 | 0x00 | X | Continuous Mode See the Continuous mode (#s 2A & 2B) . |
| 2B | 1 | 0 | 0 | X | 0x00 | |
| 3A | 1 | 0 | 1 | 0x01 | X | Sampled, Non-Filtered mode See the Sampled, Non-Filtered mode (#s 3A & 3B) . |
| 3B | 1 | 0 | 0 | 0x01 | > 0x00 | |
| 4A | 1 | 0 | 1 | > 0x01 | X | Sampled, Filtered mode See the Sampled, Filtered mode (#s 4A & 4B) . |
| 4B | 1 | 0 | 0 | > 0x01 | > 0x00 | |
| 5A | 1 | 1 | 0 | 0x00 | X | Windowed mode Comparator output is sampled on every rising bus clock edge when SAMPLE=1 to generate COUTA. See the Windowed mode (#s 5A & 5B) . |
| 5B | 1 | 1 | 0 | X | 0x00 | |
| 6 | 1 | 1 | 0 | 0x01 | 0x01–0xFF | Windowed/Resampled mode Comparator output is sampled on every rising bus clock edge when SAMPLE=1 to generate COUTA, which is then resampled on an interval determined by FILT_PER to generate COUT. See the Windowed/Resampled mode (# 6) . |
| 7 | 1 | 1 | 0 | > 0x01 | 0x01–0xFF | Windowed/Filtered mode Comparator output is sampled on every rising bus clock edge when SAMPLE=1 to generate COUTA, which is then resampled and filtered to generate COUT. See the Windowed/Filtered mode (#7) . |
| All other combinations of CR1[EN], CR1[WE], CR1[SE], CR0[FILTER_CNT], and FPR[FILT_PER] are illegal. | | | | | | |

For cases where a comparator is used to drive a fault input, for example, for a motor-control module such as FTM, it must be configured to operate in Continuous mode so that an external fault can immediately pass through the comparator to the target fault circuitry.

Note

Filtering and sampling settings must be changed only after setting CR1[SE]=0 and CR0[FILTER_CNT]=0x00. This resets the filter to a known state.

34.3.1.1 Disabled mode (# 1)

In Disabled mode, the analog comparator is non-functional and consumes no power. CMPO is 0 in this mode.

34.3.1.2 Continuous mode (#s 2A & 2B)

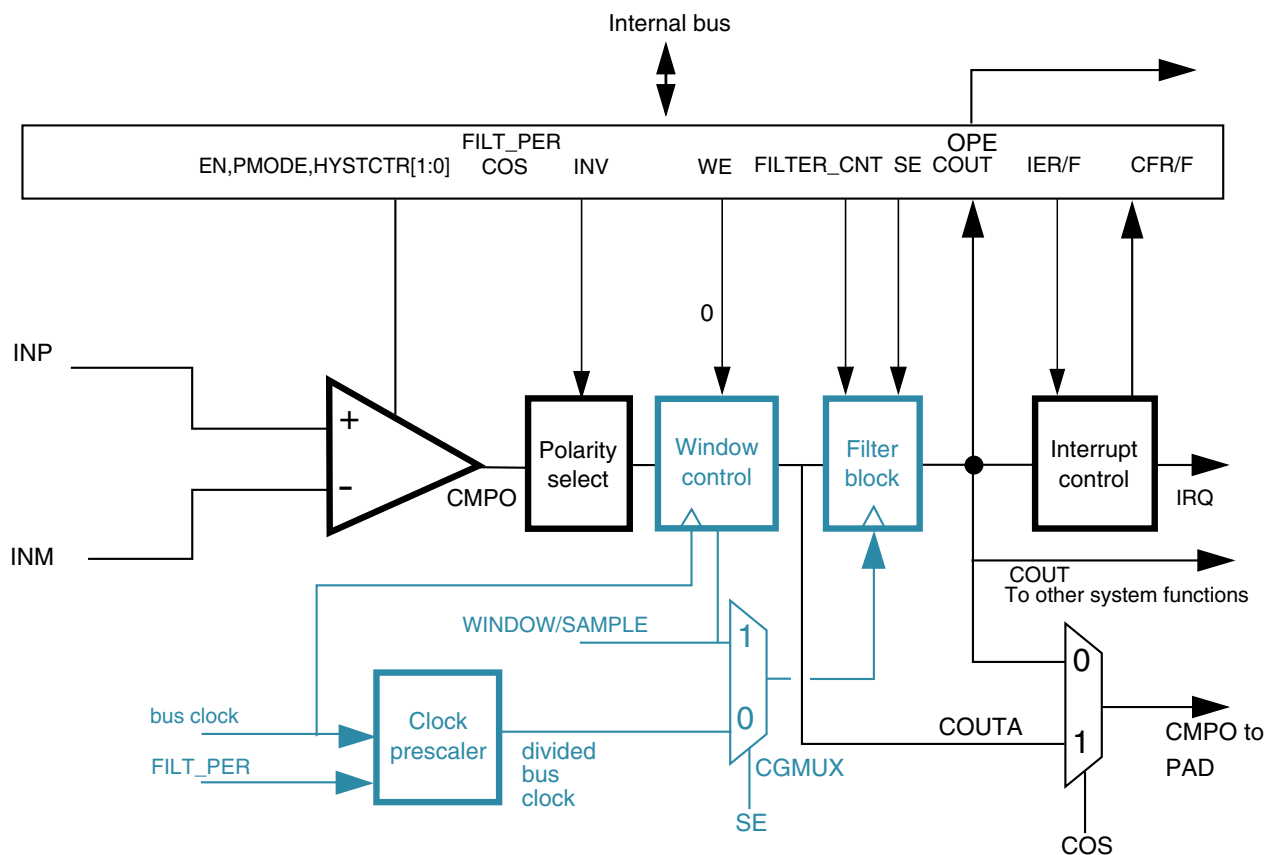


Figure 34-21. Comparator operation in Continuous mode

NOTE

See the chip configuration section for the source of sample/window input.

The analog comparator block is powered and active. CMPO may be optionally inverted, but is not subject to external sampling or filtering. Both window control and filter blocks are completely bypassed. SCR[COUT] is updated continuously. The path from comparator input pins to output pin is operating in combinational unlocked mode. COUT and COUTA are identical.

For control configurations which result in disabling the filter block, see the [Filter Block Bypass Logic](#) diagram.

34.3.1.3 Sampled, Non-Filtered mode (#s 3A & 3B)

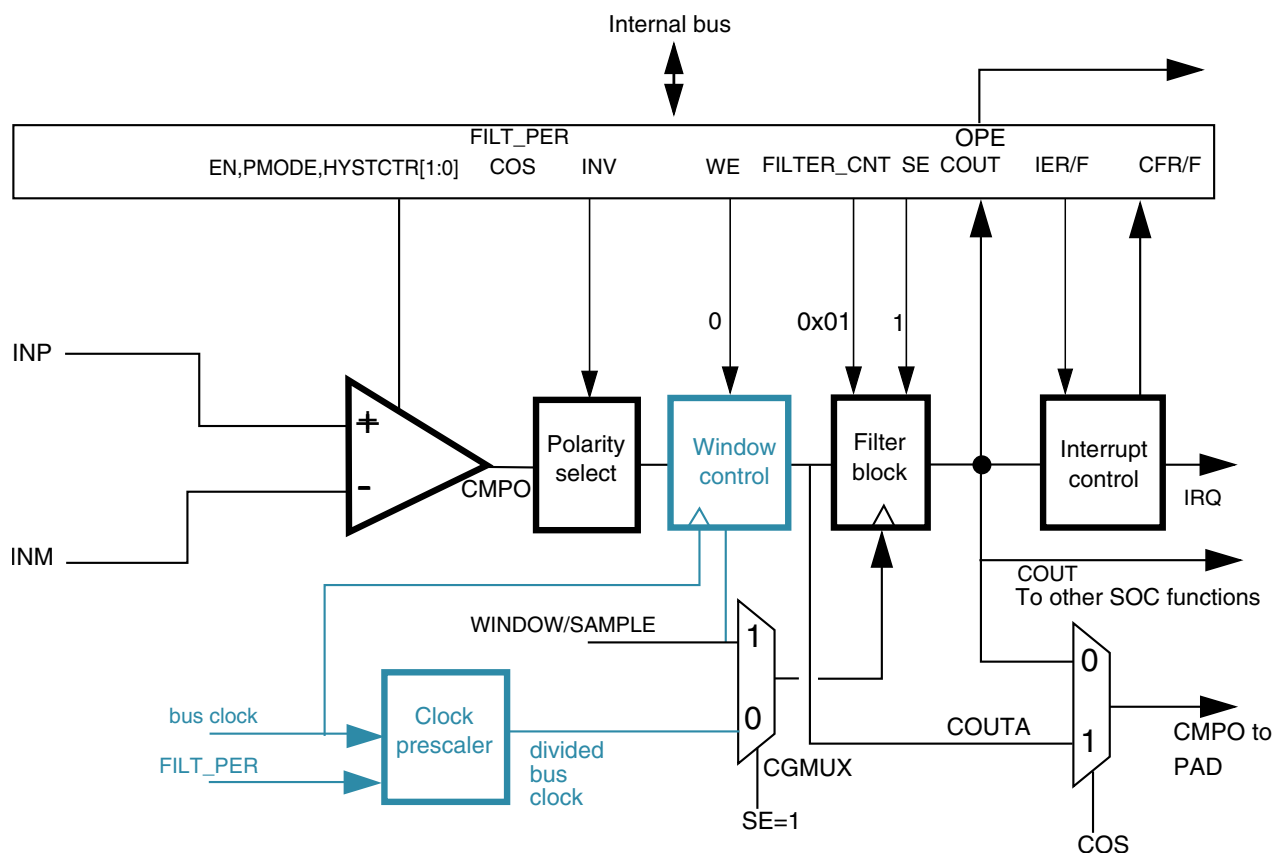


Figure 34-22. Sampled, Non-Filtered (# 3A): sampling point externally driven

In Sampled, Non-Filtered mode, the analog comparator block is powered and active. The path from analog inputs to COUTA is combinational unlocked. Windowing control is completely bypassed. COUTA is sampled whenever a rising-edge is detected on the filter block clock input.

The only difference in operation between Sampled, Non-Filtered (# 3A) and Sampled, Non-Filtered (# 3B) is in how the clock to the filter block is derived. In #3A, the clock to filter block is externally derived while in #3B, the clock to filter block is internally derived.

The comparator filter has no other function than sample/hold of the comparator output in this mode (# 3B).

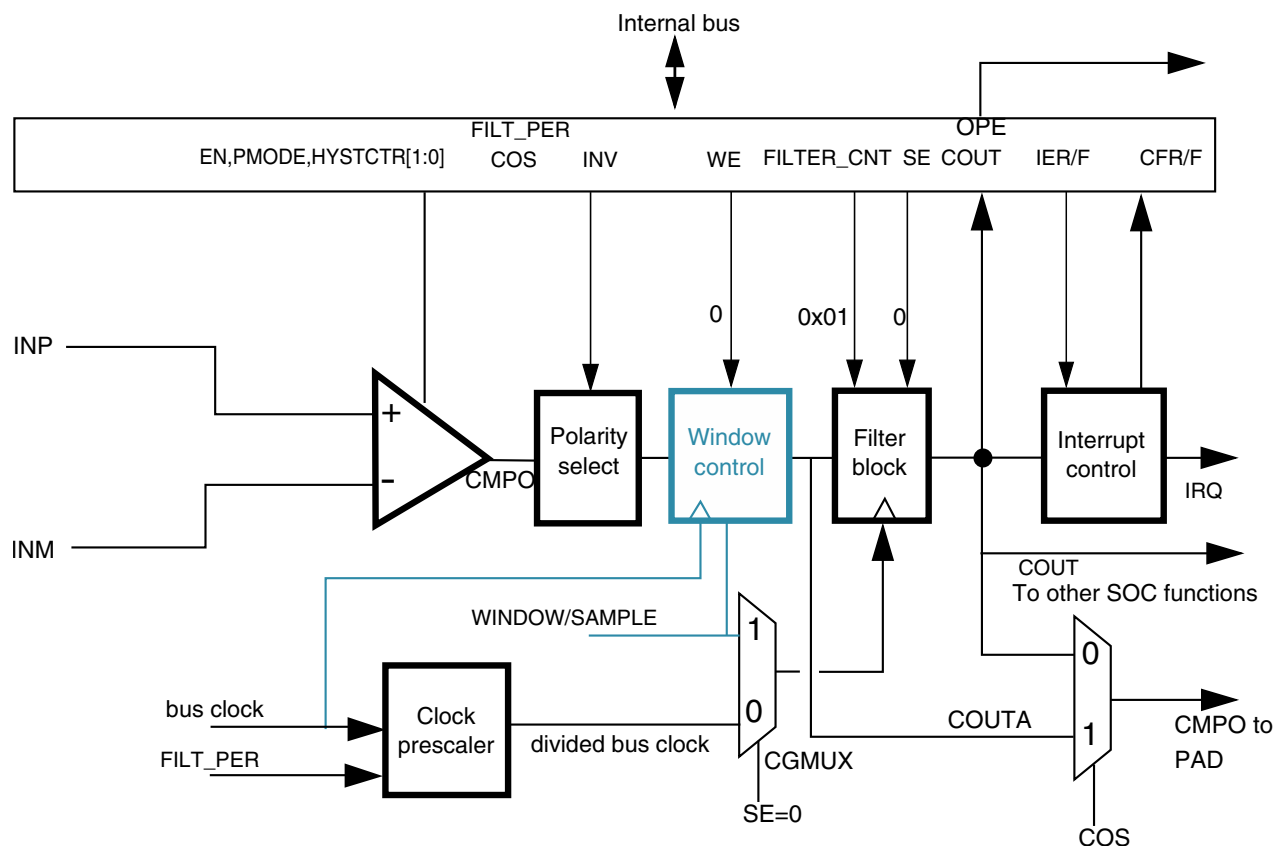


Figure 34-23. Sampled, Non-Filtered (# 3B): sampling interval internally derived

34.3.1.4 Sampled, Filtered mode (#s 4A & 4B)

In Sampled, Filtered mode, the analog comparator block is powered and active. The path from analog inputs to COUTA is combinational unlocked. Windowing control is completely bypassed. COUTA is sampled whenever a rising edge is detected on the filter block clock input.

The only difference in operation between Sampled, Non-Filtered (# 3A) and Sampled, Filtered (# 4A) is that, now, CR0[FILTER_CNT]>1, which activates filter operation.



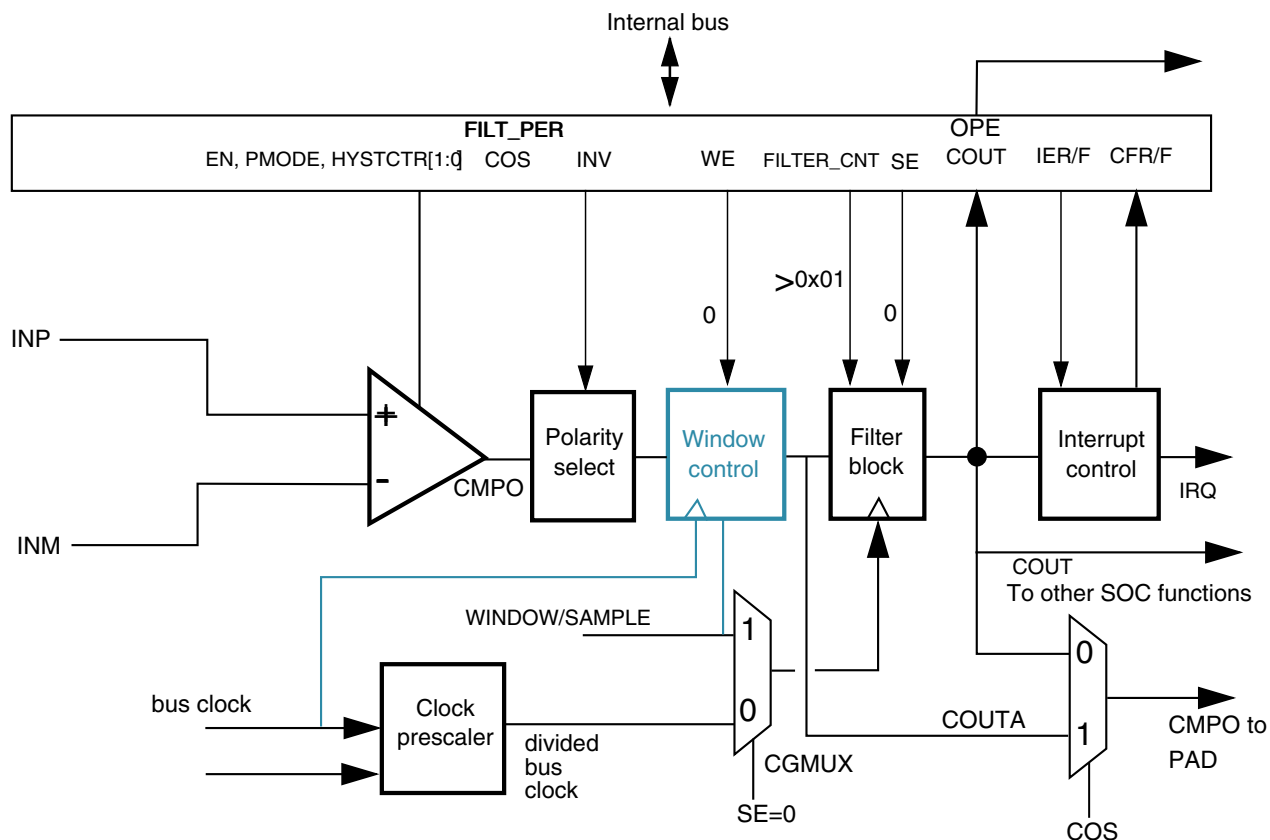


Figure 34-25. Sampled, Filtered (# 4B): sampling point internally derived

The only difference in operation between Sampled, Non-Filtered (# 3B) and Sampled, Filtered (# 4B) is that now, CR0[FILTER_CNT]>1, which activates filter operation.

34.3.1.5 Windowed mode (#s 5A & 5B)

The following figure illustrates comparator operation in the Windowed mode, ignoring latency of the analog comparator, polarity select, and window control block. It also assumes that the polarity select is set to non-inverting state.

NOTE

The analog comparator output is passed to COUTA only when the WINDOW signal is high.

In actual operation, COUTA may lag the analog inputs by up to one bus clock cycle plus the combinational path delay through the comparator and polarity select logic.

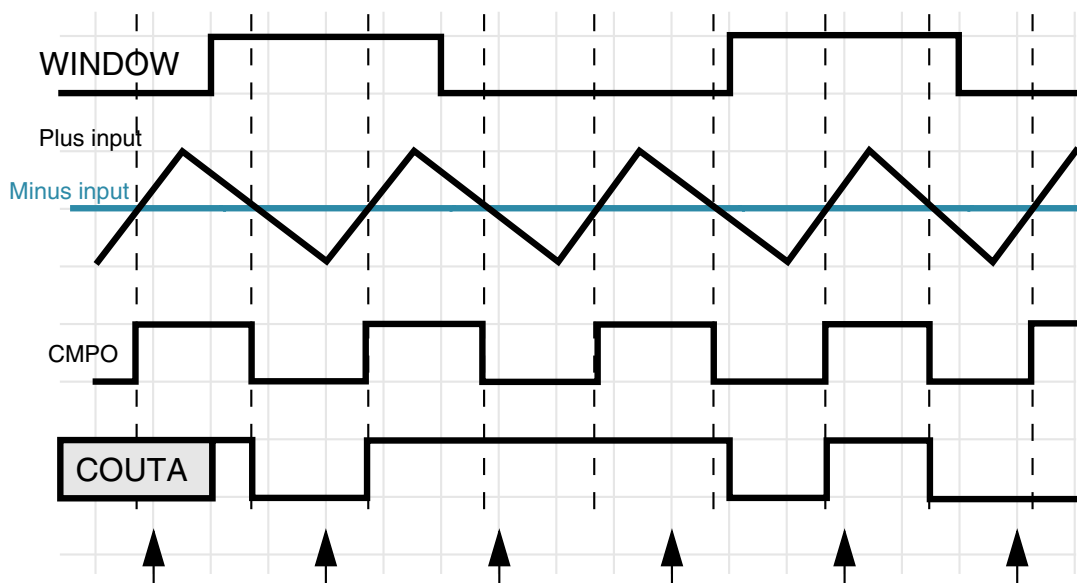


Figure 34-26. Windowed mode operation

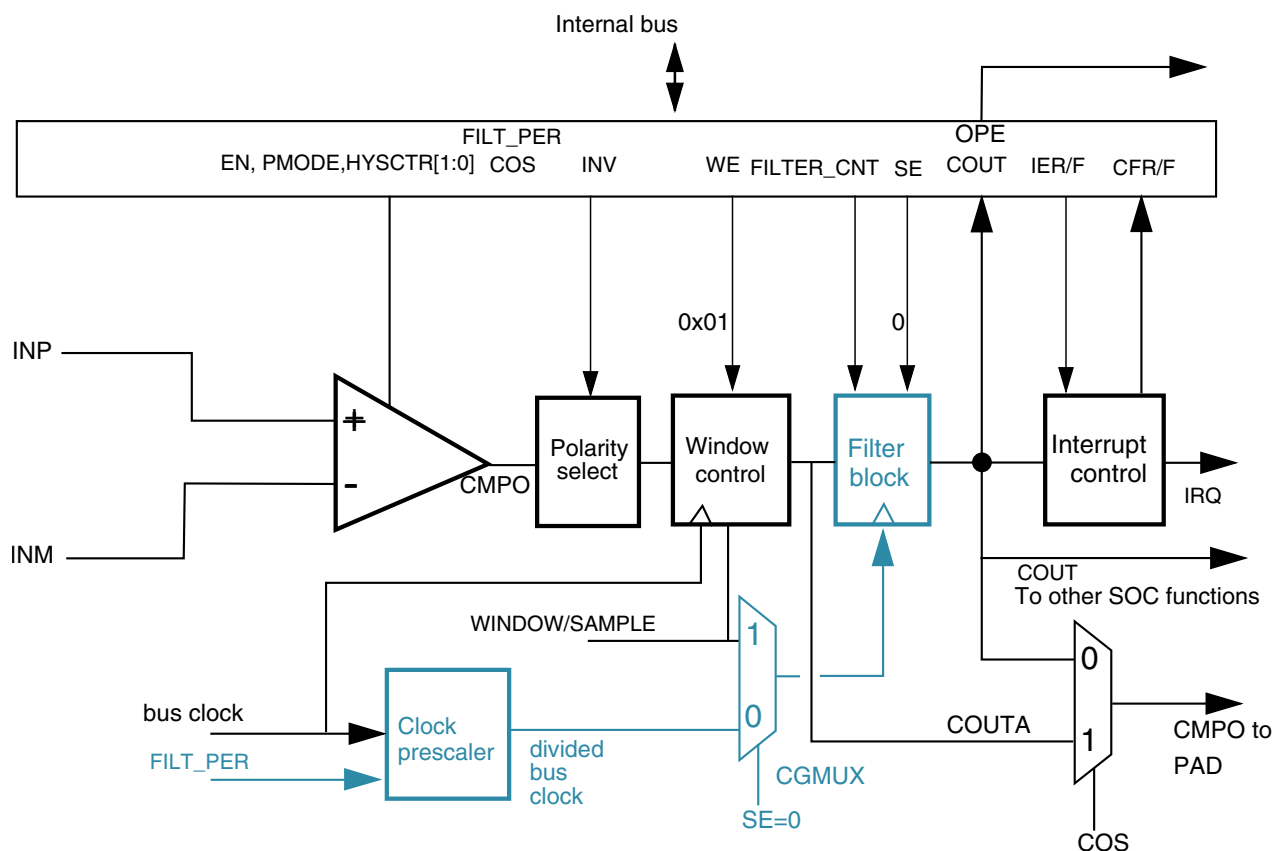


Figure 34-27. Windowed mode

For control configurations which result in disabling the filter block, see [Filter Block Bypass Logic](#) diagram.

When any windowed mode is active, COUTA is clocked by the bus clock whenever WINDOW = 1. The last latched value is held when WINDOW = 0.

34.3.1.6 Windowed/Resampled mode (# 6)

The following figure uses the same input stimulus shown in Figure 34-26, and adds resampling of COUTA to generate COUT. Samples are taken at the time points indicated by the arrows in the figure. Again, prop delays and latency are ignored for the sake of clarity.

This example was generated solely to demonstrate operation of the comparator in windowed/resampled mode, and does not reflect any specific application. Depending upon the sampling rate and window placement, COUT may not see zero-crossing events detected by the analog comparator. Sampling period and/or window placement must be carefully considered for a given application.

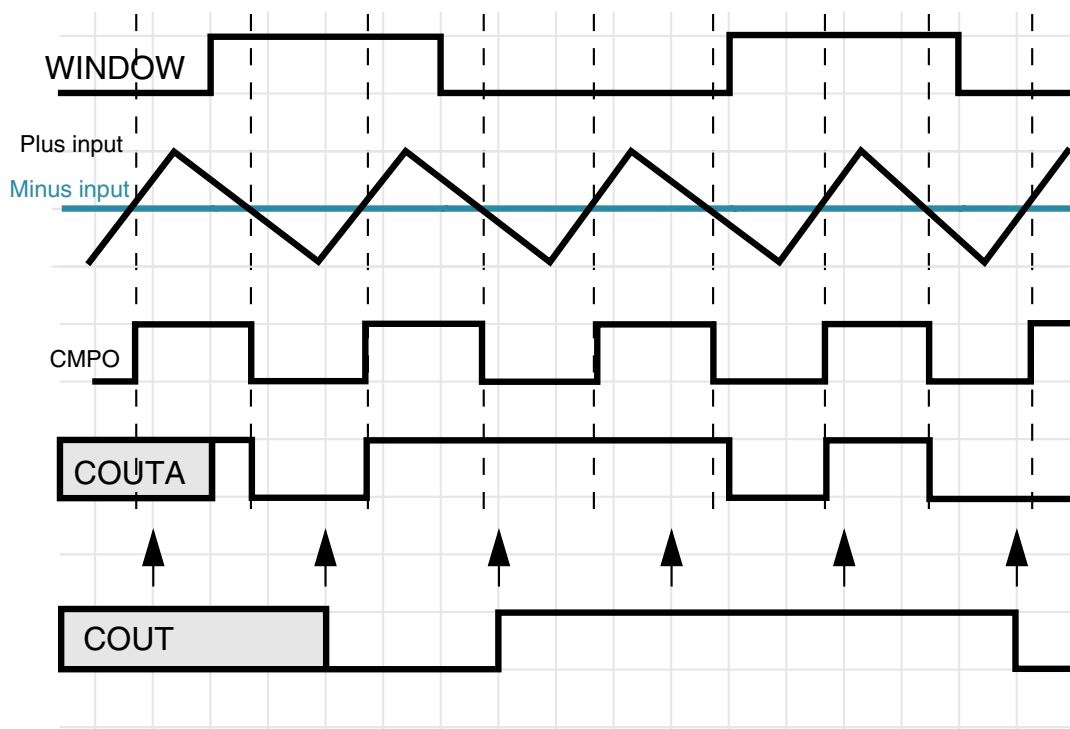


Figure 34-28. Windowed/resampled mode operation

This mode of operation results in an unfiltered string of comparator samples where the interval between the samples is determined by FPR[FILT_PER] and the bus clock rate. Configuration for this mode is virtually identical to that for the Windowed/Filtered Mode shown in the next section. The only difference is that the value of CR0[FILTER_CNT] must be 1.

34.3.1.7 Windowed/Filtered mode (#7)

This is the most complex mode of operation for the comparator block, as it uses both windowing and filtering features. It also has the highest latency of any of the modes. This can be approximated: up to 1 bus clock synchronization in the window function + $((CR0[FILTER_CNT] * FPR[FILT_PER]) + 1) * \text{bus clock}$ for the filter function.

When any windowed mode is active, COUTA is clocked by the bus clock whenever WINDOW = 1. The last latched value is held when WINDOW = 0.

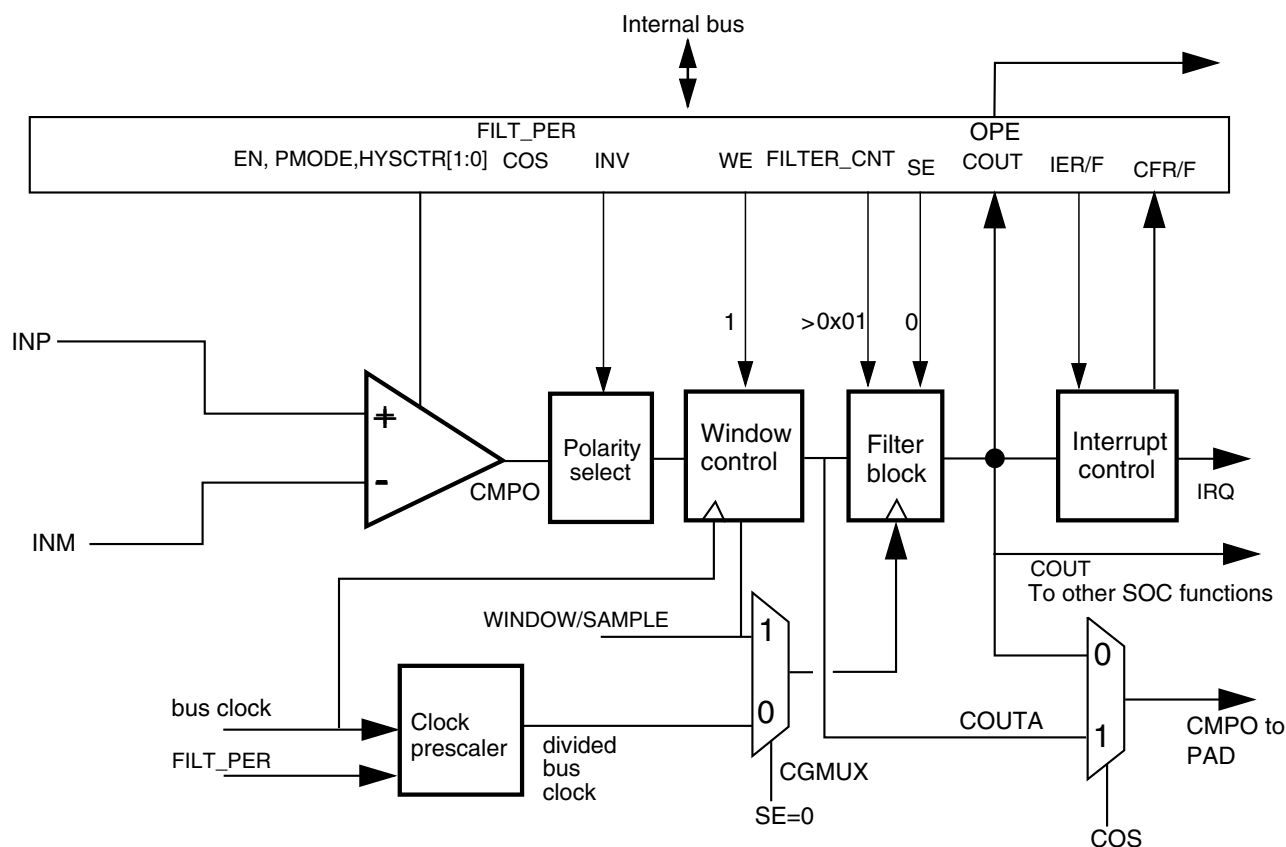


Figure 34-29. Windowed/Filtered mode

34.3.2 Power modes

34.3.2.1 Wait mode operation

During Wait and VLPW modes, the CMP, if enabled, continues to operate normally and a CMP interrupt can wake the MCU.

34.3.2.2 Stop mode operation

Depending on clock restrictions related to the MCU core or core peripherals, the MCU is brought out of stop when a compare event occurs and the corresponding interrupt is enabled. Similarly, if CR1[OPE] is enabled, the comparator output operates as in the normal operating mode and comparator output is placed onto the external pin. In Stop modes, the comparator can be operational in both:

- High-Speed (HS) Comparison mode when CR1[PMODE] = 1
- Low-Speed (LS) Comparison mode when CR1[PMODE] = 0

It is recommended to use the LS mode to minimize power consumption.

If stop is exited with a reset, all comparator registers are put into their reset state.

34.3.2.3 Low-Leakage mode operation

When the chip is in Low-Leakage modes:

- The CMP module is partially functional and is limited to Low-Speed mode, regardless of CR1[PMODE] setting
- Windowed, Sampled, and Filtered modes are not supported
- The CMP output pin is latched and does not reflect the compare output state.

The positive- and negative-input voltage can be supplied from external pins or the DAC output. The MCU can be brought out of the Low-Leakage mode if a compare event occurs and the CMP interrupt is enabled. After wakeup from low-leakage modes, the CMP module is in the reset state except for SCR[CFF] and SCR[CFR].

34.3.3 Startup and operation

A typical startup sequence is listed here.

- The time required to stabilize COUT will be the power-on delay of the comparators plus the largest propagation delay from a selected analog source through the analog comparator, windowing function and filter. See the Data Sheets for power-on delays of the comparators. The windowing function has a maximum of one bus clock period delay. The filter delay is specified in the [Low-pass filter](#).
- During operation, the propagation delay of the selected data paths must always be considered. It may take many bus clock cycles for COUT and SCR[CFR]/SCR[CFF]

to reflect an input change or a configuration change to one of the components involved in the data path.

- When programmed for filtering modes, COUT will initially be equal to 0, until sufficient clock cycles have elapsed to fill all stages of the filter. This occurs even if COUTA is at a logic 1.

34.3.4 Low-pass filter

The low-pass filter operates on the unfiltered and unsynchronized and optionally inverted comparator output COUTA and generates the filtered and synchronized output COUT.

Both COUTA and COUT can be configured as module outputs and are used for different purposes within the system.

Synchronization and edge detection are always used to determine status register bit values. They also apply to COUT for all sampling and windowed modes. Filtering can be performed using an internal timebase defined by FPR[FILT_PER], or using an external SAMPLE input to determine sample time.

The need for digital filtering and the amount of filtering is dependent on user requirements. Filtering can become more useful in the absence of an external hysteresis circuit. Without external hysteresis, high-frequency oscillations can be generated at COUTA when the selected INM and INP input voltages differ by less than the offset voltage of the differential comparator.

34.3.4.1 Enabling filter modes

Filter modes can be enabled by:

- Setting CR0[FILTER_CNT] > 0x01 and
- Setting FPR[FILT_PER] to a nonzero value or setting CR1[SE]=1

If using the divided bus clock to drive the filter, it will take samples of COUTA every FPR[FILT_PER] bus clock cycles.

The filter output will be at logic 0 when first initialized, and will subsequently change when all the consecutive CR0[FILTER_CNT] samples agree that the output value has changed. In other words, SCR[COUT] will be 0 for some initial period, even when COUTA is at logic 1.

Setting both CR1[SE] and FPR[FILT_PER] to 0 disables the filter and eliminates switching current associated with the filtering process.

Note

Always switch to this setting prior to making any changes in filter parameters. This resets the filter to a known state. Switching CR0[FILTER_CNT] on the fly without this intermediate step can result in unexpected behavior.

If CR1[SE]=1, the filter takes samples of COUTA on each positive transition of the sample input. The output state of the filter changes when all the consecutive CR0[FILTER_CNT] samples agree that the output value has changed.

34.3.4.2 Latency issues

The value of FPR[FILT_PER] or SAMPLE period must be set such that the sampling period is just longer than the period of the expected noise. This way a noise spike will corrupt only one sample. The value of CR0[FILTER_CNT] must be chosen to reduce the probability of noisy samples causing an incorrect transition to be recognized. The probability of an incorrect transition is defined as the probability of an incorrect sample raised to the power of CR0[FILTER_CNT].

The values of FPR[FILT_PER] or SAMPLE period and CR0[FILTER_CNT] must also be traded off against the desire for minimal latency in recognizing actual comparator output transitions. The probability of detecting an actual output change within the nominal latency is the probability of a correct sample raised to the power of CR0[FILTER_CNT].

The following table summarizes maximum latency values for the various modes of operation *in the absence of noise*. Filtering latency is restarted each time an actual output transition is masked by noise.

Table 34-23. Comparator sample/filter maximum latencies

| Mode # | CR1[EN] | CR1[WE] | CR1[SE] | CR0[FILTER_CNT] | FPR[FILT_PER] | Operation | Maximum latency ¹ |
|--------|---------|---------|---------|-----------------|---------------|----------------------------|--|
| 1 | 0 | X | X | X | X | Disabled | N/A |
| 2A | 1 | 0 | 0 | 0x00 | X | Continuous Mode | T_{PD} |
| 2B | 1 | 0 | 0 | X | 0x00 | | |
| 3A | 1 | 0 | 1 | 0x01 | X | Sampled, Non-Filtered mode | $T_{PD} + T_{SAMPLE} + T_{per}$ |
| 3B | 1 | 0 | 0 | 0x01 | > 0x00 | | $T_{PD} + (FPR[FILT_PER] * T_{per}) + T_{per}$ |
| 4A | 1 | 0 | 1 | > 0x01 | X | Sampled, Filtered mode | $T_{PD} + (CR0[FILTER_CNT] * T_{SAMPLE}) + T_{per}$ |
| 4B | 1 | 0 | 0 | > 0x01 | > 0x00 | | $T_{PD} + (CR0[FILTER_CNT] * FPR[FILT_PER] * T_{per}) + T_{per}$ |

Table continues on the next page...

Table 34-23. Comparator sample/filter maximum latencies (continued)

| Mode # | CR1[EN] | CR1[WE] | CR1[SE] | CR0[FILTER_CNT] | FPR[FILT_PER] | Operation | Maximum latency ¹ |
|--------|---------|---------|---------|-----------------|---------------|---------------------------|---|
| 5A | 1 | 1 | 0 | 0x00 | X | Windowed mode | $T_{PD} + T_{per}$ |
| 5B | 1 | 1 | 0 | X | 0x00 | | $T_{PD} + T_{per}$ |
| 6 | 1 | 1 | 0 | 0x01 | 0x01 - 0xFF | Windowed / Resampled mode | $T_{PD} + (FPR[FILT_PER] * T_{per}) + 2T_{per}$ |
| 7 | 1 | 1 | 0 | > 0x01 | 0x01 - 0xFF | Windowed / Filtered mode | $T_{PD} + (CR0[FILTER_CNT] * FPR[FILT_PER] * T_{per}) + 2T_{per}$ |

1. T_{PD} represents the intrinsic delay of the analog component plus the polarity select logic. T_{SAMPLE} is the clock period of the external sample clock. T_{per} is the period of the bus clock.

34.4 CMP interrupts

The CMP module is capable of generating an interrupt on either the rising- or falling-edge of the comparator output, or both.

The following table gives the conditions in which the interrupt request is asserted and deasserted.

| When | Then |
|--|-------------------------------------|
| SCR[IER] and SCR[CFR] are set | The interrupt request is asserted |
| SCR[IEF] and SCR[CFF] are set | The interrupt request is asserted |
| SCR[IER] and SCR[CFR] are cleared for a rising-edge interrupt | The interrupt request is deasserted |
| SCR[IEF] and SCR[CFF] are cleared for a falling-edge interrupt | The interrupt request is deasserted |

34.5 DMA support

Normally, the CMP generates a CPU interrupt if there is a change on the COUT. When DMA support is enabled by setting SCR[DMAEN] and the interrupt is enabled by setting SCR[IER], SCR[IEF], or both, the corresponding change on COUT forces a DMA transfer request rather than a CPU interrupt instead. When the DMA has completed the transfer, it sends a transfer completing indicator that deasserts the DMA transfer request and clears the flag to allow a subsequent change on comparator output to occur and force another DMA request.

The comparator can remain functional in STOP modes.

When DMA support is enabled by setting SCR[DMAEN] and the interrupt is enabled by setting SCR[IER], SCR[IEF], or both, the corresponding change on COUT forces a DMA transfer request to wake up the system from STOP modes. After the data transfer has finished, system will go back to STOP modes. Refer to DMA chapters in the device reference manual for the asynchronous DMA function for details.

34.6 Digital-to-analog converter

The figure found here shows the block diagram of the DAC module.

It contains a 64-tap resistor ladder network and a 64-to-1 multiplexer, which selects an output voltage from one of 64 distinct levels that outputs from DACO. It is controlled through the DAC Control Register (DACCR). Its supply reference source can be selected from two sources V_{in1} and V_{in2} . The module can be powered down or disabled when not in use. When in Disabled mode, DACO is connected to the analog ground.

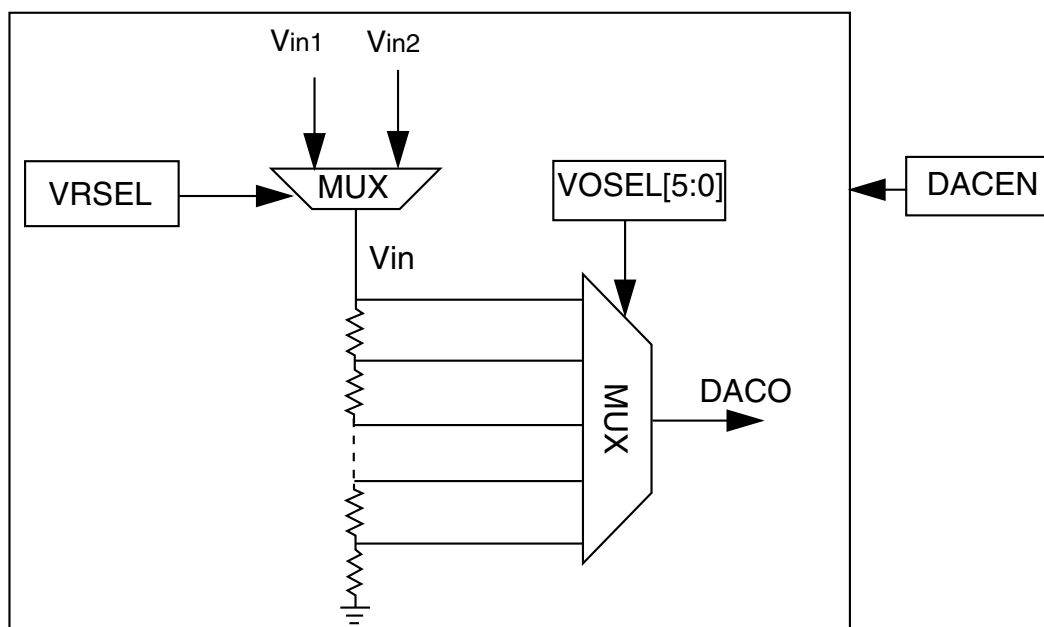


Figure 34-30. 6-bit DAC block diagram

34.7 DAC functional description

This section provides DAC functional description information.

34.7.1 Voltage reference source select

- V_{in1} connects to the primary voltage source as supply reference of 64 tap resistor ladder
- V_{in2} connects to an alternate voltage source

34.8 DAC resets

This module has a single reset input, corresponding to the chip-wide peripheral reset.

34.9 DAC clocks

This module has a single clock input, the bus clock.

34.10 DAC interrupts

This module has no interrupts.



Chapter 35

12-bit Digital-to-Analog Converter (DAC)

35.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The 12-bit digital-to-analog converter (DAC) is a low-power, general-purpose DAC. The output of the DAC can be placed on an external pin or set as one of the inputs to the analog comparator, op-amps, or ADC.

35.2 Features

The features of the DAC module include:

- On-chip programmable reference generator output. The voltage output range is from $1/4096 V_{in}$ to V_{in} , and the step is $1/4096 V_{in}$, where V_{in} is the input voltage.
- V_{in} can be selected from two reference sources
- Static operation in Normal Stop mode
- 16-word data buffer supported with configurable watermark and multiple operation modes
- DMA support

35.3 Block diagram

The block diagram of the DAC module is as follows:

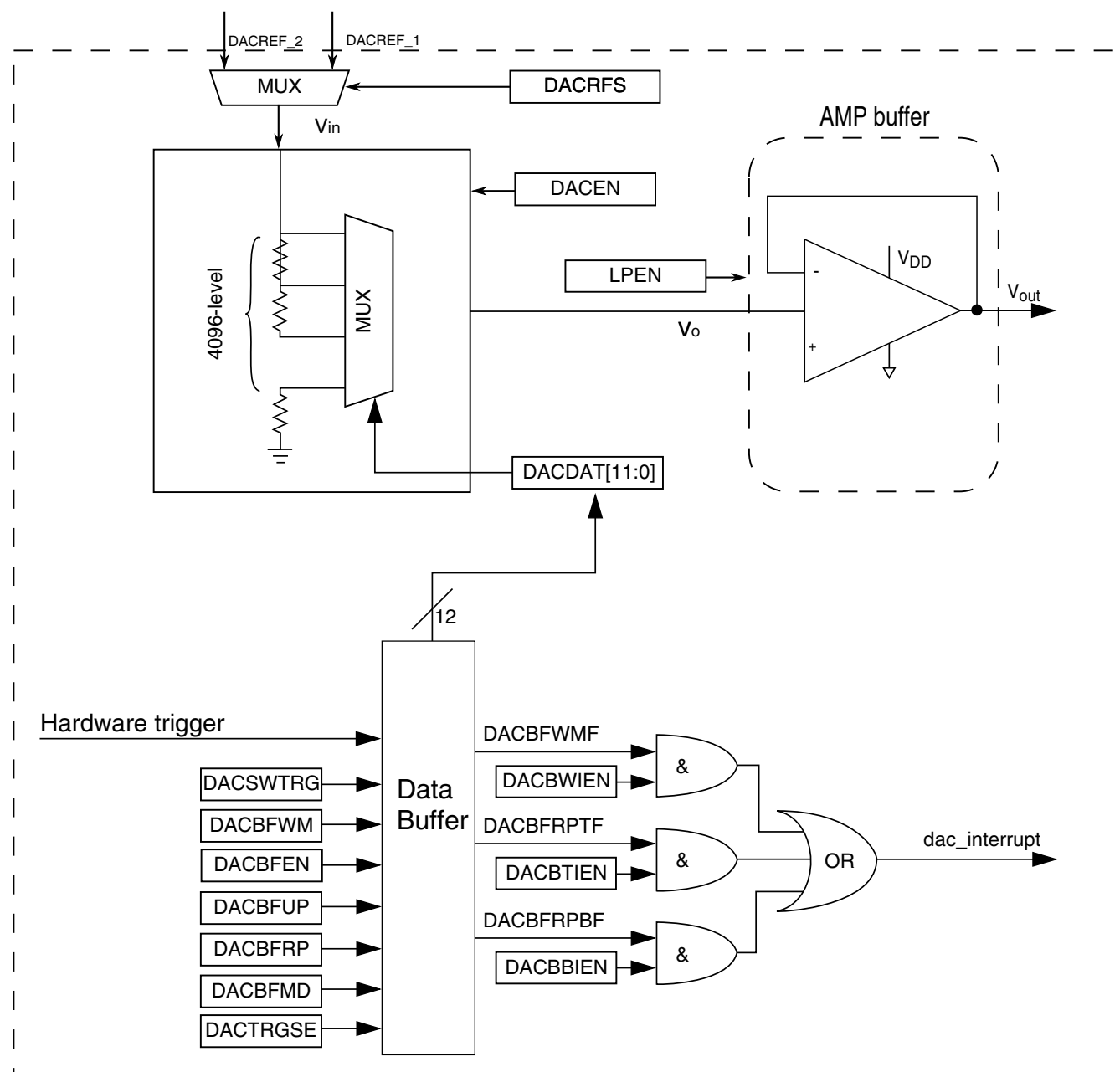


Figure 35-1. DAC block diagram

35.4 Memory map/register definition

The DAC has registers to control analog comparator and programmable voltage divider to perform the digital-to-analog functions.

DAC memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--------------------------------------|-----------------|--------|-------------|----------------------------|
| 4003_F000 | DAC Data Low Register (DAC0_DAT0L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F001 | DAC Data High Register (DAC0_DAT0H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F002 | DAC Data Low Register (DAC0_DAT1L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F003 | DAC Data High Register (DAC0_DAT1H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F004 | DAC Data Low Register (DAC0_DAT2L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F005 | DAC Data High Register (DAC0_DAT2H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F006 | DAC Data Low Register (DAC0_DAT3L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F007 | DAC Data High Register (DAC0_DAT3H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F008 | DAC Data Low Register (DAC0_DAT4L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F009 | DAC Data High Register (DAC0_DAT4H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F00A | DAC Data Low Register (DAC0_DAT5L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F00B | DAC Data High Register (DAC0_DAT5H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F00C | DAC Data Low Register (DAC0_DAT6L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F00D | DAC Data High Register (DAC0_DAT6H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F00E | DAC Data Low Register (DAC0_DAT7L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F00F | DAC Data High Register (DAC0_DAT7H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F010 | DAC Data Low Register (DAC0_DAT8L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F011 | DAC Data High Register (DAC0_DAT8H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F012 | DAC Data Low Register (DAC0_DAT9L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F013 | DAC Data High Register (DAC0_DAT9H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F014 | DAC Data Low Register (DAC0_DAT10L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F015 | DAC Data High Register (DAC0_DAT10H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F016 | DAC Data Low Register (DAC0_DAT11L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F017 | DAC Data High Register (DAC0_DAT11H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F018 | DAC Data Low Register (DAC0_DAT12L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F019 | DAC Data High Register (DAC0_DAT12H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F01A | DAC Data Low Register (DAC0_DAT13L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F01B | DAC Data High Register (DAC0_DAT13H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F01C | DAC Data Low Register (DAC0_DAT14L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F01D | DAC Data High Register (DAC0_DAT14H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F01E | DAC Data Low Register (DAC0_DAT15L) | 8 | R/W | 00h | 35.4.1/732 |
| 4003_F01F | DAC Data High Register (DAC0_DAT15H) | 8 | R/W | 00h | 35.4.2/732 |
| 4003_F020 | DAC Status Register (DAC0_SR) | 8 | R/W | 02h | 35.4.3/732 |
| 4003_F021 | DAC Control Register (DAC0_C0) | 8 | R/W | 00h | 35.4.4/733 |
| 4003_F022 | DAC Control Register 1 (DAC0_C1) | 8 | R/W | 00h | 35.4.5/735 |
| 4003_F023 | DAC Control Register 2 (DAC0_C2) | 8 | R/W | 0Fh | 35.4.6/736 |

35.4.1 DAC Data Low Register (DACx_DATnL)

Address: 4003_F000h base + 0h offset + (2d × i), where i=0d to 15d

| | | | | | | | | |
|-------|-------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | DATA0 | | | | | | | |
| Write | DATA0 | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DACx_DATnL field descriptions

| Field | Description |
|--------------|--|
| 7–0 DATA0 | <p>DATA0</p> <p>When the DAC buffer is not enabled, DATA[11:0] controls the output voltage based on the following formula: $V_{out} = V_{in} * (1 + DACDAT0[11:0])/4096$</p> <p>When the DAC buffer is enabled, DATA is mapped to the 16-word buffer.</p> |

35.4.2 DAC Data High Register (DACx_DATnH)

Address: 4003_F000h base + 1h offset + (2d × i), where i=0d to 15d

| | | | | | | | | |
|-------|---|---|---|---|-------|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | DATA1 | | | |
| Write | 0 | | | | DATA1 | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DACx_DATnH field descriptions

| Field | Description |
|-----------------|--|
| 7–4 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 3–0 DATA1 | <p>DATA1</p> <p>When the DAC Buffer is not enabled, DATA[11:0] controls the output voltage based on the following formula. $V_{out} = V_{in} * (1 + DACDAT0[11:0])/4096$</p> <p>When the DAC buffer is enabled, DATA[11:0] is mapped to the 16-word buffer.</p> |

35.4.3 DAC Status Register (DACx_SR)

If DMA is enabled, the flags can be cleared automatically by DMA when the DMA request is done. Writing 0 to a field clears it whereas writing 1 has no effect. After reset, DACBFRPTF is set and can be cleared by software, if needed. The flags are set only when the data buffer status is changed.

NOTE

Do not use 32/16-bit accesses to this register.

Address: 4003_F000h base + 20h offset = 4003_F020h

| | | | | | | | | |
|-------|---|---|---|---|---|---------|----------|----------|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | | DACBFWM | DACBFRPT | DACBFRPB |
| Write | | | | | | F | F | F |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

DACx_SR field descriptions

| Field | Description |
|-----------------|--|
| 7-3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 DACBFWMF | DAC Buffer Watermark Flag 0 The DAC buffer read pointer has not reached the watermark level. 1 The DAC buffer read pointer has reached the watermark level. |
| 1 DACBFRPTF | DAC Buffer Read Pointer Top Position Flag 0 The DAC buffer read pointer is not zero. 1 The DAC buffer read pointer is zero. |
| 0 DACBFRPBF | DAC Buffer Read Pointer Bottom Position Flag 0 The DAC buffer read pointer is not equal to C2[DACBFUP]. 1 The DAC buffer read pointer is equal to C2[DACBFUP]. |

35.4.4 DAC Control Register (DACx_C0)

NOTE

Do not use 32- or 16-bit accesses to this register.

Address: 4003_F000h base + 21h offset = 4003_F021h

| | | | | | | | | |
|-------|-------|--------|----------|----------|------|----------|----------|----------|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | DACEN | DACRFS | DACTRGSE | 0 | LPEN | DACBWIEN | DACBTIEN | DACBBIEN |
| Write | | | L | DACSWTRG | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DACx_C0 field descriptions

| Field | Description |
|------------|--|
| 7 DACEN | DAC Enable Starts the Programmable Reference Generator operation. |

Table continues on the next page...

DACx_C0 field descriptions (continued)

| Field | Description |
|----------------|--|
| | 0 The DAC system is disabled. 1 The DAC system is enabled. |
| 6 DACRFS | DAC Reference Select 0 The DAC selects DACREF_1 as the reference voltage. 1 The DAC selects DACREF_2 as the reference voltage. |
| 5 DACTRGSEL | DAC Trigger Select 0 The DAC hardware trigger is selected. 1 The DAC software trigger is selected. |
| 4 DACSCTR | DAC Software Trigger Active high. This is a write-only field, which always reads 0. If DAC software trigger is selected and buffer is enabled, writing 1 to this field will advance the buffer read pointer once. 0 The DAC soft trigger is not valid. 1 The DAC soft trigger is valid. |
| 3 LPEN | DAC Low Power Control NOTE: See the 12-bit DAC electrical characteristics of the device data sheet for details on the impact of the modes below. 0 High-Power mode 1 Low-Power mode |
| 2 DACBWEN | DAC Buffer Watermark Interrupt Enable 0 The DAC buffer watermark interrupt is disabled. 1 The DAC buffer watermark interrupt is enabled. |
| 1 DACBTEN | DAC Buffer Read Pointer Top Flag Interrupt Enable 0 The DAC buffer read pointer top flag interrupt is disabled. 1 The DAC buffer read pointer top flag interrupt is enabled. |
| 0 DACBBEN | DAC Buffer Read Pointer Bottom Flag Interrupt Enable 0 The DAC buffer read pointer bottom flag interrupt is disabled. 1 The DAC buffer read pointer bottom flag interrupt is enabled. |

35.4.5 DAC Control Register 1 (DACx_C1)

NOTE

Do not use 32- or 16-bit accesses to this register.

Address: 4003_F000h base + 22h offset = 4003_F022h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|---|---|---|---------|---------|---|---------|
| Read | DMAEN | 0 | | | DACBFWM | DACBFMD | | DACBFEN |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

DACx_C1 field descriptions

| Field | Description |
|-----------------|---|
| 7 DMAEN | DMA Enable Select 0 DMA is disabled. 1 DMA is enabled. When DMA is enabled, the DMA request will be generated by original interrupts. The interrupts will not be presented on this module at the same time. |
| 6–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4–3 DACBFWM | DAC Buffer Watermark Select Controls when SR[DACBFWMF] is set. When the DAC buffer read pointer reaches the word defined by this field, which is 1–4 words away from the upper limit (DACBUP), SR[DACBFWMF] will be set. This allows user configuration of the watermark interrupt. 00 1 word 01 2 words 10 3 words 11 4 words |
| 2–1 DACBFMD | DAC Buffer Work Mode Select 00 Normal mode 01 Swing mode 10 One-Time Scan mode 11 Reserved |
| 0 DACBFEN | DAC Buffer Enable 0 Buffer read pointer is disabled. The converted data is always the first word of the buffer. 1 Buffer read pointer is enabled. The converted data is the word that the read pointer points to. It means converted data can be from any word of the buffer. |

35.4.6 DAC Control Register 2 (DACx_C2)

Address: 4003_F000h base + 23h offset = 4003_F023h

| | | | | | | | | |
|-------|---------|---|---|---|---------|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | DACBFRP | | | | DACBFUP | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |

DACx_C2 field descriptions

| Field | Description |
|----------------|--|
| 7–4 DACBFRP | DAC Buffer Read Pointer Keeps the current value of the buffer read pointer. |
| 3–0 DACBFUP | DAC Buffer Upper Limit Selects the upper limit of the DAC buffer. The buffer read pointer cannot exceed it. |

35.5 Functional description

The 12-bit DAC module can select one of the two reference inputs—DACREF_1 and DACREF_2 as the DAC reference voltage, V_{in} by C0[DACRFS]. See the module introduction for information on the source for DACREF_1 and DACREF_2.

When the DAC is enabled, it converts the data in DACDAT0[11:0] or the data from the DAC data buffer to a stepped analog output voltage. The output voltage range is from V_{in} to $V_{in}/4096$, and the step is $V_{in}/4096$.

35.5.1 DAC data buffer operation

When the DAC is enabled and the buffer is not enabled, the DAC module always converts the data in DAT0 to analog output voltage.

When both the DAC and the buffer are enabled, the DAC converts the data in the data buffer to analog output voltage. The data buffer read pointer advances to the next word whenever any hardware or software trigger event occurs.

The data buffer can be configured to operate in Normal mode, Swing mode, One-Time Scan mode or FIFO mode. When the buffer operation is switched from one mode to another, the read pointer does not change. The read pointer can be set to any value between 0 and C2[DACBFUP] by writing C2[DACBFRP].

35.5.1.1 DAC data buffer interrupts

There are several interrupts and associated flags that can be configured for the DAC buffer. SR[DACBFRPBF] is set when the DAC buffer read pointer reaches the DAC buffer upper limit, that is, C2[DACBFRP] = C2[DACBFUP]. SR[DACBFRPTF] is set when the DAC read pointer is equal to the start position, 0. Finally, SR[DACBFWMF] is set when the DAC buffer read pointer has reached the position defined by C1[DACBFWM]. C1[DACBFWM] can be used to generate an interrupt when the DAC buffer read pointer is between 1 to 4 words from C2[DACBFUP].

35.5.1.2 Modes of DAC data buffer operation

The following table describes the different modes of data buffer operation for the DAC module.

Table 35-79. Modes of DAC data buffer operation

| Modes | Description |
|---------------------------|--|
| Buffer Normal mode | This is the default mode. The buffer works as a circular buffer. The read pointer increases by one, every time the trigger occurs. When the read pointer reaches the upper limit, it goes to 0 directly in the next trigger event. |
| Buffer Swing mode | This mode is similar to the normal mode. However, when the read pointer reaches the upper limit, it does not go to 0. It will descend by 1 in the next trigger events until 0 is reached. |
| Buffer One-time Scan mode | The read pointer increases by 1 every time the trigger occurs. When it reaches the upper limit, it stops there. If read pointer is reset to the address other than the upper limit, it will increase to the upper address and stop there again. NOTE: If the software set the read pointer to the upper limit, the read pointer will not advance in this mode. |

35.5.2 DMA operation

When DMA is enabled, DMA requests are generated instead of interrupt requests. The DMA Done signal clears the DMA request.

The status register flags are still set and are cleared automatically when the DMA completes.

35.5.3 Resets

During reset, the DAC is configured in the default mode and is disabled.

35.5.4 Low-Power mode operation

The following table shows the wait mode and the stop mode operation of the DAC module.

Table 35-80. Modes of operation

| Modes of operation | Description |
|--------------------|--|
| Wait mode | The DAC will operate normally, if enabled. |
| Stop mode | <p>If enabled, the DAC module continues to operate in Normal Stop mode and the output voltage will hold the value before stop.</p> <p>In low-power stop modes, the DAC is fully shut down.</p> |

NOTE

The assignment of module modes to core modes is chip-specific. For module-to-core mode assignments, see the chapter that describes how modules are configured.

Chapter 36

Voltage Reference (VREFV1)

36.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The Voltage Reference(VREF) is intended to supply an accurate voltage output that can be trimmed in 0.5 mV steps. The VREF can be used in applications to provide a reference voltage to external devices or used internally as a reference to analog peripherals such as the ADC, DAC, or CMP. The voltage reference has three operating modes that provide different levels of supply rejection and power consumption..

The following figure is a block diagram of the Voltage Reference.

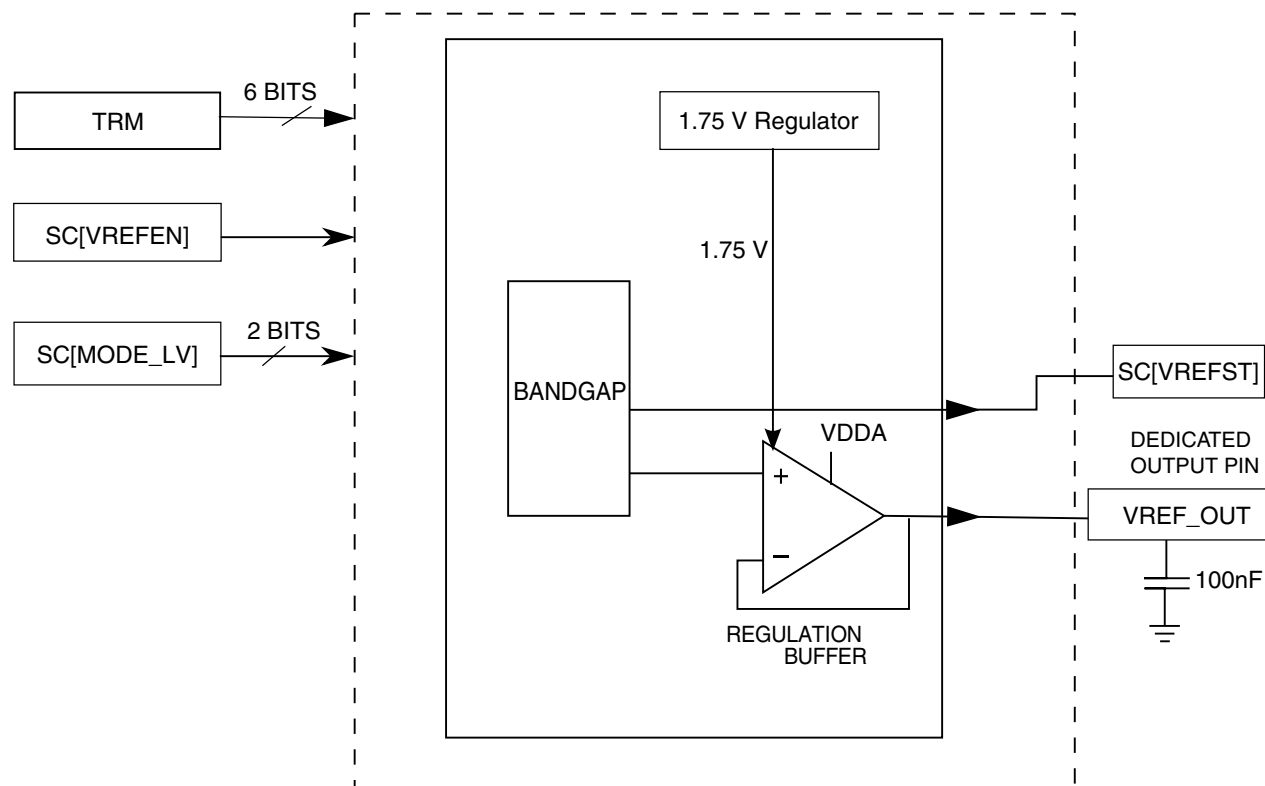


Figure 36-1. Voltage reference block diagram

36.1.1 Overview

The Voltage Reference provides a buffered reference voltage for use as an external reference. In addition, the buffered reference is available internally for use with on chip peripherals such as ADCs and DACs. Refer to the chip configuration details for a description of these options. The reference voltage is output on a dedicated output pin when the VREF is enabled. The Voltage Reference output can be trimmed with a resolution of 0.5mV by means of the TRM register TRIM[5:0] bitfield.

36.1.2 Features

The Voltage Reference has the following features:

- Programmable trim register with 0.5 mV steps, automatically loaded with factory trimmed value upon reset
- Programmable buffer mode selection:
 - Off

- Bandgap enabled/standby (output buffer disabled)
- Low power buffer mode (output buffer enabled)
- High power buffer mode (output buffer enabled)
- 1.2 V output at room temperature
- Dedicated output pin, VREF_OUT

36.1.3 Modes of Operation

The Voltage Reference continues normal operation in Run, Wait, and Stop modes. The Voltage Reference can also run in Very Low Power Run (VLPR), Very Low Power Wait (VLPW) and Very Low Power Stop (VLPS). If it is desired to use the VREF regulator and/or the chop oscillator in the very low power modes, the system reference voltage (also referred to as the bandgap voltage reference) must be enabled in these modes. Refer to the chip configuration details for information on enabling this mode of operation. Having the VREF regulator enabled does increase current consumption. In very low power modes it may be desirable to disable the VREF regulator to minimize current consumption. Note however that the accuracy of the output voltage will be reduced (by as much as several mVs) when the VREF regulator is not used.

NOTE

The assignment of module modes to core modes is chip-specific. For module-to-core mode assignments, see the chapter that describes how modules are configured.

36.1.4 VREF Signal Descriptions

The following table shows the Voltage Reference signals properties.

Table 36-1. VREF Signal Descriptions

| Signal | Description | I/O |
|----------|---|-----|
| VREF_OUT | Internally-generated Voltage Reference output | O |

NOTE

When the VREF output buffer is disabled, the status of the VREF_OUT signal is high-impedence.

36.2 Memory Map and Register Definition

VREF memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|--|-----------------|--------|-----------------------------|----------------------------|
| 4007_4000 | VREF Trim Register (VREF_TRM) | 8 | R/W | See section | 36.2.1/742 |
| 4007_4001 | VREF Status and Control Register (VREF_SC) | 8 | R/W | 00h | 36.2.2/743 |

36.2.1 VREF Trim Register (VREF_TRM)

This register contains bits that contain the trim data for the Voltage Reference.

Address: 4007_4000h base + 0h offset = 4007_4000h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|---|----|----|----|----|----|----|
| Read | | | | | | | | |
| Write | | | | | | | | |
| Reset | x* | 0 | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

VREF_TRM field descriptions

| Field | Description |
|---------------|---|
| 7 Reserved | This field is reserved. Upon reset this value is loaded with a factory trim value. |
| 6 CHOPEN | Chop oscillator enable. When set, internal chopping operation is enabled and the internal analog offset will be minimized. This bit is set during factory trimming of the VREF voltage. This bit should be written to 1 to achieve the performance stated in the data sheet. If the chop oscillator is to be used in very low power modes, the system (bandgap) voltage reference must also be enabled. See the chip-specific VREF information (also known as "chip configuration" details) for a description of how this can be achieved. 0 Chop oscillator is disabled. 1 Chop oscillator is enabled. |
| 5–0 TRIM | Trim bits These bits change the resulting VREF by approximately ± 0.5 mV for each step. NOTE: Min = minimum and max = maximum voltage reference output. For minimum and maximum voltage reference output values, refer to the Data Sheet for this chip. 000000 Min |

Table continues on the next page...

VREF_TRM field descriptions (continued)

| Field | Description |
|----------------|-------------|
| 111111 | Max |

36.2.2 VREF Status and Control Register (VREF_SC)

This register contains the control bits used to enable the internal voltage reference and to select the buffer mode to be used.

Address: 4007_4000h base + 1h offset = 4007_4001h

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|--------|-------|---------|---|---|--------|---------|---|
| Read | VREFEN | REGEN | ICOMPEN | 0 | 0 | VREFST | MODE_LV | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

VREF_SC field descriptions

| Field | Description |
|---------------|---|
| 7 VREFEN | Internal Voltage Reference enable This bit is used to enable the bandgap reference within the Voltage Reference module. NOTE: After the VREF is enabled, turning off the clock to the VREF module via the corresponding clock gate register will not disable the VREF. VREF must be disabled via this VREFEN bit. 0 The module is disabled. 1 The module is enabled. |
| 6 REGEN | Regulator enable This bit is used to enable the internal 1.75 V regulator to produce a constant internal voltage supply in order to reduce the sensitivity to external supply noise and variation. If it is desired to keep the regulator enabled in very low power modes, refer to the Chip Configuration details for a description on how this can be achieved. This bit should be written to 1 to achieve the performance stated in the data sheet. 0 Internal 1.75 V regulator is disabled. 1 Internal 1.75 V regulator is enabled. |
| 5 ICOMPEN | Second order curvature compensation enable This bit should be written to 1 to achieve the performance stated in the data sheet. 0 Disabled 1 Enabled |
| 4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

Table continues on the next page...

VREF_SC field descriptions (continued)

| Field | Description |
|----------------|--|
| 3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 VREFST | Internal Voltage Reference stable This bit indicates that the bandgap reference within the Voltage Reference module has completed its startup and stabilization. NOTE: This bit is valid only when the chop oscillator is not being used. 0 The module is disabled or not stable. 1 The module is stable. |
| 1–0 MODE_LV | Buffer Mode selection These bits select the buffer modes for the Voltage Reference module. 00 Bandgap on only, for stabilization and startup 01 High power buffer mode enabled 10 Low-power buffer mode enabled 11 Reserved |

36.3 Functional Description

The Voltage Reference is a bandgap buffer system. Unity gain amplifiers are used.

The VREF_OUT signal can be used by both internal and external peripherals in low and high power buffer mode. A 100 nF capacitor must always be connected between VREF_OUT and VSSA if the VREF is being used.

The following table shows all possible function configurations of the Voltage Reference.

Table 36-5. Voltage Reference function configurations

| SC[VREFEN] | SC[MODE_LV] | Configuration | Functionality |
|------------|-------------|---|---|
| 0 | X | Voltage Reference disabled | Off |
| 1 | 00 | Voltage Reference enabled, bandgap on only | Startup and standby |
| 1 | 01 | Voltage Reference enabled, high-power buffer on | VREF_OUT available for internal and external use. 100 nF capacitor is required. |
| 1 | 10 | Voltage Reference enabled, low power buffer on | VREF_OUT available for internal and external use. 100 nF capacitor is required. |
| 1 | 11 | Reserved | Reserved |

36.3.1 Voltage Reference Disabled, SC[VREFEN] = 0

When SC[VREFEN] = 0, the Voltage Reference is disabled, the VREF bandgap and the output buffers are disabled. The Voltage Reference is in off mode.

36.3.2 Voltage Reference Enabled, SC[VREFEN] = 1

When SC[VREFEN] = 1, the Voltage Reference is enabled, and different modes should be set by the SC[MODE_LV] bits.

36.3.2.1 SC[MODE_LV]=00

The internal VREF bandgap is enabled to generate an accurate 1.2 V output that can be trimmed with the TRM register's TRIM[5:0] bitfield. The bandgap requires some time for startup and stabilization. SC[VREFST] can be monitored to determine if the stabilization and startup is complete when the chop oscillator is not enabled.

If the chop oscillator is being used, the internal bandgap reference voltage settles within the chop oscillator start up time, Tchop_osc_stup.

The output buffer is disabled in this mode, and there is no buffered voltage output. The Voltage Reference is in standby mode. If this mode is first selected and the low power or high power buffer mode is subsequently enabled, there will be a delay before the buffer output is settled at the final value. This is the buffer start up delay (Tstup) and the value is specified in the appropriate device data sheet.

36.3.2.2 SC[MODE_LV] = 01

The internal VREF bandgap is on. The high power buffer is enabled to generate a buffered 1.2 V voltage to VREF_OUT. It can also be used as a reference to internal analog peripherals such as an ADC channel or analog comparator input.

If this mode is entered from the standby mode (SC[MODE_LV] = 00, SC[VREFEN] = 1) there will be a delay before the buffer output is settled at the final value. This is the buffer start up delay (Tstup) and the value is specified in the appropriate device data sheet. If this mode is entered when the VREF module is enabled then you must wait the longer of Tstup or until SC[VREFST] = 1 when the chop oscillator is not enabled. If the chop oscillator is being used, you must wait the time specified by Tchop_osc_stup (chop oscillator start up time) to ensure the VREF output has stabilized.

In this mode, a 100 nF capacitor is required to connect between the VREF_OUT pin and VSSA.

36.3.2.3 SC[MODE_LV] = 10

The internal VREF bandgap is on. The low power buffer is enabled to generate a buffered 1.2 V voltage to VREF_OUT. It can also be used as a reference to internal analog peripherals such as an ADC channel or analog comparator input.

If this mode is entered from the standby mode (SC[MODE_LV] = 00, SC[VREFEN] = 1) there will be a delay before the buffer output is settled at the final value. This is the buffer start up delay (Tstup) and the value is specified in the appropriate device data sheet. If this mode is entered when the VREF module is enabled then you must wait the longer of Tstup or until SC[VREFST] = 1 when the chop oscillator is not enabled. If the chop oscillator is being used, you must wait the time specified by Tchop_osc_stup (chop oscillator start up time) to ensure the VREF output has stabilized.

In this mode, a 100 nF capacitor is required to connect between the VREF_OUT pin and VSSA.

36.3.2.4 SC[MODE_LV] = 11

Reserved

36.3.3 Internal voltage regulator

The VREF module contains an internal voltage regulator that can be enabled to provide additional supply noise rejection. It is recommended that when possible, this regulator be enabled to provide the optimum VREF performance.

1. Enable the chop oscillator (VREF_TRM[CHOPEN] = 1)
2. Configure the VREF_SC register to the desired settings with the internal regulator disabled, VREF_SC[REGEN] = 0
3. Wait > 300ns
4. Enable the internal regulator by setting VREF_SC[REGEN] to 1

36.4 Initialization/Application Information

The Voltage Reference requires some time for startup and stabilization. After `SC[VREFEN] = 1`, `SC[VREFST]` can be monitored to determine if the stabilization and startup is completed when the chop oscillator is not enabled. When the chop oscillator is enabled, the settling time of the internal bandgap reference is defined by `Tchop_osc_stup` (chop oscillator start up time). You must wait this time (`Tchop_osc_stup`) after the internal bandgap has been enabled to ensure the VREF internal reference voltage has stabilized.

When the Voltage Reference is already enabled and stabilized, changing `SC[MODE_LV]` will not clear `SC[VREFST]` but there will be some startup time before the output voltage at the `VREF_OUT` pin has settled. This is the buffer start up delay (`Tstup`) and the value is specified in the appropriate device data sheet. Also, there will be some settling time when a step change of the load current is applied to the `VREF_OUT` pin. When the 1.75V VREF regulator is disabled, the `VREF_OUT` voltage will be more sensitive to supply voltage variation. It is recommended to use this regulator to achieve optimum `VREF_OUT` performance.

The `TRM[CHOPEN]`, `SC[REGEN]` and `SC[ICOMPEN]` bits must be written to 1 to achieve the performance stated in the device data sheet.



Chapter 37

Programmable Delay Block (PDB)

37.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The Programmable Delay Block (PDB) provides controllable delays from either an internal or an external trigger, or a programmable interval tick, to the hardware trigger inputs of ADCs and/or generates the interval triggers to DACs, so that the precise timing between ADC conversions and/or DAC updates can be achieved. The PDB can optionally provide pulse outputs (Pulse-Out's) that are used as the sample window in the CMP block.

37.1.1 Features

- Up to 15 trigger input sources and one software trigger source
- Up to 8 configurable PDB channels for ADC hardware trigger
 - One PDB channel is associated with one ADC
 - One trigger output for ADC hardware trigger and up to 8 pre-trigger outputs for ADC trigger select per PDB channel
 - Trigger outputs can be enabled or disabled independently
 - One 16-bit delay register per pre-trigger output
 - Optional bypass of the delay registers of the pre-trigger outputs
 - Operation in One-Shot or Continuous modes

- Optional back-to-back mode operation, which enables the ADC conversions complete to trigger the next PDB channel
- One programmable delay interrupt
- One sequence error interrupt
- One channel flag and one sequence error flag per pre-trigger
- DMA support
- Up to 8 pulse outputs (pulse-out's)
 - Pulse-out's can be enabled or disabled independently
 - Programmable pulse width

NOTE

The number of PDB input and output triggers are chip-specific. See the chip-specific PDB information for details.

37.1.2 Implementation

In this section, the following letters refer to the number of output triggers:

- N —Total available number of PDB channels.
- n —PDB channel number, valid from 0 to $N-1$.
- M —Total available pre-trigger per PDB channel.
- m —Pre-trigger number, valid from 0 to $M-1$.
- X —Total number of DAC interval triggers.
- x —DAC interval trigger output number, valid from 0 to $X-1$.
- Y —Total number of Pulse-Out's.
- y —Pulse-Out number, valid value is from 0 to $Y-1$.

NOTE

The number of module output triggers to core is chip-specific. For module to core output triggers implementation, see the chip configuration information.

37.1.3 Back-to-back acknowledgment connections

PDB back-to-back operation acknowledgment connections are chip-specific. For implementation, see the chip configuration information.

37.1.4 DAC External Trigger Input Connections

The implementation of DAC external trigger inputs is chip-specific. See the chip configuration information for details.

37.1.5 Block diagram

This diagram illustrates the major components of the PDB.

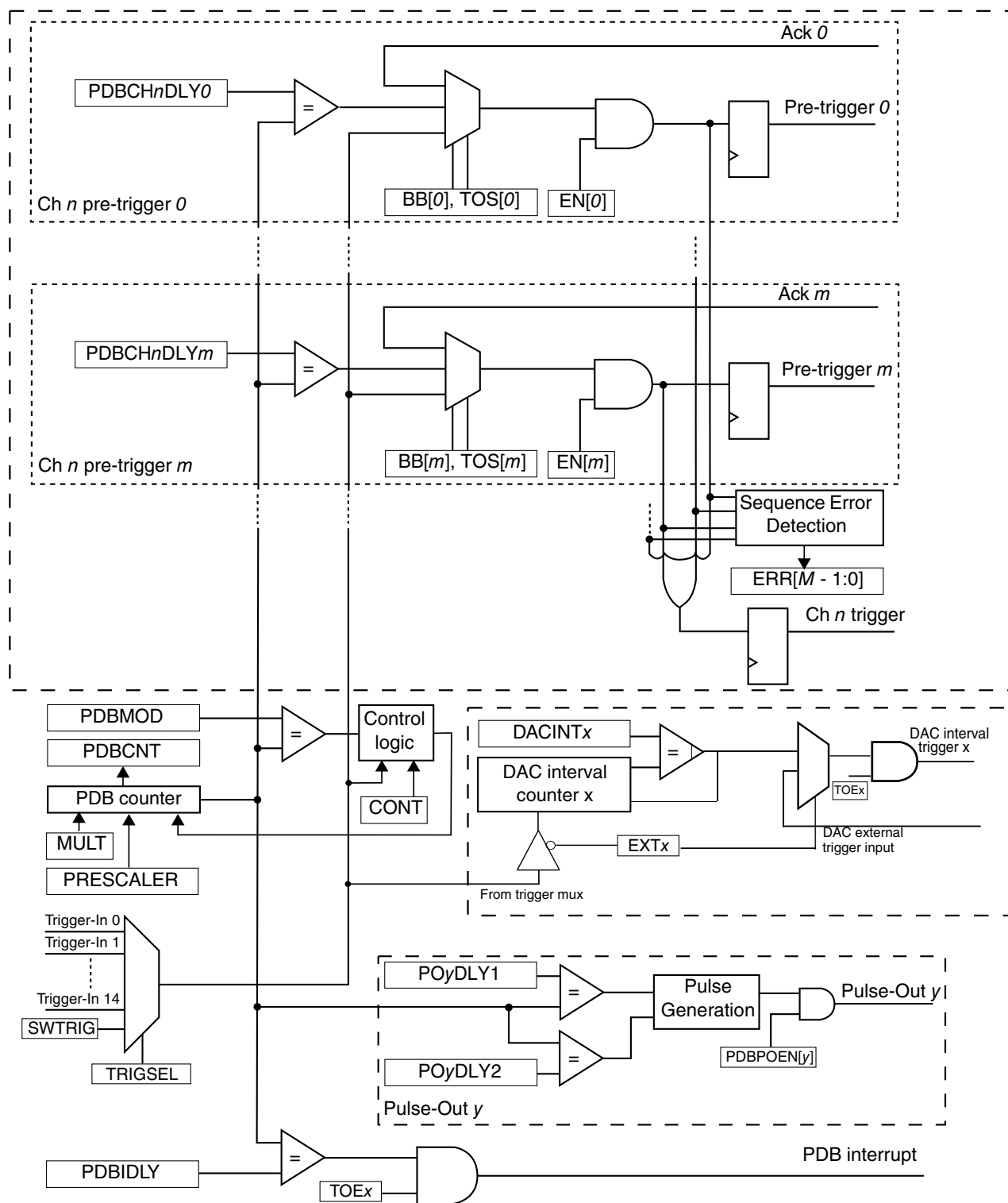


Figure 37-1. PDB block diagram

In this diagram, only one PDB channel n , one DAC interval trigger x , and one Pulse-Out y are shown. The PDB-enabled control logic and the sequence error interrupt logic are not shown.

37.1.6 Modes of operation

PDB ADC trigger operates in the following modes:

- Disabled—Counter is off, all pre-trigger and trigger outputs are low if PDB is not in back-to-back operation of Bypass mode.
- Debug—Counter is paused when processor is in Debug mode, and the counter for the DAC trigger is also paused in Debug mode.
- Enabled One-Shot—Counter is enabled and restarted at count zero upon receiving a positive edge on the selected trigger input source or software trigger is selected and SC[SWTRIG] is written with 1. In each PDB channel, an enabled pre-trigger asserts once per trigger input event. The trigger output asserts whenever any of the pre-triggers is asserted.
- Enabled Continuous—Counter is enabled and restarted at count zero. The counter is rolled over to zero again when the count reaches the value specified in the modulus register, and the counting is restarted. This enables a continuous stream of pre-triggers/trigger outputs as a result of a single trigger input event.
- Enabled Bypassed—The pre-trigger and trigger outputs assert immediately after a positive edge on the selected trigger input source or software trigger is selected and SC[SWTRIG] is written with 1, that is the delay registers are bypassed. It is possible to bypass any one or more of the delay registers; therefore, this mode can be used in conjunction with One-Shot or Continuous mode.

37.2 PDB signal descriptions

This table shows the detailed description of the external signal.

Table 37-1. PDB signal descriptions

| Signal | Description | I/O |
|--------|--|-----|
| EXTRG | External Trigger Input Source If the PDB is enabled and external trigger input source is selected, a positive edge on the EXTRG signal resets and starts the counter. | I |

37.3 Memory map and register definition

PDB memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4003_6000 | Status and Control register (PDB0_SC) | 32 | R/W | 0000_0000h | 37.3.1/755 |
| 4003_6004 | Modulus register (PDB0_MOD) | 32 | R/W | 0000_FFFFh | 37.3.2/757 |
| 4003_6008 | Counter register (PDB0_CNT) | 32 | R | 0000_0000h | 37.3.3/758 |
| 4003_600C | Interrupt Delay register (PDB0_IDLY) | 32 | R/W | 0000_FFFFh | 37.3.4/758 |
| 4003_6010 | Channel n Control register 1 (PDB0_CH0C1) | 32 | R/W | 0000_0000h | 37.3.5/759 |
| 4003_6014 | Channel n Status register (PDB0_CH0S) | 32 | R/W | 0000_0000h | 37.3.6/760 |
| 4003_6018 | Channel n Delay 0 register (PDB0_CH0DLY0) | 32 | R/W | 0000_0000h | 37.3.7/760 |
| 4003_601C | Channel n Delay 1 register (PDB0_CH0DLY1) | 32 | R/W | 0000_0000h | 37.3.8/761 |
| 4003_6038 | Channel n Control register 1 (PDB0_CH1C1) | 32 | R/W | 0000_0000h | 37.3.5/759 |
| 4003_603C | Channel n Status register (PDB0_CH1S) | 32 | R/W | 0000_0000h | 37.3.6/760 |
| 4003_6040 | Channel n Delay 0 register (PDB0_CH1DLY0) | 32 | R/W | 0000_0000h | 37.3.7/760 |
| 4003_6044 | Channel n Delay 1 register (PDB0_CH1DLY1) | 32 | R/W | 0000_0000h | 37.3.8/761 |
| 4003_6150 | DAC Interval Trigger n Control register (PDB0_DACINTC0) | 32 | R/W | 0000_0000h | 37.3.9/761 |
| 4003_6154 | DAC Interval n register (PDB0_DACINT0) | 32 | R/W | 0000_0000h | 37.3.10/762 |
| 4003_6190 | Pulse-Out n Enable register (PDB0_POEN) | 32 | R/W | 0000_0000h | 37.3.11/762 |
| 4003_6194 | Pulse-Out n Delay register (PDB0_PO0DLY) | 32 | R/W | 0000_0000h | 37.3.12/763 |
| 4003_6198 | Pulse-Out n Delay register (PDB0_PO1DLY) | 32 | R/W | 0000_0000h | 37.3.12/763 |

37.3.1 Status and Control register (PDBx_SC)

Address: 4003_6000h base + 0h offset = 4003_6000h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|-------|----|--------|--------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | LDMOD | | PDBEIE | 0 |
| W | | | | | | | | | | | | | | | | SWTRIG |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | | |
|-------|-------|-----------|----|----|----|--------|---|---|---|-------|-------|-------|---|------|---|------|------|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |
| R | DMAEN | PRESCALER | | | | TRGSEL | | | | PDBEN | PDBIF | PDBIE | 0 | MULT | | CONT | LDOK |
| W | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

PDBx_SC field descriptions

| Field | Description |
|-------------------|--|
| 31–20 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 19–18 LDMOD | Load Mode Select Selects the mode to load the MOD, IDLY, CHnDLYm, INTx, and POyDLY registers, after 1 is written to LDOK. 00 The internal registers are loaded with the values from their buffers immediately after 1 is written to LDOK. 01 The internal registers are loaded with the values from their buffers when the PDB counter reaches the MOD register value after 1 is written to LDOK. 10 The internal registers are loaded with the values from their buffers when a trigger input event is detected after 1 is written to LDOK. 11 The internal registers are loaded with the values from their buffers when either the PDB counter reaches the MOD register value or a trigger input event is detected, after 1 is written to LDOK. |
| 17 PDBEIE | PDB Sequence Error Interrupt Enable Enables the PDB sequence error interrupt. When this field is set, any of the PDB channel sequence error flags generates a PDB sequence error interrupt. |

Table continues on the next page...

PDBx_SC field descriptions (continued)

| Field | Description |
|--------------------|---|
| | 0 PDB sequence error interrupt disabled. 1 PDB sequence error interrupt enabled. |
| 16 SWTRIG | Software Trigger When PDB is enabled and the software trigger is selected as the trigger input source, writing 1 to this field resets and restarts the counter. Writing 0 to this field has no effect. Reading this field results 0. |
| 15 DMAEN | DMA Enable When DMA is enabled, the PDBIF flag generates a DMA request instead of an interrupt. 0 DMA disabled. 1 DMA enabled. |
| 14–12 PRESCALER | Prescaler Divider Select 000 Counting uses the peripheral clock divided by multiplication factor selected by MULT. 001 Counting uses the peripheral clock divided by twice of the multiplication factor selected by MULT. 010 Counting uses the peripheral clock divided by four times of the multiplication factor selected by MULT. 011 Counting uses the peripheral clock divided by eight times of the multiplication factor selected by MULT. 100 Counting uses the peripheral clock divided by 16 times of the multiplication factor selected by MULT. 101 Counting uses the peripheral clock divided by 32 times of the multiplication factor selected by MULT. 110 Counting uses the peripheral clock divided by 64 times of the multiplication factor selected by MULT. 111 Counting uses the peripheral clock divided by 128 times of the multiplication factor selected by MULT. |
| 11–8 TRGSEL | Trigger Input Source Select Selects the trigger input source for the PDB. The trigger input source can be internal or external (EXTRG pin), or the software trigger. Refer to chip configuration details for the actual PDB input trigger connections. 0000 Trigger-In 0 is selected. 0001 Trigger-In 1 is selected. 0010 Trigger-In 2 is selected. 0011 Trigger-In 3 is selected. 0100 Trigger-In 4 is selected. 0101 Trigger-In 5 is selected. 0110 Trigger-In 6 is selected. 0111 Trigger-In 7 is selected. 1000 Trigger-In 8 is selected. 1001 Trigger-In 9 is selected. 1010 Trigger-In 10 is selected. 1011 Trigger-In 11 is selected. 1100 Trigger-In 12 is selected. 1101 Trigger-In 13 is selected. 1110 Trigger-In 14 is selected. 1111 Software trigger is selected. |

Table continues on the next page...

PDBx_SC field descriptions (continued)

| Field | Description |
|---------------|--|
| 7 PDBEN | PDB Enable 0 PDB disabled. Counter is off. 1 PDB enabled. |
| 6 PDBIF | PDB Interrupt Flag This field is set when the counter value is equal to the IDLY register. Writing zero clears this field. |
| 5 PDBIE | PDB Interrupt Enable Enables the PDB interrupt. When this field is set and DMAEN is cleared, PDBIF generates a PDB interrupt. 0 PDB interrupt disabled. 1 PDB interrupt enabled. |
| 4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3–2 MULT | Multiplication Factor Select for Prescaler Selects the multiplication factor of the prescaler divider for the counter clock. 00 Multiplication factor is 1. 01 Multiplication factor is 10. 10 Multiplication factor is 20. 11 Multiplication factor is 40. |
| 1 CONT | Continuous Mode Enable Enables the PDB operation in Continuous mode. 0 PDB operation in One-Shot mode 1 PDB operation in Continuous mode |
| 0 LDOK | Load OK Writing 1 to this bit updates the internal registers of MOD, IDLY, CHnDLYm, DACINTx, and POyDLY with the values written to their buffers. The MOD, IDLY, CHnDLYm, DACINTx, and POyDLY will take effect according to the LDMOD. After 1 is written to the LDOK field, the values in the buffers of above registers are not effective and the buffers cannot be written until the values in buffers are loaded into their internal registers. LDOK can be written only when PDBEN is set or it can be written at the same time with PDBEN being written to 1. It is automatically cleared when the values in buffers are loaded into the internal registers or the PDBEN is cleared. Writing 0 to it has no effect. |

37.3.2 Modulus register (PDBx_MOD)

Address: 4003_6000h base + 4h offset = 4003_6004h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | MOD | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

PDBx_MOD field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 MOD | PDB Modulus Specifies the period of the counter. When the counter reaches this value, it will be reset back to zero. If the PDB is in Continuous mode, the count begins anew. Reading this field returns the value of the internal register that is effective for the current cycle of PDB. |

37.3.3 Counter register (PDBx_CNT)

Address: 4003_6000h base + 8h offset = 4003_6008h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | CNT | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PDBx_CNT field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 CNT | PDB Counter Contains the current value of the counter. |

37.3.4 Interrupt Delay register (PDBx_IDLY)

Address: 4003_6000h base + Ch offset = 4003_600Ch

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | IDLY | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

PDBx_IDLY field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 IDLY | PDB Interrupt Delay Specifies the delay value to schedule the PDB interrupt. It can be used to schedule an independent interrupt at some point in the PDB cycle. If enabled, a PDB interrupt is generated, when the counter is |

Table continues on the next page...

PDBx_IDLY field descriptions (continued)

| Field | Description |
|-------|--|
| | equal to the IDLY. Reading this field returns the value of internal register that is effective for the current cycle of the PDB. |

37.3.5 Channel n Control register 1 (PDBx_CHnC1)

Each PDB channel has one control register, CHnC1. The bits in this register control the functionality of each PDB channel operation.

Address: 4003_6000h base + 10h offset + (40d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|---|---|----|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | BB | | | | | | | | TOS | | | | | | | | EN | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PDBx_CHnC1 field descriptions

| Field | Description |
|-------------------|---|
| 31–24 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 23–16 BB | PDB Channel Pre-Trigger Back-to-Back Operation Enable These bits enable the PDB ADC pre-trigger operation as back-to-back mode. Only lower M pre-trigger bits are implemented in this MCU. Back-to-back operation enables the ADC conversions complete to trigger the next PDB channel pre-trigger and trigger output, so that the ADC conversions can be triggered on next set of configuration and results registers. Application code must only enable the back-to-back operation of the PDB pre-triggers at the leading of the back-to-back connection chain. 0 PDB channel's corresponding pre-trigger back-to-back operation disabled. 1 PDB channel's corresponding pre-trigger back-to-back operation enabled. |
| 15–8 TOS | PDB Channel Pre-Trigger Output Select Selects the PDB ADC pre-trigger outputs. Only lower M pre-trigger fields are implemented in this MCU. 0 PDB channel's corresponding pre-trigger is in bypassed mode. The pre-trigger asserts one peripheral clock cycle after a rising edge is detected on selected trigger input source or software trigger is selected and SWTRIG is written with 1. 1 PDB channel's corresponding pre-trigger asserts when the counter reaches the channel delay register and one peripheral clock cycle after a rising edge is detected on selected trigger input source or software trigger is selected and SETRIG is written with 1. |
| 7–0 EN | PDB Channel Pre-Trigger Enable These bits enable the PDB ADC pre-trigger outputs. Only lower M pre-trigger bits are implemented in this MCU. 0 PDB channel's corresponding pre-trigger disabled. 1 PDB channel's corresponding pre-trigger enabled. |

37.3.6 Channel n Status register (PDBx_CHnS)

Address: 4003_6000h base + 14h offset + (40d × i), where i=0d to 1d

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|-----|---|---|---|---|---|---|---|
| R | 0 | | | | | | | | CF | | | | | | | | 0 | | | | | | | | ERR | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PDBx_CHnS field descriptions

| Field | Description |
|-------------------|--|
| 31–24 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 23–16 CF | PDB Channel Flags The CF[m] bit is set when the PDB counter matches the CHnDLYm. Write 0 to clear these bits. |
| 15–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–0 ERR | PDB Channel Sequence Error Flags Only the lower M bits are implemented in this MCU. 0 Sequence error not detected on PDB channel's corresponding pre-trigger. 1 Sequence error detected on PDB channel's corresponding pre-trigger. ADCn block can be triggered for a conversion by one pre-trigger from PDB channel n. When one conversion, which is triggered by one of the pre-triggers from PDB channel n, is in progress, new trigger from PDB channel's corresponding pre-trigger m cannot be accepted by ADCn, and ERR[m] is set. Writing 0's to clear the sequence error flags. |

37.3.7 Channel n Delay 0 register (PDBx_CHnDLY0)

Address: 4003_6000h base + 18h offset + (40d × i), where i=0d to 1d

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | 0 | | | | | | | | | | | | | | | | DLY | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PDBx_CHnDLY0 field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 DLY | PDB Channel Delay Specifies the delay value for the channel's corresponding pre-trigger. The pre-trigger asserts when the counter is equal to DLY. Reading this field returns the value of internal register that is effective for the current PDB cycle. |

37.3.8 Channel n Delay 1 register (PDBx_CHnDLY1)

Address: 4003_6000h base + 1Ch offset + (40d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | DLY | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PDBx_CHnDLY1 field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 DLY | PDB Channel Delay These bits specify the delay value for the channel's corresponding pre-trigger. The pre-trigger asserts when the counter is equal to DLY. Reading these bits returns the value of internal register that is effective for the current PDB cycle. |

37.3.9 DAC Interval Trigger n Control register (PDBx_DACINTCn)

Address: 4003_6000h base + 150h offset + (8d × i), where i=0d to 0d

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|-----|-----|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | EXT | TOE |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PDBx_DACINTCn field descriptions

| Field | Description |
|------------------|---|
| 31–2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 EXT | DAC External Trigger Input Enable This bit enables the external trigger for DAC interval counter. 0 DAC external trigger input disabled. DAC interval counter is reset and started counting when a rising edge is detected on selected trigger input source or software trigger is selected and SWTRIG is written with 1. 1 DAC external trigger input enabled. DAC interval counter is bypassed and DAC external trigger input triggers the DAC interval trigger. |

Table continues on the next page...

PDBx_DACINTCn field descriptions (continued)

| Field | Description |
|----------|---|
| 0 TOE | DAC Interval Trigger Enable Enables the DAC interval trigger. 0 DAC interval trigger disabled. 1 DAC interval trigger enabled. |

37.3.10 DAC Interval n register (PDBx_DACINTn)

Address: 4003_6000h base + 154h offset + (8d × i), where i=0d to 0d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | INT | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PDBx_DACINTn field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 INT | DAC Interval These bits specify the interval value for DAC interval trigger. DAC interval trigger triggers DAC[1:0] update when the DAC interval counter is equal to the DACINT. Reading these bits returns the value of internal register that is effective for the current PDB cycle. |

37.3.11 Pulse-Out n Enable register (PDBx_POEN)

Address: 4003_6000h base + 190h offset = 4003_6190h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | POEN | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PDBx_POEN field descriptions

| Field | Description |
|------------------|--|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–0 POEN | PDB Pulse-Out Enable Enables the pulse output. Only lower Y bits are implemented in this MCU. |

Table continues on the next page...

PDBx_POEN field descriptions (continued)

| Field | Description |
|-------|------------------------|
| 0 | PDB Pulse-Out disabled |
| 1 | PDB Pulse-Out enabled |

37.3.12 Pulse-Out n Delay register (PDBx_POnDLY)

Address: 4003_6000h base + 194h offset + (4d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | DLY1 | | | | | | | | | | | | | | | | DLY2 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

PDBx_POnDLY field descriptions

| Field | Description |
|---------------|---|
| 31–16 DLY1 | PDB Pulse-Out Delay 1 Specifies the delay 1 value for the PDB Pulse-Out. Pulse-Out goes high when the PDB counter is equal to the DLY1. Reading this field returns the value of internal register that is effective for the current PDB cycle. |
| 15–0 DLY2 | PDB Pulse-Out Delay 2 Specifies the delay 2 value for the PDB Pulse-Out. Pulse-Out goes low when the PDB counter is equal to the DLY2. Reading this field returns the value of internal register that is effective for the current PDB cycle. |

37.4 Functional description

37.4.1 PDB pre-trigger and trigger outputs

The PDB contains a counter whose output is compared to several different digital values. If the PDB is enabled, then a trigger input event will reset the counter and make it start to count. A trigger input event is defined as a rising edge being detected on a selected trigger input source, or if a software trigger is selected and SC[SWTRIG] is written with 1. For each channel, a delay *m* determines the time between assertion of the trigger input event to the time at which changes in the pre-trigger *m* output signal are started. The time is defined as:

- Trigger input event to pre-trigger $m = (\text{prescaler} \times \text{multiplication factor} \times \text{delay } m) + 2$ peripheral clock cycles
- Add 1 additional peripheral clock cycle to determine the time when the channel trigger output changes.

Each channel is associated with 1 ADC block. PDB channel n pre-trigger outputs 0 to M ; each pre-trigger output is connected to ADC hardware trigger select and hardware trigger inputs. The pre-triggers are used to precondition the ADC block before the actual trigger occurs. When the ADC receives the rising edge of the trigger, the ADC will start the conversion according to the precondition determined by the pre-triggers. The ADC contains M sets of configuration and result registers, allowing it to alternate conversions between M different analog sources (like a ping-pong game). The pre-trigger outputs are used to specify which signal will be sampled next. When a pre-trigger m is asserted, the ADC conversion is triggered with set m of the configuration and result registers.

The waveforms shown in the following diagram show the pre-trigger and trigger outputs of PDB channel n . The delays can be independently set using the CHnDLYm registers, and the pre-triggers can be enabled or disabled in $\text{CHnC1[EN}[m]]$.

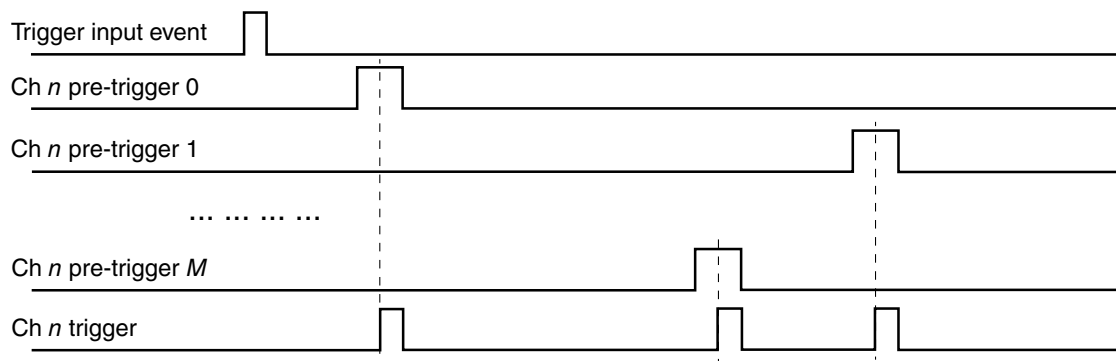


Figure 37-50. Pre-trigger and trigger outputs

The delay in CHnDLYm register can be optionally bypassed, if $\text{CHnC1[TOS}[m]]$ is cleared. In this case, when the trigger input event occurs, the pre-trigger m is asserted after 2 peripheral clock cycles.

The PDB can be configured for back-to-back operation. Back-to-back operation enables the ADC conversion completions to trigger the next PDB channel pre-trigger and trigger outputs, so that the ADC conversions can be triggered on the next set of configuration and results registers. When back-to-back operation is enabled by setting $\text{CHnC1[BB}[m]]$, then the delay m is ignored and the pre-trigger m is asserted 2 peripheral cycles after the acknowledgment m is received. The acknowledgment connections in this MCU are described in [Back-to-back acknowledgment connections](#).

When a pre-trigger from a PDB channel n is asserted, the associated lock of the pre-trigger becomes active. The associated lock is released by the rising edge of the corresponding ; the should be cleared after the conversion result is read, so that the next rising edge of can be generated to clear the lock later. The lock becomes inactive when:

- the rising edge of corresponding occurs,
- or the corresponding PDB pre-trigger is disabled,
- or the PDB is disabled

The channel n trigger output is suppressed when any of the locks of the pre-triggers in channel n is active. If a new pre-trigger m asserts when there is active lock in the PDB channel n , then a register flag bit $CHnS[ERR[m]]$ (associated with the pre-trigger m) is set. If $SC[PDBEIE]$ is set, then the sequence error interrupt is generated. A sequence error typically happens because the delay m is set too short and the pre-trigger m asserts before the previously triggered ADC conversion finishes.

When the PDB counter reaches the value set in $IDLY$ register, the $SC[PDBIF]$ flag is set. A PDB interrupt can be generated if $SC[PDBIE]$ is set and $SC[DMAEN]$ is cleared. If $SC[DMAEN]$ is set, then the PDB requests a DMA transfer when the $SC[PDBIF]$ flag is set.

The modulus value in the MOD register is used to reset the counter back to zero at the end of the count. If $SC[CONT]$ is set, then the counter will then resume a new count; otherwise, the counter operation will stop until the next trigger input event occurs.

37.4.2 PDB trigger input source selection

The PDB has up to 15 trigger input sources, namely Trigger-In 14. They are connected to on-chip or off-chip event sources. The PDB can be triggered by software through $SC[SWTRIG]$. $SC[TRIGSEL]$ selects the active trigger input source or software trigger.

For the trigger input sources implemented in this MCU, see chip configuration information.

37.4.3 Pulse-Out's

PDB can generate pulse outputs of configurable width. When PDB counter reaches the value set in $POyDLY[DLY1]$, the Pulse-Out goes high; when the counter reaches $POyDLY[DLY2]$, it goes low. $POyDLY[DLY2]$ can be set either greater or less than $POyDLY[DLY1]$.

ADC pre-trigger/trigger outputs and Pulse-Out generation have the same time base, because they both share the PDB counter.

The pulse-out connections implemented in this MCU are described in the device's chip configuration details.

37.4.4 Updating the delay registers

The following registers control the timing of the PDB operation; and in some of the applications, they may need to become effective at the same time.

- PDB Modulus register (MOD)
- PDB Interrupt Delay register (IDLY)
- PDB Channel n Delay m register (CH n DLY m)
- DAC Interval x register (DACINT x)
- PDB Pulse-Out y Delay register (PO y DLY)

The internal registers of them are buffered and any values written to them are written first to their buffers. The circumstances that cause their internal registers to be updated with the values from the buffers are summarized as shown in the table below.

Table 37-52. Circumstances of update to the delay registers

| SC[LDMOD] | Update to the delay registers |
|-----------|--|
| 00 | The internal registers are loaded with the values from their buffers immediately after 1 is written to SC[LDOK]. |
| 01 | The PDB counter reaches the MOD register value after 1 is written to SC[LDOK]. |
| 10 | A trigger input event is detected after 1 is written to SC[LDOK]. |
| 11 | Either the PDB counter reaches the MOD register value, or a trigger input event is detected, after 1 is written to SC[LDOK]. |

After 1 is written to SC[LDOK], the buffers cannot be written until the values in buffers are loaded into their internal registers. SC[LDOK] is self-cleared when the internal registers are loaded, so the application code can read it to determine the updates to the internal registers.

The following diagrams show the cases of the internal registers being updated with SC[LDMOD] is 00 and x1.

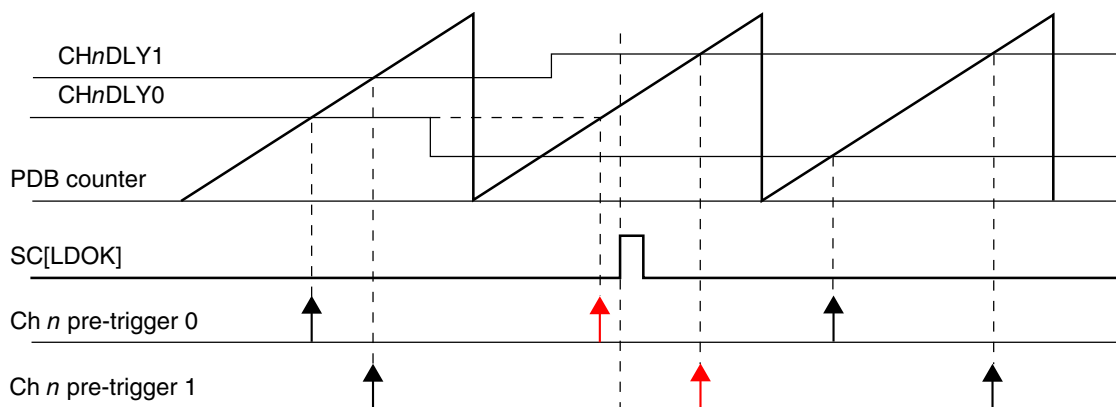


Figure 37-51. Registers update with SC[LDMOD] = 00

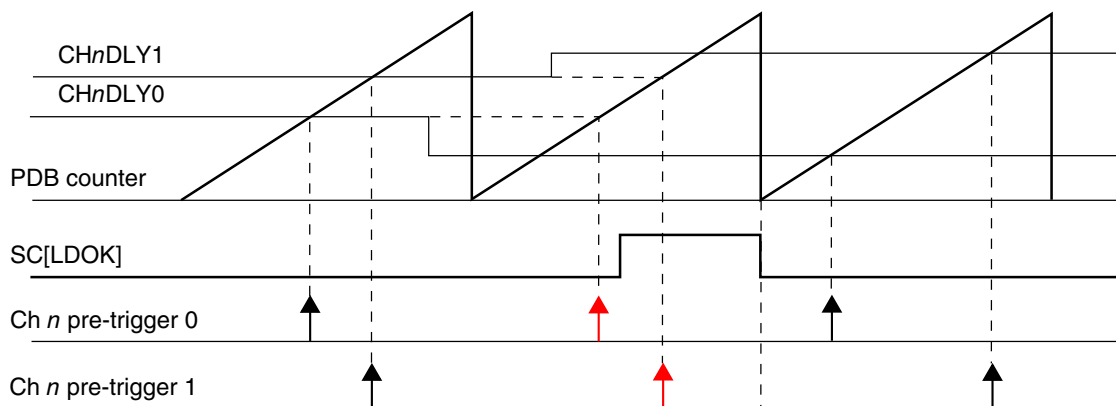


Figure 37-52. Registers update with SC[LDMOD] = x1

37.4.5 Interrupts

PDB can generate two interrupts: PDB interrupt and PDB sequence error interrupt. The following table summarizes the interrupts.

Table 37-53. PDB interrupt summary

| Interrupt | Flags | Enable bit |
|------------------------------|------------|---------------------------------|
| PDB Interrupt | SC[PDBIF] | SC[PDBIE] = 1 and SC[DMAEN] = 0 |
| PDB Sequence Error Interrupt | CHnS[ERRm] | SC[PDBEIE] = 1 |

37.4.6 DMA

If SC[DMAEN] is set, PDB can generate a DMA transfer request when SC[PDBIF] is set. When DMA is enabled, the PDB interrupt is not issued.

37.5 Application information

37.5.1 Impact of using the prescaler and multiplication factor on timing resolution

Use of prescaler and multiplication factor greater than 1 limits the count/delay accuracy in terms of peripheral clock cycles (to the modulus of the prescaler X multiplication factor). If the multiplication factor is set to 1 and the prescaler is set to 2 then the only values of total peripheral clocks that can be detected are even values; if prescaler is set to 4 then the only values of total peripheral clocks that can be decoded as detected are mod(4) and so forth. If the applications need a really long delay value and use a prescaler set to 128, then the resolution would be limited to 128 peripheral clock cycles.

Therefore, use the lowest possible prescaler and multiplication factor for a given application.

Chapter 38

FlexTimer Module (FTM)

38.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The FlexTimer module (FTM) is a two-to-eight channel timer that supports input capture, output compare, and the generation of PWM signals to control electric motor and power management applications. The FTM time reference is a 16-bit counter that can be used as an unsigned or signed counter.

38.1.1 FlexTimer philosophy

The FlexTimer is built upon a simple timer, the HCS08 Timer PWM Module – TPM, used for many years on Freescale's 8-bit microcontrollers. The FlexTimer extends the functionality to meet the demands of motor control, digital lighting solutions, and power conversion, while providing low cost and backwards compatibility with the TPM module.

Several key enhancements are made:

- Signed up counter
- Deadtime insertion hardware
- Fault control inputs
- Enhanced triggering functionality
- Initialization and polarity control

All of the features common with the TPM have fully backwards compatible register assignments. The FlexTimer can also use code on the same core platform without change to perform the same functions.

Motor control and power conversion features have been added through a dedicated set of registers and defaults turn off all new features. The new features, such as hardware deadtime insertion, polarity, fault control, and output forcing and masking, greatly reduce loading on the execution software and are usually each controlled by a group of registers.

FlexTimer input triggers can be from comparators, ADC, or other submodules to initiate timer functions automatically. These triggers can be linked in a variety of ways during integration of the sub modules so please note the options available for used FlexTimer configuration.

More than one FlexTimers may be synchronized to provide a larger timer with their counters incrementing in unison, assuming the initialization, the input clocks, the initial and final counting values are the same in each FlexTimer.

All main user access registers are buffered to ease the load on the executing software. A number of trigger options exist to determine which registers are updated with this user defined data.

38.1.2 Features

The FTM features include:

- FTM source clock is selectable
 - Source clock can be the system clock, the fixed frequency clock, or an external clock
 - Fixed frequency clock is an additional clock input to allow the selection of an on chip clock source other than the system clock
 - Selecting external clock connects FTM clock to a chip level input pin therefore allowing to synchronize the FTM counter with an off chip clock source
- Prescaler divide-by 1, 2, 4, 8, 16, 32, 64, or 128
- 16-bit counter
 - It can be a free-running counter or a counter with initial and final value
 - The counting can be up or up-down
- Each channel can be configured for input capture, output compare, or edge-aligned PWM mode
- In Input Capture mode:

- The capture can occur on rising edges, falling edges or both edges
- An input filter can be selected for some channels
- In Output Compare mode the output signal can be set, cleared, or toggled on match
- All channels can be configured for center-aligned PWM mode
- Each pair of channels can be combined to generate a PWM signal with independent control of both edges of PWM signal
- The FTM channels can operate as pairs with equal outputs, pairs with complementary outputs, or independent channels with independent outputs
- The deadtime insertion is available for each complementary pair
- Generation of match triggers
- Software control of PWM outputs
- Up to 4 fault inputs for global fault control
- The polarity of each channel is configurable
- The generation of an interrupt per channel
- The generation of an interrupt when the counter overflows
- The generation of an interrupt when the fault condition is detected
- Synchronized loading of write buffered FTM registers
- Write protection for critical registers
- Backwards compatible with TPM
- Testing of input captures for a stuck at zero and one conditions
- Dual edge capture for pulse and period width measurement
- Quadrature decoder with input filters, relative position counting, and interrupt on position count or capture of position count on external event

38.1.3 Modes of operation

When the MCU is in an active BDM mode, the FTM temporarily suspends all counting until the MCU returns to normal user operating mode. During Stop mode, all FTM input clocks are stopped, so the FTM is effectively disabled until clocks resume. During Wait mode, the FTM continues to operate normally. If the FTM does not need to produce a

real time reference or provide the interrupt sources needed to wake the MCU from Wait mode, the power can then be saved by disabling FTM functions before entering Wait mode.

38.1.4 Block diagram

The FTM uses one input/output (I/O) pin per channel, CHn (FTM channel (n)) where n is the channel number (0–7).

The following figure shows the FTM structure. The central component of the FTM is the 16-bit counter with programmable initial and final values and its counting can be up or up-down.

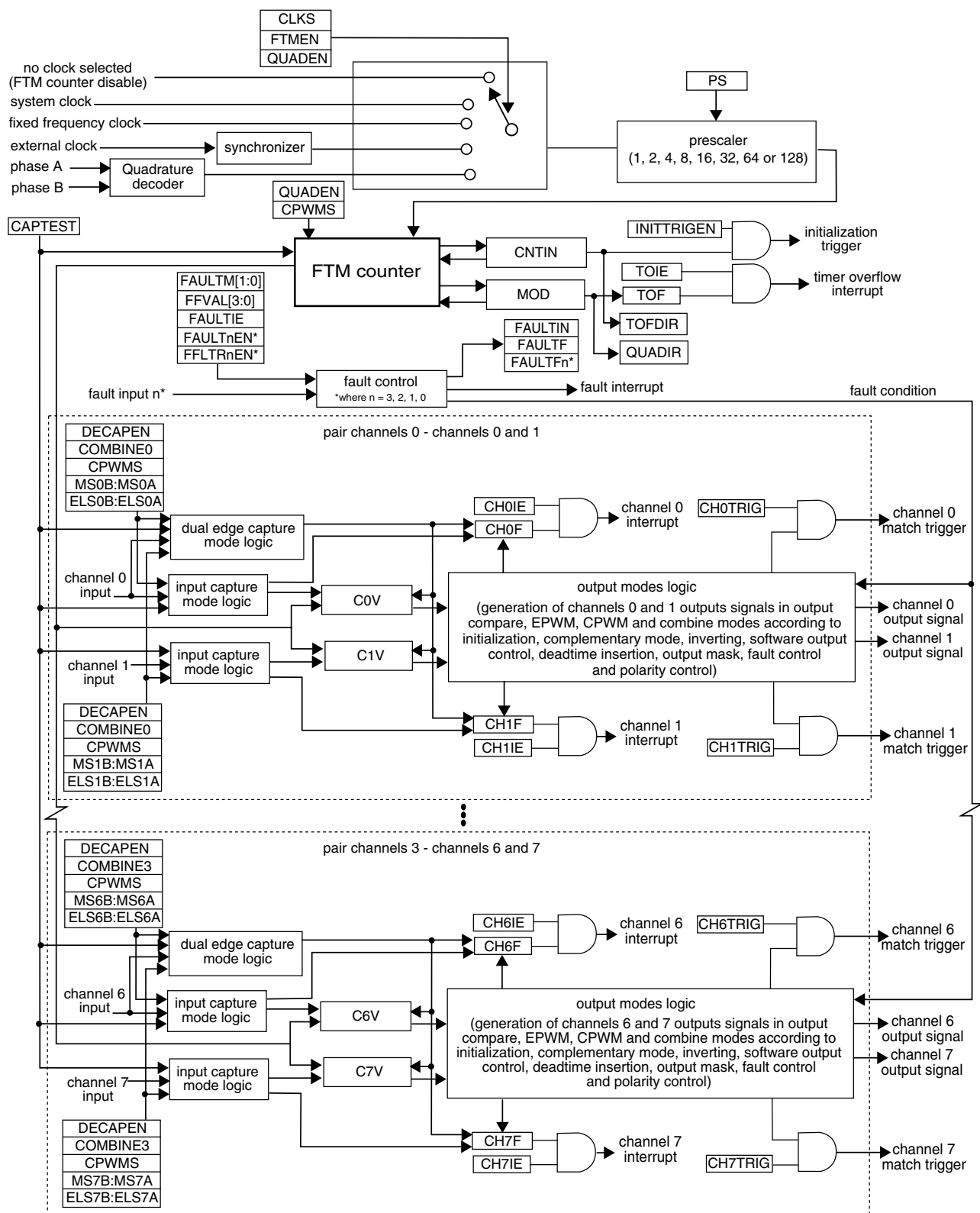


Figure 38-1. FTM block diagram

38.2 FTM signal descriptions

Table 38-1 shows the user-accessible signals for the FTM.

Table 38-1. FTM signal descriptions

| Signal | Description | I/O | Function |
|--------|---|-----|---|
| EXTCLK | External clock. FTM external clock can be selected to drive the FTM counter. | I | The external clock input signal is used as the FTM counter clock if selected by CLKS[1:0] bits in the SC register. This clock signal must not exceed 1/4 of system clock frequency. The FTM counter prescaler selection and settings are also used when an external clock is selected. |
| CHn | FTM channel (n), where n can be 7-0 | I/O | Each FTM channel can be configured to operate either as input or output. The direction associated with each channel, input or output, is selected according to the mode assigned for that channel. |
| FAULTj | Fault input (j), where j can be 3-0 | I | The fault input signals are used to control the CHn channel output state. If a fault is detected, the FAULTj signal is asserted and the channel output is put in a safe state. The behavior of the fault logic is defined by the FAULTM[1:0] control bits in the MODE register and FAULTEN bit in the COMBINEm register. Note that each FAULTj input may affect all channels selectively since FAULTM[1:0] and FAULTEN control bits are defined for each pair of channels. Because there are several FAULTj inputs, maximum of 4 for the FTM module, each one of these inputs is activated by the FAULTJEN bit in the FLTCTRL register. |
| PHA | Quadrature decoder phase A input. Input pin associated with quadrature decoder phase A. | I | The quadrature decoder phase A input is used as the Quadrature Decoder mode is selected. The phase A input signal is one of the signals that control the FTM counter increment or decrement in the Quadrature Decoder mode . |
| PHB | Quadrature decoder phase B input. Input pin associated with quadrature decoder phase B. | I | The quadrature decoder phase B input is used as the Quadrature Decoder mode is selected. The phase B input signal is one of the signals that control the FTM counter increment or decrement in the Quadrature Decoder mode . |

38.3 Memory map and register definition

38.3.1 Memory map

This section presents a high-level summary of the FTM registers and how they are mapped.

The registers and bits of an unavailable function in the FTM remain in the memory map and in the reset value, but they have no active function.

Note

Do not write in the region from the CNTIN register through the PWMLOAD register when FTMEN = 0.

38.3.2 Register descriptions

Accesses to reserved addresses result in transfer errors. Registers for absent channels are considered reserved.

FTM memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|-----------------------------|
| 4003_8000 | Status And Control (FTM0_SC) | 32 | R/W | 0000_0000h | 38.3.3/780 |
| 4003_8004 | Counter (FTM0_CNT) | 32 | R/W | 0000_0000h | 38.3.4/781 |
| 4003_8008 | Modulo (FTM0_MOD) | 32 | R/W | 0000_0000h | 38.3.5/782 |
| 4003_800C | Channel (n) Status And Control (FTM0_C0SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_8010 | Channel (n) Value (FTM0_C0V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_8014 | Channel (n) Status And Control (FTM0_C1SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_8018 | Channel (n) Value (FTM0_C1V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_801C | Channel (n) Status And Control (FTM0_C2SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_8020 | Channel (n) Value (FTM0_C2V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_8024 | Channel (n) Status And Control (FTM0_C3SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_8028 | Channel (n) Value (FTM0_C3V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_802C | Channel (n) Status And Control (FTM0_C4SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_8030 | Channel (n) Value (FTM0_C4V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_8034 | Channel (n) Status And Control (FTM0_C5SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_8038 | Channel (n) Value (FTM0_C5V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_803C | Channel (n) Status And Control (FTM0_C6SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_8040 | Channel (n) Value (FTM0_C6V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_8044 | Channel (n) Status And Control (FTM0_C7SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_8048 | Channel (n) Value (FTM0_C7V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_804C | Counter Initial Value (FTM0_CNTIN) | 32 | R/W | 0000_0000h | 38.3.8/786 |
| 4003_8050 | Capture And Compare Status (FTM0_STATUS) | 32 | R/W | 0000_0000h | 38.3.9/786 |
| 4003_8054 | Features Mode Selection (FTM0_MODE) | 32 | R/W | 0000_0004h | 38.3.10/788 |
| 4003_8058 | Synchronization (FTM0_SYNC) | 32 | R/W | 0000_0000h | 38.3.11/790 |
| 4003_805C | Initial State For Channels Output (FTM0_OUTINIT) | 32 | R/W | 0000_0000h | 38.3.12/793 |
| 4003_8060 | Output Mask (FTM0_OUTMASK) | 32 | R/W | 0000_0000h | 38.3.13/794 |

Table continues on the next page...

FTM memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4003_8064 | Function For Linked Channels (FTM0_COMBINE) | 32 | R/W | 0000_0000h | 38.3.14/796 |
| 4003_8068 | Deadtime Insertion Control (FTM0_DEADTIME) | 32 | R/W | 0000_0000h | 38.3.15/801 |
| 4003_806C | FTM External Trigger (FTM0_EXTTRIG) | 32 | R/W | 0000_0000h | 38.3.16/802 |
| 4003_8070 | Channels Polarity (FTM0_POL) | 32 | R/W | 0000_0000h | 38.3.17/804 |
| 4003_8074 | Fault Mode Status (FTM0_FMS) | 32 | R/W | 0000_0000h | 38.3.18/806 |
| 4003_8078 | Input Capture Filter Control (FTM0_FILTER) | 32 | R/W | 0000_0000h | 38.3.19/808 |
| 4003_807C | Fault Control (FTM0_FLTCTRL) | 32 | R/W | 0000_0000h | 38.3.20/809 |
| 4003_8080 | Quadrature Decoder Control And Status (FTM0_QDCTRL) | 32 | R/W | 0000_0000h | 38.3.21/811 |
| 4003_8084 | Configuration (FTM0_CONF) | 32 | R/W | 0000_0000h | 38.3.22/813 |
| 4003_8088 | FTM Fault Input Polarity (FTM0_FLTPOL) | 32 | R/W | 0000_0000h | 38.3.23/814 |
| 4003_808C | Synchronization Configuration (FTM0_SYNCONF) | 32 | R/W | 0000_0000h | 38.3.24/816 |
| 4003_8090 | FTM Inverting Control (FTM0_INVCTRL) | 32 | R/W | 0000_0000h | 38.3.25/818 |
| 4003_8094 | FTM Software Output Control (FTM0_SWOCTRL) | 32 | R/W | 0000_0000h | 38.3.26/819 |
| 4003_8098 | FTM PWM Load (FTM0_PWMLOAD) | 32 | R/W | 0000_0000h | 38.3.27/821 |
| 4003_9000 | Status And Control (FTM1_SC) | 32 | R/W | 0000_0000h | 38.3.3/780 |
| 4003_9004 | Counter (FTM1_CNT) | 32 | R/W | 0000_0000h | 38.3.4/781 |
| 4003_9008 | Modulo (FTM1_MOD) | 32 | R/W | 0000_0000h | 38.3.5/782 |
| 4003_900C | Channel (n) Status And Control (FTM1_C0SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_9010 | Channel (n) Value (FTM1_C0V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_9014 | Channel (n) Status And Control (FTM1_C1SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_9018 | Channel (n) Value (FTM1_C1V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_901C | Channel (n) Status And Control (FTM1_C2SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_9020 | Channel (n) Value (FTM1_C2V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_9024 | Channel (n) Status And Control (FTM1_C3SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_9028 | Channel (n) Value (FTM1_C3V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_902C | Channel (n) Status And Control (FTM1_C4SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_9030 | Channel (n) Value (FTM1_C4V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_9034 | Channel (n) Status And Control (FTM1_C5SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |

Table continues on the next page...

FTM memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4003_9038 | Channel (n) Value (FTM1_C5V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_903C | Channel (n) Status And Control (FTM1_C6SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_9040 | Channel (n) Value (FTM1_C6V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_9044 | Channel (n) Status And Control (FTM1_C7SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_9048 | Channel (n) Value (FTM1_C7V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_904C | Counter Initial Value (FTM1_CNTIN) | 32 | R/W | 0000_0000h | 38.3.8/786 |
| 4003_9050 | Capture And Compare Status (FTM1_STATUS) | 32 | R/W | 0000_0000h | 38.3.9/786 |
| 4003_9054 | Features Mode Selection (FTM1_MODE) | 32 | R/W | 0000_0004h | 38.3.10/788 |
| 4003_9058 | Synchronization (FTM1_SYNC) | 32 | R/W | 0000_0000h | 38.3.11/790 |
| 4003_905C | Initial State For Channels Output (FTM1_OUTINIT) | 32 | R/W | 0000_0000h | 38.3.12/793 |
| 4003_9060 | Output Mask (FTM1_OUTMASK) | 32 | R/W | 0000_0000h | 38.3.13/794 |
| 4003_9064 | Function For Linked Channels (FTM1_COMBINE) | 32 | R/W | 0000_0000h | 38.3.14/796 |
| 4003_9068 | Deadtime Insertion Control (FTM1_DEADTIME) | 32 | R/W | 0000_0000h | 38.3.15/801 |
| 4003_906C | FTM External Trigger (FTM1_EXTTRIG) | 32 | R/W | 0000_0000h | 38.3.16/802 |
| 4003_9070 | Channels Polarity (FTM1_POL) | 32 | R/W | 0000_0000h | 38.3.17/804 |
| 4003_9074 | Fault Mode Status (FTM1_FMS) | 32 | R/W | 0000_0000h | 38.3.18/806 |
| 4003_9078 | Input Capture Filter Control (FTM1_FILTER) | 32 | R/W | 0000_0000h | 38.3.19/808 |
| 4003_907C | Fault Control (FTM1_FLTCTRL) | 32 | R/W | 0000_0000h | 38.3.20/809 |
| 4003_9080 | Quadrature Decoder Control And Status (FTM1_QDCTRL) | 32 | R/W | 0000_0000h | 38.3.21/811 |
| 4003_9084 | Configuration (FTM1_CONF) | 32 | R/W | 0000_0000h | 38.3.22/813 |
| 4003_9088 | FTM Fault Input Polarity (FTM1_FLTPOL) | 32 | R/W | 0000_0000h | 38.3.23/814 |
| 4003_908C | Synchronization Configuration (FTM1_SYNCONF) | 32 | R/W | 0000_0000h | 38.3.24/816 |
| 4003_9090 | FTM Inverting Control (FTM1_INVCTRL) | 32 | R/W | 0000_0000h | 38.3.25/818 |
| 4003_9094 | FTM Software Output Control (FTM1_SWOCTRL) | 32 | R/W | 0000_0000h | 38.3.26/819 |
| 4003_9098 | FTM PWM Load (FTM1_PWMLOAD) | 32 | R/W | 0000_0000h | 38.3.27/821 |

FTM memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|-----------------------------|
| 4003_A000 | Status And Control (FTM2_SC) | 32 | R/W | 0000_0000h | 38.3.3/780 |
| 4003_A004 | Counter (FTM2_CNT) | 32 | R/W | 0000_0000h | 38.3.4/781 |
| 4003_A008 | Modulo (FTM2_MOD) | 32 | R/W | 0000_0000h | 38.3.5/782 |
| 4003_A00C | Channel (n) Status And Control (FTM2_C0SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_A010 | Channel (n) Value (FTM2_C0V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_A014 | Channel (n) Status And Control (FTM2_C1SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_A018 | Channel (n) Value (FTM2_C1V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_A01C | Channel (n) Status And Control (FTM2_C2SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_A020 | Channel (n) Value (FTM2_C2V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_A024 | Channel (n) Status And Control (FTM2_C3SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_A028 | Channel (n) Value (FTM2_C3V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_A02C | Channel (n) Status And Control (FTM2_C4SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_A030 | Channel (n) Value (FTM2_C4V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_A034 | Channel (n) Status And Control (FTM2_C5SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_A038 | Channel (n) Value (FTM2_C5V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_A03C | Channel (n) Status And Control (FTM2_C6SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_A040 | Channel (n) Value (FTM2_C6V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_A044 | Channel (n) Status And Control (FTM2_C7SC) | 32 | R/W | 0000_0000h | 38.3.6/783 |
| 4003_A048 | Channel (n) Value (FTM2_C7V) | 32 | R/W | 0000_0000h | 38.3.7/785 |
| 4003_A04C | Counter Initial Value (FTM2_CNTIN) | 32 | R/W | 0000_0000h | 38.3.8/786 |
| 4003_A050 | Capture And Compare Status (FTM2_STATUS) | 32 | R/W | 0000_0000h | 38.3.9/786 |
| 4003_A054 | Features Mode Selection (FTM2_MODE) | 32 | R/W | 0000_0004h | 38.3.10/788 |
| 4003_A058 | Synchronization (FTM2_SYNC) | 32 | R/W | 0000_0000h | 38.3.11/790 |
| 4003_A05C | Initial State For Channels Output (FTM2_OUTINIT) | 32 | R/W | 0000_0000h | 38.3.12/793 |
| 4003_A060 | Output Mask (FTM2_OUTMASK) | 32 | R/W | 0000_0000h | 38.3.13/794 |
| 4003_A064 | Function For Linked Channels (FTM2_COMBINE) | 32 | R/W | 0000_0000h | 38.3.14/796 |
| 4003_A068 | Deadtime Insertion Control (FTM2_DEADTIME) | 32 | R/W | 0000_0000h | 38.3.15/801 |
| 4003_A06C | FTM External Trigger (FTM2_EXTTRIG) | 32 | R/W | 0000_0000h | 38.3.16/802 |
| 4003_A070 | Channels Polarity (FTM2_POL) | 32 | R/W | 0000_0000h | 38.3.17/804 |
| 4003_A074 | Fault Mode Status (FTM2_FMS) | 32 | R/W | 0000_0000h | 38.3.18/806 |
| 4003_A078 | Input Capture Filter Control (FTM2_FILTER) | 32 | R/W | 0000_0000h | 38.3.19/808 |

Table continues on the next page...

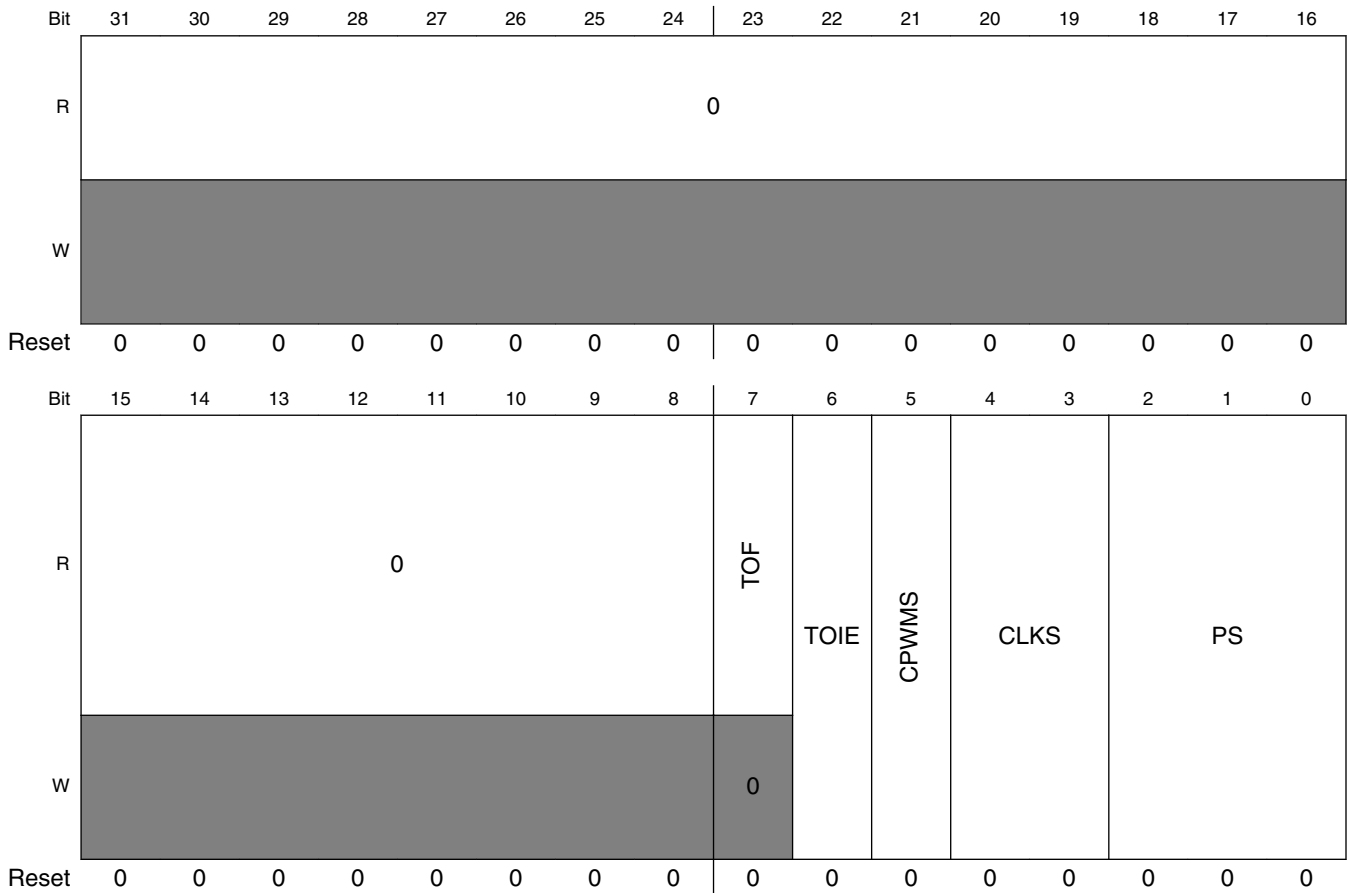
FTM memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4003_A07C | Fault Control (FTM2_FLTCTRL) | 32 | R/W | 0000_0000h | 38.3.20/809 |
| 4003_A080 | Quadrature Decoder Control And Status (FTM2_QDCTRL) | 32 | R/W | 0000_0000h | 38.3.21/811 |
| 4003_A084 | Configuration (FTM2_CONF) | 32 | R/W | 0000_0000h | 38.3.22/813 |
| 4003_A088 | FTM Fault Input Polarity (FTM2_FLTPOL) | 32 | R/W | 0000_0000h | 38.3.23/814 |
| 4003_A08C | Synchronization Configuration (FTM2_SYNCONF) | 32 | R/W | 0000_0000h | 38.3.24/816 |
| 4003_A090 | FTM Inverting Control (FTM2_INVCTRL) | 32 | R/W | 0000_0000h | 38.3.25/818 |
| 4003_A094 | FTM Software Output Control (FTM2_SWOCTRL) | 32 | R/W | 0000_0000h | 38.3.26/819 |
| 4003_A098 | FTM PWM Load (FTM2_PWMLOAD) | 32 | R/W | 0000_0000h | 38.3.27/821 |

38.3.3 Status And Control (FTMx_SC)

SC contains the overflow status flag and control bits used to configure the interrupt enable, FTM configuration, clock source, and prescaler factor. These controls relate to all channels within this module.

Address: Base address + 0h offset



FTMx_SC field descriptions

| Field | Description |
|------------------|--|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 TOF | <p>Timer Overflow Flag</p> <p>Set by hardware when the FTM counter passes the value in the MOD register. The TOF bit is cleared by reading the SC register while TOF is set and then writing a 0 to TOF bit. Writing a 1 to TOF has no effect.</p> <p>If another FTM overflow occurs between the read and write operations, the write operation has no effect; therefore, TOF remains set indicating an overflow has occurred. In this case, a TOF interrupt request is not lost due to the clearing sequence for a previous TOF.</p> <p>0 FTM counter has not overflowed. 1 FTM counter has overflowed.</p> |

Table continues on the next page...

FTMx_SC field descriptions (continued)

| Field | Description |
|-------------|---|
| 6 TOIE | <p>Timer Overflow Interrupt Enable</p> <p>Enables FTM overflow interrupts.</p> <p>0 Disable TOF interrupts. Use software polling. 1 Enable TOF interrupts. An interrupt is generated when TOF equals one.</p> |
| 5 CPWMS | <p>Center-Aligned PWM Select</p> <p>Selects CPWM mode. This mode configures the FTM to operate in Up-Down Counting mode.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 FTM counter operates in Up Counting mode. 1 FTM counter operates in Up-Down Counting mode.</p> |
| 4–3 CLKS | <p>Clock Source Selection</p> <p>Selects one of the three FTM counter clock sources.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>00 No clock selected. This in effect disables the FTM counter. 01 System clock 10 Fixed frequency clock 11 External clock</p> |
| 2–0 PS | <p>Prescale Factor Selection</p> <p>Selects one of 8 division factors for the clock source selected by CLKS. The new prescaler factor affects the clock source on the next system clock cycle after the new value is updated into the register bits.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>000 Divide by 1 001 Divide by 2 010 Divide by 4 011 Divide by 8 100 Divide by 16 101 Divide by 32 110 Divide by 64 111 Divide by 128</p> |

38.3.4 Counter (FTMx_CNT)

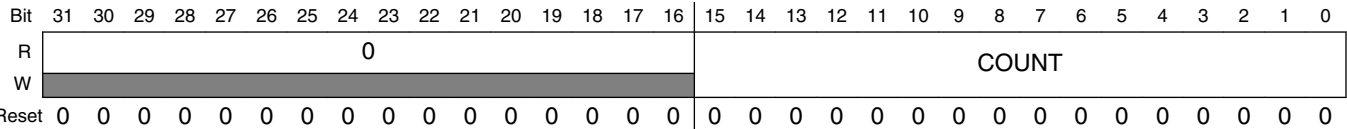
The CNT register contains the FTM counter value.

Reset clears the CNT register. Writing any value to COUNT updates the counter with its initial value, CNTIN.

When BDM is active, the FTM counter is frozen. This is the value that you may read.

memory map and register definition

Address: Base address + 4h offset



FTMx_CNT field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 COUNT | Counter Value |

38.3.5 Modulo (FTMx_MOD)

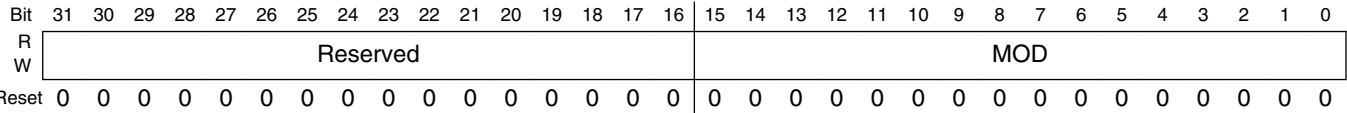
The Modulo register contains the modulo value for the FTM counter. After the FTM counter reaches the modulo value, the overflow flag (TOF) becomes set at the next clock, and the next value of FTM counter depends on the selected counting method; see [Counter](#).

Writing to the MOD register latches the value into a buffer. The MOD register is updated with the value of its write buffer according to [Registers updated from write buffers](#).

If FTMEN = 0, this write coherency mechanism may be manually reset by writing to the SC register whether BDM is active or not.

Initialize the FTM counter, by writing to CNT, before writing to the MOD register to avoid confusion about when the first counter overflow will occur.

Address: Base address + 8h offset



FTMx_MOD field descriptions

| Field | Description |
|-------------------|-------------------------|
| 31–16 Reserved | This field is reserved. |
| 15–0 MOD | Modulo Value |

38.3.6 Channel (n) Status And Control (FTMx_CnSC)

CnSC contains the channel-interrupt-status flag and control bits used to configure the interrupt enable, channel configuration, and pin function.

Table 38-67. Mode, edge, and level selection

| DECAPEN | COMBINE | CPWMS | MSnB:MSnA | ELSnB:ELSnA | Mode | Configuration |
|---------|---------|-------|-----------|-------------|--|---|
| X | X | X | XX | 0 | Pin not used for FTM—revert the channel pin to general purpose I/O or other peripheral control | |
| 0 | 0 | 0 | 0 | 1 | Input Capture | Capture on Rising Edge Only |
| | | | | 10 | | Capture on Falling Edge Only |
| | | | | 11 | | Capture on Rising or Falling Edge |
| | | | 1 | 1 | Output Compare | Toggle Output on match |
| | | | | 10 | | Clear Output on match |
| | | | | 11 | | Set Output on match |
| | | | 1X | 10 | Edge-Aligned PWM | High-true pulses (clear Output on match) |
| | | | | X1 | | Low-true pulses (set Output on match) |
| | | 1 | XX | 10 | Center-Aligned PWM | High-true pulses (clear Output on match-up) |
| | | | | X1 | | Low-true pulses (set Output on match-up) |
| | 1 | 0 | XX | 10 | Combine PWM | High-true pulses (set on channel (n) match, and clear on channel (n+1) match) |
| | | | | X1 | | Low-true pulses (clear on channel (n) match, and set on channel (n +1) match) |

Table continues on the next page...

Table 38-67. Mode, edge, and level selection (continued)

| DECAPEN | COMBINE | CPWMS | MSnB:MSnA | ELSnB:ELSnA | Mode | Configuration |
|---------|---------|-------|-----------|---------------------------------------|-------------------|-------------------------|
| 1 | 0 | 0 | X0 | See the following table (Table 38-8). | Dual Edge Capture | One-Shot Capture mode |
| | | | X1 | | | Continuous Capture mode |

Table 38-68. Dual Edge Capture mode — edge polarity selection

| ELSnB | ELSnA | Channel Port Enable | Detected Edges |
|-------|-------|---------------------|--------------------------|
| 0 | 0 | Disabled | No edge |
| 0 | 1 | Enabled | Rising edge |
| 1 | 0 | Enabled | Falling edge |
| 1 | 1 | Enabled | Rising and falling edges |

Address: Base address + Ch offset + (8d × i), where i=0d to 7d

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|-----|------|-----|-----|------|------|----|-----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | CHF | CHIE | MSB | MSA | ELSB | ELSA | 0 | DMA |
| W | | | | | | | | | 0 | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_CnSC field descriptions

| Field | Description |
|------------------|---|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 CHF | Channel Flag Set by hardware when an event occurs on the channel. CHF is cleared by reading the CSC register while CHnF is set and then writing a 0 to the CHF bit. Writing a 1 to CHF has no effect. If another event occurs between the read and write operations, the write operation has no effect; therefore, CHF remains set indicating an event has occurred. In this case a CHF interrupt request is not lost due to the clearing sequence for a previous CHF. 0 No channel event has occurred. 1 A channel event has occurred. |
| 6 CHIE | Channel Interrupt Enable Enables channel interrupts. |

Table continues on the next page...

FTMx_CnSC field descriptions (continued)

| Field | Description |
|---------------|--|
| | 0 Disable channel interrupts. Use software polling. 1 Enable channel interrupts. |
| 5 MSB | Channel Mode Select Used for further selections in the channel logic. Its functionality is dependent on the channel mode. See Table 38-7 . This field is write protected. It can be written only when MODE[WPDIS] = 1. |
| 4 MSA | Channel Mode Select Used for further selections in the channel logic. Its functionality is dependent on the channel mode. See Table 38-7 . This field is write protected. It can be written only when MODE[WPDIS] = 1. |
| 3 ELSB | Edge or Level Select The functionality of EL SB and EL SA depends on the channel mode. See Table 38-7 . This field is write protected. It can be written only when MODE[WPDIS] = 1. |
| 2 ELSA | Edge or Level Select The functionality of EL SB and EL SA depends on the channel mode. See Table 38-7 . This field is write protected. It can be written only when MODE[WPDIS] = 1. |
| 1 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 0 DMA | DMA Enable Enables DMA transfers for the channel. 0 Disable DMA transfers. 1 Enable DMA transfers. |

38.3.7 Channel (n) Value (FTMx_CnV)

These registers contain the captured FTM counter value for the input modes or the match value for the output modes.

In Input Capture, Capture Test, and Dual Edge Capture modes, any write to a CnV register is ignored.

In output modes, writing to a CnV register latches the value into a buffer. A CnV register is updated with the value of its write buffer according to [Registers updated from write buffers](#).

If FTMEN = 0, this write coherency mechanism may be manually reset by writing to the CnSC register whether BDM mode is active or not.

memory map and register definition

Address: Base address + 10h offset + (8d × i), where i=0d to 7d

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | 0 | | | | | | | | | | | | | | | | VAL | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_CnV field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 VAL | Channel Value Captured FTM counter value of the input modes or the match value for the output modes |

38.3.8 Counter Initial Value (FTMx_CNTIN)

The Counter Initial Value register contains the initial value for the FTM counter.

Writing to the CNTIN register latches the value into a buffer. The CNTIN register is updated with the value of its write buffer according to [Registers updated from write buffers](#).

When the FTM clock is initially selected, by writing a non-zero value to the CLKS bits, the FTM counter starts with the value 0x0000. To avoid this behavior, before the first write to select the FTM clock, write the new value to the the CNTIN register and then initialize the FTM counter by writing any value to the CNT register.

Address: Base address + 4Ch offset

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | Reserved | | | | | | | | | | | | | | | | INIT | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_CNTIN field descriptions

| Field | Description |
|-------------------|----------------------------------|
| 31–16 Reserved | This field is reserved. |
| 15–0 INIT | Initial Value Of The FTM Counter |

38.3.9 Capture And Compare Status (FTMx_STATUS)

The STATUS register contains a copy of the status flag CHnF bit in CnSC for each FTM channel for software convenience.

Each CHnF bit in STATUS is a mirror of CHnF bit in CnSC. All CHnF bits can be checked using only one read of STATUS. All CHnF bits can be cleared by reading STATUS followed by writing 0x00 to STATUS.

Hardware sets the individual channel flags when an event occurs on the channel. CHnF is cleared by reading STATUS while CHnF is set and then writing a 0 to the CHnF bit. Writing a 1 to CHnF has no effect.

If another event occurs between the read and write operations, the write operation has no effect; therefore, CHnF remains set indicating an event has occurred. In this case, a CHnF interrupt request is not lost due to the clearing sequence for a previous CHnF.

Address: Base address + 50h offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|------|------|------|------|------|------|------|------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | CH7F | CH6F | CH5F | CH4F | CH3F | CH2F | CH1F | CH0F |
| W | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_STATUS field descriptions

| Field | Description |
|------------------|--|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 CH7F | Channel 7 Flag See the register description. 0 No channel event has occurred. 1 A channel event has occurred. |
| 6 CH6F | Channel 6 Flag |

Table continues on the next page...

FTMx_STATUS field descriptions (continued)

| Field | Description |
|-----------|--|
| | See the register description. 0 No channel event has occurred. 1 A channel event has occurred. |
| 5 CH5F | Channel 5 Flag See the register description. 0 No channel event has occurred. 1 A channel event has occurred. |
| 4 CH4F | Channel 4 Flag See the register description. 0 No channel event has occurred. 1 A channel event has occurred. |
| 3 CH3F | Channel 3 Flag See the register description. 0 No channel event has occurred. 1 A channel event has occurred. |
| 2 CH2F | Channel 2 Flag See the register description. 0 No channel event has occurred. 1 A channel event has occurred. |
| 1 CH1F | Channel 1 Flag See the register description. 0 No channel event has occurred. 1 A channel event has occurred. |
| 0 CH0F | Channel 0 Flag See the register description. 0 No channel event has occurred. 1 A channel event has occurred. |

38.3.10 Features Mode Selection (FTMx_MODE)

This register contains the global enable bit for FTM-specific features and the control bits used to configure:

- Fault control mode and interrupt
- Capture Test mode
- PWM synchronization

- Write protection
- Channel output initialization

These controls relate to all channels within this module.

Address: Base address + 54h offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|---------|--------|----|---------|---------|-------|------|-------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | FAULTIE | FAULTM | | CAPTEST | PWMSYNC | WPDIS | INIT | FTMEN |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

FTMx_MODE field descriptions

| Field | Description |
|------------------|--|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 FAULTIE | Fault Interrupt Enable Enables the generation of an interrupt when a fault is detected by FTM and the FTM fault control is enabled. 0 Fault control interrupt is disabled. 1 Fault control interrupt is enabled. |
| 6–5 FAULTM | Fault Control Mode Defines the FTM fault control mode. This field is write protected. It can be written only when MODE[WPDIS] = 1. 00 Fault control is disabled for all channels. 01 Fault control is enabled for even channels only (channels 0, 2, 4, and 6), and the selected mode is the manual fault clearing. 10 Fault control is enabled for all channels, and the selected mode is the manual fault clearing. 11 Fault control is enabled for all channels, and the selected mode is the automatic fault clearing. |
| 4 CAPTEST | Capture Test Mode Enable Enables the capture test mode. This field is write protected. It can be written only when MODE[WPDIS] = 1. 0 Capture test mode is disabled. 1 Capture test mode is enabled. |
| 3 PWMSYNC | PWM Synchronization Mode |

Table continues on the next page...

FTMx_MODE field descriptions (continued)

| Field | Description |
|------------|--|
| | <p>Selects which triggers can be used by MOD, CnV, OUTMASK, and FTM counter synchronization. See PWM synchronization. The PWMSYNC bit configures the synchronization when SYNCMODE is 0.</p> <p>0 No restrictions. Software and hardware triggers can be used by MOD, CnV, OUTMASK, and FTM counter synchronization.</p> <p>1 Software trigger can only be used by MOD and CnV synchronization, and hardware triggers can only be used by OUTMASK and FTM counter synchronization.</p> |
| 2 WPDIS | <p>Write Protection Disable</p> <p>When write protection is enabled (WPDIS = 0), write protected bits cannot be written. When write protection is disabled (WPDIS = 1), write protected bits can be written. The WPDIS bit is the negation of the WPEN bit. WPDIS is cleared when 1 is written to WPEN. WPDIS is set when WPEN bit is read as a 1 and then 1 is written to WPDIS. Writing 0 to WPDIS has no effect.</p> <p>0 Write protection is enabled.</p> <p>1 Write protection is disabled.</p> |
| 1 INIT | <p>Initialize The Channels Output</p> <p>When a 1 is written to INIT bit the channels output is initialized according to the state of their corresponding bit in the OUTINIT register. Writing a 0 to INIT bit has no effect.</p> <p>The INIT bit is always read as 0.</p> |
| 0 FTMEN | <p>FTM Enable</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 TPM compatibility. Free running counter and synchronization compatible with TPM.</p> <p>1 Free running counter and synchronization are different from TPM behavior.</p> |

38.3.11 Synchronization (FTMx_SYNC)

This register configures the PWM synchronization.

A synchronization event can perform the synchronized update of MOD, CV, and OUTMASK registers with the value of their write buffer and the FTM counter initialization.

NOTE

The software trigger, SWSYNC bit, and hardware triggers TRIG0, TRIG1, and TRIG2 bits have a potential conflict if used together when SYNCMODE = 0. Use only hardware or software triggers but not both at the same time, otherwise unpredictable behavior is likely to happen.

The selection of the loading point, CNTMAX and CNTMIN bits, is intended to provide the update of MOD, CNTIN, and CnV registers across all enabled channels simultaneously. The use of the loading point selection together with SYNCMODE = 0 and hardware trigger selection, TRIG0, TRIG1, or TRIG2 bits, is likely to result in unpredictable behavior.

The synchronization event selection also depends on the PWMSYNC (MODE register) and SYNCMODE (SYNCONF register) bits. See [PWM synchronization](#).

Address: Base address + 58h offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|--------|-------|-------|-------|---------|--------|--------|--------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | SWSYNC | TRIG2 | TRIG1 | TRIG0 | SYNCHOM | REINIT | CNTMAX | CNTMIN |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_SYNC field descriptions

| Field | Description |
|------------------|--|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 SWSYNC | PWM Synchronization Software Trigger Selects the software trigger as the PWM synchronization trigger. The software trigger happens when a 1 is written to SWSYNC bit. 0 Software trigger is not selected. 1 Software trigger is selected. |
| 6 TRIG2 | PWM Synchronization Hardware Trigger 2 Enables hardware trigger 2 to the PWM synchronization. Hardware trigger 2 happens when a rising edge is detected at the trigger 2 input signal. 0 Trigger is disabled. 1 Trigger is enabled. |
| 5 TRIG1 | PWM Synchronization Hardware Trigger 1 Enables hardware trigger 1 to the PWM synchronization. Hardware trigger 1 happens when a rising edge is detected at the trigger 1 input signal. |

Table continues on the next page...

FTMx_SYNC field descriptions (continued)

| Field | Description |
|--------------|---|
| | 0 Trigger is disabled. 1 Trigger is enabled. |
| 4 TRIG0 | PWM Synchronization Hardware Trigger 0 Enables hardware trigger 0 to the PWM synchronization. Hardware trigger 0 occurs when a rising edge is detected at the trigger 0 input signal. 0 Trigger is disabled. 1 Trigger is enabled. |
| 3 SYNCHOM | Output Mask Synchronization Selects when the OUTMASK register is updated with the value of its buffer. 0 OUTMASK register is updated with the value of its buffer in all rising edges of the system clock. 1 OUTMASK register is updated with the value of its buffer only by the PWM synchronization. |
| 2 REINIT | FTM Counter Reinitialization By Synchronization (FTM counter synchronization) Determines if the FTM counter is reinitialized when the selected trigger for the synchronization is detected. The REINIT bit configures the synchronization when SYNCMODE is zero. 0 FTM counter continues to count normally. 1 FTM counter is updated with its initial value when the selected trigger is detected. |
| 1 CNTMAX | Maximum Loading Point Enable Selects the maximum loading point to PWM synchronization. See Boundary cycle and loading points . If CNTMAX is 1, the selected loading point is when the FTM counter reaches its maximum value (MOD register). 0 The maximum loading point is disabled. 1 The maximum loading point is enabled. |
| 0 CNTMIN | Minimum Loading Point Enable Selects the minimum loading point to PWM synchronization. See Boundary cycle and loading points . If CNTMIN is one, the selected loading point is when the FTM counter reaches its minimum value (CNTIN register). 0 The minimum loading point is disabled. 1 The minimum loading point is enabled. |

38.3.12 Initial State For Channels Output (FTMx_OUTINIT)

Address: Base address + 5Ch offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|-------|-------|-------|-------|-------|-------|-------|-------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | CH7OI | CH6OI | CH5OI | CH4OI | CH3OI | CH2OI | CH1OI | CH0OI |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_OUTINIT field descriptions

| Field | Description |
|------------------|---|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 CH7OI | Channel 7 Output Initialization Value Selects the value that is forced into the channel output when the initialization occurs. 0 The initialization value is 0. 1 The initialization value is 1. |
| 6 CH6OI | Channel 6 Output Initialization Value Selects the value that is forced into the channel output when the initialization occurs. 0 The initialization value is 0. 1 The initialization value is 1. |
| 5 CH5OI | Channel 5 Output Initialization Value Selects the value that is forced into the channel output when the initialization occurs. 0 The initialization value is 0. 1 The initialization value is 1. |
| 4 CH4OI | Channel 4 Output Initialization Value Selects the value that is forced into the channel output when the initialization occurs. 0 The initialization value is 0. 1 The initialization value is 1. |
| 3 CH3OI | Channel 3 Output Initialization Value Selects the value that is forced into the channel output when the initialization occurs. |

Table continues on the next page...

FTMx_OUTINIT field descriptions (continued)

| Field | Description |
|------------|---|
| | 0 The initialization value is 0. 1 The initialization value is 1. |
| 2 CH2OI | Channel 2 Output Initialization Value Selects the value that is forced into the channel output when the initialization occurs. 0 The initialization value is 0. 1 The initialization value is 1. |
| 1 CH1OI | Channel 1 Output Initialization Value Selects the value that is forced into the channel output when the initialization occurs. 0 The initialization value is 0. 1 The initialization value is 1. |
| 0 CH0OI | Channel 0 Output Initialization Value Selects the value that is forced into the channel output when the initialization occurs. 0 The initialization value is 0. 1 The initialization value is 1. |

38.3.13 Output Mask (FTMx_OUTMASK)

This register provides a mask for each FTM channel. The mask of a channel determines if its output responds, that is, it is masked or not, when a match occurs. This feature is used for BLDC control where the PWM signal is presented to an electric motor at specific times to provide electronic commutation.

Any write to the OUTMASK register, stores the value in its write buffer. The register is updated with the value of its write buffer according to [PWM synchronization](#).

Address: Base address + 60h offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|-------|-------|-------|-------|-------|-------|-------|-------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | CH7OM | CH6OM | CH5OM | CH4OM | CH3OM | CH2OM | CH1OM | CH0OM |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_OUTMASK field descriptions

| Field | Description |
|------------------|---|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 CH7OM | Channel 7 Output Mask Defines if the channel output is masked or unmasked. 0 Channel output is not masked. It continues to operate normally. 1 Channel output is masked. It is forced to its inactive state. |
| 6 CH6OM | Channel 6 Output Mask Defines if the channel output is masked or unmasked. 0 Channel output is not masked. It continues to operate normally. 1 Channel output is masked. It is forced to its inactive state. |
| 5 CH5OM | Channel 5 Output Mask Defines if the channel output is masked or unmasked. 0 Channel output is not masked. It continues to operate normally. 1 Channel output is masked. It is forced to its inactive state. |
| 4 CH4OM | Channel 4 Output Mask Defines if the channel output is masked or unmasked. 0 Channel output is not masked. It continues to operate normally. 1 Channel output is masked. It is forced to its inactive state. |
| 3 CH3OM | Channel 3 Output Mask Defines if the channel output is masked or unmasked. 0 Channel output is not masked. It continues to operate normally. 1 Channel output is masked. It is forced to its inactive state. |
| 2 CH2OM | Channel 2 Output Mask Defines if the channel output is masked or unmasked. 0 Channel output is not masked. It continues to operate normally. 1 Channel output is masked. It is forced to its inactive state. |
| 1 CH1OM | Channel 1 Output Mask Defines if the channel output is masked or unmasked. 0 Channel output is not masked. It continues to operate normally. 1 Channel output is masked. It is forced to its inactive state. |
| 0 CH0OM | Channel 0 Output Mask Defines if the channel output is masked or unmasked. 0 Channel output is not masked. It continues to operate normally. 1 Channel output is masked. It is forced to its inactive state. |

38.3.14 Function For Linked Channels (FTMx_COMBINE)

This register contains the control bits used to configure the fault control, synchronization, deadtime insertion, Dual Edge Capture mode, Complementary, and Combine mode for each pair of channels (n) and (n+1), where n equals 0, 2, 4, and 6.

Address: Base address + 64h offset

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|----|----------|---------|-------|--------|----------|-------|----------|----|----------|---------|-------|--------|----------|-------|----------|
| R | 0 | FAULTEN3 | SYNCEN3 | DTEN3 | DECAP3 | DECAPEN3 | COMP3 | COMBINE3 | 0 | FAULTEN2 | SYNCEN2 | DTEN2 | DECAP2 | DECAPEN2 | COMP2 | COMBINE2 |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----------|---------|-------|--------|----------|-------|----------|---|----------|---------|-------|--------|----------|-------|----------|
| R | 0 | FAULTEN1 | SYNCEN1 | DTEN1 | DECAP1 | DECAPEN1 | COMP1 | COMBINE1 | 0 | FAULTEN0 | SYNCEN0 | DTEN0 | DECAP0 | DECAPEN0 | COMP0 | COMBINE0 |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_COMBINE field descriptions

| Field | Description |
|----------------|--|
| 31 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 30 FAULTEN3 | Fault Control Enable For n = 6 Enables the fault control in channels (n) and (n+1). This field is write protected. It can be written only when MODE[WPDIS] = 1. 0 The fault control in this pair of channels is disabled. 1 The fault control in this pair of channels is enabled. |
| 29 SYNCEN3 | Synchronization Enable For n = 6 Enables PWM synchronization of registers C(n)V and C(n+1)V. 0 The PWM synchronization in this pair of channels is disabled. 1 The PWM synchronization in this pair of channels is enabled. |
| 28 DTEN3 | Deadtime Enable For n = 6 Enables the deadtime insertion in the channels (n) and (n+1). This field is write protected. It can be written only when MODE[WPDIS] = 1. |

Table continues on the next page...

FTMx_COMBINE field descriptions (continued)

| Field | Description |
|----------------|---|
| | <p>0 The deadtime insertion in this pair of channels is disabled.</p> <p>1 The deadtime insertion in this pair of channels is enabled.</p> |
| 27 DECAP3 | <p>Dual Edge Capture Mode Captures For n = 6</p> <p>Enables the capture of the FTM counter value according to the channel (n) input event and the configuration of the dual edge capture bits.</p> <p>This field applies only when DECAPEN = 1.</p> <p>DECAP bit is cleared automatically by hardware if dual edge capture – one-shot mode is selected and when the capture of channel (n+1) event is made.</p> <p>0 The dual edge captures are inactive.</p> <p>1 The dual edge captures are active.</p> |
| 26 DECAPEN3 | <p>Dual Edge Capture Mode Enable For n = 6</p> <p>Enables the Dual Edge Capture mode in the channels (n) and (n+1). This bit reconfigures the function of MSnA, ELSnB:ELSnA and ELS(n+1)B:ELS(n+1)A bits in Dual Edge Capture mode according to Table 38-7.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The Dual Edge Capture mode in this pair of channels is disabled.</p> <p>1 The Dual Edge Capture mode in this pair of channels is enabled.</p> |
| 25 COMP3 | <p>Complement Of Channel (n) for n = 6</p> <p>Enables Complementary mode for the combined channels. In Complementary mode the channel (n+1) output is the inverse of the channel (n) output.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The channel (n+1) output is the same as the channel (n) output.</p> <p>1 The channel (n+1) output is the complement of the channel (n) output.</p> |
| 24 COMBINE3 | <p>Combine Channels For n = 6</p> <p>Enables the combine feature for channels (n) and (n+1).</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 Channels (n) and (n+1) are independent.</p> <p>1 Channels (n) and (n+1) are combined.</p> |
| 23 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 22 FAULTEN2 | <p>Fault Control Enable For n = 4</p> <p>Enables the fault control in channels (n) and (n+1).</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The fault control in this pair of channels is disabled.</p> <p>1 The fault control in this pair of channels is enabled.</p> |
| 21 SYNCEN2 | <p>Synchronization Enable For n = 4</p> <p>Enables PWM synchronization of registers C(n)V and C(n+1)V.</p> |

Table continues on the next page...

FTMx_COMBINE field descriptions (continued)

| Field | Description |
|----------------|---|
| | <p>0 The PWM synchronization in this pair of channels is disabled.</p> <p>1 The PWM synchronization in this pair of channels is enabled.</p> |
| 20 DTEN2 | <p>Deadtime Enable For n = 4</p> <p>Enables the deadtime insertion in the channels (n) and (n+1).</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The deadtime insertion in this pair of channels is disabled.</p> <p>1 The deadtime insertion in this pair of channels is enabled.</p> |
| 19 DECAP2 | <p>Dual Edge Capture Mode Captures For n = 4</p> <p>Enables the capture of the FTM counter value according to the channel (n) input event and the configuration of the dual edge capture bits.</p> <p>This field applies only when DECAPEN = 1.</p> <p>DECAP bit is cleared automatically by hardware if dual edge capture – one-shot mode is selected and when the capture of channel (n+1) event is made.</p> <p>0 The dual edge captures are inactive.</p> <p>1 The dual edge captures are active.</p> |
| 18 DECAPEN2 | <p>Dual Edge Capture Mode Enable For n = 4</p> <p>Enables the Dual Edge Capture mode in the channels (n) and (n+1). This bit reconfigures the function of MSnA, ELSnB:ELSnA and ELS(n+1)B:ELS(n+1)A bits in Dual Edge Capture mode according to Table 38-7.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The Dual Edge Capture mode in this pair of channels is disabled.</p> <p>1 The Dual Edge Capture mode in this pair of channels is enabled.</p> |
| 17 COMP2 | <p>Complement Of Channel (n) For n = 4</p> <p>Enables Complementary mode for the combined channels. In Complementary mode the channel (n+1) output is the inverse of the channel (n) output.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The channel (n+1) output is the same as the channel (n) output.</p> <p>1 The channel (n+1) output is the complement of the channel (n) output.</p> |
| 16 COMBINE2 | <p>Combine Channels For n = 4</p> <p>Enables the combine feature for channels (n) and (n+1).</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 Channels (n) and (n+1) are independent.</p> <p>1 Channels (n) and (n+1) are combined.</p> |
| 15 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 14 FAULTEN1 | <p>Fault Control Enable For n = 2</p> <p>Enables the fault control in channels (n) and (n+1).</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> |

Table continues on the next page...

FTMx_COMBINE field descriptions (continued)

| Field | Description |
|----------------|---|
| | <p>0 The fault control in this pair of channels is disabled.</p> <p>1 The fault control in this pair of channels is enabled.</p> |
| 13 SYNCE1 | <p>Synchronization Enable For n = 2</p> <p>Enables PWM synchronization of registers C(n)V and C(n+1)V.</p> <p>0 The PWM synchronization in this pair of channels is disabled.</p> <p>1 The PWM synchronization in this pair of channels is enabled.</p> |
| 12 DTEN1 | <p>Deadtime Enable For n = 2</p> <p>Enables the deadtime insertion in the channels (n) and (n+1).</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The deadtime insertion in this pair of channels is disabled.</p> <p>1 The deadtime insertion in this pair of channels is enabled.</p> |
| 11 DECAP1 | <p>Dual Edge Capture Mode Captures For n = 2</p> <p>Enables the capture of the FTM counter value according to the channel (n) input event and the configuration of the dual edge capture bits.</p> <p>This field applies only when DECAPEN = 1.</p> <p>DECAP bit is cleared automatically by hardware if Dual Edge Capture – One-Shot mode is selected and when the capture of channel (n+1) event is made.</p> <p>0 The dual edge captures are inactive.</p> <p>1 The dual edge captures are active.</p> |
| 10 DECAPEN1 | <p>Dual Edge Capture Mode Enable For n = 2</p> <p>Enables the Dual Edge Capture mode in the channels (n) and (n+1). This bit reconfigures the function of MSnA, ELSnB:ELSnA and ELS(n+1)B:ELS(n+1)A bits in Dual Edge Capture mode according to Table 38-7.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The Dual Edge Capture mode in this pair of channels is disabled.</p> <p>1 The Dual Edge Capture mode in this pair of channels is enabled.</p> |
| 9 COMP1 | <p>Complement Of Channel (n) For n = 2</p> <p>Enables Complementary mode for the combined channels. In Complementary mode the channel (n+1) output is the inverse of the channel (n) output.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The channel (n+1) output is the same as the channel (n) output.</p> <p>1 The channel (n+1) output is the complement of the channel (n) output.</p> |
| 8 COMBINE1 | <p>Combine Channels For n = 2</p> <p>Enables the combine feature for channels (n) and (n+1).</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 Channels (n) and (n+1) are independent.</p> <p>1 Channels (n) and (n+1) are combined.</p> |

Table continues on the next page...

FTMx_COMBINE field descriptions (continued)

| Field | Description |
|---------------|---|
| 7 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 6 FAULTEN0 | Fault Control Enable For n = 0 Enables the fault control in channels (n) and (n+1). This field is write protected. It can be written only when MODE[WPDIS] = 1. 0 The fault control in this pair of channels is disabled. 1 The fault control in this pair of channels is enabled. |
| 5 SYNCEN0 | Synchronization Enable For n = 0 Enables PWM synchronization of registers C(n)V and C(n+1)V. 0 The PWM synchronization in this pair of channels is disabled. 1 The PWM synchronization in this pair of channels is enabled. |
| 4 DTEN0 | Deadtime Enable For n = 0 Enables the deadtime insertion in the channels (n) and (n+1). This field is write protected. It can be written only when MODE[WPDIS] = 1. 0 The deadtime insertion in this pair of channels is disabled. 1 The deadtime insertion in this pair of channels is enabled. |
| 3 DECAP0 | Dual Edge Capture Mode Captures For n = 0 Enables the capture of the FTM counter value according to the channel (n) input event and the configuration of the dual edge capture bits. This field applies only when DECAPEN = 1. DECAP bit is cleared automatically by hardware if dual edge capture – one-shot mode is selected and when the capture of channel (n+1) event is made. 0 The dual edge captures are inactive. 1 The dual edge captures are active. |
| 2 DECAPEN0 | Dual Edge Capture Mode Enable For n = 0 Enables the Dual Edge Capture mode in the channels (n) and (n+1). This bit reconfigures the function of MSnA, ELSnB:ELSnA and ELS(n+1)B:ELS(n+1)A bits in Dual Edge Capture mode according to Table 38-7 . This field is write protected. It can be written only when MODE[WPDIS] = 1. 0 The Dual Edge Capture mode in this pair of channels is disabled. 1 The Dual Edge Capture mode in this pair of channels is enabled. |
| 1 COMP0 | Complement Of Channel (n) For n = 0 Enables Complementary mode for the combined channels. In Complementary mode the channel (n+1) output is the inverse of the channel (n) output. This field is write protected. It can be written only when MODE[WPDIS] = 1. 0 The channel (n+1) output is the same as the channel (n) output. 1 The channel (n+1) output is the complement of the channel (n) output. |

Table continues on the next page...

FTMx_COMBINE field descriptions (continued)

| Field | Description |
|---------------|---|
| 0 COMBINE0 | <p>Combine Channels For $n = 0$</p> <p>Enables the combine feature for channels (n) and (n+1).</p> <p>This field is write protected. It can be written only when $MODE[WPDIS] = 1$.</p> <p>0 Channels (n) and (n+1) are independent. 1 Channels (n) and (n+1) are combined.</p> |

38.3.15 Deadtime Insertion Control (FTMx_DEADTIME)

This register selects the deadtime prescaler factor and deadtime value. All FTM channels use this clock prescaler and this deadtime value for the deadtime insertion.

Address: Base address + 68h offset

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|------|----|-------|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | DTPS | | DTVAL | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

FTMx_DEADTIME field descriptions

| Field | Description |
|------------------|--|
| 31–8 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 7–6 DTPS | <p>Deadtime Prescaler Value</p> <p>Selects the division factor of the system clock. This prescaled clock is used by the deadtime counter.</p> <p>This field is write protected. It can be written only when $MODE[WPDIS] = 1$.</p> <p>0x Divide the system clock by 1. 10 Divide the system clock by 4. 11 Divide the system clock by 16.</p> |
| 5–0 DTVAL | <p>Deadtime Value</p> <p>Selects the deadtime insertion value for the deadtime counter. The deadtime counter is clocked by a scaled version of the system clock. See the description of DTPS.</p> <p>Deadtime insert value = $(DTPS \times DTVAL)$.</p> <p>DTVAL selects the number of deadtime counts inserted as follows:</p> <p>When DTVAL is 0, no counts are inserted. When DTVAL is 1, 1 count is inserted. When DTVAL is 2, 2 counts are inserted.</p> <p>This pattern continues up to a possible 63 counts.</p> <p>This field is write protected. It can be written only when $MODE[WPDIS] = 1$.</p> |

38.3.16 FTM External Trigger (FTMx_EXTTRIG)

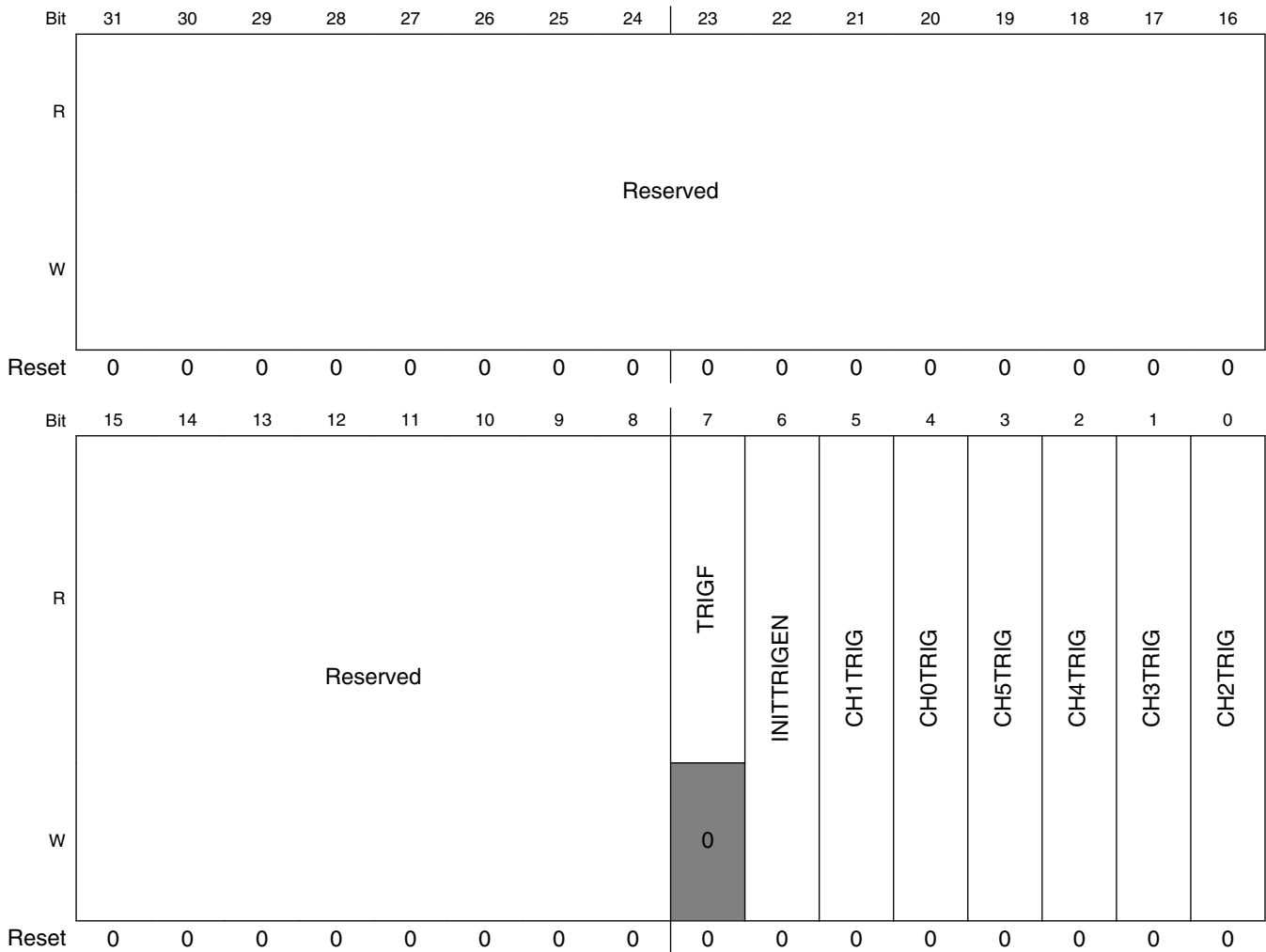
This register:

- Indicates when a channel trigger was generated
- Enables the generation of a trigger when the FTM counter is equal to its initial value
- Selects which channels are used in the generation of the channel triggers

Several channels can be selected to generate multiple triggers in one PWM period.

Channels 6 and 7 are not used to generate channel triggers.

Address: Base address + 6Ch offset



FTMx_EXTTRIG field descriptions

| Field | Description |
|------------------|--|
| 31–8 Reserved | This field is reserved. |
| 7 TRIGF | <p>Channel Trigger Flag</p> <p>Set by hardware when a channel trigger is generated. Clear TRIGF by reading EXTTRIG while TRIGF is set and then writing a 0 to TRIGF. Writing a 1 to TRIGF has no effect.</p> <p>If another channel trigger is generated before the clearing sequence is completed, the sequence is reset so TRIGF remains set after the clear sequence is completed for the earlier TRIGF.</p> <p>0 No channel trigger was generated. 1 A channel trigger was generated.</p> |
| 6 INITTRIGEN | <p>Initialization Trigger Enable</p> <p>Enables the generation of the trigger when the FTM counter is equal to the CNTIN register.</p> <p>0 The generation of initialization trigger is disabled. 1 The generation of initialization trigger is enabled.</p> |
| 5 CH1TRIG | <p>Channel 1 Trigger Enable</p> <p>Enables the generation of the channel trigger when the FTM counter is equal to the CnV register.</p> <p>0 The generation of the channel trigger is disabled. 1 The generation of the channel trigger is enabled.</p> |
| 4 CH0TRIG | <p>Channel 0 Trigger Enable</p> <p>Enables the generation of the channel trigger when the FTM counter is equal to the CnV register.</p> <p>0 The generation of the channel trigger is disabled. 1 The generation of the channel trigger is enabled.</p> |
| 3 CH5TRIG | <p>Channel 5 Trigger Enable</p> <p>Enables the generation of the channel trigger when the FTM counter is equal to the CnV register.</p> <p>0 The generation of the channel trigger is disabled. 1 The generation of the channel trigger is enabled.</p> |
| 2 CH4TRIG | <p>Channel 4 Trigger Enable</p> <p>Enables the generation of the channel trigger when the FTM counter is equal to the CnV register.</p> <p>0 The generation of the channel trigger is disabled. 1 The generation of the channel trigger is enabled.</p> |
| 1 CH3TRIG | <p>Channel 3 Trigger Enable</p> <p>Enables the generation of the channel trigger when the FTM counter is equal to the CnV register.</p> <p>0 The generation of the channel trigger is disabled. 1 The generation of the channel trigger is enabled.</p> |
| 0 CH2TRIG | <p>Channel 2 Trigger Enable</p> <p>Enables the generation of the channel trigger when the FTM counter is equal to the CnV register.</p> |

Table continues on the next page...

FTMx_EXTTRIG field descriptions (continued)

| Field | Description |
|-------|--|
| 0 | The generation of the channel trigger is disabled. |
| 1 | The generation of the channel trigger is enabled. |

38.3.17 Channels Polarity (FTMx_POL)

This register defines the output polarity of the FTM channels.

NOTE

The safe value that is driven in a channel output when the fault control is enabled and a fault condition is detected is the inactive state of the channel. That is, the safe value of a channel is the value of its POL bit.

Address: Base address + 70h offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_POL field descriptions

| Field | Description |
|------------------|---|
| 31–8 Reserved | This field is reserved. |
| 7 POL7 | Channel 7 Polarity Defines the polarity of the channel output. This field is write protected. It can be written only when MODE[WPDIS] = 1. 0 The channel polarity is active high. 1 The channel polarity is active low. |
| 6 POL6 | Channel 6 Polarity Defines the polarity of the channel output. This field is write protected. It can be written only when MODE[WPDIS] = 1. 0 The channel polarity is active high. 1 The channel polarity is active low. |
| 5 POL5 | Channel 5 Polarity Defines the polarity of the channel output. This field is write protected. It can be written only when MODE[WPDIS] = 1. |

Table continues on the next page...

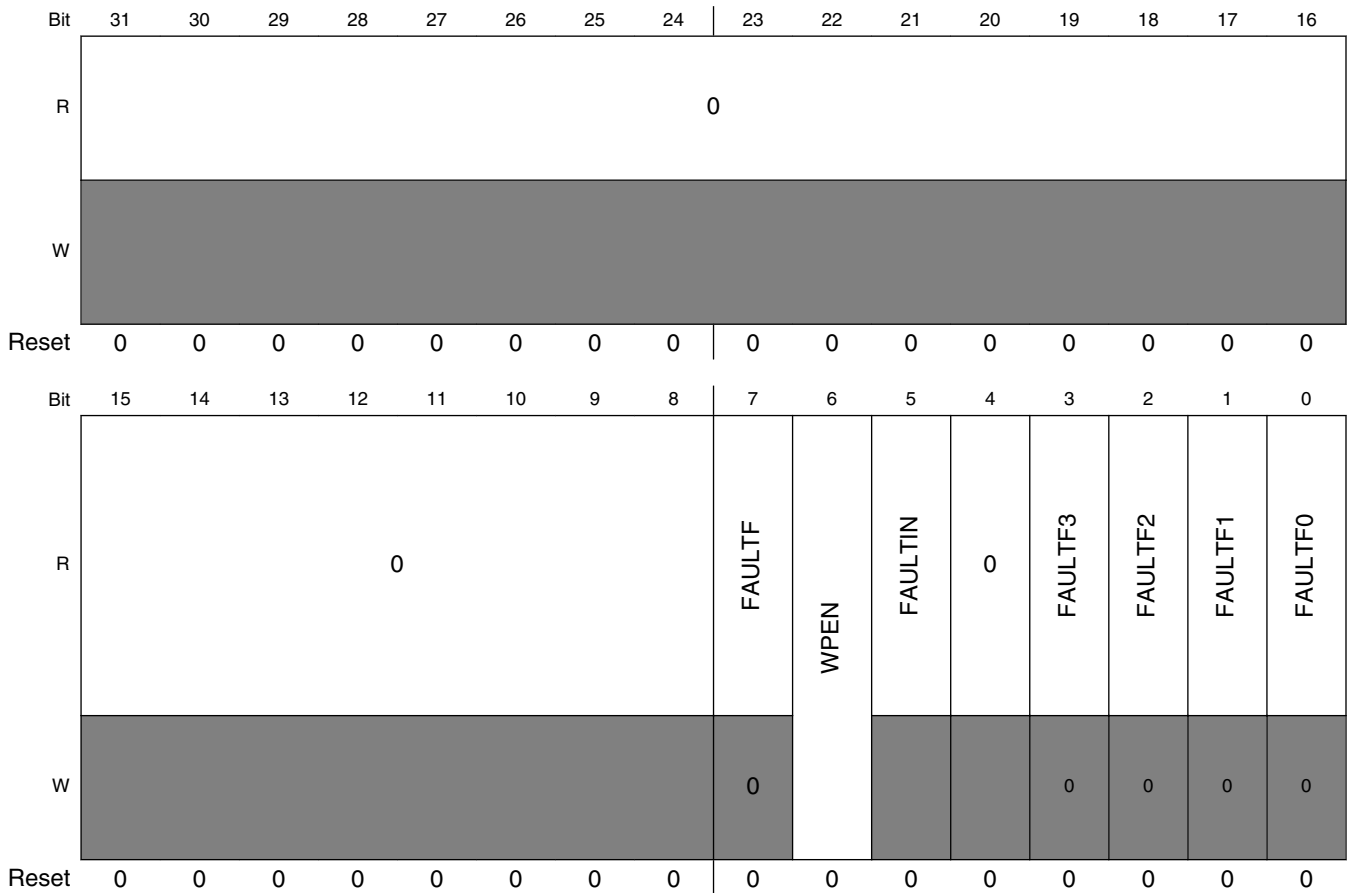
FTMx_POL field descriptions (continued)

| Field | Description |
|-----------|--|
| | <p>0 The channel polarity is active high.</p> <p>1 The channel polarity is active low.</p> |
| 4 POL4 | <p>Channel 4 Polarity</p> <p>Defines the polarity of the channel output.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The channel polarity is active high.</p> <p>1 The channel polarity is active low.</p> |
| 3 POL3 | <p>Channel 3 Polarity</p> <p>Defines the polarity of the channel output.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The channel polarity is active high.</p> <p>1 The channel polarity is active low.</p> |
| 2 POL2 | <p>Channel 2 Polarity</p> <p>Defines the polarity of the channel output.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The channel polarity is active high.</p> <p>1 The channel polarity is active low.</p> |
| 1 POL1 | <p>Channel 1 Polarity</p> <p>Defines the polarity of the channel output.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The channel polarity is active high.</p> <p>1 The channel polarity is active low.</p> |
| 0 POL0 | <p>Channel 0 Polarity</p> <p>Defines the polarity of the channel output.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The channel polarity is active high.</p> <p>1 The channel polarity is active low.</p> |

38.3.18 Fault Mode Status (FTMx_FMS)

This register contains the fault detection flags, write protection enable bit, and the logic OR of the enabled fault inputs.

Address: Base address + 74h offset



FTMx_FMS field descriptions

| Field | Description |
|------------------|--|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 FAULTF | <p>Fault Detection Flag</p> <p>Represents the logic OR of the individual FAULTFj bits where j = 3, 2, 1, 0. Clear FAULTF by reading the FMS register while FAULTF is set and then writing a 0 to FAULTF while there is no existing fault condition at the enabled fault inputs. Writing a 1 to FAULTF has no effect.</p> <p>If another fault condition is detected in an enabled fault input before the clearing sequence is completed, the sequence is reset so FAULTF remains set after the clearing sequence is completed for the earlier fault condition. FAULTF is also cleared when FAULTFj bits are cleared individually.</p> <p>0 No fault condition was detected. 1 A fault condition was detected.</p> |

Table continues on the next page...

FTMx_FMS field descriptions (continued)

| Field | Description |
|---------------|--|
| 6 WPEN | <p>Write Protection Enable</p> <p>The WPEN bit is the negation of the WPDIS bit. WPEN is set when 1 is written to it. WPEN is cleared when WPEN bit is read as a 1 and then 1 is written to WPDIS. Writing 0 to WPEN has no effect.</p> <p>0 Write protection is disabled. Write protected bits can be written. 1 Write protection is enabled. Write protected bits cannot be written.</p> |
| 5 FAULTIN | <p>Fault Inputs</p> <p>Represents the logic OR of the enabled fault inputs after their filter (if their filter is enabled) when fault control is enabled.</p> <p>0 The logic OR of the enabled fault inputs is 0. 1 The logic OR of the enabled fault inputs is 1.</p> |
| 4 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 3 FAULTF3 | <p>Fault Detection Flag 3</p> <p>Set by hardware when fault control is enabled, the corresponding fault input is enabled and a fault condition is detected at the fault input.</p> <p>Clear FAULTF3 by reading the FMS register while FAULTF3 is set and then writing a 0 to FAULTF3 while there is no existing fault condition at the corresponding fault input. Writing a 1 to FAULTF3 has no effect. FAULTF3 bit is also cleared when FAULTF bit is cleared.</p> <p>If another fault condition is detected at the corresponding fault input before the clearing sequence is completed, the sequence is reset so FAULTF3 remains set after the clearing sequence is completed for the earlier fault condition.</p> <p>0 No fault condition was detected at the fault input. 1 A fault condition was detected at the fault input.</p> |
| 2 FAULTF2 | <p>Fault Detection Flag 2</p> <p>Set by hardware when fault control is enabled, the corresponding fault input is enabled and a fault condition is detected at the fault input.</p> <p>Clear FAULTF2 by reading the FMS register while FAULTF2 is set and then writing a 0 to FAULTF2 while there is no existing fault condition at the corresponding fault input. Writing a 1 to FAULTF2 has no effect. FAULTF2 bit is also cleared when FAULTF bit is cleared.</p> <p>If another fault condition is detected at the corresponding fault input before the clearing sequence is completed, the sequence is reset so FAULTF2 remains set after the clearing sequence is completed for the earlier fault condition.</p> <p>0 No fault condition was detected at the fault input. 1 A fault condition was detected at the fault input.</p> |
| 1 FAULTF1 | <p>Fault Detection Flag 1</p> <p>Set by hardware when fault control is enabled, the corresponding fault input is enabled and a fault condition is detected at the fault input.</p> <p>Clear FAULTF1 by reading the FMS register while FAULTF1 is set and then writing a 0 to FAULTF1 while there is no existing fault condition at the corresponding fault input. Writing a 1 to FAULTF1 has no effect. FAULTF1 bit is also cleared when FAULTF bit is cleared.</p> |

Table continues on the next page...

FTMx_FMS field descriptions (continued)

| Field | Description |
|--------------|--|
| | <p>If another fault condition is detected at the corresponding fault input before the clearing sequence is completed, the sequence is reset so FAULTF1 remains set after the clearing sequence is completed for the earlier fault condition.</p> <p>0 No fault condition was detected at the fault input. 1 A fault condition was detected at the fault input.</p> |
| 0 FAULTF0 | <p>Fault Detection Flag 0</p> <p>Set by hardware when fault control is enabled, the corresponding fault input is enabled and a fault condition is detected at the fault input.</p> <p>Clear FAULTF0 by reading the FMS register while FAULTF0 is set and then writing a 0 to FAULTF0 while there is no existing fault condition at the corresponding fault input. Writing a 1 to FAULTF0 has no effect. FAULTF0 bit is also cleared when FAULTF bit is cleared.</p> <p>If another fault condition is detected at the corresponding fault input before the clearing sequence is completed, the sequence is reset so FAULTF0 remains set after the clearing sequence is completed for the earlier fault condition.</p> <p>0 No fault condition was detected at the fault input. 1 A fault condition was detected at the fault input.</p> |

38.3.19 Input Capture Filter Control (FTMx_FILTER)

This register selects the filter value for the inputs of channels.

Channels 4, 5, 6 and 7 do not have an input filter.

NOTE

Writing to the FILTER register has immediate effect and must be done only when the channels 0, 1, 2, and 3 are not in input modes. Failure to do this could result in a missing valid signal.

Address: Base address + 78h offset

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_FILTER field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | This field is reserved. |
| 15–12 CH3FVAL | <p>Channel 3 Input Filter</p> <p>Selects the filter value for the channel input.</p> <p>The filter is disabled when the value is zero.</p> |

Table continues on the next page...

FTMx_FILTER field descriptions (continued)

| Field | Description |
|-----------------|---|
| 11–8 CH2FVAL | Channel 2 Input Filter Selects the filter value for the channel input. The filter is disabled when the value is zero. |
| 7–4 CH1FVAL | Channel 1 Input Filter Selects the filter value for the channel input. The filter is disabled when the value is zero. |
| 3–0 CH0FVAL | Channel 0 Input Filter Selects the filter value for the channel input. The filter is disabled when the value is zero. |

38.3.20 Fault Control (FTMx_FLTCTRL)

This register selects the filter value for the fault inputs, enables the fault inputs and the fault inputs filter.

Address: Base address + 7Ch offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|-------|----|----|----|----------|----------|----------|----------|----------|----------|----------|----------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | FFVAL | | | | FFLTR3EN | FFLTR2EN | FFLTR1EN | FFLTR0EN | FAULT3EN | FAULT2EN | FAULT1EN | FAULT0EN |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_FLTCTRL field descriptions

| Field | Description |
|-------------------|--|
| 31–12 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 11–8 FFVAL | Fault Input Filter Selects the filter value for the fault inputs. The fault filter is disabled when the value is zero. |

Table continues on the next page...

FTMx_FLTCTRL field descriptions (continued)

| Field | Description |
|---------------|--|
| | NOTE: Writing to this field has immediate effect and must be done only when the fault control or all fault inputs are disabled. Failure to do this could result in a missing fault detection. |
| 7 FFLTR3EN | <p>Fault Input 3 Filter Enable</p> <p>Enables the filter for the fault input.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 Fault input filter is disabled. 1 Fault input filter is enabled.</p> |
| 6 FFLTR2EN | <p>Fault Input 2 Filter Enable</p> <p>Enables the filter for the fault input.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 Fault input filter is disabled. 1 Fault input filter is enabled.</p> |
| 5 FFLTR1EN | <p>Fault Input 1 Filter Enable</p> <p>Enables the filter for the fault input.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 Fault input filter is disabled. 1 Fault input filter is enabled.</p> |
| 4 FFLTR0EN | <p>Fault Input 0 Filter Enable</p> <p>Enables the filter for the fault input.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 Fault input filter is disabled. 1 Fault input filter is enabled.</p> |
| 3 FAULT3EN | <p>Fault Input 3 Enable</p> <p>Enables the fault input.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 Fault input is disabled. 1 Fault input is enabled.</p> |
| 2 FAULT2EN | <p>Fault Input 2 Enable</p> <p>Enables the fault input.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 Fault input is disabled. 1 Fault input is enabled.</p> |
| 1 FAULT1EN | <p>Fault Input 1 Enable</p> <p>Enables the fault input.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> |

Table continues on the next page...

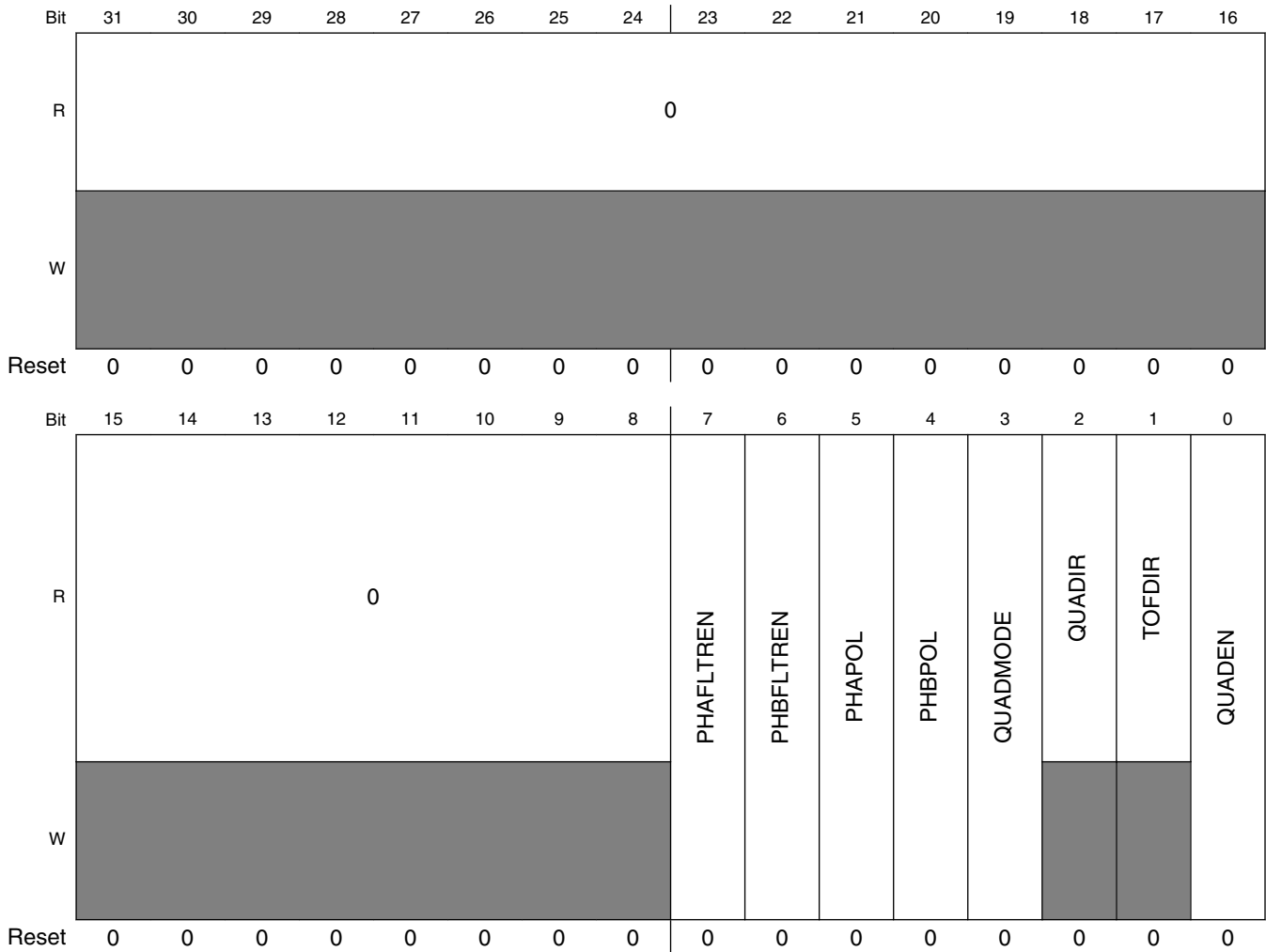
FTMx_FLTCTRL field descriptions (continued)

| Field | Description |
|---------------|--|
| | 0 Fault input is disabled. 1 Fault input is enabled. |
| 0 FAULT0EN | Fault Input 0 Enable Enables the fault input. This field is write protected. It can be written only when MODE[WPDIS] = 1. 0 Fault input is disabled. 1 Fault input is enabled. |

38.3.21 Quadrature Decoder Control And Status (FTMx_QDCTRL)

This register has the control and status bits for the Quadrature Decoder mode.

Address: Base address + 80h offset



FTMx_QDCTRL field descriptions

| Field | Description |
|------------------|--|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 PHAFLTREN | Phase A Input Filter Enable Enables the filter for the quadrature decoder phase A input. The filter value for the phase A input is defined by the CH0FVAL field of FILTER. The phase A filter is also disabled when CH0FVAL is zero. 0 Phase A input filter is disabled. 1 Phase A input filter is enabled. |
| 6 PHBFLTREN | Phase B Input Filter Enable Enables the filter for the quadrature decoder phase B input. The filter value for the phase B input is defined by the CH1FVAL field of FILTER. The phase B filter is also disabled when CH1FVAL is zero. 0 Phase B input filter is disabled. 1 Phase B input filter is enabled. |
| 5 PHAPOL | Phase A Input Polarity Selects the polarity for the quadrature decoder phase A input. 0 Normal polarity. Phase A input signal is not inverted before identifying the rising and falling edges of this signal. 1 Inverted polarity. Phase A input signal is inverted before identifying the rising and falling edges of this signal. |
| 4 PHBPOL | Phase B Input Polarity Selects the polarity for the quadrature decoder phase B input. 0 Normal polarity. Phase B input signal is not inverted before identifying the rising and falling edges of this signal. 1 Inverted polarity. Phase B input signal is inverted before identifying the rising and falling edges of this signal. |
| 3 QUADMODE | Quadrature Decoder Mode Selects the encoding mode used in the Quadrature Decoder mode. 0 Phase A and phase B encoding mode. 1 Count and direction encoding mode. |
| 2 QUADIR | FTM Counter Direction In Quadrature Decoder Mode Indicates the counting direction. 0 Counting direction is decreasing (FTM counter decrement). 1 Counting direction is increasing (FTM counter increment). |
| 1 TOFDIR | Timer Overflow Direction In Quadrature Decoder Mode Indicates if the TOF bit was set on the top or the bottom of counting. 0 TOF bit was set on the bottom of counting. There was an FTM counter decrement and FTM counter changes from its minimum value (CNTIN register) to its maximum value (MOD register). 1 TOF bit was set on the top of counting. There was an FTM counter increment and FTM counter changes from its maximum value (MOD register) to its minimum value (CNTIN register). |

Table continues on the next page...

FTMx_QDCTRL field descriptions (continued)

| Field | Description |
|-------------|--|
| 0 QUADEN | <p>Quadrature Decoder Mode Enable</p> <p>Enables the Quadrature Decoder mode. In this mode, the phase A and B input signals control the FTM counter direction. The Quadrature Decoder mode has precedence over the other modes. See Table 38-7.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 Quadrature Decoder mode is disabled. 1 Quadrature Decoder mode is enabled.</p> |

38.3.22 Configuration (FTMx_CONF)

This register selects the number of times that the FTM counter overflow should occur before the TOF bit to be set, the FTM behavior in BDM modes, the use of an external global time base, and the global time base signal generation.

Address: Base address + 84h offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|---------|--------|----|---------|----|----|--------|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | GTBEOUT | GTBEEN | 0 | BDMMODE | | 0 | NUMTOF | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_CONF field descriptions

| Field | Description |
|-------------------|---|
| 31–11 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 10 GTBEOUT | <p>Global Time Base Output</p> <p>Enables the global time base signal generation to other FTMs.</p> <p>0 A global time base signal generation is disabled. 1 A global time base signal generation is enabled.</p> |
| 9 GTBEEN | Global Time Base Enable |

Table continues on the next page...

FTMx_CONF field descriptions (continued)

| Field | Description |
|---------------|---|
| | Configures the FTM to use an external global time base signal that is generated by another FTM. 0 Use of an external global time base is disabled. 1 Use of an external global time base is enabled. |
| 8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–6 BDMODE | BDM Mode Selects the FTM behavior in BDM mode. See BDM mode . |
| 5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4–0 NUMTOF | TOF Frequency Selects the ratio between the number of counter overflows to the number of times the TOF bit is set. NUMTOF = 0: The TOF bit is set for each counter overflow. NUMTOF = 1: The TOF bit is set for the first counter overflow but not for the next overflow. NUMTOF = 2: The TOF bit is set for the first counter overflow but not for the next 2 overflows. NUMTOF = 3: The TOF bit is set for the first counter overflow but not for the next 3 overflows. This pattern continues up to a maximum of 31. |

38.3.23 FTM Fault Input Polarity (FTMx_FLTPOL)

This register defines the fault inputs polarity.

Address: Base address + 88h offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|---------|---------|---------|---------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | FLT3POL | FLT2POL | FLT1POL | FLT0POL |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_FLTPOL field descriptions

| Field | Description |
|------------------|---|
| 31–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

Table continues on the next page...

FTMx_FLTPOL field descriptions (continued)

| Field | Description |
|--------------|---|
| 3 FLT3POL | <p>Fault Input 3 Polarity</p> <p>Defines the polarity of the fault input.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The fault input polarity is active high. A 1 at the fault input indicates a fault.</p> <p>1 The fault input polarity is active low. A 0 at the fault input indicates a fault.</p> |
| 2 FLT2POL | <p>Fault Input 2 Polarity</p> <p>Defines the polarity of the fault input.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The fault input polarity is active high. A 1 at the fault input indicates a fault.</p> <p>1 The fault input polarity is active low. A 0 at the fault input indicates a fault.</p> |
| 1 FLT1POL | <p>Fault Input 1 Polarity</p> <p>Defines the polarity of the fault input.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The fault input polarity is active high. A 1 at the fault input indicates a fault.</p> <p>1 The fault input polarity is active low. A 0 at the fault input indicates a fault.</p> |
| 0 FLT0POL | <p>Fault Input 0 Polarity</p> <p>Defines the polarity of the fault input.</p> <p>This field is write protected. It can be written only when MODE[WPDIS] = 1.</p> <p>0 The fault input polarity is active high. A 1 at the fault input indicates a fault.</p> <p>1 The fault input polarity is active low. A 0 at the fault input indicates a fault.</p> |

38.3.24 Synchronization Configuration (FTMx_SYNCONF)

This register selects the PWM synchronization configuration, SWOCTRL, INVCTRL and CNTIN registers synchronization, if FTM clears the TRIGj bit, where j = 0, 1, 2, when the hardware trigger j is detected.

Address: Base address + 8Ch offset

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|----|----|----|-------|--------|------|---------|----------|----------|----|------|-------|--------|--------|---------|------------|
| R | 0 | | | | | | | | | | | HWSOC | HWINVC | HWOM | HWWRBUF | HWRSTCNT |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | SWSOC | SWINVC | SWOM | SWWRBUF | SWRSTCNT | SYNCMODE | 0 | SWOC | INVC | 0 | CNTINC | 0 | HWTRIGMODE |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_SYNCONF field descriptions

| Field | Description |
|-------------------|--|
| 31–21 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 20 HWSOC | Software output control synchronization is activated by a hardware trigger. 0 A hardware trigger does not activate the SWOCTRL register synchronization. 1 A hardware trigger activates the SWOCTRL register synchronization. |
| 19 HWINVC | Inverting control synchronization is activated by a hardware trigger. 0 A hardware trigger does not activate the INVCTRL register synchronization. 1 A hardware trigger activates the INVCTRL register synchronization. |
| 18 HWOM | Output mask synchronization is activated by a hardware trigger. 0 A hardware trigger does not activate the OUTMASK register synchronization. 1 A hardware trigger activates the OUTMASK register synchronization. |
| 17 HWWRBUF | MOD, CNTIN, and CV registers synchronization is activated by a hardware trigger. 0 A hardware trigger does not activate MOD, CNTIN, and CV registers synchronization. 1 A hardware trigger activates MOD, CNTIN, and CV registers synchronization. |
| 16 HWRSTCNT | FTM counter synchronization is activated by a hardware trigger. 0 A hardware trigger does not activate the FTM counter synchronization. 1 A hardware trigger activates the FTM counter synchronization. |

Table continues on the next page...

FTMx_SYNCONF field descriptions (continued)

| Field | Description |
|-------------------|--|
| 15–13 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 12 SWSOC | Software output control synchronization is activated by the software trigger. 0 The software trigger does not activate the SWOCTRL register synchronization. 1 The software trigger activates the SWOCTRL register synchronization. |
| 11 SWINVC | Inverting control synchronization is activated by the software trigger. 0 The software trigger does not activate the INVCTRL register synchronization. 1 The software trigger activates the INVCTRL register synchronization. |
| 10 SWOM | Output mask synchronization is activated by the software trigger. 0 The software trigger does not activate the OUTMASK register synchronization. 1 The software trigger activates the OUTMASK register synchronization. |
| 9 SWWRBUF | MOD, CNTIN, and CV registers synchronization is activated by the software trigger. 0 The software trigger does not activate MOD, CNTIN, and CV registers synchronization. 1 The software trigger activates MOD, CNTIN, and CV registers synchronization. |
| 8 SWRSTCNT | FTM counter synchronization is activated by the software trigger. 0 The software trigger does not activate the FTM counter synchronization. 1 The software trigger activates the FTM counter synchronization. |
| 7 SYNCMODE | Synchronization Mode Selects the PWM Synchronization mode. 0 Legacy PWM synchronization is selected. 1 Enhanced PWM synchronization is selected. |
| 6 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 5 SWOC | SWOCTRL Register Synchronization 0 SWOCTRL register is updated with its buffer value at all rising edges of system clock. 1 SWOCTRL register is updated with its buffer value by the PWM synchronization. |
| 4 INVC | INVCTRL Register Synchronization 0 INVCTRL register is updated with its buffer value at all rising edges of system clock. 1 INVCTRL register is updated with its buffer value by the PWM synchronization. |
| 3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 CNTINC | CNTIN Register Synchronization 0 CNTIN register is updated with its buffer value at all rising edges of system clock. 1 CNTIN register is updated with its buffer value by the PWM synchronization. |
| 1 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 0 HWTRIGMODE | Hardware Trigger Mode |

Table continues on the next page...

FTMx_SYNCONF field descriptions (continued)

| Field | Description |
|-------|--|
| 0 | FTM clears the TRIGj bit when the hardware trigger j is detected, where j = 0, 1, 2. |
| 1 | FTM does not clear the TRIGj bit when the hardware trigger j is detected, where j = 0, 1, 2. |

38.3.25 FTM Inverting Control (FTMx_INVCTRL)

This register controls when the channel (n) output becomes the channel (n+1) output, and channel (n+1) output becomes the channel (n) output. Each INVmEN bit enables the inverting operation for the corresponding pair channels m.

This register has a write buffer. The INVmEN bit is updated by the INVCTRL register synchronization.

Address: Base address + 90h offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|--------|--------|--------|--------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | INV3EN | INV2EN | INV1EN | INV0EN |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_INVCTRL field descriptions

| Field | Description |
|------------------|---|
| 31–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3 INV3EN | Pair Channels 3 Inverting Enable 0 Inverting is disabled. 1 Inverting is enabled. |
| 2 INV2EN | Pair Channels 2 Inverting Enable 0 Inverting is disabled. 1 Inverting is enabled. |
| 1 INV1EN | Pair Channels 1 Inverting Enable 0 Inverting is disabled. 1 Inverting is enabled. |

Table continues on the next page...

FTMx_INVCTRL field descriptions (continued)

| Field | Description |
|-------------|---|
| 0 INV0EN | Pair Channels 0 Inverting Enable 0 Inverting is disabled. 1 Inverting is enabled. |

38.3.26 FTM Software Output Control (FTMx_SWOCTRL)

This register enables software control of channel (n) output and defines the value forced to the channel (n) output:

- The CHnOC bits enable the control of the corresponding channel (n) output by software.
- The CHnOCV bits select the value that is forced at the corresponding channel (n) output.

This register has a write buffer. The fields are updated by the SWOCTRL register synchronization.

Address: Base address + 94h offset

| | | | | | | | | | | | | | | | | |
|-------|--------|--------|--------|--------|--------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | CH7OCV | CH6OCV | CH5OCV | CH4OCV | CH3OCV | CH2OCV | CH1OCV | CH0OCV | CH7OC | CH6OC | CH5OC | CH4OC | CH3OC | CH2OC | CH1OC | CH0OC |
| W | CH7OCV | CH6OCV | CH5OCV | CH4OCV | CH3OCV | CH2OCV | CH1OCV | CH0OCV | CH7OC | CH6OC | CH5OC | CH4OC | CH3OC | CH2OC | CH1OC | CH0OC |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_SWOCTRL field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15 CH7OCV | Channel 7 Software Output Control Value 0 The software output control forces 0 to the channel output. 1 The software output control forces 1 to the channel output. |
| 14 CH6OCV | Channel 6 Software Output Control Value |

Table continues on the next page...

FTMx_SWOCTRL field descriptions (continued)

| Field | Description |
|--------------|--|
| | 0 The software output control forces 0 to the channel output. 1 The software output control forces 1 to the channel output. |
| 13 CH5OCV | Channel 5 Software Output Control Value 0 The software output control forces 0 to the channel output. 1 The software output control forces 1 to the channel output. |
| 12 CH4OCV | Channel 4 Software Output Control Value 0 The software output control forces 0 to the channel output. 1 The software output control forces 1 to the channel output. |
| 11 CH3OCV | Channel 3 Software Output Control Value 0 The software output control forces 0 to the channel output. 1 The software output control forces 1 to the channel output. |
| 10 CH2OCV | Channel 2 Software Output Control Value 0 The software output control forces 0 to the channel output. 1 The software output control forces 1 to the channel output. |
| 9 CH1OCV | Channel 1 Software Output Control Value 0 The software output control forces 0 to the channel output. 1 The software output control forces 1 to the channel output. |
| 8 CH0OCV | Channel 0 Software Output Control Value 0 The software output control forces 0 to the channel output. 1 The software output control forces 1 to the channel output. |
| 7 CH7OC | Channel 7 Software Output Control Enable 0 The channel output is not affected by software output control. 1 The channel output is affected by software output control. |
| 6 CH6OC | Channel 6 Software Output Control Enable 0 The channel output is not affected by software output control. 1 The channel output is affected by software output control. |
| 5 CH5OC | Channel 5 Software Output Control Enable 0 The channel output is not affected by software output control. 1 The channel output is affected by software output control. |
| 4 CH4OC | Channel 4 Software Output Control Enable 0 The channel output is not affected by software output control. 1 The channel output is affected by software output control. |
| 3 CH3OC | Channel 3 Software Output Control Enable 0 The channel output is not affected by software output control. 1 The channel output is affected by software output control. |
| 2 CH2OC | Channel 2 Software Output Control Enable |

Table continues on the next page...

FTMx_SWOCTRL field descriptions (continued)

| Field | Description |
|------------|--|
| | 0 The channel output is not affected by software output control. 1 The channel output is affected by software output control. |
| 1 CH1OC | Channel 1 Software Output Control Enable 0 The channel output is not affected by software output control. 1 The channel output is affected by software output control. |
| 0 CH0OC | Channel 0 Software Output Control Enable 0 The channel output is not affected by software output control. 1 The channel output is affected by software output control. |

38.3.27 FTM PWM Load (FTMx_PWMLOAD)

Enables the loading of the MOD, CNTIN, C(n)V, and C(n+1)V registers with the values of their write buffers when the FTM counter changes from the MOD register value to its next value or when a channel (j) match occurs. A match occurs for the channel (j) when FTM counter = C(j)V.

Address: Base address + 98h offset

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|------|--------|--------|--------|--------|--------|--------|--------|--------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | 0 | CH7SEL | CH6SEL | CH5SEL | CH4SEL | CH3SEL | CH2SEL | CH1SEL | CH0SEL |
| W | | | | | | | | LDOK | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

FTMx_PWMLOAD field descriptions

| Field | Description |
|-------------------|---|
| 31–10 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 9 LDOK | Load Enable Enables the loading of the MOD, CNTIN, and CV registers with the values of their write buffers. 0 Loading updated values is disabled. 1 Loading updated values is enabled. |

Table continues on the next page...

FTMx_PWMLOAD field descriptions (continued)

| Field | Description |
|---------------|---|
| 8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 CH7SEL | Channel 7 Select 0 Do not include the channel in the matching process. 1 Include the channel in the matching process. |
| 6 CH6SEL | Channel 6 Select 0 Do not include the channel in the matching process. 1 Include the channel in the matching process. |
| 5 CH5SEL | Channel 5 Select 0 Do not include the channel in the matching process. 1 Include the channel in the matching process. |
| 4 CH4SEL | Channel 4 Select 0 Do not include the channel in the matching process. 1 Include the channel in the matching process. |
| 3 CH3SEL | Channel 3 Select 0 Do not include the channel in the matching process. 1 Include the channel in the matching process. |
| 2 CH2SEL | Channel 2 Select 0 Do not include the channel in the matching process. 1 Include the channel in the matching process. |
| 1 CH1SEL | Channel 1 Select 0 Do not include the channel in the matching process. 1 Include the channel in the matching process. |
| 0 CH0SEL | Channel 0 Select 0 Do not include the channel in the matching process. 1 Include the channel in the matching process. |

38.4 Functional description

The notation used in this document to represent the counters and the generation of the signals is shown in the following figure.

FTM counting is up.
Channel (n) is in high-true EPWM mode.
PS[2:0] = 001
CNTIN = 0x0000
MOD = 0x0004
CnV = 0x0002

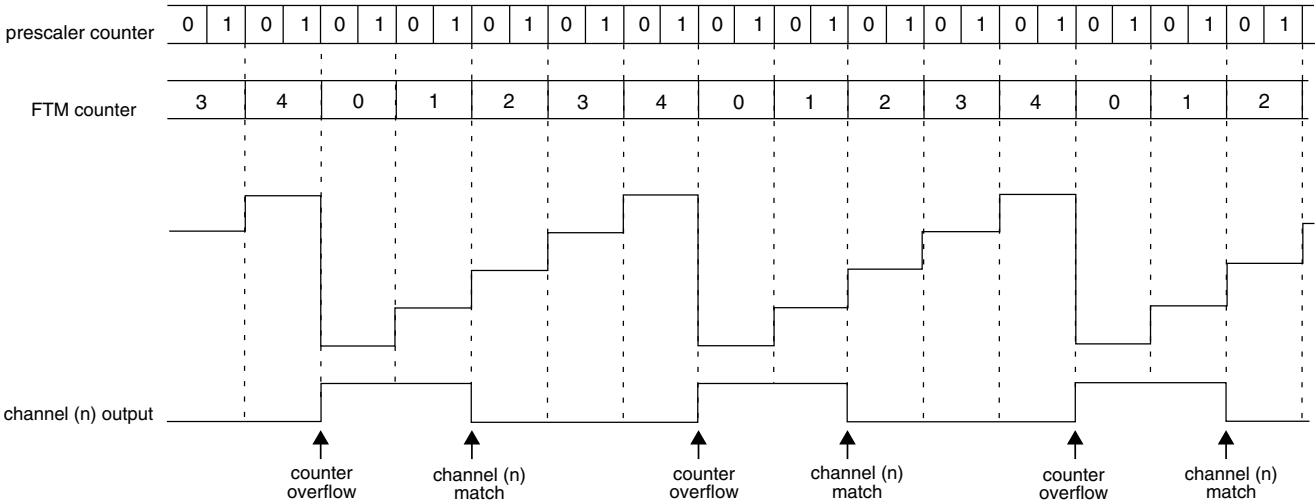


Figure 38-166. Notation used

38.4.1 Clock source

The FTM has only one clock domain: the system clock.

38.4.1.1 Counter clock source

The CLKS[1:0] bits in the SC register select one of three possible clock sources for the FTM counter or disable the FTM counter. After any MCU reset, CLKS[1:0] = 0:0 so no clock source is selected.

The CLKS[1:0] bits may be read or written at any time. Disabling the FTM counter by writing 0:0 to the CLKS[1:0] bits does not affect the FTM counter value or other registers.

The fixed frequency clock is an alternative clock source for the FTM counter that allows the selection of a clock other than the system clock or an external clock. This clock input is defined by chip integration. Refer to the chip specific documentation for further information. Due to FTM hardware implementation limitations, the frequency of the fixed frequency clock must not exceed 1/2 of the system clock frequency.

The external clock passes through a synchronizer clocked by the system clock to assure that counter transitions are properly aligned to system clock transitions. Therefore, to meet Nyquist criteria considering also jitter, the frequency of the external clock source must not exceed 1/4 of the system clock frequency.

38.4.2 Prescaler

The selected counter clock source passes through a prescaler that is a 7-bit counter. The value of the prescaler is selected by the PS[2:0] bits. The following figure shows an example of the prescaler counter and FTM counter.

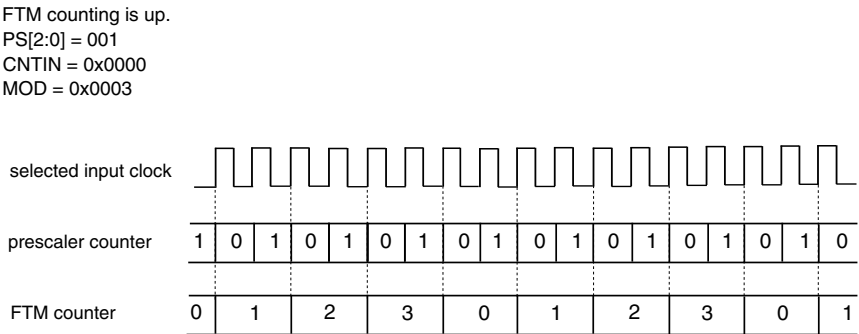


Figure 38-167. Example of the prescaler counter

38.4.3 Counter

The FTM has a 16-bit counter that is used by the channels either for input or output modes. The FTM counter clock is the selected clock divided by the prescaler.

The FTM counter has these modes of operation:

- [Up counting](#)
- [Up-down counting](#)
- [Quadrature Decoder mode](#)

38.4.3.1 Up counting

Up counting is selected when:

- QUADEN = 0, and
- CPWMS = 0

CNTIN defines the starting value of the count and MOD defines the final value of the count, see the following figure. The value of CNTIN is loaded into the FTM counter, and the counter increments until the value of MOD is reached, at which point the counter is reloaded with the value of CNTIN.

The FTM period when using up counting is $(MOD - CNTIN + 0x0001) \times \text{period of the FTM counter clock}$.

The TOF bit is set when the FTM counter changes from MOD to CNTIN.

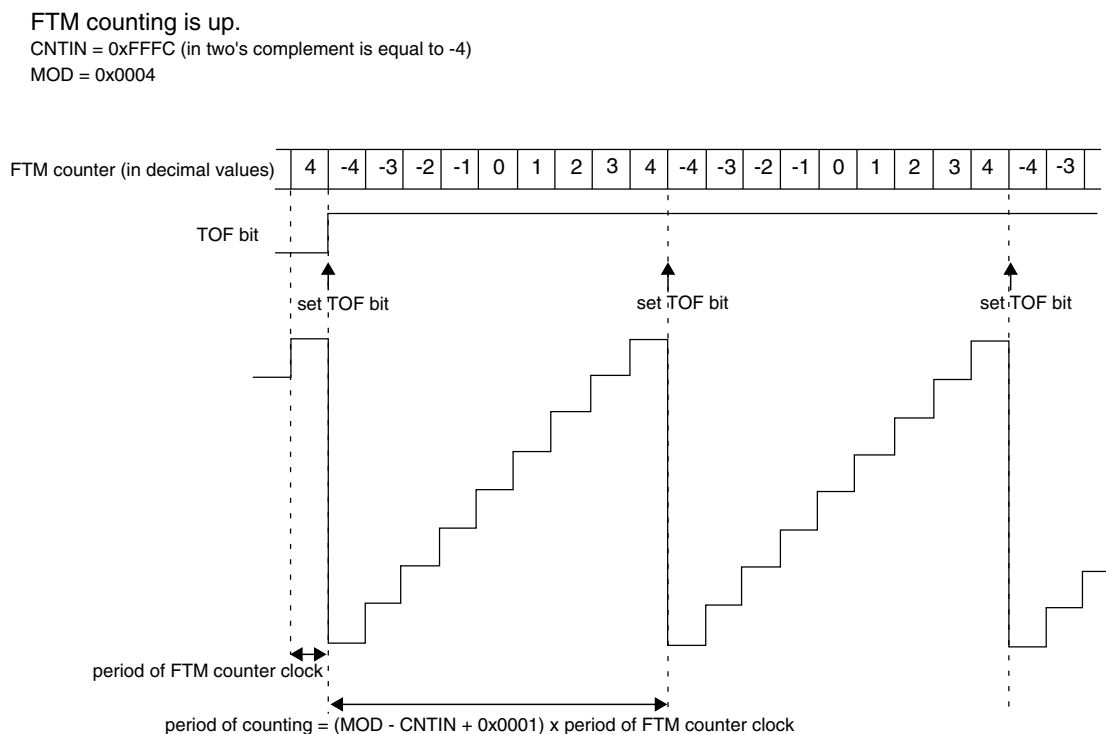


Figure 38-168. Example of FTM up and signed counting

Table 38-242. FTM counting based on CNTIN value

| When | Then |
|---------------------------------------|--|
| CNTIN = 0x0000 | The FTM counting is equivalent to TPM up counting, that is, up and unsigned counting. See the following figure. |
| CNTIN[15] = 1 | The initial value of the FTM counter is a negative number in two's complement, so the FTM counting is up and signed. |
| CNTIN[15] = 0 and CNTIN \neq 0x0000 | The initial value of the FTM counter is a positive number, so the FTM counting is up and unsigned. |

functional description

FTM counting is up

CNTIN = 0x0000

MOD = 0x0004

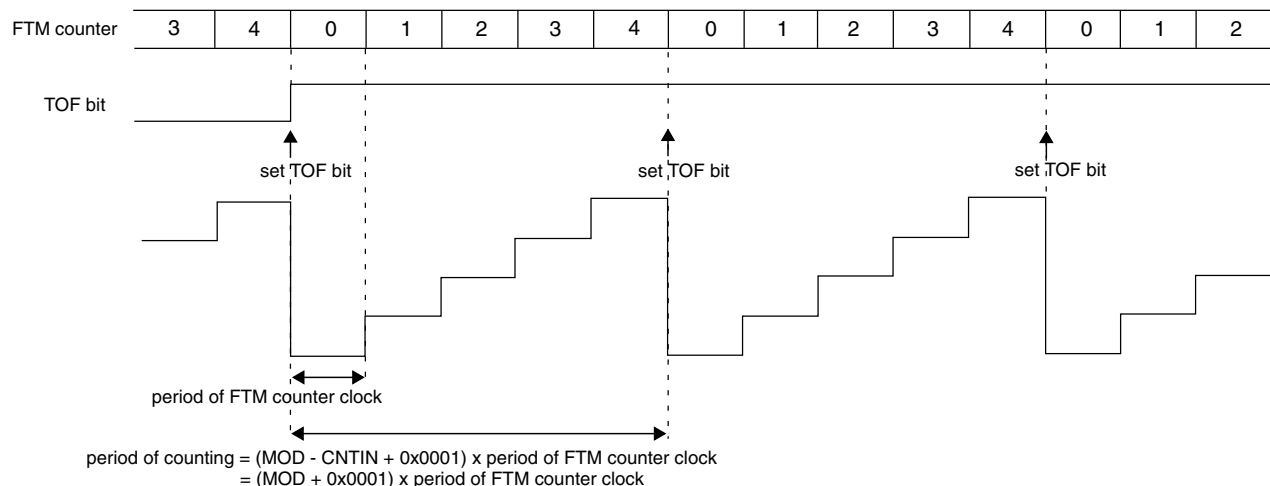


Figure 38-169. Example of FTM up counting with CNTIN = 0x0000

Note

- FTM operation is only valid when the value of the CNTIN register is less than the value of the MOD register, either in the unsigned counting or signed counting. It is the responsibility of the software to ensure that the values in the CNTIN and MOD registers meet this requirement. Any values of CNTIN and MOD that do not satisfy this criteria can result in unpredictable behavior.
- MOD = CNTIN is a redundant condition. In this case, the FTM counter is always equal to MOD and the TOF bit is set in each rising edge of the FTM counter clock.
- When MOD = 0x0000, CNTIN = 0x0000, for example after reset, and FTMMEN = 1, the FTM counter remains stopped at 0x0000 until a non-zero value is written into the MOD or CNTIN registers.
- Setting CNTIN to be greater than the value of MOD is not recommended as this unusual setting may make the FTM operation difficult to comprehend. However, there is no restriction on this configuration, and an example is shown in the following figure.

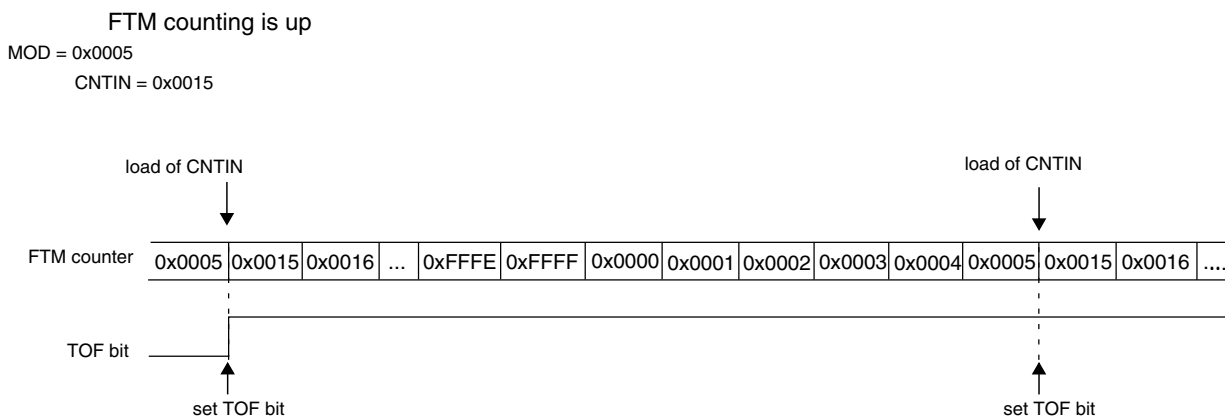


Figure 38-170. Example of up counting when the value of CNTIN is greater than the value of MOD

38.4.3.2 Up-down counting

Up-down counting is selected when:

- QUADEN = 0, and
- CPWMS = 1

CNTIN defines the starting value of the count and MOD defines the final value of the count. The value of CNTIN is loaded into the FTM counter, and the counter increments until the value of MOD is reached, at which point the counter is decremented until it returns to the value of CNTIN and the up-down counting restarts.

The FTM period when using up-down counting is $2 \times (\text{MOD} - \text{CNTIN}) \times \text{period of the FTM counter clock}$.

The TOF bit is set when the FTM counter changes from MOD to (MOD – 1).

If (CNTIN = 0x0000), the FTM counting is equivalent to TPM up-down counting, that is, up-down and unsigned counting. See the following figure.

functional description

FTM counting is up-down
 CNTIN = 0x0000
 MOD = 0x0004

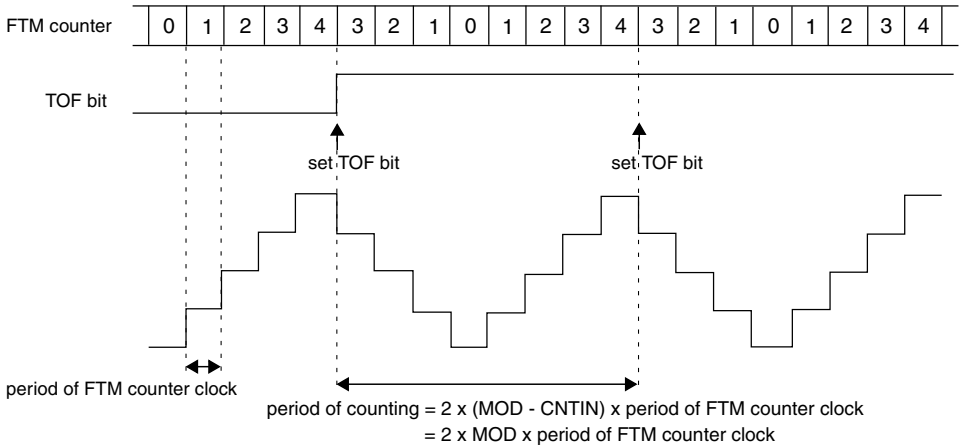


Figure 38-171. Example of up-down counting when CNTIN = 0x0000

Note

When CNTIN is different from zero in the up-down counting, a valid CPWM signal is generated:

- if $\text{CnV} > \text{CNTIN}$, or
- if $\text{CnV} = 0$ or if $\text{CnV}[15] = 1$. In this case, 0% CPWM is generated.

38.4.3.3 Free running counter

If (FTMEN = 0) and (MOD = 0x0000 or MOD = 0xFFFF), the FTM counter is a free running counter. In this case, the FTM counter runs free from 0x0000 through 0xFFFF and the TOF bit is set when the FTM counter changes from 0xFFFF to 0x0000. See the following figure.

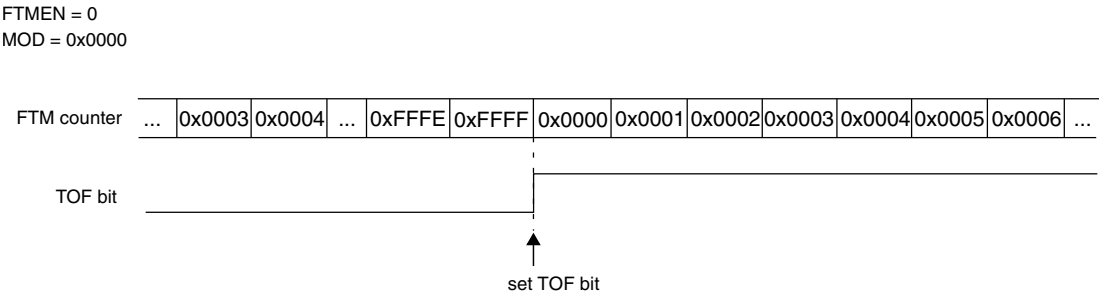


Figure 38-172. Example when the FTM counter is free running

The FTM counter is also a free running counter when:

- $FTMEN = 1$
- $QUADEN = 0$
- $CPWMS = 0$
- $CNTIN = 0x0000$, and
- $MOD = 0xFFFF$

38.4.3.4 Counter reset

Any one of the following cases resets the FTM counter to the value in the CNTIN register and the channels output to its initial value, except for channels in Output Compare mode.

- Any write to CNT.
- [FTM counter synchronization](#).

38.4.3.5 When the TOF bit is set

The NUMTOF[4:0] bits define the number of times that the FTM counter overflow should occur before the TOF bit to be set. If NUMTOF[4:0] = 0x00, then the TOF bit is set at each FTM counter overflow.

Initialize the FTM counter, by writing to CNT, after writing to the NUMTOF[4:0] bits to avoid confusion about when the first counter overflow will occur.

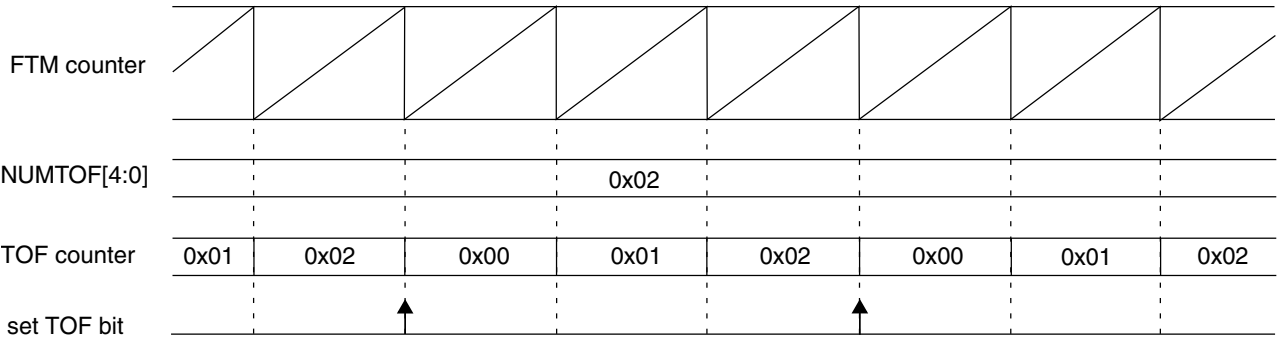


Figure 38-173. Periodic TOF when NUMTOF = 0x02

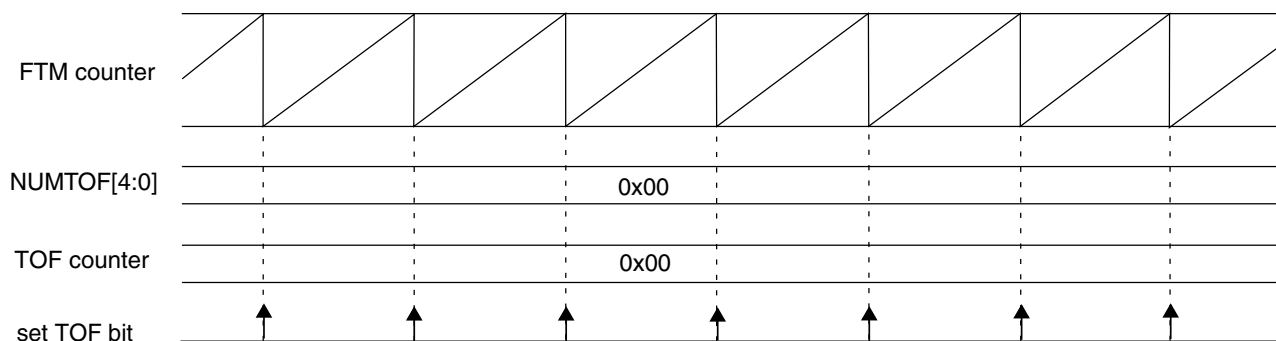


Figure 38-174. Periodic TOF when NUMTOF = 0x00

38.4.4 Input Capture mode

The Input Capture mode is selected when:

- DECAPEN = 0
- COMBINE = 0
- CPWMS = 0
- MSnB:MSnA = 0:0, and
- ELSnB:ELSnA ≠ 0:0

When a selected edge occurs on the channel input, the current value of the FTM counter is captured into the CnV register, at the same time the CHnF bit is set and the channel interrupt is generated if enabled by CHnIE = 1. See the following figure.

When a channel is configured for input capture, the FTMxCHn pin is an edge-sensitive input. ELSnB:ELSnA control bits determine which edge, falling or rising, triggers input-capture event. Note that the maximum frequency for the channel input signal to be detected correctly is system clock divided by 4, which is required to meet Nyquist criteria for signal sampling.

Writes to the CnV register is ignored in Input Capture mode.

While in BDM, the input capture function works as configured. When a selected edge event occurs, the FTM counter value, which is frozen because of BDM, is captured into the CnV register and the CHnF bit is set.

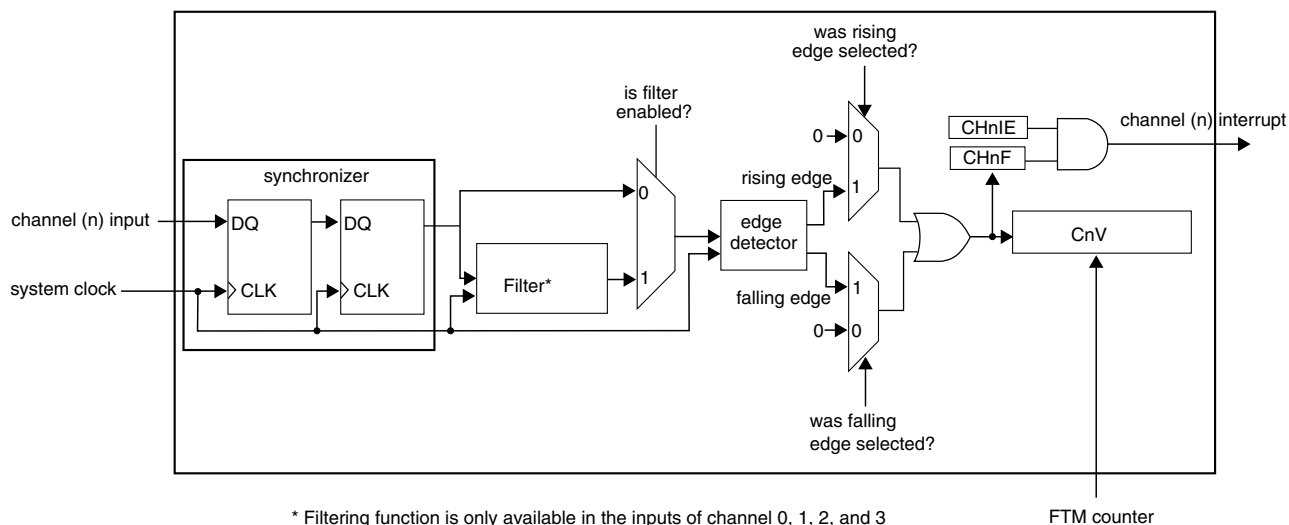


Figure 38-175. Input Capture mode

If the channel input does not have a filter enabled, then the input signal is always delayed 3 rising edges of the system clock, that is, two rising edges to the synchronizer plus one more rising edge to the edge detector. In other words, the CHnF bit is set on the third rising edge of the system clock after a valid edge occurs on the channel input.

38.4.4.1 Filter for Input Capture mode

The filter function is only available on channels 0, 1, 2, and 3.

First, the input signal is synchronized by the system clock. Following synchronization, the input signal enters the filter block. See the following figure.

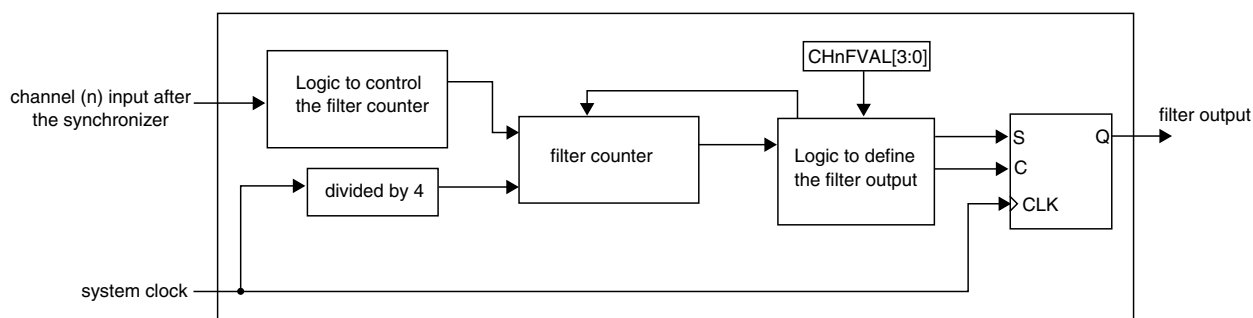


Figure 38-176. Channel input filter

When there is a state change in the input signal, the counter is reset and starts counting up. As long as the new state is stable on the input, the counter continues to increment. When the counter is equal to CHnFVAL[3:0], the state change of the input signal is validated. It is then transmitted as a pulse edge to the edge detector.

If the opposite edge appears on the input signal before it can be validated, the counter is reset. At the next input transition, the counter starts counting again. Any pulse that is shorter than the minimum value selected by CHnFVAL[3:0] ($\times 4$ system clocks) is regarded as a glitch and is not passed on to the edge detector. A timing diagram of the input filter is shown in the following figure.

The filter function is disabled when CHnFVAL[3:0] bits are zero. In this case, the input signal is delayed 3 rising edges of the system clock. If (CHnFVAL[3:0] \neq 0000), then the input signal is delayed by the minimum pulse width (CHnFVAL[3:0] $\times 4$ system clocks) plus a further 4 rising edges of the system clock: two rising edges to the synchronizer, one rising edge to the filter output, plus one more to the edge detector. In other words, CHnF is set $(4 + 4 \times \text{CHnFVAL}[3:0])$ system clock periods after a valid edge occurs on the channel input.

The clock for the counter in the channel input filter is the system clock divided by 4.

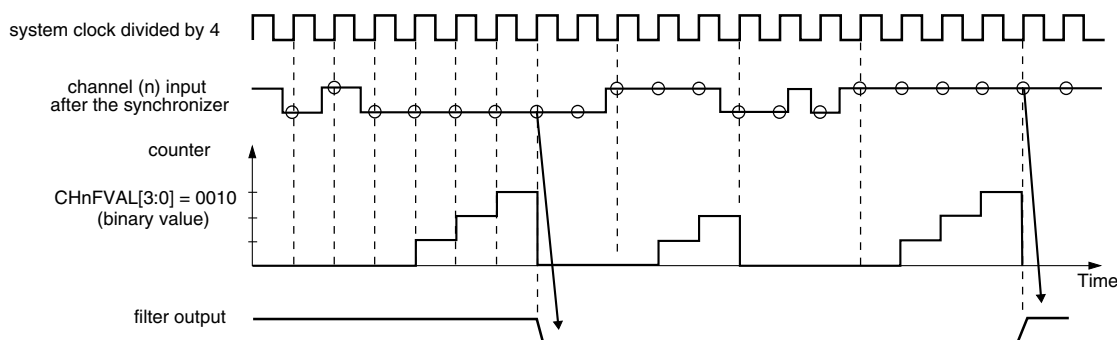


Figure 38-177. Channel input filter example

38.4.5 Output Compare mode

The Output Compare mode is selected when:

- DECAPEN = 0
- COMBINE = 0
- CPWMS = 0, and
- MSnB:MSnA = 0:1

In Output Compare mode, the FTM can generate timed pulses with programmable position, polarity, duration, and frequency. When the counter matches the value in the CnV register of an output compare channel, the channel (n) output can be set, cleared, or toggled.

When a channel is initially configured to Toggle mode, the previous value of the channel output is held until the first output compare event occurs.

The CHnF bit is set and the channel (n) interrupt is generated if CHnIE = 1 at the channel (n) match (FTM counter = CnV).

MOD = 0x0005
CnV = 0x0003

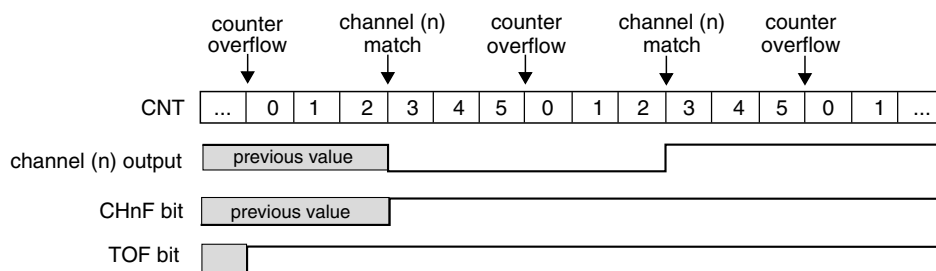


Figure 38-178. Example of the Output Compare mode when the match toggles the channel output

MOD = 0x0005
CnV = 0x0003

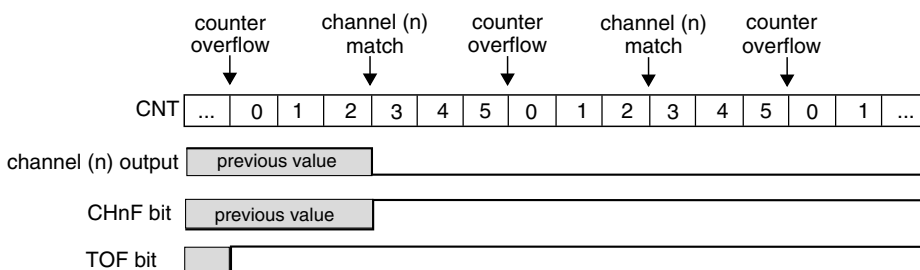


Figure 38-179. Example of the Output Compare mode when the match clears the channel output

MOD = 0x0005
CnV = 0x0003

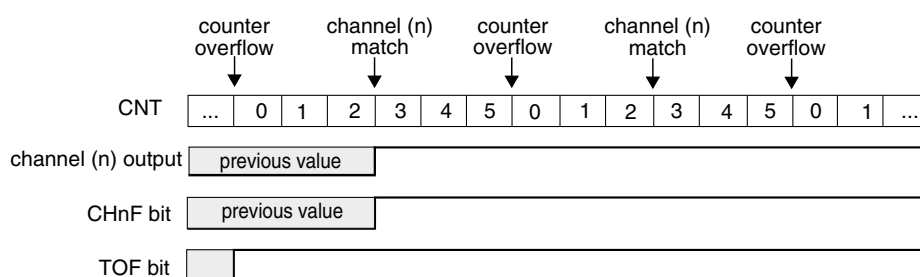


Figure 38-180. Example of the Output Compare mode when the match sets the channel output

If (ELSnB:ELSnA = 0:0) when the counter reaches the value in the CnV register, the CHnF bit is set and the channel (n) interrupt is generated if CHnIE = 1, however the channel (n) output is not modified and controlled by FTM.

38.4.6 Edge-Aligned PWM (EPWM) mode

The Edge-Aligned mode is selected when:

- QUADEN = 0
- DECAPEN = 0
- COMBINE = 0
- CPWMS = 0, and
- MSnB = 1

The EPWM period is determined by $(MOD - CNTIN + 0x0001)$ and the pulse width (duty cycle) is determined by $(CnV - CNTIN)$.

The CHnF bit is set and the channel (n) interrupt is generated if CHnIE = 1 at the channel (n) match (FTM counter = CnV), that is, at the end of the pulse width.

This type of PWM signal is called edge-aligned because the leading edges of all PWM signals are aligned with the beginning of the period, which is the same for all channels within an FTM.

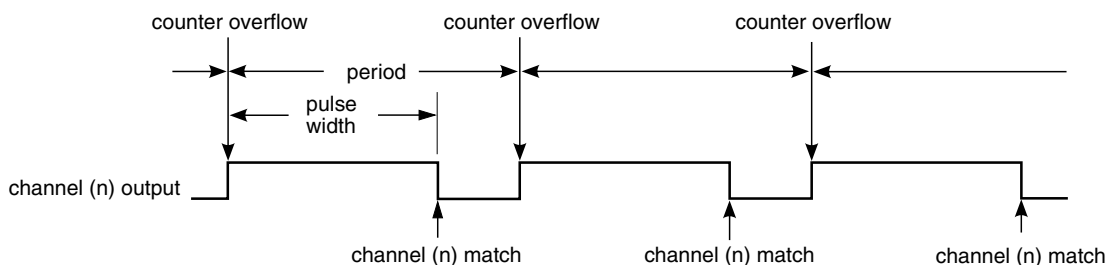


Figure 38-181. EPWM period and pulse width with ELSnB:ELSnA = 1:0

If (ELSnB:ELSnA = 0:0) when the counter reaches the value in the CnV register, the CHnF bit is set and the channel (n) interrupt is generated if CHnIE = 1, however the channel (n) output is not controlled by FTM.

If (ELSnB:ELSnA = 1:0), then the channel (n) output is forced high at the counter overflow when the CNTIN register value is loaded into the FTM counter, and it is forced low at the channel (n) match (FTM counter = CnV). See the following figure.

MOD = 0x0008
CnV = 0x0005

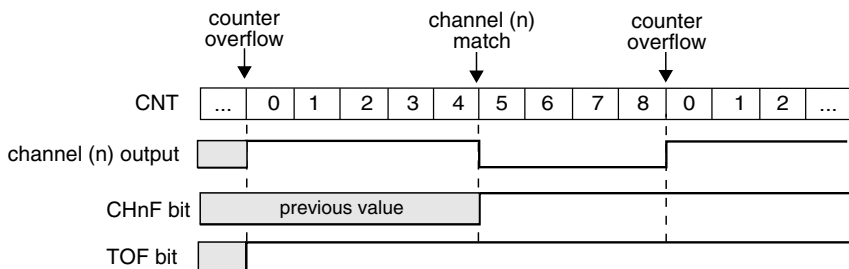


Figure 38-182. EPWM signal with ELSnB:ELSnA = 1:0

If (ELSnB:ELSnA = X:1), then the channel (n) output is forced low at the counter overflow when the CNTIN register value is loaded into the FTM counter, and it is forced high at the channel (n) match (FTM counter = CnV). See the following figure.

MOD = 0x0008
CnV = 0x0005

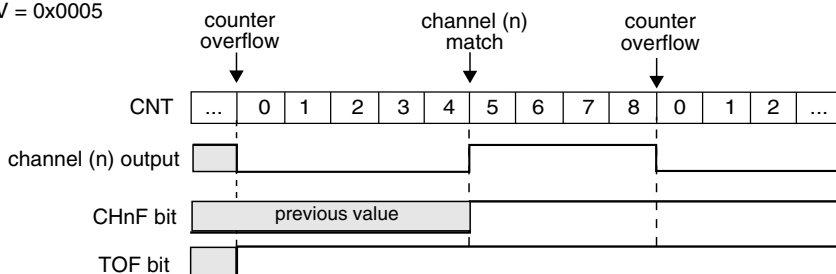


Figure 38-183. EPWM signal with ELSnB:ELSnA = X:1

If (CnV = 0x0000), then the channel (n) output is a 0% duty cycle EPWM signal and CHnF bit is not set even when there is the channel (n) match. If (CnV > MOD), then the channel (n) output is a 100% duty cycle EPWM signal and CHnF bit is not set even when there is the channel (n) match. Therefore, MOD must be less than 0xFFFF in order to get a 100% duty cycle EPWM signal.

Note

When CNTIN is different from zero the following EPWM signals can be generated:

- 0% EPWM signal if CnV = CNTIN,
- EPWM signal between 0% and 100% if $CNTIN < CnV \leq MOD$,
- 100% EPWM signal when $CNTIN > CnV$ or $CnV > MOD$.

38.4.7 Center-Aligned PWM (CPWM) mode

The Center-Aligned mode is selected when:

functional description

- QUADEN = 0
- DECAPEN = 0
- COMBINE = 0, and
- CPWMS = 1

The CPWM pulse width (duty cycle) is determined by $2 \times (\text{CnV} - \text{CNTIN})$ and the period is determined by $2 \times (\text{MOD} - \text{CNTIN})$. See the following figure. MOD must be kept in the range of 0x0001 to 0x7FFF because values outside this range can produce ambiguous results.

In the CPWM mode, the FTM counter counts up until it reaches MOD and then counts down until it reaches CNTIN.

The CHnF bit is set and channel (n) interrupt is generated (if CHnIE = 1) at the channel (n) match (FTM counter = CnV) when the FTM counting is down (at the begin of the pulse width) and when the FTM counting is up (at the end of the pulse width).

This type of PWM signal is called center-aligned because the pulse width centers for all channels are aligned with the value of CNTIN.

The other channel modes are not compatible with the up-down counter (CPWMS = 1). Therefore, all FTM channels must be used in CPWM mode when (CPWMS = 1).

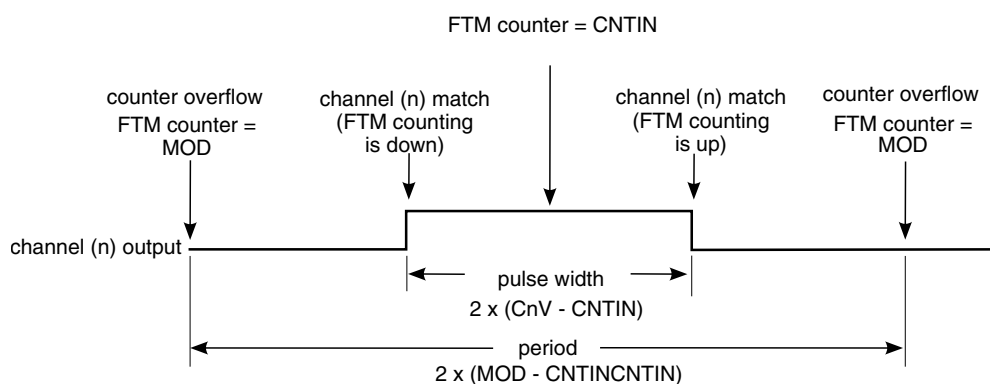


Figure 38-184. CPWM period and pulse width with ELSnB:ELSnA = 1:0

If (ELSnB:ELSnA = 0:0) when the FTM counter reaches the value in the CnV register, the CHnF bit is set and the channel (n) interrupt is generated (if CHnIE = 1), however the channel (n) output is not controlled by FTM.

If (ELSnB:ELSnA = 1:0), then the channel (n) output is forced high at the channel (n) match (FTM counter = CnV) when counting down, and it is forced low at the channel (n) match when counting up. See the following figure.

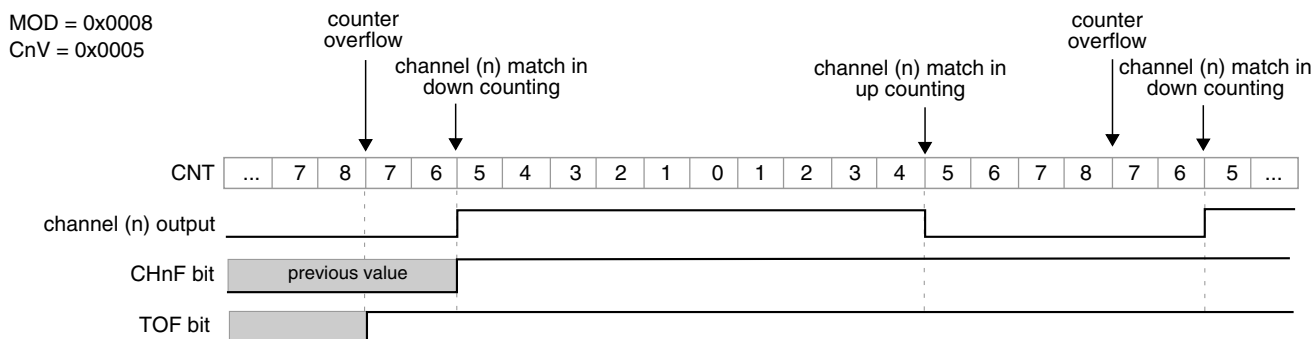


Figure 38-185. CPWM signal with ELSnB:ELSnA = 1:0

If (ELSnB:ELSnA = X:1), then the channel (n) output is forced low at the channel (n) match (FTM counter = CnV) when counting down, and it is forced high at the channel (n) match when counting up. See the following figure.

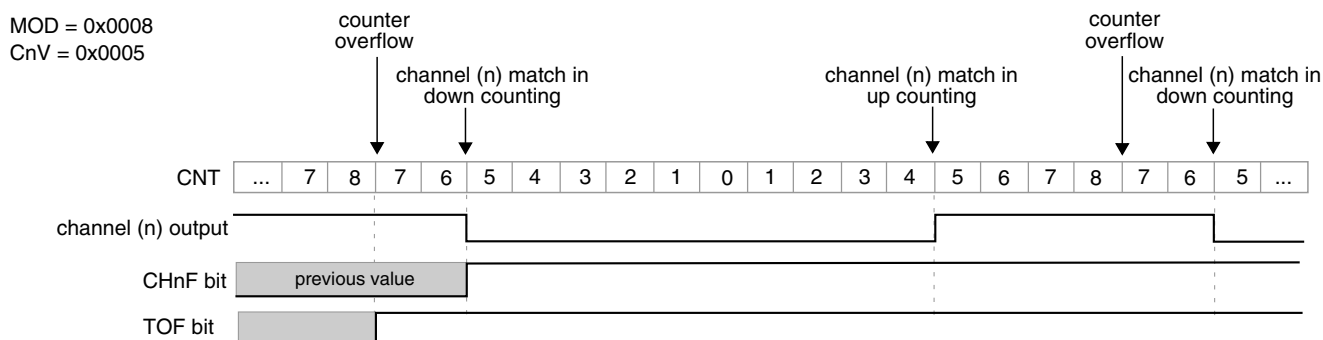


Figure 38-186. CPWM signal with ELSnB:ELSnA = X:1

If (CnV = 0x0000) or CnV is a negative value, that is (CnV[15] = 1), then the channel (n) output is a 0% duty cycle CPWM signal and CHnF bit is not set even when there is the channel (n) match.

If CnV is a positive value, that is (CnV[15] = 0), (CnV ≥ MOD), and (MOD ≠ 0x0000), then the channel (n) output is a 100% duty cycle CPWM signal and CHnF bit is not set even when there is the channel (n) match. This implies that the usable range of periods set by MOD is 0x0001 through 0x7FFE, 0x7FFF if you do not need to generate a 100% duty cycle CPWM signal. This is not a significant limitation because the resulting period is much longer than required for normal applications.

The CPWM mode must not be used when the FTM counter is a free running counter.

38.4.8 Combine mode

The Combine mode is selected when:

- QUADEN = 0

functional description

- $DECAPEN = 0$
- $COMBINE = 1$, and
- $CPWMS = 0$

In Combine mode, an even channel (n) and adjacent odd channel (n+1) are combined to generate a PWM signal in the channel (n) output.

In the Combine mode, the PWM period is determined by $(MOD - CNTIN + 0x0001)$ and the PWM pulse width (duty cycle) is determined by $(IC(n+1)V - C(n)V)$.

The $CHnF$ bit is set and the channel (n) interrupt is generated (if $CHnIE = 1$) at the channel (n) match (FTM counter = $C(n)V$). The $CH(n+1)F$ bit is set and the channel (n+1) interrupt is generated, if $CH(n+1)IE = 1$, at the channel (n+1) match (FTM counter = $C(n+1)V$).

If $(ELSnB:ELSnA = 1:0)$, then the channel (n) output is forced low at the beginning of the period (FTM counter = $CNTIN$) and at the channel (n+1) match (FTM counter = $C(n+1)V$). It is forced high at the channel (n) match (FTM counter = $C(n)V$). See the following figure.

If $(ELSnB:ELSnA = X:1)$, then the channel (n) output is forced high at the beginning of the period (FTM counter = $CNTIN$) and at the channel (n+1) match (FTM counter = $C(n+1)V$). It is forced low at the channel (n) match (FTM counter = $C(n)V$). See the following figure.

In Combine mode, the $ELS(n+1)B$ and $ELS(n+1)A$ bits are not used in the generation of the channels (n) and (n+1) output. However, if $(ELSnB:ELSnA = 0:0)$ then the channel (n) output is not controlled by FTM, and if $(ELS(n+1)B:ELS(n+1)A = 0:0)$ then the channel (n+1) output is not controlled by FTM.

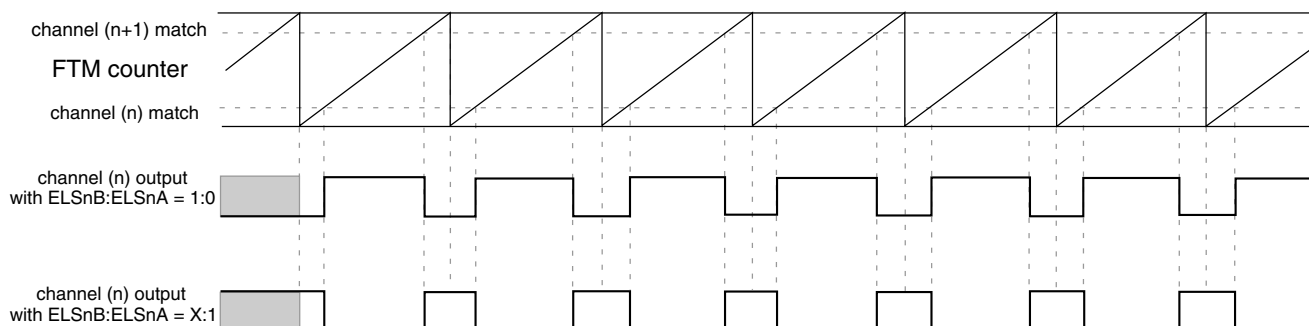


Figure 38-187. Combine mode

The following figures illustrate the PWM signals generation using Combine mode.

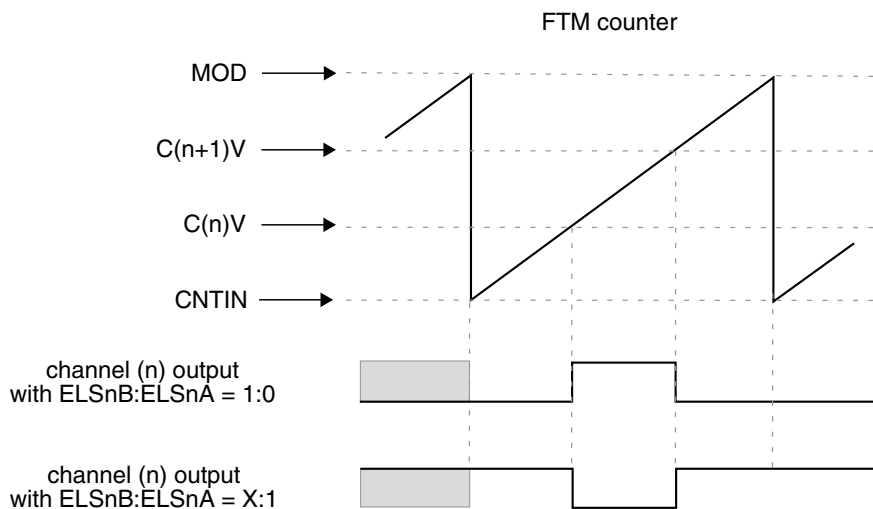


Figure 38-188. Channel (n) output if $(CNTIN < C(n)V < MOD)$ and $(CNTIN < C(n+1)V < MOD)$ and $(C(n)V < C(n+1)V)$

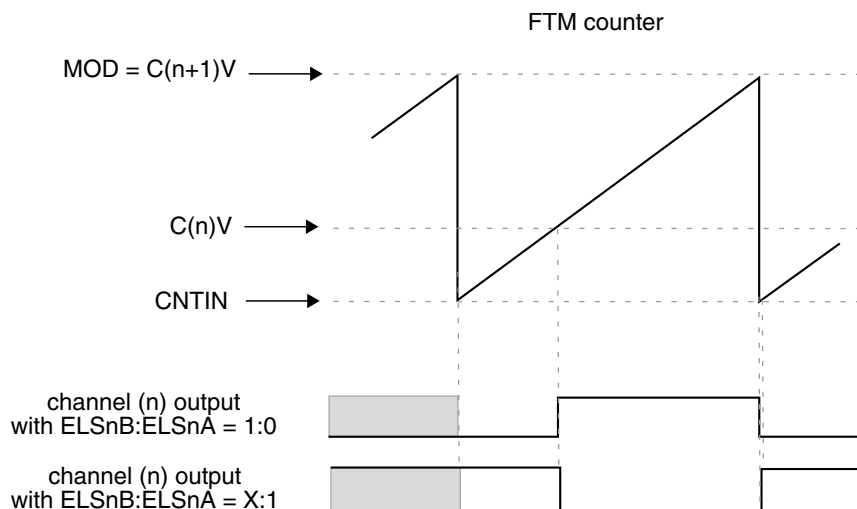


Figure 38-189. Channel (n) output if $(CNTIN < C(n)V < MOD)$ and $(C(n+1)V = MOD)$

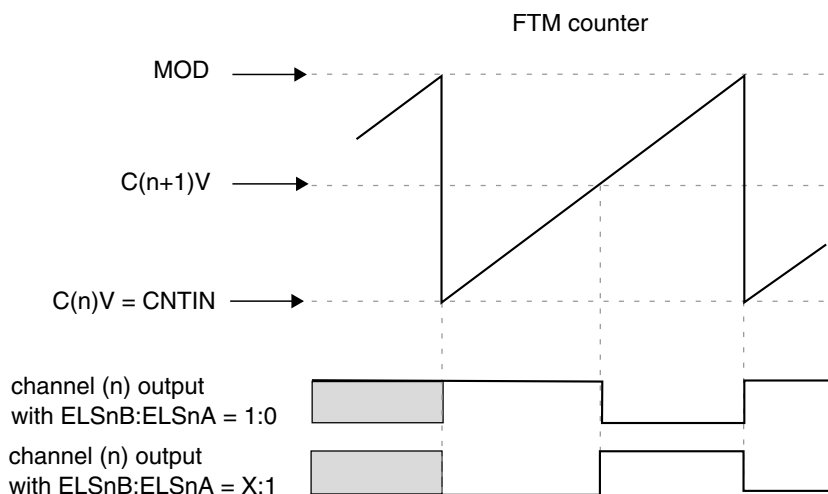


Figure 38-190. Channel (n) output if $(C(n)V = CNTIN)$ and $(CNTIN < C(n+1)V < MOD)$

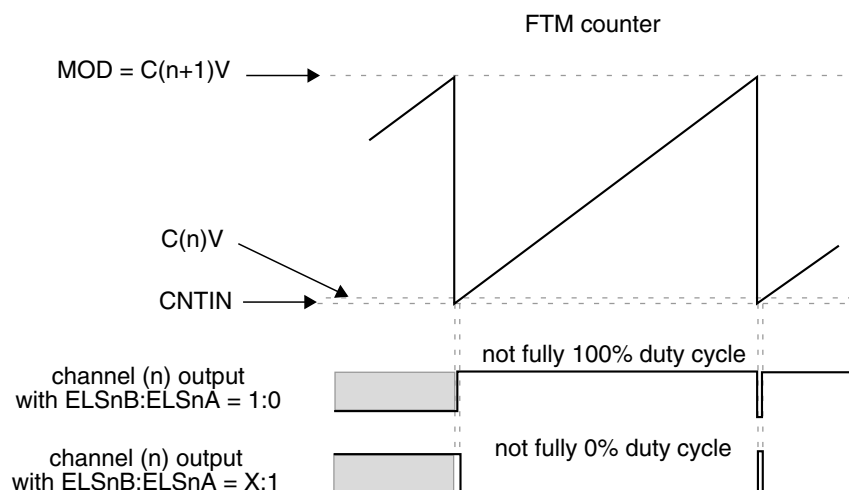


Figure 38-191. Channel (n) output if $(CNTIN < C(n)V < MOD)$ and $(C(n)V$ is Almost Equal to $CNTIN$) and $(C(n+1)V = MOD)$

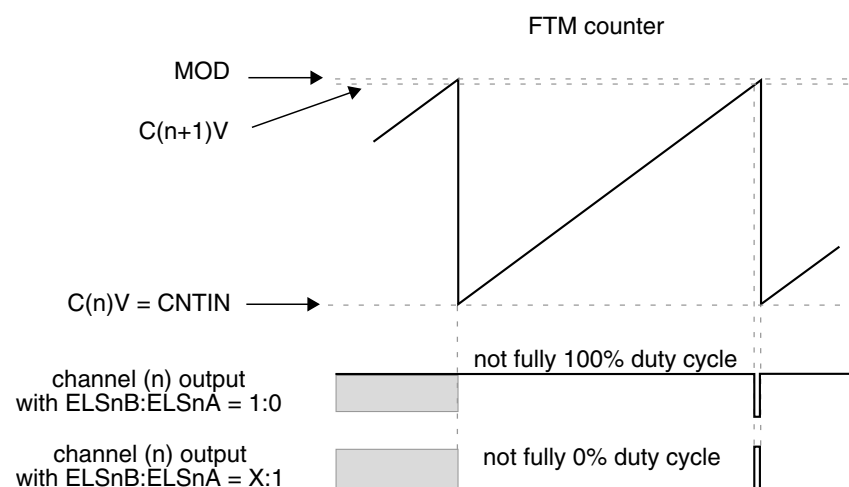


Figure 38-192. Channel (n) output if $(C(n)V = CNTIN)$ and $(CNTIN < C(n+1)V < MOD)$ and $(C(n+1)V$ is Almost Equal to MOD)

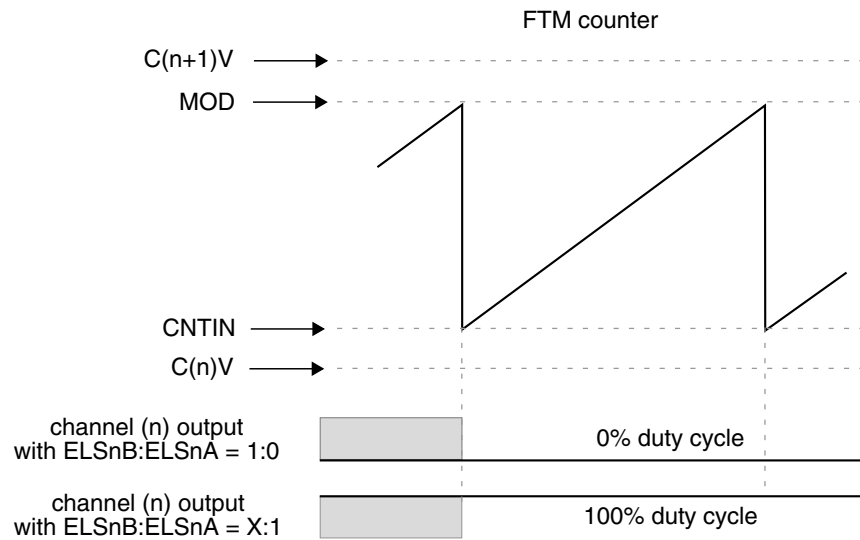


Figure 38-193. Channel (n) output if $C(n)V$ and $C(n+1)V$ are not between CNTIN and MOD

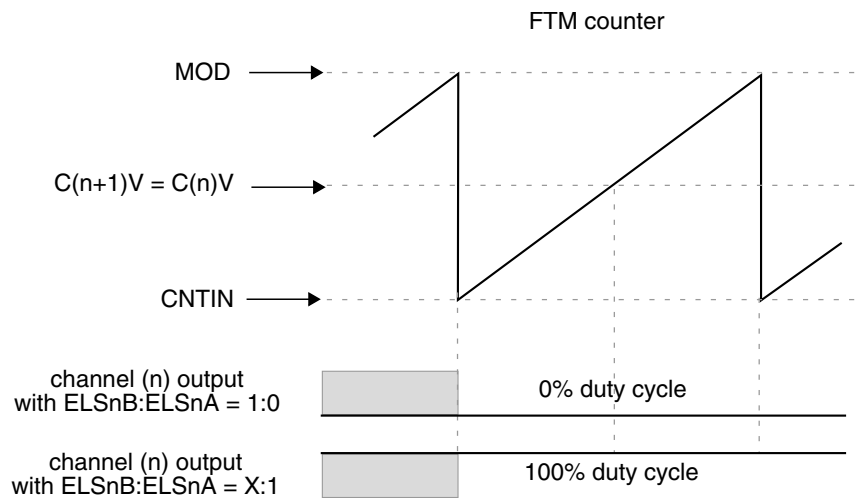


Figure 38-194. Channel (n) output if $(CNTIN < C(n)V < MOD)$ and $(CNTIN < C(n+1)V < MOD)$ and $(C(n)V = C(n+1)V)$

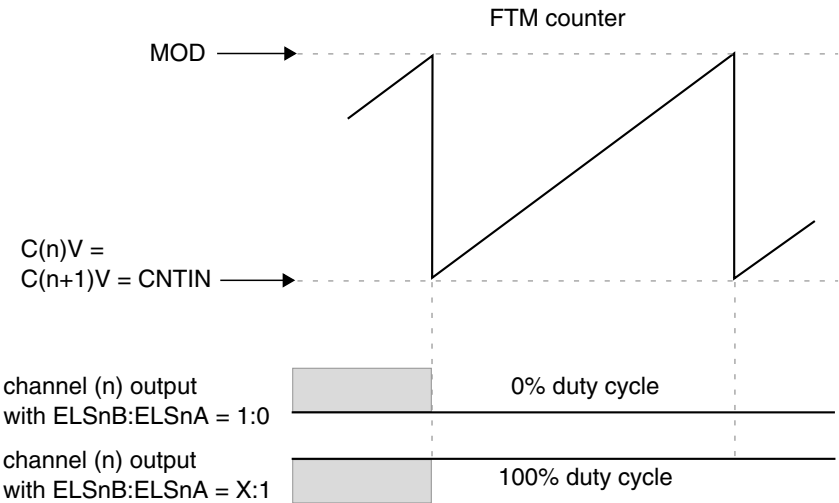


Figure 38-195. Channel (n) output if $(C(n)V = C(n+1)V = \text{CNTIN})$

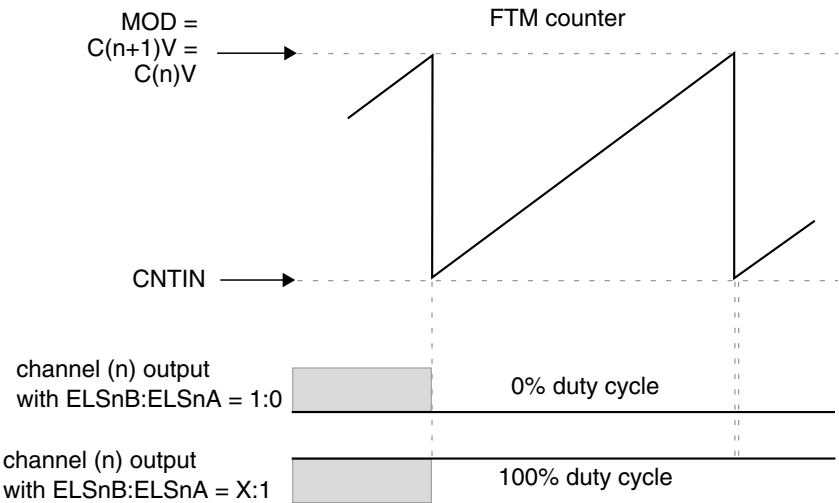


Figure 38-196. Channel (n) output if $(C(n)V = C(n+1)V = \text{MOD})$

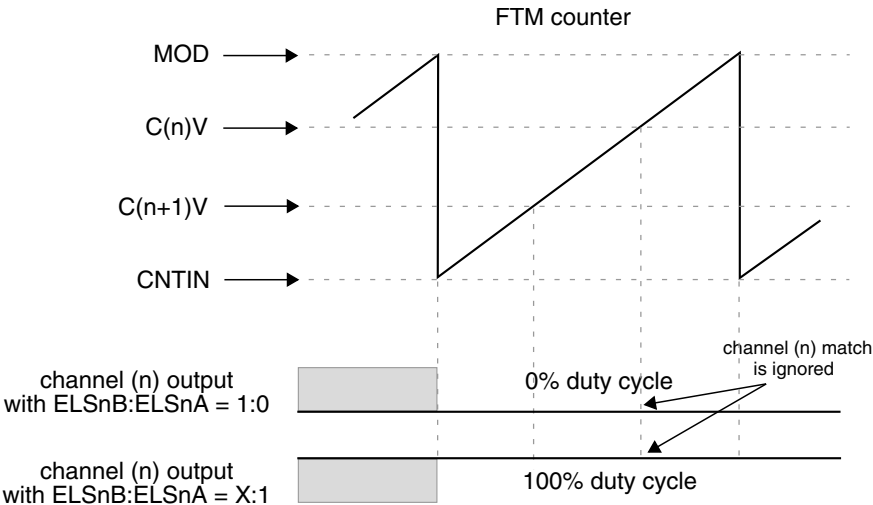


Figure 38-197. Channel (n) output if $(\text{CNTIN} < C(n)V < \text{MOD})$ and $(\text{CNTIN} < C(n+1)V < \text{MOD})$ and $(C(n)V > C(n+1)V)$

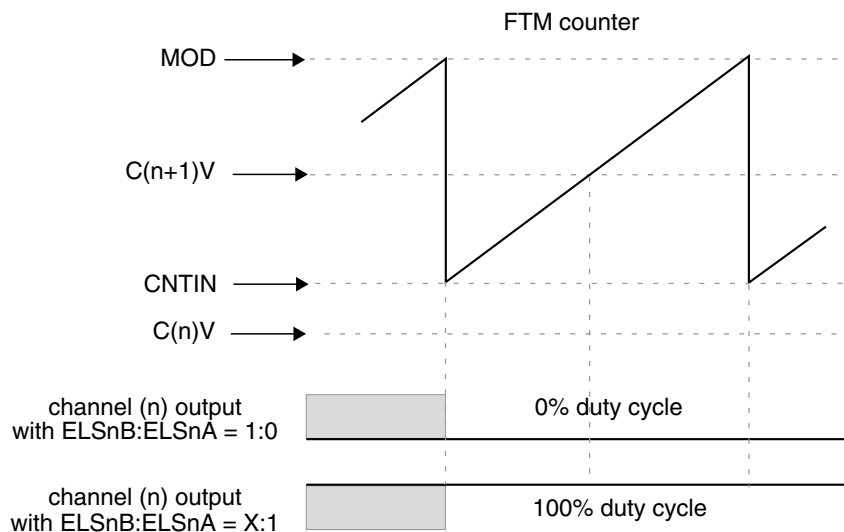


Figure 38-198. Channel (n) output if $(C(n)V < CNTIN)$ and $(CNTIN < C(n+1)V < MOD)$

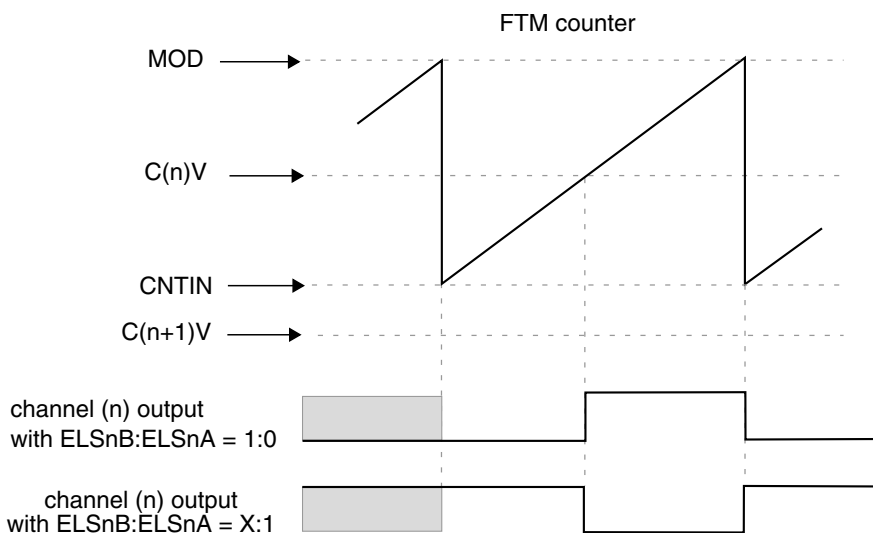


Figure 38-199. Channel (n) output if $(C(n+1)V < CNTIN)$ and $(CNTIN < C(n)V < MOD)$

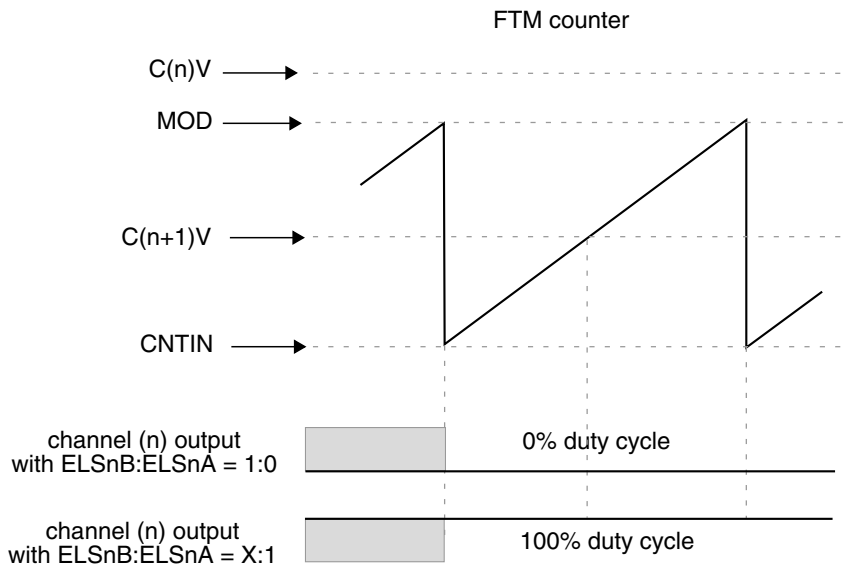


Figure 38-200. Channel (n) output if $(C(n)V > MOD)$ and $(CNTIN < C(n+1)V < MOD)$

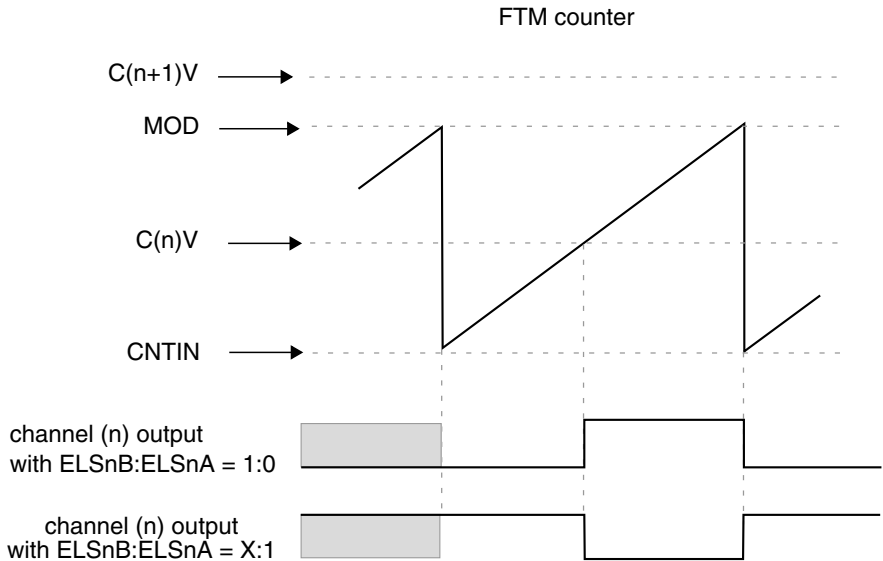


Figure 38-201. Channel (n) output if $(C(n+1)V > MOD)$ and $(CNTIN < C(n)V < MOD)$

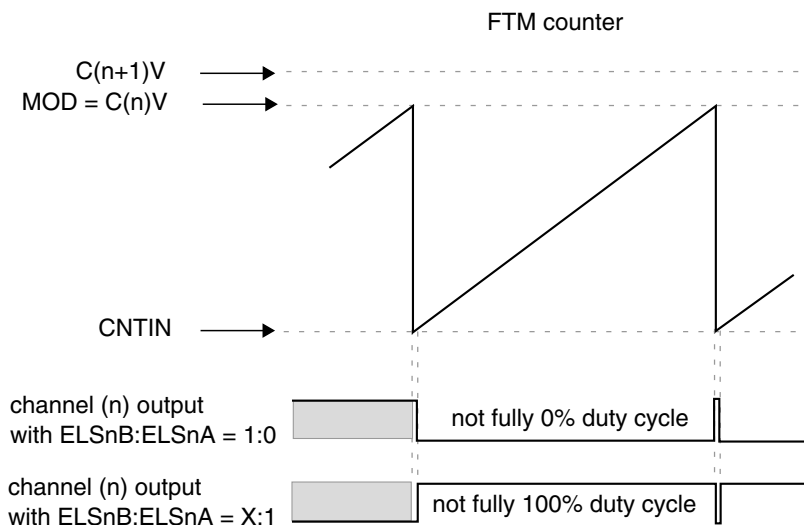


Figure 38-202. Channel (n) output if $(C(n+1)V > MOD$ and $(CNTIN < C(n)V = MOD$)

38.4.8.1 Asymmetrical PWM

In Combine mode, the control of the PWM signal first edge, when the channel (n) match occurs, that is, FTM counter = $C(n)V$, is independent of the control of the PWM signal second edge, when the channel (n+1) match occurs, that is, FTM counter = $C(n+1)V$. So, Combine mode allows the generation of asymmetrical PWM signals.

38.4.9 Complementary mode

The Complementary mode is selected when:

- $QUADEN = 0$
- $DECAPEN = 0$
- $COMP = 1$

In Complementary mode, the channel (n+1) output is the inverse of the channel (n) output.

So, the channel (n+1) output is the same as the channel (n) output when:

- $QUADEN = 0$
- $DECAPEN = 0$
- $COMP = 0$

functional description

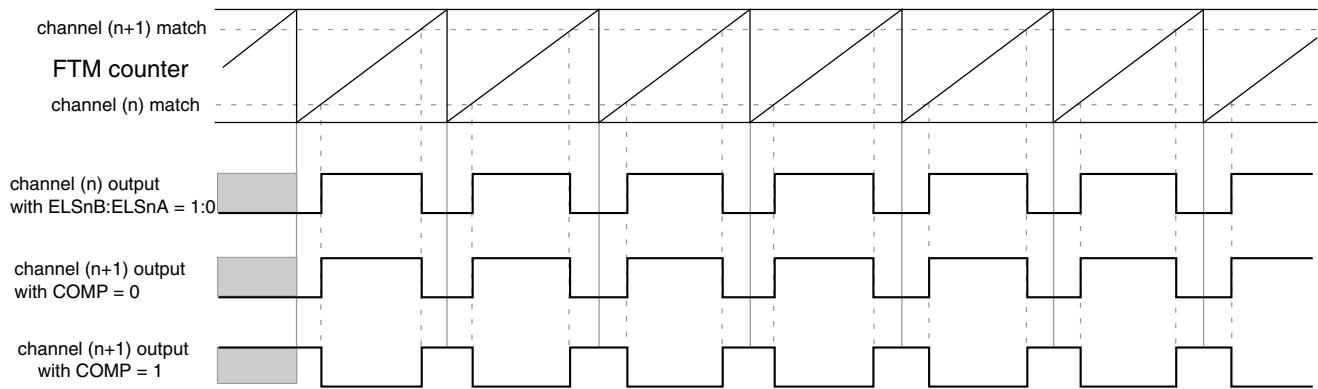


Figure 38-203. Channel (n+1) output in Complementary mode with $(ELSnB:ELSnA = 1:0)$

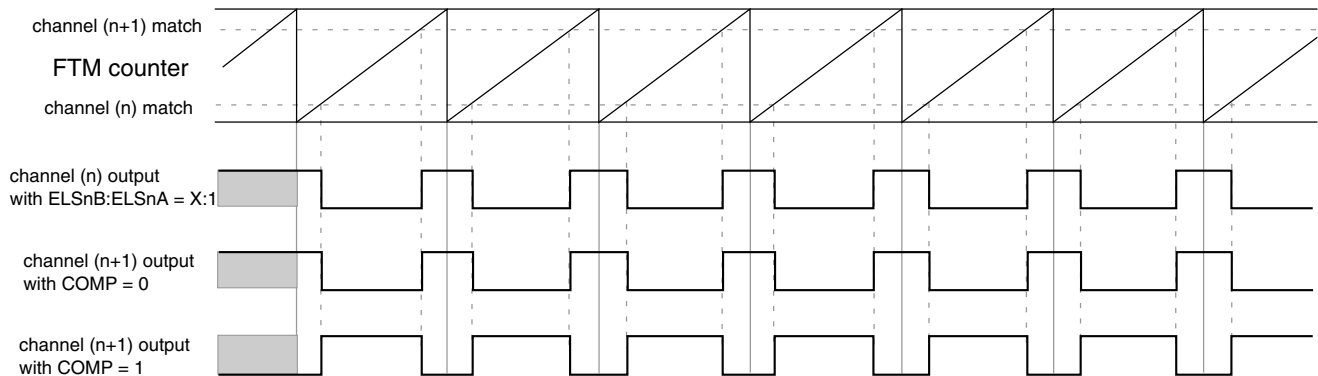


Figure 38-204. Channel (n+1) output in Complementary mode with $(ELSnB:ELSnA = X:1)$

NOTE

The complementary mode is not available in Output Compare mode.

38.4.10 Registers updated from write buffers

38.4.10.1 CNTIN register update

The following table describes when CNTIN register is updated:

Table 38-243. CNTIN register update

| When | Then CNTIN register is updated |
|---|---|
| $CLKS[1:0] = 0:0$ | When CNTIN register is written, independent of FTMEN bit. |
| <ul style="list-style-type: none"> FTMEN = 0, or CNTINC = 0 | At the next system clock after CNTIN was written. |
| <ul style="list-style-type: none"> FTMEN = 1, SYNCMODE = 1, and CNTINC = 1 | By the CNTIN register synchronization . |

38.4.10.2 MOD register update

The following table describes when MOD register is updated:

Table 38-244. MOD register update

| When | Then MOD register is updated |
|---|---|
| CLKS[1:0] = 0:0 | When MOD register is written, independent of FTMEN bit. |
| <ul style="list-style-type: none"> CLKS[1:0] ≠ 0:0, and FTMEN = 0 | According to the CPWMS bit, that is: <ul style="list-style-type: none"> If the selected mode is not CPWM then MOD register is updated after MOD register was written and the FTM counter changes from MOD to CNTIN. If the FTM counter is at free-running counter mode then this update occurs when the FTM counter changes from 0xFFFF to 0x0000. If the selected mode is CPWM then MOD register is updated after MOD register was written and the FTM counter changes from MOD to (MOD – 0x0001). |
| <ul style="list-style-type: none"> CLKS[1:0] ≠ 0:0, and FTMEN = 1 | By the MOD register synchronization . |

38.4.10.3 CnV register update

The following table describes when CnV register is updated:

Table 38-245. CnV register update

| When | Then CnV register is updated |
|---|--|
| CLKS[1:0] = 0:0 | When CnV register is written, independent of FTMEN bit. |
| <ul style="list-style-type: none"> CLKS[1:0] ≠ 0:0, and FTMEN = 0 | According to the selected mode, that is: <ul style="list-style-type: none"> If the selected mode is Output Compare, then CnV register is updated on the next FTM counter change, end of the prescaler counting, after CnV register was written. If the selected mode is EPWM, then CnV register is updated after CnV register was written and the FTM counter changes from MOD to CNTIN. If the FTM counter is at free-running counter mode then this update occurs when the FTM counter changes from 0xFFFF to 0x0000. If the selected mode is CPWM, then CnV register is updated after CnV register was written and the FTM counter changes from MOD to (MOD – 0x0001). |
| <ul style="list-style-type: none"> CLKS[1:0] ≠ 0:0, and FTMEN = 1 | According to the selected mode, that is: <ul style="list-style-type: none"> If the selected mode is output compare then CnV register is updated according to the SYNCEN bit. If (SYNCEN = 0) then CnV register is updated after CnV register was written at the next change of the FTM counter, the end of the prescaler counting. If (SYNCEN = 1) then CnV register is updated by the C(n)V and C(n+1)V register synchronization. If the selected mode is not output compare and (SYNCEN = 1) then CnV register is updated by the C(n)V and C(n+1)V register synchronization. |

38.4.11 PWM synchronization

The PWM synchronization provides an opportunity to update the MOD, CNTIN, CnV, OUTMASK, INVCTRL and SWOCTRL registers with their buffered value and force the FTM counter to the CNTIN register value.

Note

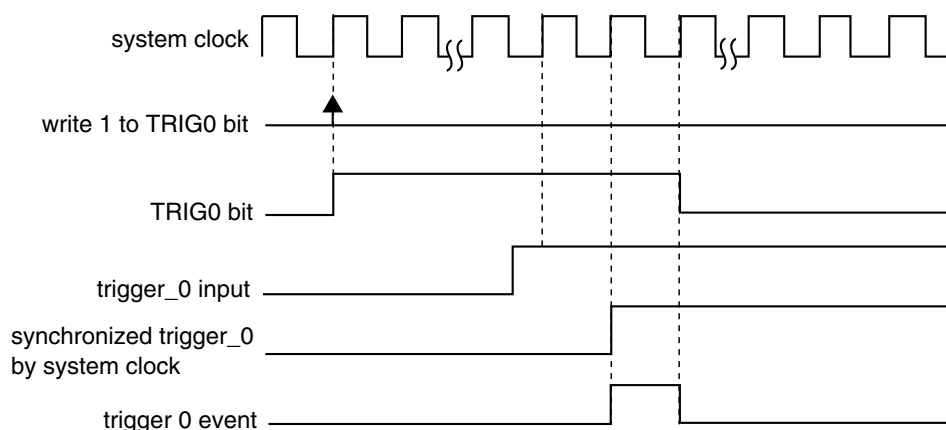
The legacy PWM synchronization (SYNCMODE = 0) is a subset of the enhanced PWM synchronization (SYNCMODE = 1). Thus, only the enhanced PWM synchronization must be used.

38.4.11.1 Hardware trigger

Three hardware trigger signal inputs of the FTM module are enabled when TRIGN = 1, where n = 0, 1 or 2 corresponding to each one of the input signals, respectively. The hardware trigger input n is synchronized by the system clock. The PWM synchronization with hardware trigger is initiated when a rising edge is detected at the enabled hardware trigger inputs.

If (HWTRIGMODE = 0) then the TRIGN bit is cleared when 0 is written to it or when the trigger n event is detected.

In this case, if two or more hardware triggers are enabled (for example, TRIG0 and TRIG1 = 1) and only trigger 1 event occurs, then only TRIG1 bit is cleared. If a trigger n event occurs together with a write setting TRIGN bit, then the synchronization is initiated, but TRIGN bit remains set due to the write operation.



Note
All hardware trigger inputs have the same behavior.

Figure 38-205. Hardware trigger event with HWTRIGMODE = 0

If HWTRIGMODE = 1, then the TRIGn bit is only cleared when 0 is written to it.

NOTE

The HWTRIGMODE bit must be 1 only with enhanced PWM synchronization (SYNCMODE = 1).

38.4.11.2 Software trigger

A software trigger event occurs when 1 is written to the SYNC[SWSYNC] bit. The SWSYNC bit is cleared when 0 is written to it or when the PWM synchronization, initiated by the software event, is completed.

If another software trigger event occurs (by writing another 1 to the SWSYNC bit) at the same time the PWM synchronization initiated by the previous software trigger event is ending, a new PWM synchronization is started and the SWSYNC bit remains equal to 1.

If SYNCMODE = 0 then the SWSYNC bit is also cleared by FTM according to PWMSYNC and REINIT bits. In this case if (PWMSYNC = 1) or (PWMSYNC = 0 and REINIT = 0) then SWSYNC bit is cleared at the next selected loading point after that the software trigger event occurred; see [Boundary cycle and loading points](#) and the following figure. If (PWMSYNC = 0) and (REINIT = 1) then SWSYNC bit is cleared when the software trigger event occurs.

If SYNCMODE = 1 then the SWSYNC bit is also cleared by FTM according to the SWRSTCNT bit. If SWRSTCNT = 0 then SWSYNC bit is cleared at the next selected loading point after that the software trigger event occurred; see the following figure. If SWRSTCNT = 1 then SWSYNC bit is cleared when the software trigger event occurs.

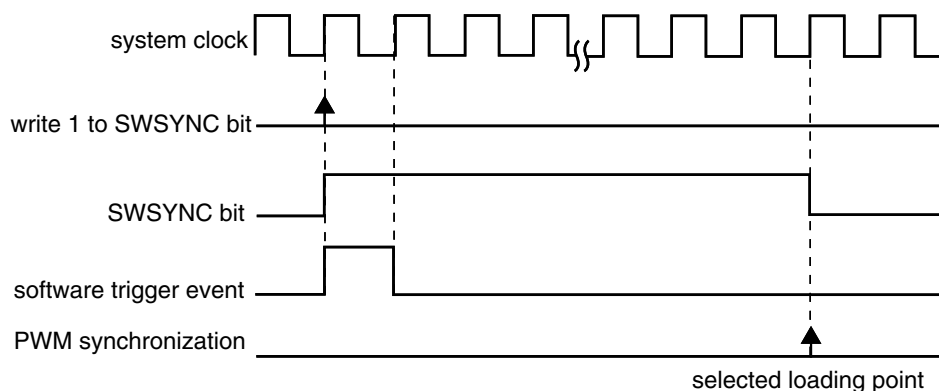


Figure 38-206. Software trigger event

38.4.11.3 Boundary cycle and loading points

The boundary cycle definition is important for the loading points for the registers MOD, CNTIN, and C(n)V.

In [Up counting](#) mode, the boundary cycle is defined as when the counter wraps to its initial value (CNTIN). If in [Up-down counting](#) mode, then the boundary cycle is defined as when the counter turns from down to up counting and when from up to down counting.

The following figure shows the boundary cycles and the loading points for the registers. In the Up Counting mode, the loading points are enabled if one of CNTMIN or CTMAX bits are 1. In the Up-Down Counting mode, the loading points are selected by CNTMIN and CNTMAX bits, as indicated in the figure. These loading points are safe places for register updates thus allowing a smooth transitions in PWM waveform generation.

For both counting modes, if neither CNTMIN nor CNTMAX are 1, then the boundary cycles are not used as loading points for registers updates. See the register synchronization descriptions in the following sections for details.

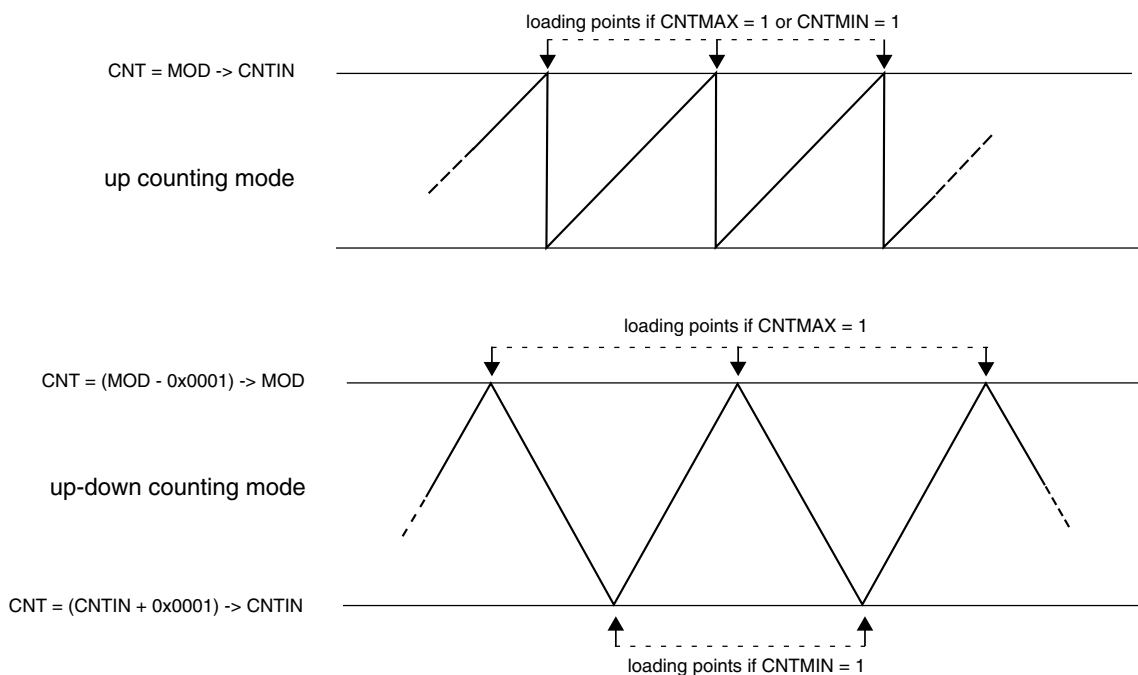


Figure 38-207. Boundary cycles and loading points

38.4.11.4 MOD register synchronization

The MOD register synchronization updates the MOD register with its buffer value. This synchronization is enabled if (FTMEN = 1).

The MOD register synchronization can be done by either the enhanced PWM synchronization (SYNCMODE = 1) or the legacy PWM synchronization (SYNCMODE = 0). However, it is expected that the MOD register be synchronized only by the enhanced PWM synchronization.

In the case of enhanced PWM synchronization, the MOD register synchronization depends on SWWRBUF, SWRSTCNT, HWWRBUF, and HWRSTCNT bits according to this flowchart:

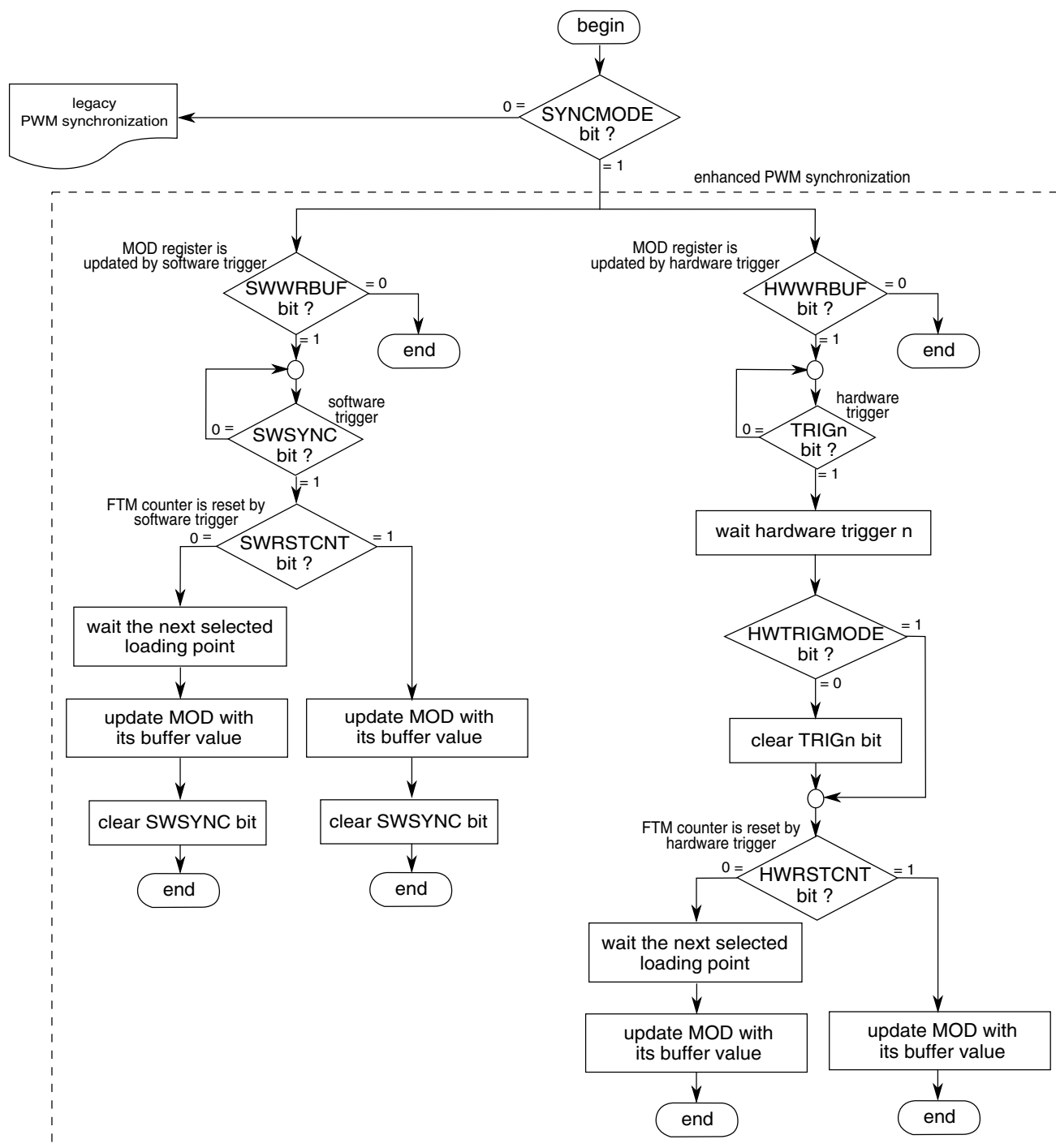


Figure 38-208. MOD register synchronization flowchart

In the case of legacy PWM synchronization, the MOD register synchronization depends on PWMSYNC and REINIT bits according to the following description.

If (SYNCMODE = 0), (PWMSYNC = 0), and (REINIT = 0), then this synchronization is made on the next selected loading point after an enabled trigger event takes place. If the trigger event was a software trigger, then the SWSYNC bit is cleared on the next selected

loading point. If the trigger event was a hardware trigger, then the trigger enable bit (TRIGn) is cleared according to [Hardware trigger](#). Examples with software and hardware triggers follow.

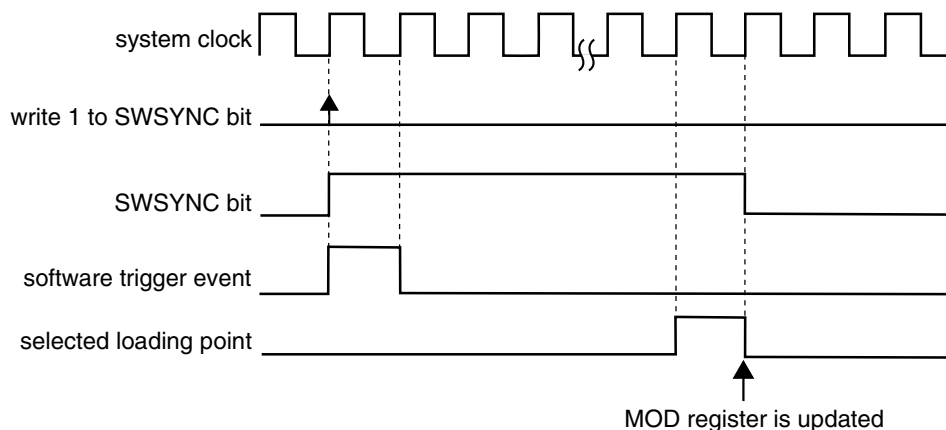


Figure 38-209. MOD synchronization with (SYNCMODE = 0), (PWMSYNC = 0), (REINIT = 0), and software trigger was used

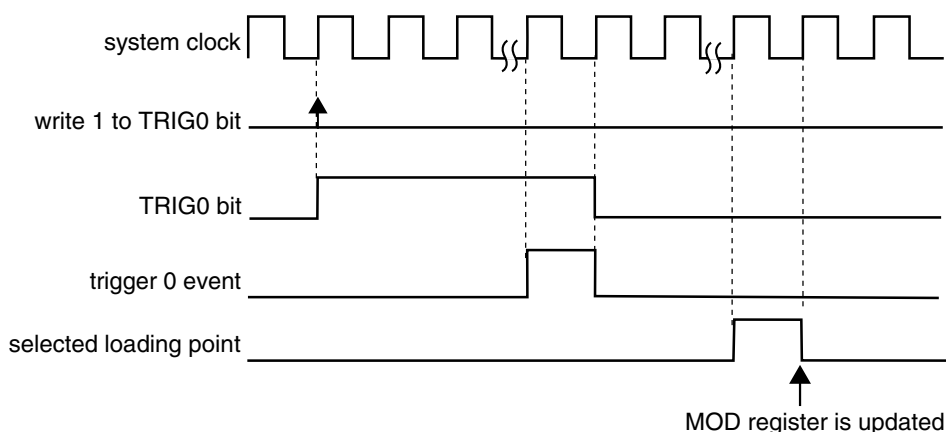


Figure 38-210. MOD synchronization with (SYNCMODE = 0), (HWTRIGMODE = 0), (PWMSYNC = 0), (REINIT = 0), and a hardware trigger was used

If (SYNCMODE = 0), (PWMSYNC = 0), and (REINIT = 1), then this synchronization is made on the next enabled trigger event. If the trigger event was a software trigger, then the SWSYNC bit is cleared according to the following example. If the trigger event was a hardware trigger, then the TRIGn bit is cleared according to [Hardware trigger](#). Examples with software and hardware triggers follow.

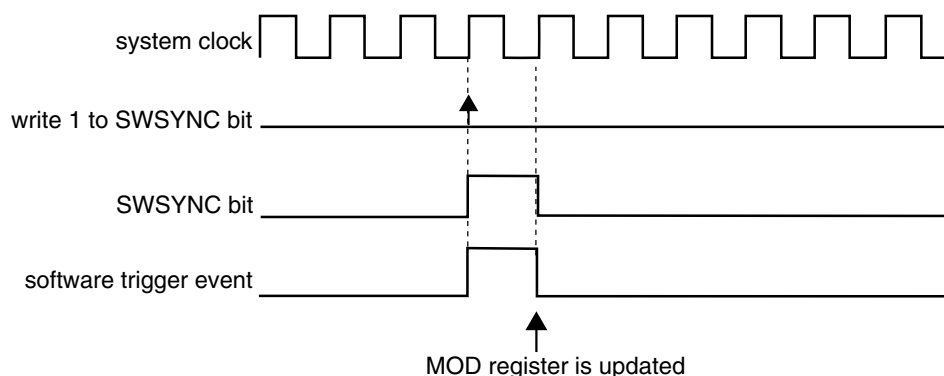


Figure 38-211. MOD synchronization with (SYNCMODE = 0), (PWMSYNC = 0), (REINIT = 1), and software trigger was used

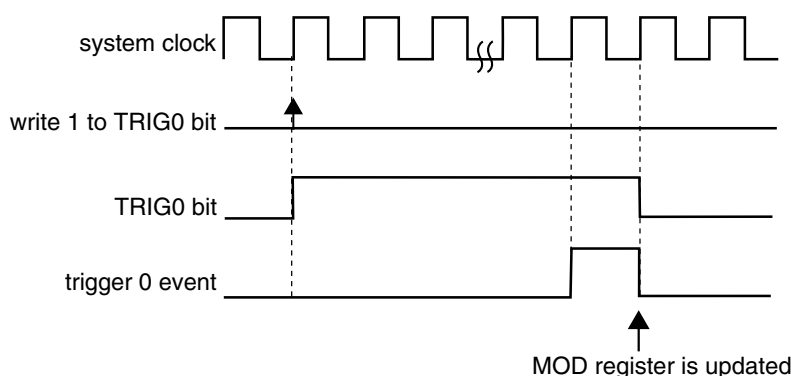


Figure 38-212. MOD synchronization with (SYNCMODE = 0), (HWTRIGMODE = 0), (PWMSYNC = 0), (REINIT = 1), and a hardware trigger was used

If (SYNCMODE = 0) and (PWMSYNC = 1), then this synchronization is made on the next selected loading point after the software trigger event takes place. The SWSYNC bit is cleared on the next selected loading point:

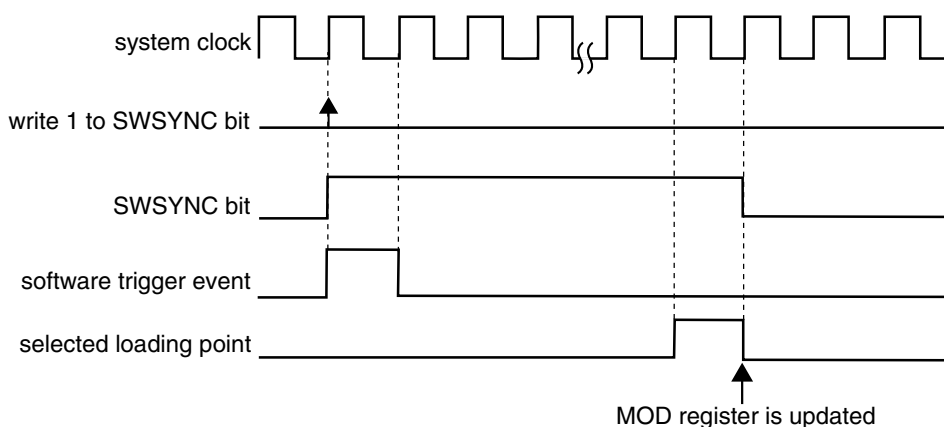


Figure 38-213. MOD synchronization with (SYNCMODE = 0) and (PWMSYNC = 1)

38.4.11.5 CNTIN register synchronization

The CNTIN register synchronization updates the CNTIN register with its buffer value.

This synchronization is enabled if (FTMEN = 1), (SYNCMODE = 1), and (CNTINC = 1). The CNTIN register synchronization can be done only by the enhanced PWM synchronization (SYNCMODE = 1). The synchronization mechanism is the same as the MOD register synchronization done by the enhanced PWM synchronization; see [MOD register synchronization](#).

38.4.11.6 C(n)V and C(n+1)V register synchronization

The C(n)V and C(n+1)V registers synchronization updates the C(n)V and C(n+1)V registers with their buffer values.

This synchronization is enabled if (FTMEN = 1) and (SYNCEN = 1). The synchronization mechanism is the same as the [MOD register synchronization](#). However, it is expected that the C(n)V and C(n+1)V registers be synchronized only by the enhanced PWM synchronization (SYNCMODE = 1).

38.4.11.7 OUTMASK register synchronization

The OUTMASK register synchronization updates the OUTMASK register with its buffer value.

The OUTMASK register can be updated at each rising edge of system clock (SYNCHOM = 0), by the enhanced PWM synchronization (SYNCHOM = 1 and SYNCMODE = 1) or by the legacy PWM synchronization (SYNCHOM = 1 and SYNCMODE = 0). However, it is expected that the OUTMASK register be synchronized only by the enhanced PWM synchronization.

In the case of enhanced PWM synchronization, the OUTMASK register synchronization depends on SWOM and HWOM bits. See the following flowchart:

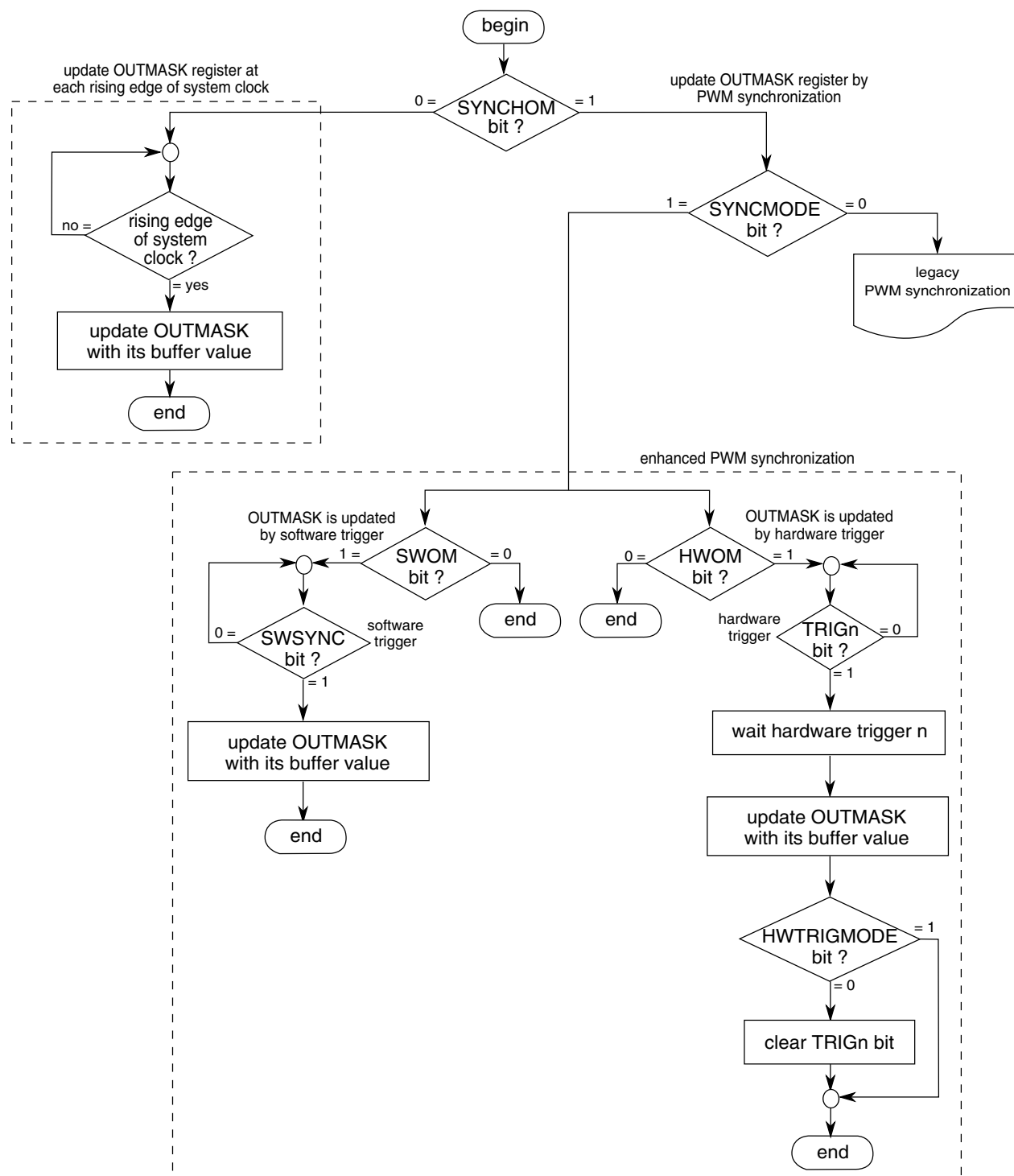


Figure 38-214. OUTMASK register synchronization flowchart

In the case of legacy PWM synchronization, the OUTMASK register synchronization depends on PWMSYNC bit according to the following description.

If (SYNCMODE = 0), (SYNCHOM = 1), and (PWMSYNC = 0), then this synchronization is done on the next enabled trigger event. If the trigger event was a software trigger, then the SWSYNC bit is cleared on the next selected loading point. If the trigger event was a hardware trigger, then the TRIGN bit is cleared according to [Hardware trigger](#). Examples with software and hardware triggers follow.

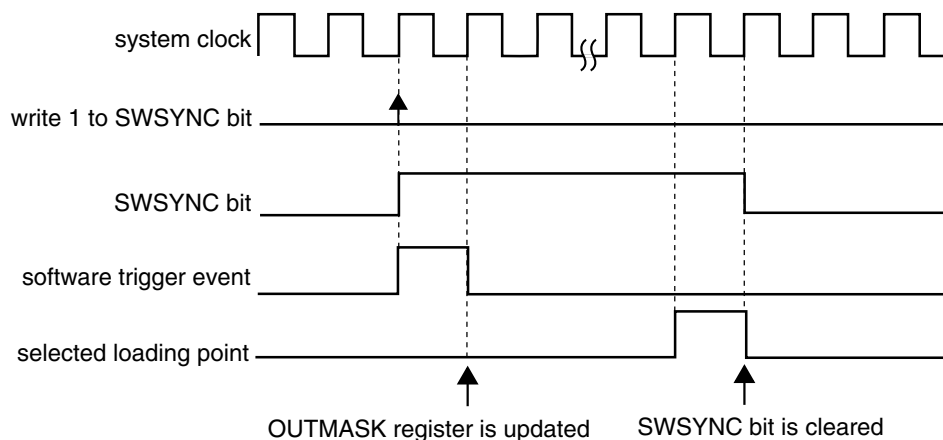


Figure 38-215. OUTMASK synchronization with (SYNCMODE = 0), (SYNCHOM = 1), (PWMSYNC = 0) and software trigger was used

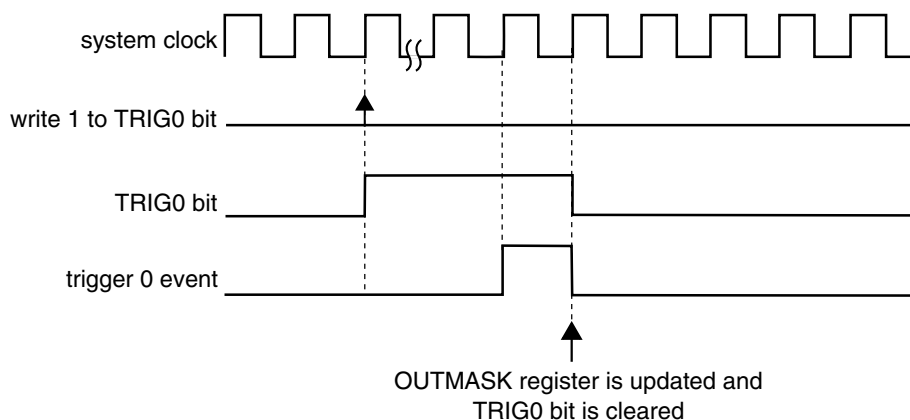


Figure 38-216. OUTMASK synchronization with (SYNCMODE = 0), (HWTRIGMODE = 0), (SYNCHOM = 1), (PWMSYNC = 0), and a hardware trigger was used

If (SYNCMODE = 0), (SYNCHOM = 1), and (PWMSYNC = 1), then this synchronization is made on the next enabled hardware trigger. The TRIGN bit is cleared according to [Hardware trigger](#). An example with a hardware trigger follows.

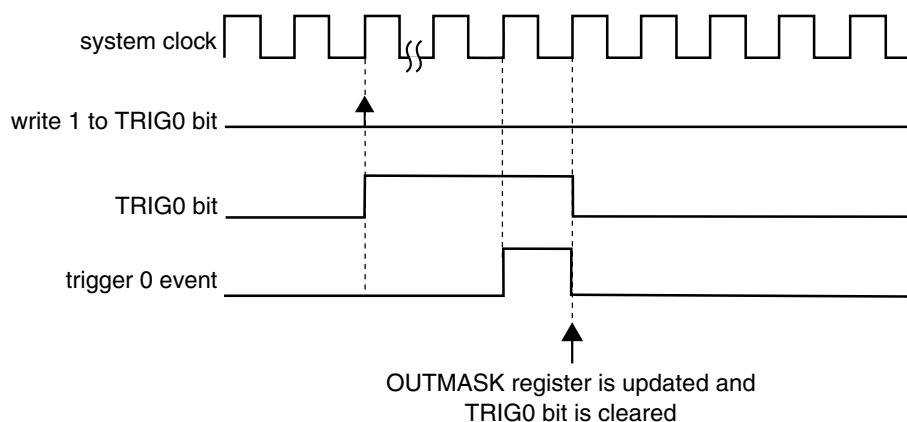


Figure 38-217. OUTMASK synchronization with (SYNCMODE = 0), (HWTRIGMODE = 0), (SYNCHOM = 1), (PWMSYNC = 1), and a hardware trigger was used

38.4.11.8 INVCTRL register synchronization

The INVCTRL register synchronization updates the INVCTRL register with its buffer value.

The INVCTRL register can be updated at each rising edge of system clock (INVC = 0) or by the enhanced PWM synchronization (INVC = 1 and SYNCMODE = 1) according to the following flowchart.

In the case of enhanced PWM synchronization, the INVCTRL register synchronization depends on SWINVC and HWINVC bits.

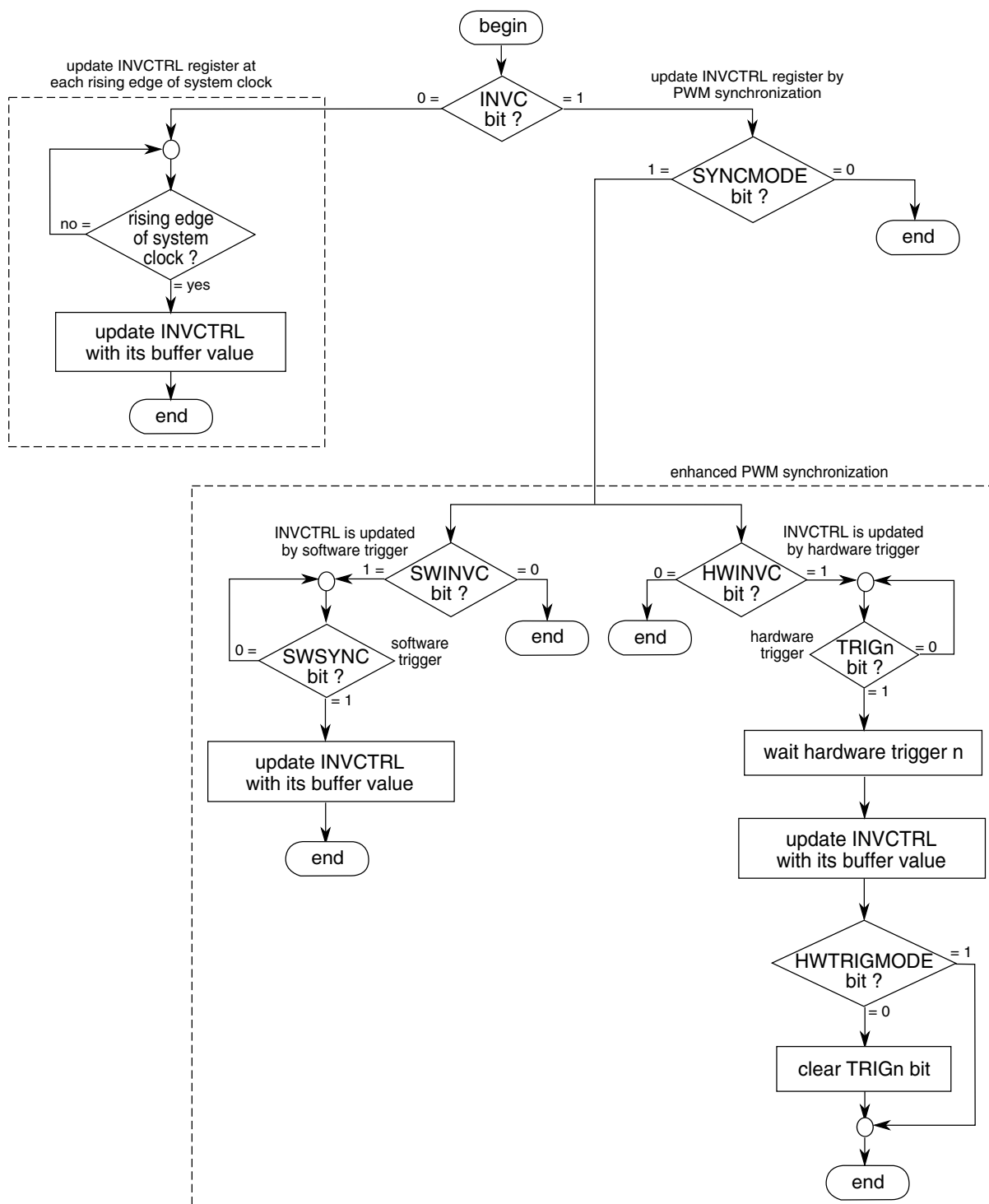


Figure 38-218. INVCTRL register synchronization flowchart

38.4.11.9 SWOCTRL register synchronization

The SWOCTRL register synchronization updates the SWOCTRL register with its buffer value.

The SWOCTRL register can be updated at each rising edge of system clock (SWOC = 0) or by the enhanced PWM synchronization (SWOC = 1 and SYNCMODE = 1) according to the following flowchart.

In the case of enhanced PWM synchronization, the SWOCTRL register synchronization depends on SWSOC and HWSOC bits.

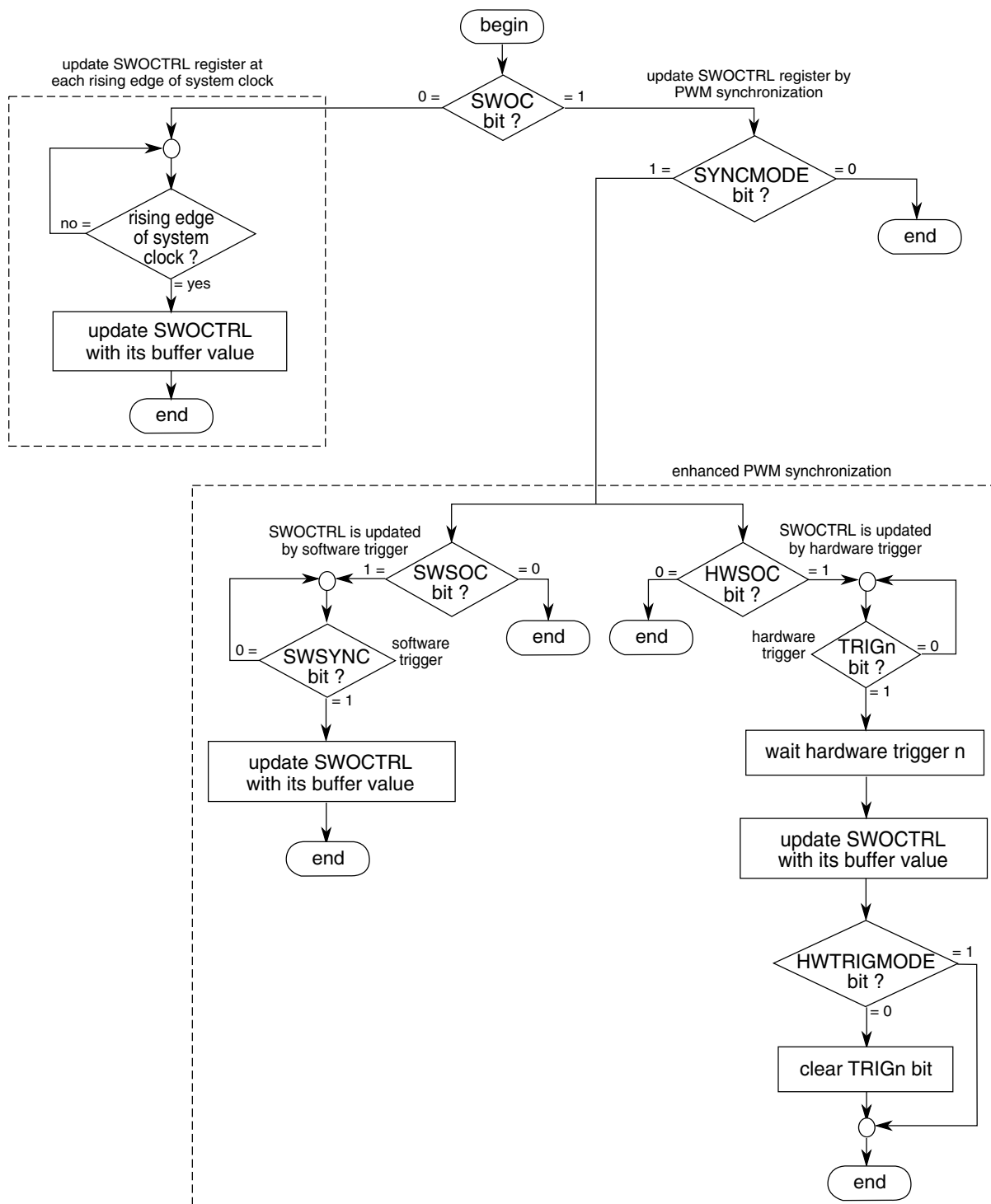


Figure 38-219. SWOCTRL register synchronization flowchart

38.4.11.10 FTM counter synchronization

The FTM counter synchronization is a mechanism that allows the FTM to restart the PWM generation at a certain point in the PWM period. The channels outputs are forced to their initial value, except for channels in Output Compare mode, and the FTM counter is forced to its initial counting value defined by CNTIN register.

The following figure shows the FTM counter synchronization. Note that after the synchronization event occurs, the channel (n) is set to its initial value and the channel (n+1) is not set to its initial value due to a specific timing of this figure in which the deadtime insertion prevents this channel output from transitioning to 1. If no deadtime insertion is selected, then the channel (n+1) transitions to logical value 1 immediately after the synchronization event occurs.

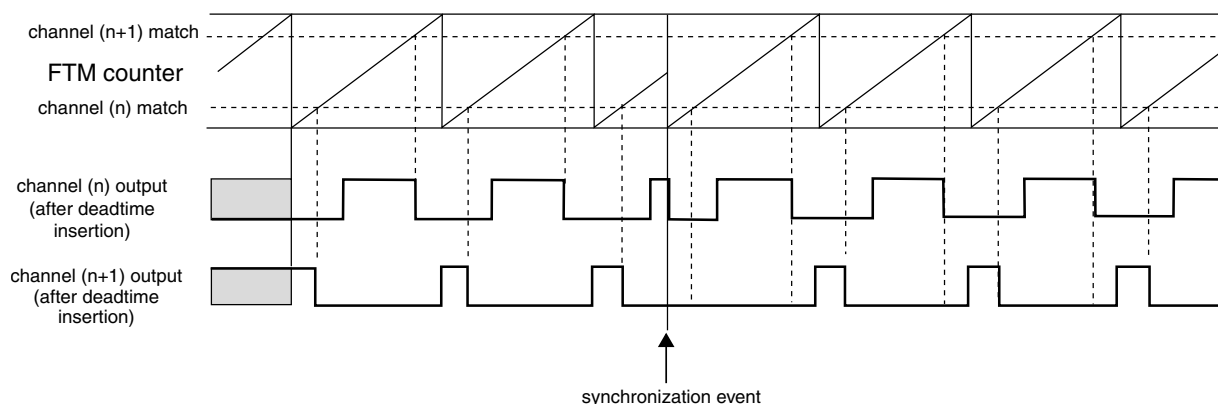


Figure 38-220. FTM counter synchronization

The FTM counter synchronization can be done by either the enhanced PWM synchronization (SYNCMODE = 1) or the legacy PWM synchronization (SYNCMODE = 0). However, the FTM counter must be synchronized only by the enhanced PWM synchronization.

In the case of enhanced PWM synchronization, the FTM counter synchronization depends on SWRSTCNT and HWRSTCNT bits according to the following flowchart.

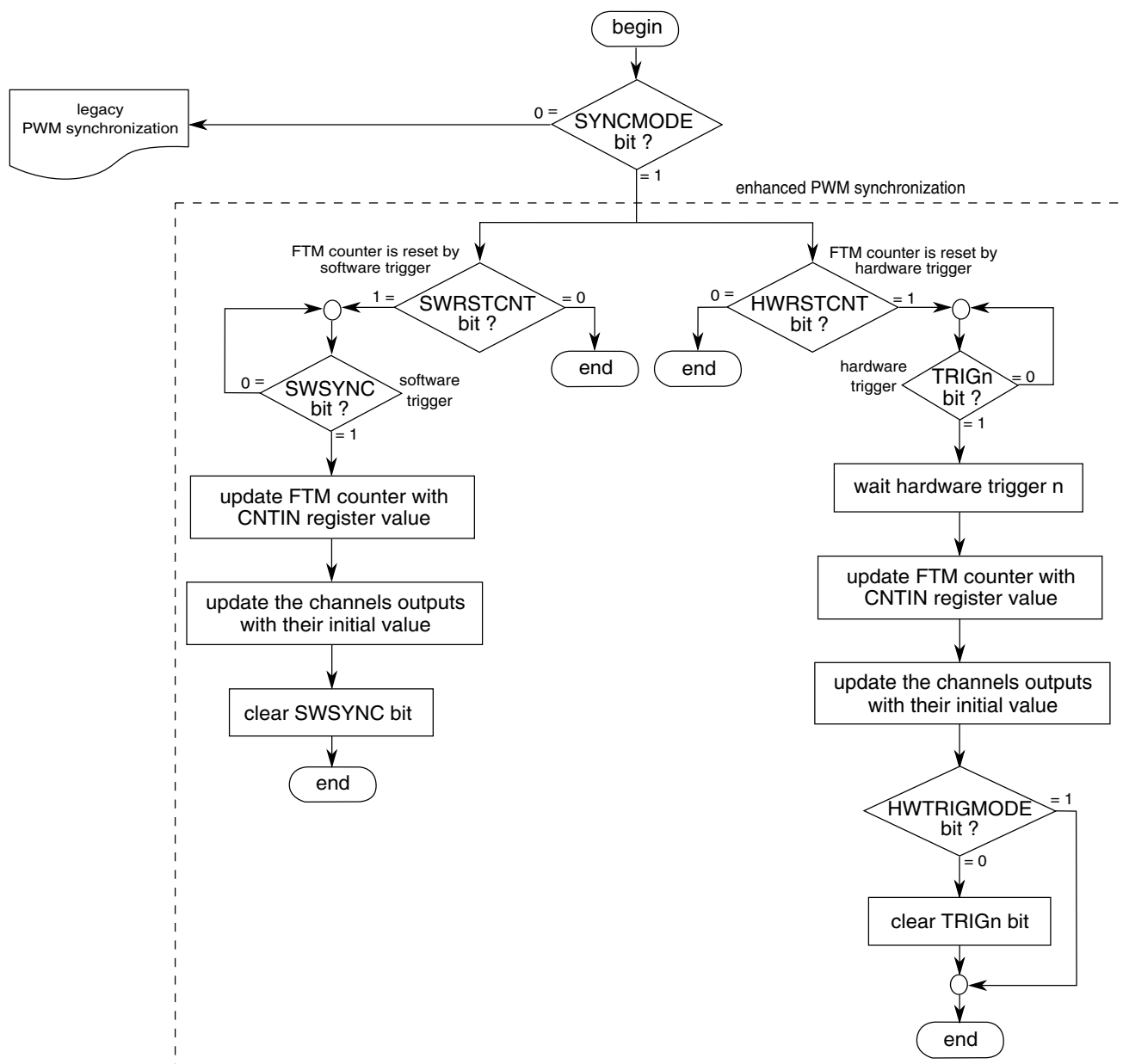


Figure 38-221. FTM counter synchronization flowchart

In the case of legacy PWM synchronization, the FTM counter synchronization depends on REINIT and PWMSYNC bits according to the following description.

If (SYNCMODE = 0), (REINIT = 1), and (PWMSYNC = 0) then this synchronization is made on the next enabled trigger event. If the trigger event was a software trigger then the SWSYNC bit is cleared according to the following example. If the trigger event was a hardware trigger then the TRIGN bit is cleared according to [Hardware trigger](#). Examples with software and hardware triggers follow.

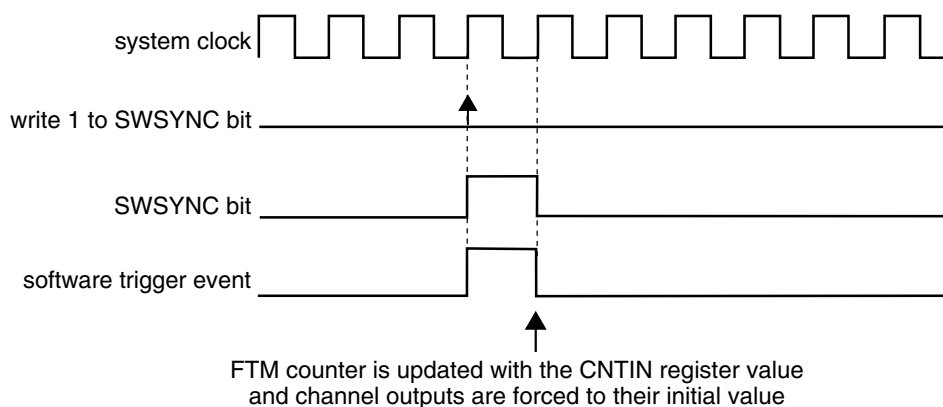


Figure 38-222. FTM counter synchronization with (SYNCMODE = 0), (REINIT = 1), (PWMSYNC = 0), and software trigger was used

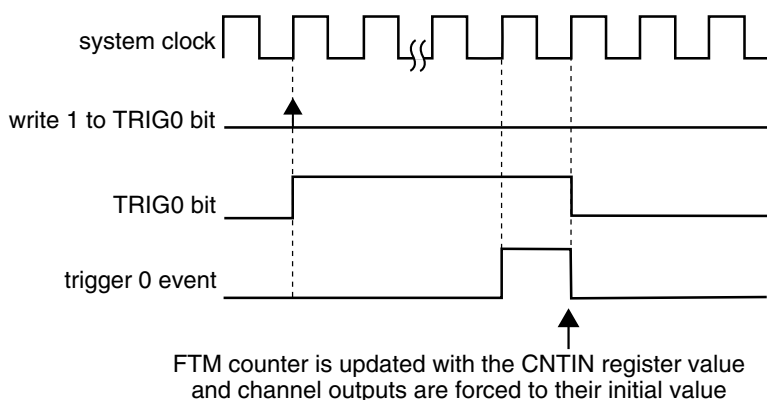


Figure 38-223. FTM counter synchronization with (SYNCMODE = 0), (HWTRIGMODE = 0), (REINIT = 1), (PWMSYNC = 0), and a hardware trigger was used

If (SYNCMODE = 0), (REINIT = 1), and (PWMSYNC = 1) then this synchronization is made on the next enabled hardware trigger. The TRIGn bit is cleared according to [Hardware trigger](#).

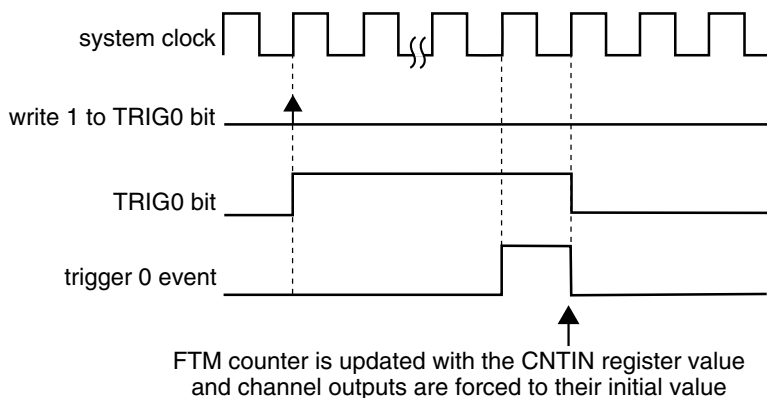


Figure 38-224. FTM counter synchronization with (SYNCMODE = 0), (HWTRIGMODE = 0), (REINIT = 1), (PWMSYNC = 1), and a hardware trigger was used

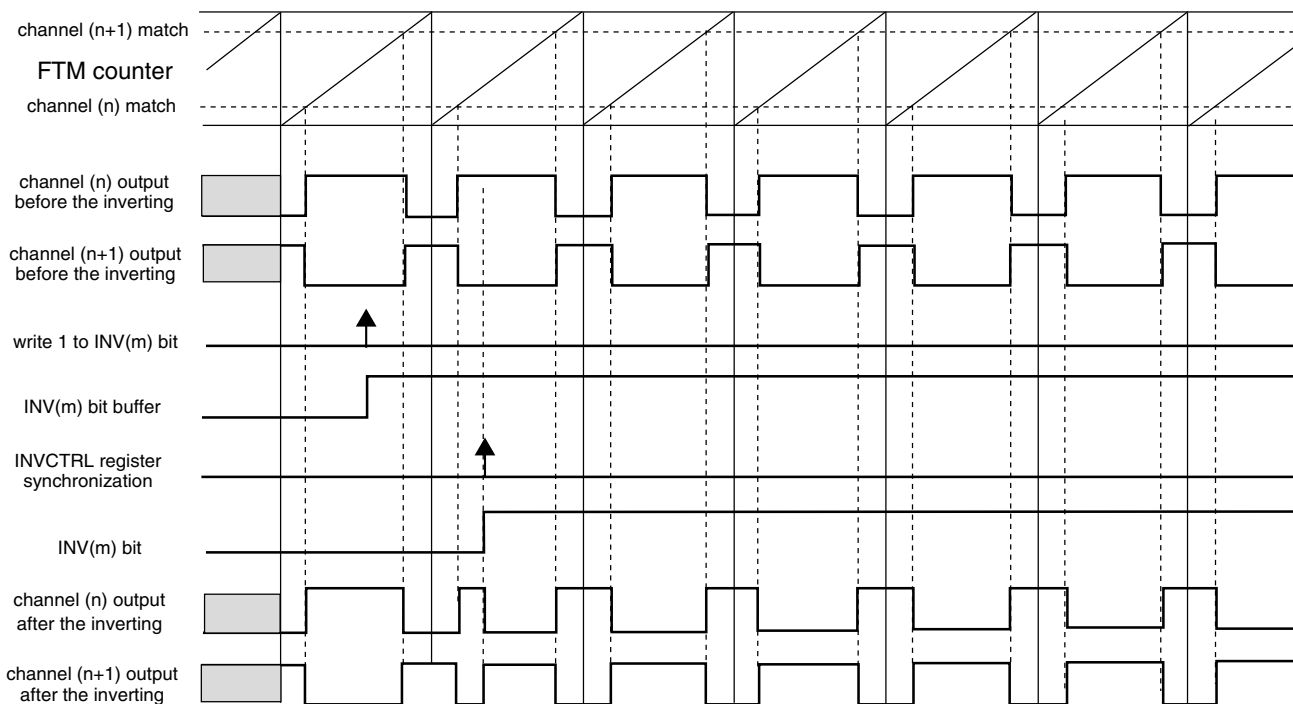
38.4.12 Inverting

The invert functionality swaps the signals between channel (n) and channel (n+1) outputs. The inverting operation is selected when:

- QUADEN = 0
- DECAPEN = 0
- COMP = 1, and
- INV_m = 1 (where m represents a channel pair)

The INV_m bit in INVCTRL register is updated with its buffer value according to [INVCTRL register synchronization](#)

In High-True (ELSnB:ELSnA = 1:0) Combine mode, the channel (n) output is forced low at the beginning of the period (FTM counter = CNTIN), forced high at the channel (n) match and forced low at the channel (n+1) match. If the inverting is selected, the channel (n) output behavior is changed to force high at the beginning of the PWM period, force low at the channel (n) match and force high at the channel (n+1) match. See the following figure.

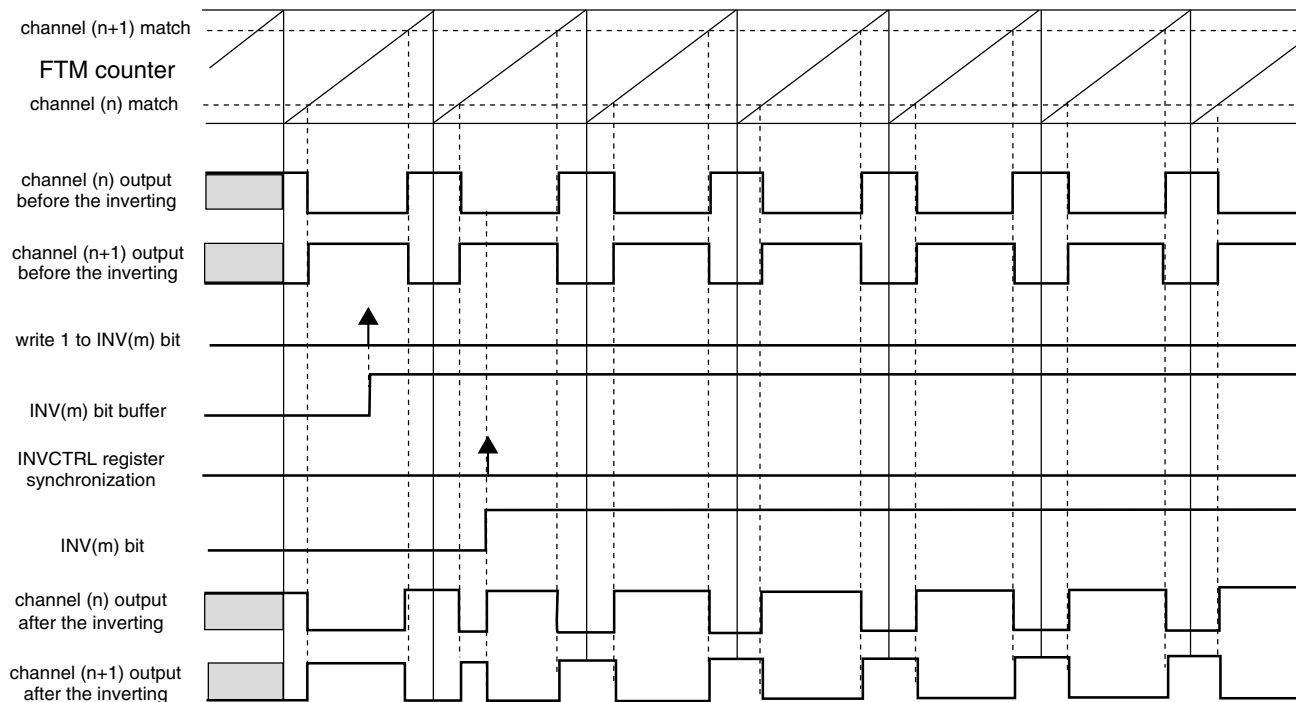


NOTE

INV(m) bit selects the inverting to the pair channels (n) and (n+1).

Figure 38-225. Channels (n) and (n+1) outputs after the inverting in High-True (ELSnB:ELSnA = 1:0) Combine mode

Note that the ELSnB:ELSnA bits value should be considered because they define the active state of the channels outputs. In Low-True (ELSnB:ELSnA = X:1) Combine mode, the channel (n) output is forced high at the beginning of the period, forced low at the channel (n) match and forced high at the channel (n+1) match. When inverting is selected, the channels (n) and (n+1) present waveforms as shown in the following figure.



NOTE

INV(m) bit selects the inverting to the pair channels (n) and (n+1).

Figure 38-226. Channels (n) and (n+1) outputs after the inverting in Low-True (ELSnB:ELSnA = X:1) Combine mode

Note

The inverting feature is not available in Output Compare mode.

38.4.13 Software output control

The software output control forces the channel output according to software defined values at a specific time in the PWM generation.

The software output control is selected when:

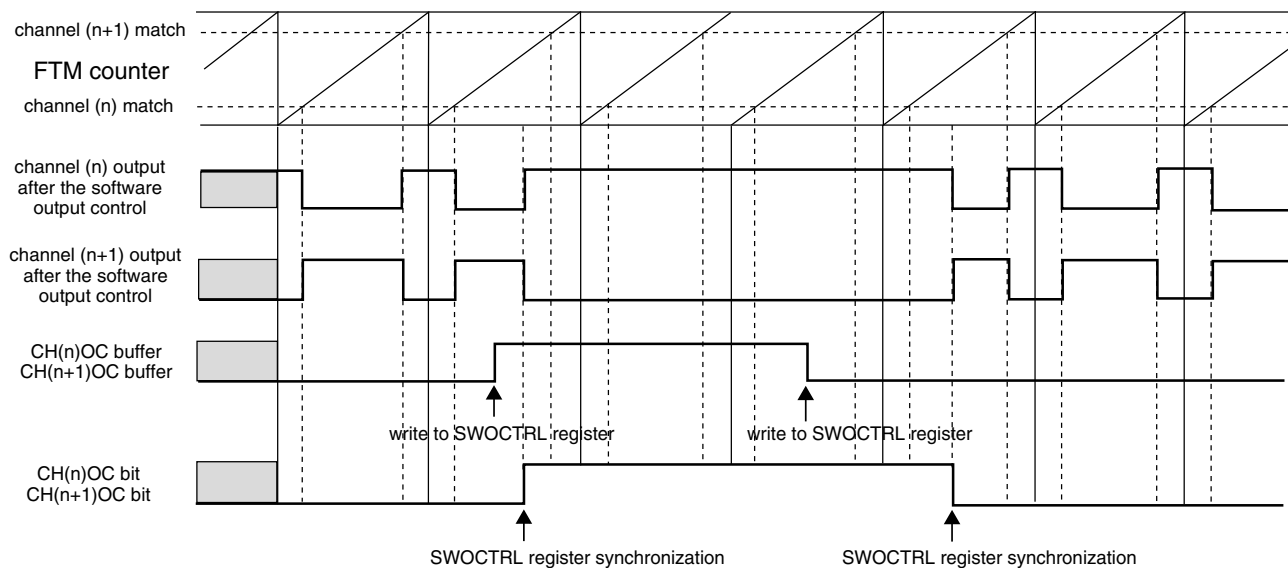
- QUADEN = 0
- DECAPEN = 0, and
- CHnOC = 1

functional description

The CHnOC bit enables the software output control for a specific channel output and the CHnOCV selects the value that is forced to this channel output.

Both CHnOC and CHnOCV bits in SWOCTRL register are buffered and updated with their buffer value according to [SWOCTRL register synchronization](#).

The following figure shows the channels (n) and (n+1) outputs signals when the software output control is used. In this case the channels (n) and (n+1) are set to Combine and Complementary mode.



NOTE

CH(n)OCV = 1 and CH(n+1)OCV = 0.

Figure 38-227. Example of software output control in Combine and Complementary mode

Software output control forces the following values on channels (n) and (n+1) when the COMP bit is zero.

Table 38-246. Software output control behavior when (COMP = 0)

| CH(n)OC | CH(n+1)OC | CH(n)OCV | CH(n+1)OCV | Channel (n) Output | Channel (n+1) Output |
|---------|-----------|----------|------------|-------------------------|-------------------------|
| 0 | 0 | X | X | is not modified by SWOC | is not modified by SWOC |
| 1 | 1 | 0 | 0 | is forced to zero | is forced to zero |
| 1 | 1 | 0 | 1 | is forced to zero | is forced to one |
| 1 | 1 | 1 | 0 | is forced to one | is forced to zero |
| 1 | 1 | 1 | 1 | is forced to one | is forced to one |

Software output control forces the following values on channels (n) and (n+1) when the COMP bit is one.

Table 38-247. Software output control behavior when (COMP = 1)

| CH(n)OC | CH(n+1)OC | CH(n)OCV | CH(n+1)OCV | Channel (n) Output | Channel (n+1) Output |
|---------|-----------|----------|------------|-------------------------|-------------------------|
| 0 | 0 | X | X | is not modified by SWOC | is not modified by SWOC |
| 1 | 1 | 0 | 0 | is forced to zero | is forced to zero |
| 1 | 1 | 0 | 1 | is forced to zero | is forced to one |
| 1 | 1 | 1 | 0 | is forced to one | is forced to zero |
| 1 | 1 | 1 | 1 | is forced to one | is forced to zero |

Note

- The CH(n)OC and CH(n+1)OC bits should be equal.
- The COMP bit must not be modified when software output control is enabled, that is, CH(n)OC = 1 and/or CH(n+1)OC = 1.
- Software output control has the same behavior with disabled or enabled FTM counter (see the CLKS field description in the Status and Control register).

38.4.14 Deadtime insertion

The deadtime insertion is enabled when (DTEN = 1) and (DTVAL[5:0] is non-zero).

DEADTIME register defines the deadtime delay that can be used for all FTM channels. The DTPS[1:0] bits define the prescaler for the system clock and the DTVAL[5:0] bits define the deadtime modulo, that is, the number of the deadtime prescaler clocks.

The deadtime delay insertion ensures that no two complementary signals (channels (n) and (n+1)) drive the active state at the same time.

If POL(n) = 0, POL(n+1) = 0, and the deadtime is enabled, then when the channel (n) match (FTM counter = C(n)V) occurs, the channel (n) output remains at the low value until the end of the deadtime delay when the channel (n) output is set. Similarly, when the channel (n+1) match (FTM counter = C(n+1)V) occurs, the channel (n+1) output remains at the low value until the end of the deadtime delay when the channel (n+1) output is set. See the following figures.

If POL(n) = 1, POL(n+1) = 1, and the deadtime is enabled, then when the channel (n) match (FTM counter = C(n)V) occurs, the channel (n) output remains at the high value until the end of the deadtime delay when the channel (n) output is cleared. Similarly,

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when the channel (n+1) match (FTM counter = $C(n+1)V$) occurs, the channel (n+1) output remains at the high value until the end of the deadtime delay when the channel (n) output is cleared.

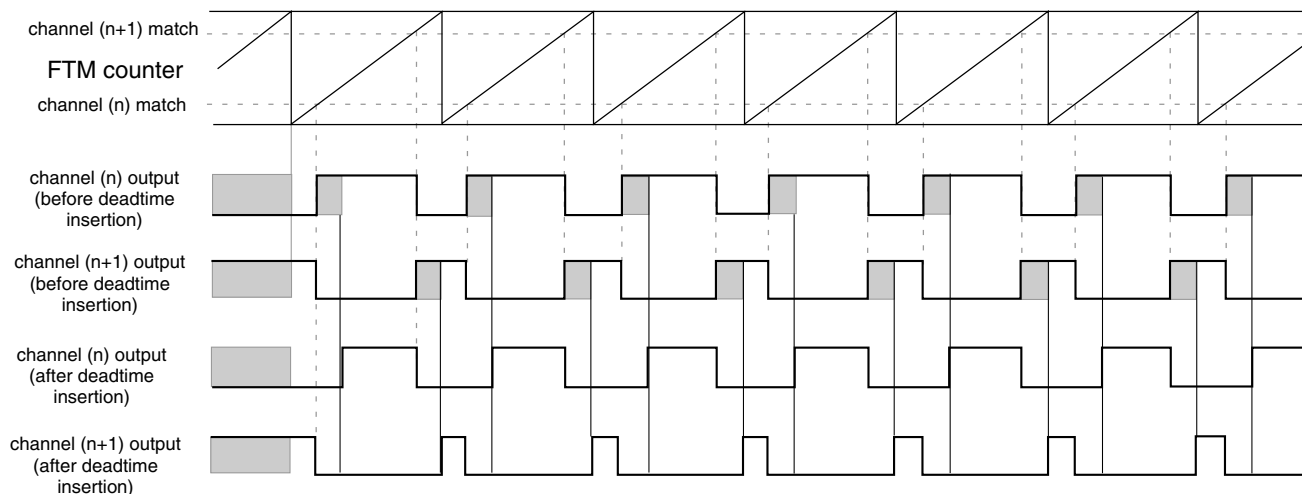


Figure 38-228. Deadtime insertion with $ELSnB:ELSnA = 1:0$, $POL(n) = 0$, and $POL(n+1) = 0$

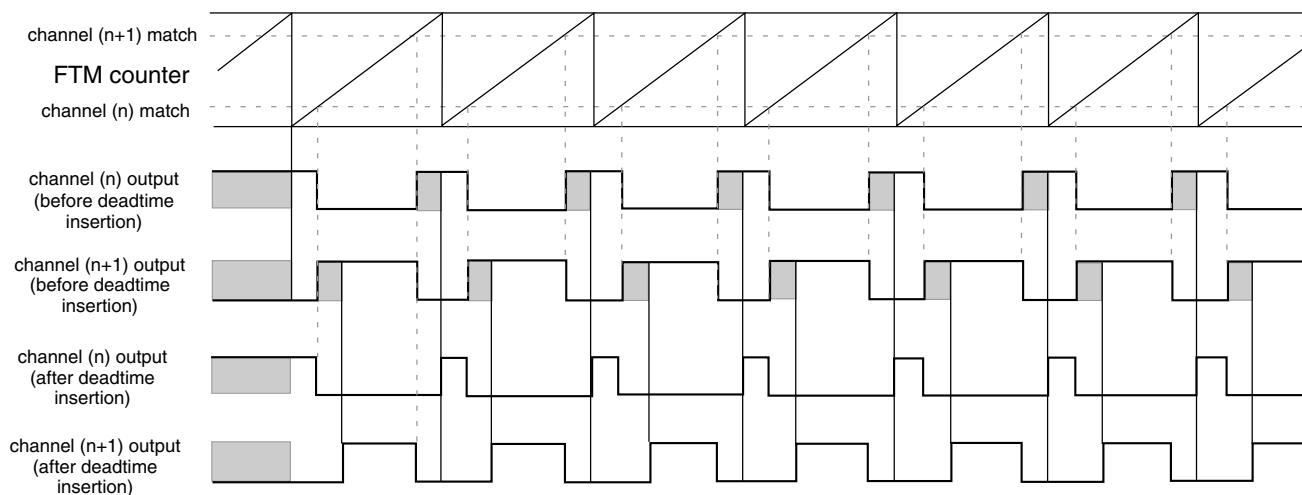


Figure 38-229. Deadtime insertion with $ELSnB:ELSnA = X:1$, $POL(n) = 0$, and $POL(n+1) = 0$

NOTE

- The deadtime feature must be used only in Complementary mode.
- The deadtime feature is not available in Output Compare mode.

38.4.14.1 Deadtime insertion corner cases

If (PS[2:0] is cleared), (DTPS[1:0] = 0:0 or DTPS[1:0] = 0:1):

- and the deadtime delay is greater than or equal to the channel (n) duty cycle ($((C(n)+1)V - C(n)V) \times \text{system clock}$), then the channel (n) output is always the inactive value (POL(n) bit value).
- and the deadtime delay is greater than or equal to the channel (n+1) duty cycle ($((\text{MOD} - \text{CNTIN} + 1 - (C(n+1)V - C(n)V)) \times \text{system clock})$), then the channel (n+1) output is always the inactive value (POL(n+1) bit value).

Although, in most cases the deadtime delay is not comparable to channels (n) and (n+1) duty cycle, the following figures show examples where the deadtime delay is comparable to the duty cycle.

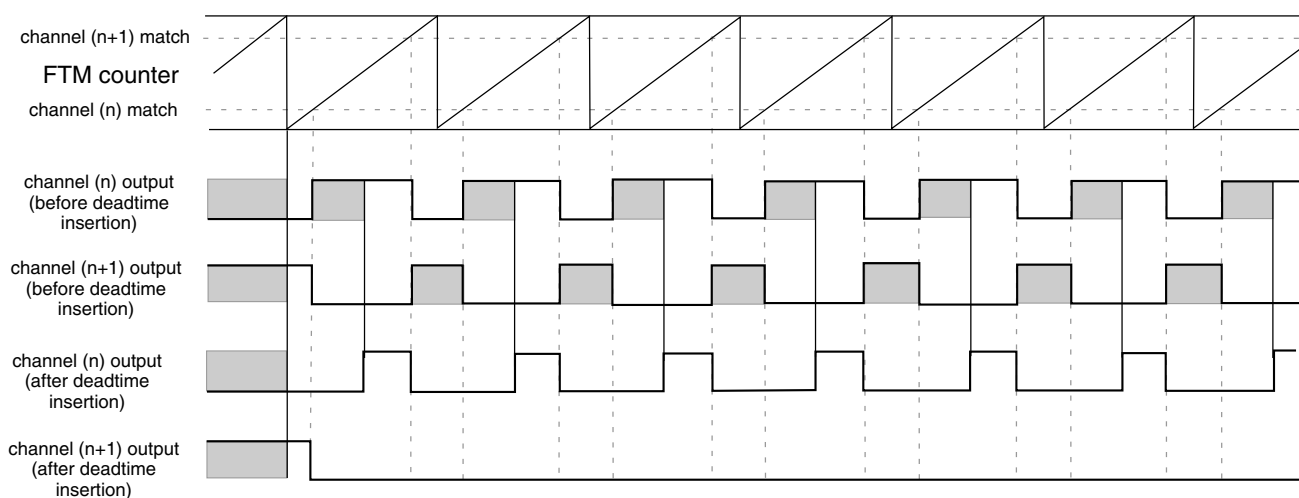


Figure 38-230. Example of the deadtime insertion (ELSnB:ELSnA = 1:0, POL(n) = 0, and POL(n+1) = 0) when the deadtime delay is comparable to channel (n+1) duty cycle

functional description

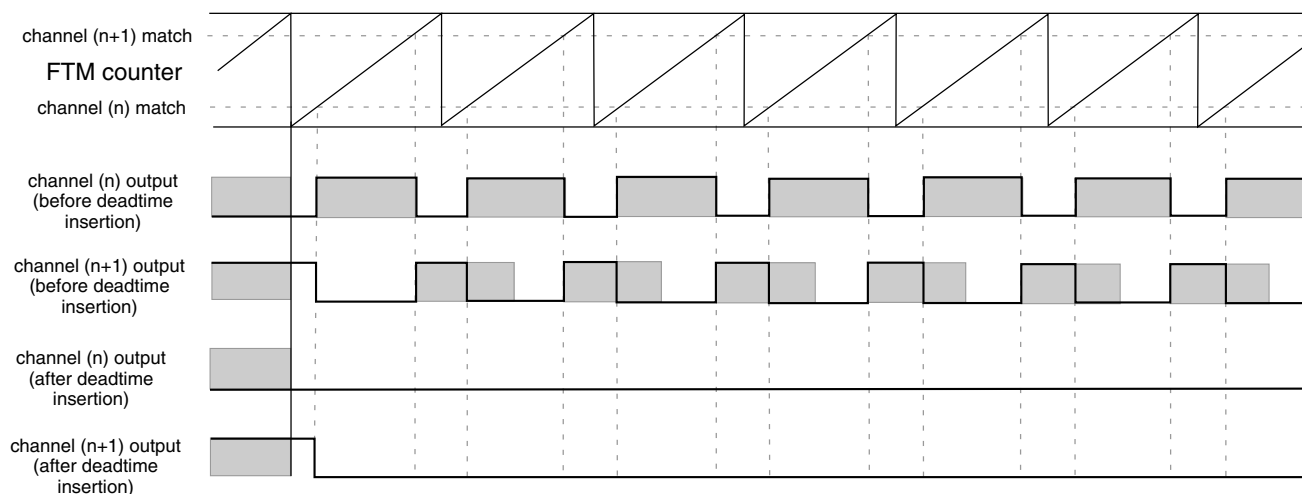


Figure 38-231. Example of the deadtime insertion ($ELSnB:ELSnA = 1:0$, $POL(n) = 0$, and $POL(n+1) = 0$) when the deadtime delay is comparable to channels (n) and (n+1) duty cycle

38.4.15 Output mask

The output mask can be used to force channels output to their inactive state through software. For example: to control a BLDC motor.

Any write to the OUTMASK register updates its write buffer. The OUTMASK register is updated with its buffer value by PWM synchronization; see [OUTMASK register synchronization](#).

If $CHnOM = 1$, then the channel (n) output is forced to its inactive state ($POLn$ bit value). If $CHnOM = 0$, then the channel (n) output is unaffected by the output mask. See the following figure.

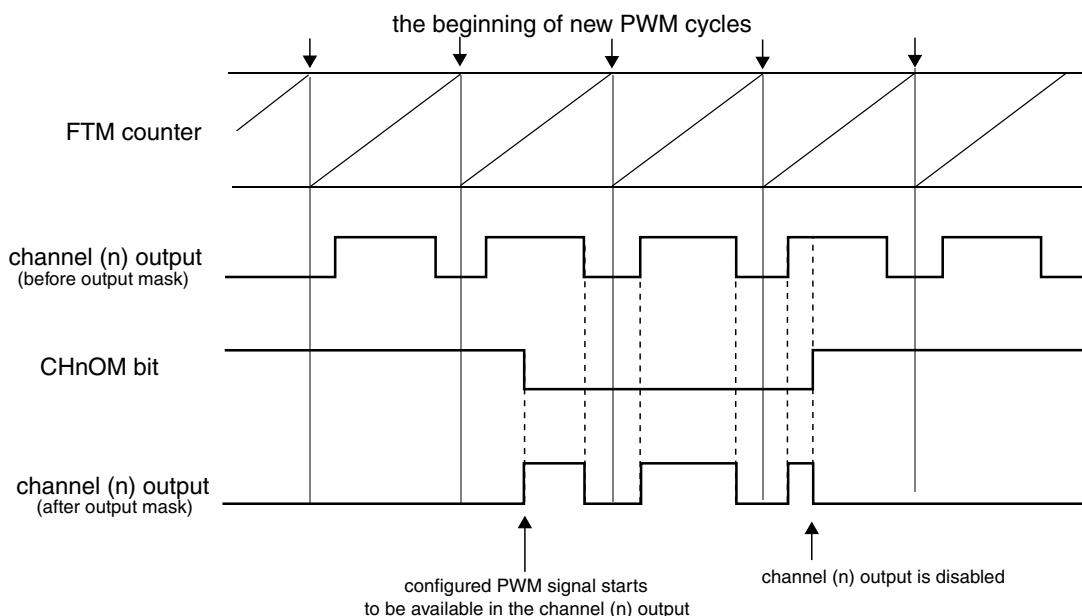


Figure 38-232. Output mask with POLn = 0

The following table shows the output mask result before the polarity control.

Table 38-248. Output mask result for channel (n) before the polarity control

| CHnOM | Output Mask Input | Output Mask Result |
|-------|-------------------|--------------------|
| 0 | inactive state | inactive state |
| | active state | active state |
| 1 | inactive state | inactive state |
| | active state | |

38.4.16 Fault control

The fault control is enabled if (FAULTM[1:0] ≠ 0:0).

FTM can have up to four fault inputs. FAULTnEN bit (where n = 0, 1, 2, 3) enables the fault input n and FFLTRnEN bit enables the fault input n filter. FFVAL[3:0] bits select the value of the enabled filter in each enabled fault input.

First, each fault input signal is synchronized by the system clock; see the synchronizer block in the following figure. Following synchronization, the fault input n signal enters the filter block. When there is a state change in the fault input n signal, the 5-bit counter is reset and starts counting up. As long as the new state is stable on the fault input n, the

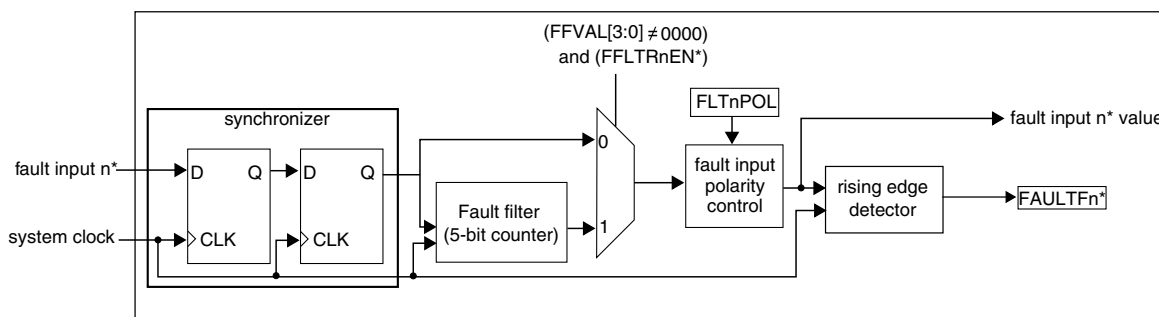
functional description

counter continues to increment. If the 5-bit counter overflows, that is, the counter exceeds the value of the FFVAL[3:0] bits, the new fault input n value is validated. It is then transmitted as a pulse edge to the edge detector.

If the opposite edge appears on the fault input n signal before validation (counter overflow), the counter is reset. At the next input transition, the counter starts counting again. Any pulse that is shorter than the minimum value selected by FFVAL[3:0] bits (\times system clock) is regarded as a glitch and is not passed on to the edge detector.

The fault input n filter is disabled when the FFVAL[3:0] bits are zero or when FAULTnEN = 0. In this case, the fault input n signal is delayed 2 rising edges of the system clock and the FAULTFn bit is set on 3th rising edge of the system clock after a rising edge occurs on the fault input n.

If FFVAL[3:0] \neq 0000 and FAULTnEN = 1, then the fault input n signal is delayed (3 + FFVAL[3:0]) rising edges of the system clock, that is, the FAULTFn bit is set (4 + FFVAL[3:0]) rising edges of the system clock after a rising edge occurs on the fault input n.



* where n = 3, 2, 1, 0

Figure 38-233. Fault input n control block diagram

If the fault control and fault input n are enabled and a rising edge at the fault input n signal is detected, a fault condition has occurred and the FAULTFn bit is set. The FAULTF bit is the logic OR of FAULTFn[3:0] bits. See the following figure.

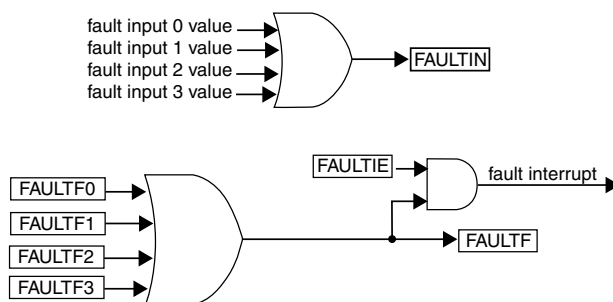


Figure 38-234. FAULTF and FAULTIN bits and fault interrupt

If the fault control is enabled ($\text{FAULTM}[1:0] \neq 0:0$), a fault condition has occurred and ($\text{FAULTEN} = 1$), then outputs are forced to their safe values:

- Channel (n) output takes the value of $\text{POL}(n)$
- Channel (n+1) takes the value of $\text{POL}(n+1)$

The fault interrupt is generated when ($\text{FAULTF} = 1$) and ($\text{FAULTIE} = 1$). This interrupt request remains set until:

- Software clears the FAULTF bit by reading FAULTF bit as 1 and writing 0 to it
- Software clears the FAULTIE bit
- A reset occurs

38.4.16.1 Automatic fault clearing

If the automatic fault clearing is selected ($\text{FAULTM}[1:0] = 1:1$), then the channels output disabled by fault control is again enabled when the fault input signal (FAULTIN) returns to zero and a new PWM cycle begins. See the following figure.

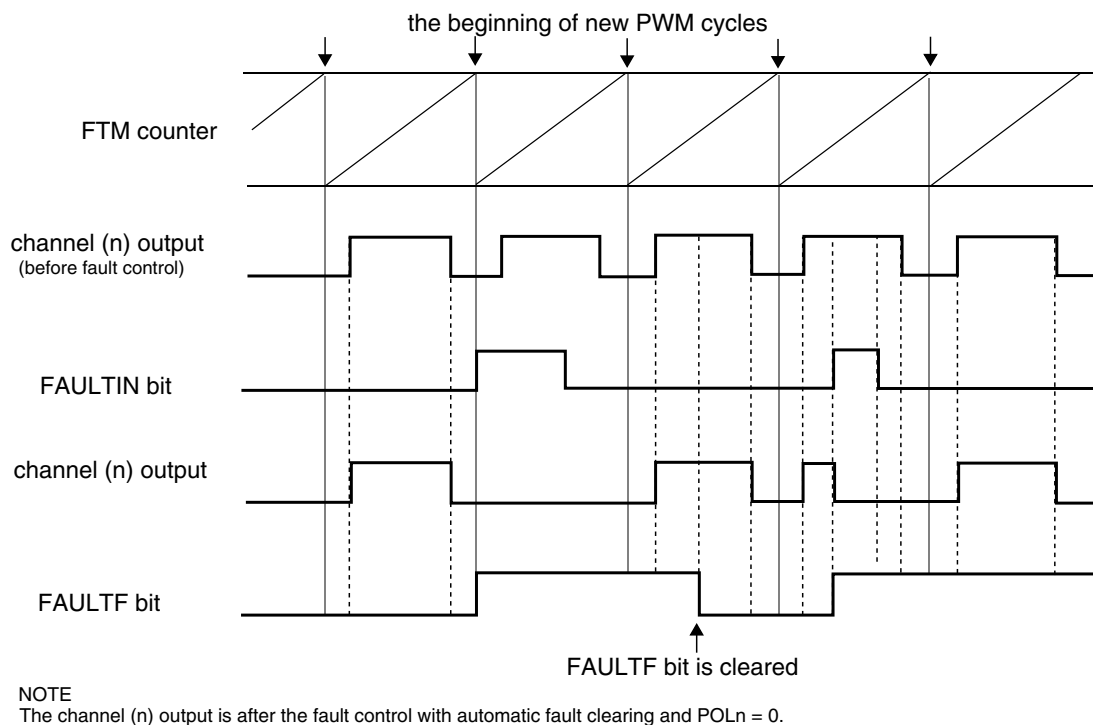
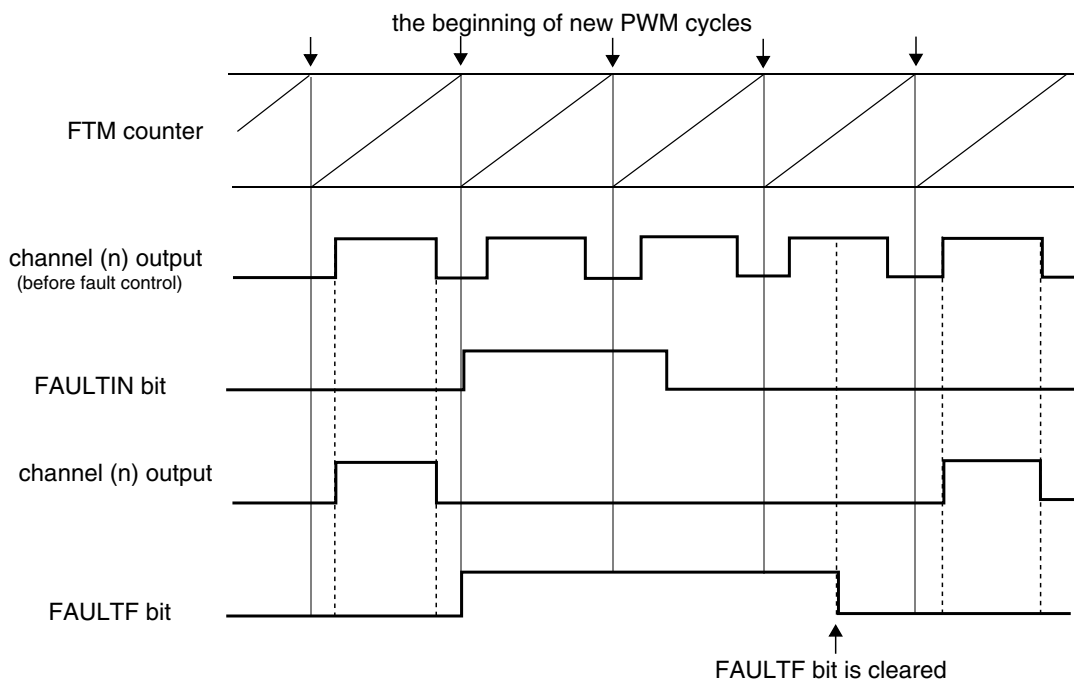


Figure 38-235. Fault control with automatic fault clearing

38.4.16.2 Manual fault clearing

If the manual fault clearing is selected ($\text{FAULTM}[1:0] = 0:1$ or $1:0$), then the channels output disabled by fault control is again enabled when the FAULTF bit is cleared and a new PWM cycle begins. See the following figure.



NOTE
The channel (n) output is after the fault control with manual fault clearing and $\text{POLn} = 0$.

Figure 38-236. Fault control with manual fault clearing

38.4.16.3 Fault inputs polarity control

The FLTjPOL bit selects the fault input j polarity, where $j = 0, 1, 2, 3$:

- If $\text{FLTjPOL} = 0$, the fault j input polarity is high, so the logical one at the fault input j indicates a fault.
- If $\text{FLTjPOL} = 1$, the fault j input polarity is low, so the logical zero at the fault input j indicates a fault.

38.4.17 Polarity control

The POLn bit selects the channel (n) output polarity:

- If $POL_n = 0$, the channel (n) output polarity is high, so the logical one is the active state and the logical zero is the inactive state.
- If $POL_n = 1$, the channel (n) output polarity is low, so the logical zero is the active state and the logical one is the inactive state.

38.4.18 Initialization

The initialization forces the CH_nOI bit value to the channel (n) output when a one is written to the INIT bit.

The initialization depends on COMP and DTEN bits. The following table shows the values that channels (n) and (n+1) are forced by initialization when the COMP and DTEN bits are zero.

Table 38-249. Initialization behavior when (COMP = 0 and DTEN = 0)

| CH(n)OI | CH(n+1)OI | Channel (n) Output | Channel (n+1) Output |
|---------|-----------|--------------------|----------------------|
| 0 | 0 | is forced to zero | is forced to zero |
| 0 | 1 | is forced to zero | is forced to one |
| 1 | 0 | is forced to one | is forced to zero |
| 1 | 1 | is forced to one | is forced to one |

The following table shows the values that channels (n) and (n+1) are forced by initialization when (COMP = 1) or (DTEN = 1).

Table 38-250. Initialization behavior when (COMP = 1 or DTEN = 1)

| CH(n)OI | CH(n+1)OI | Channel (n) Output | Channel (n+1) Output |
|---------|-----------|--------------------|----------------------|
| 0 | X | is forced to zero | is forced to one |
| 1 | X | is forced to one | is forced to zero |

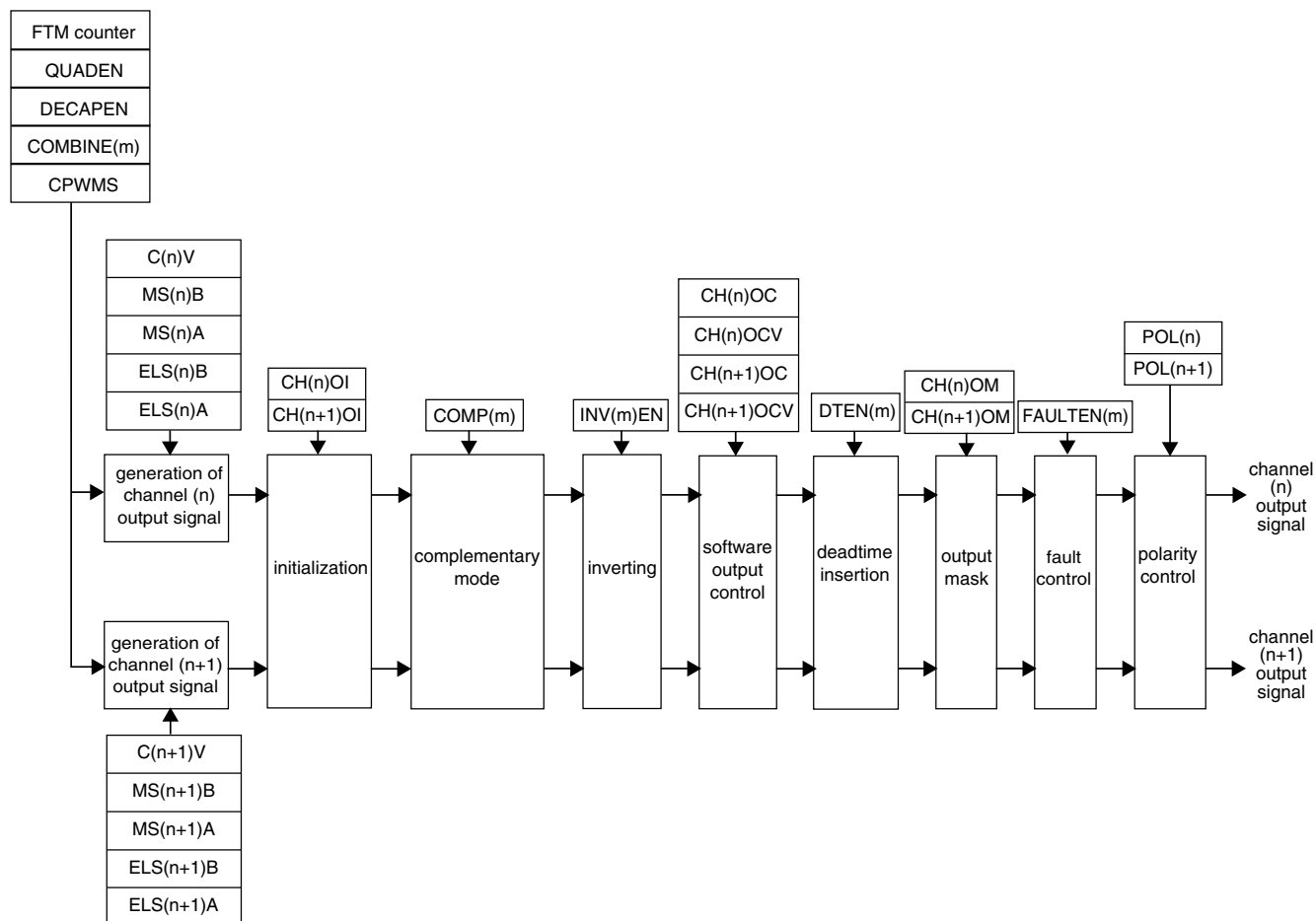
Note

The initialization feature must be used only with disabled FTM counter. See the description of the CLKS field in the Status and Control register.

38.4.19 Features priority

The following figure shows the priority of the features used at the generation of channels (n) and (n+1) outputs signals.

pair channels (m) - channels (n) and (n+1)



NOTE

The channels (n) and (n+1) are in output compare, EPWM, CPWM or combine modes.

Figure 38-237. Priority of the features used at the generation of channels (n) and (n+1) outputs signals

Note

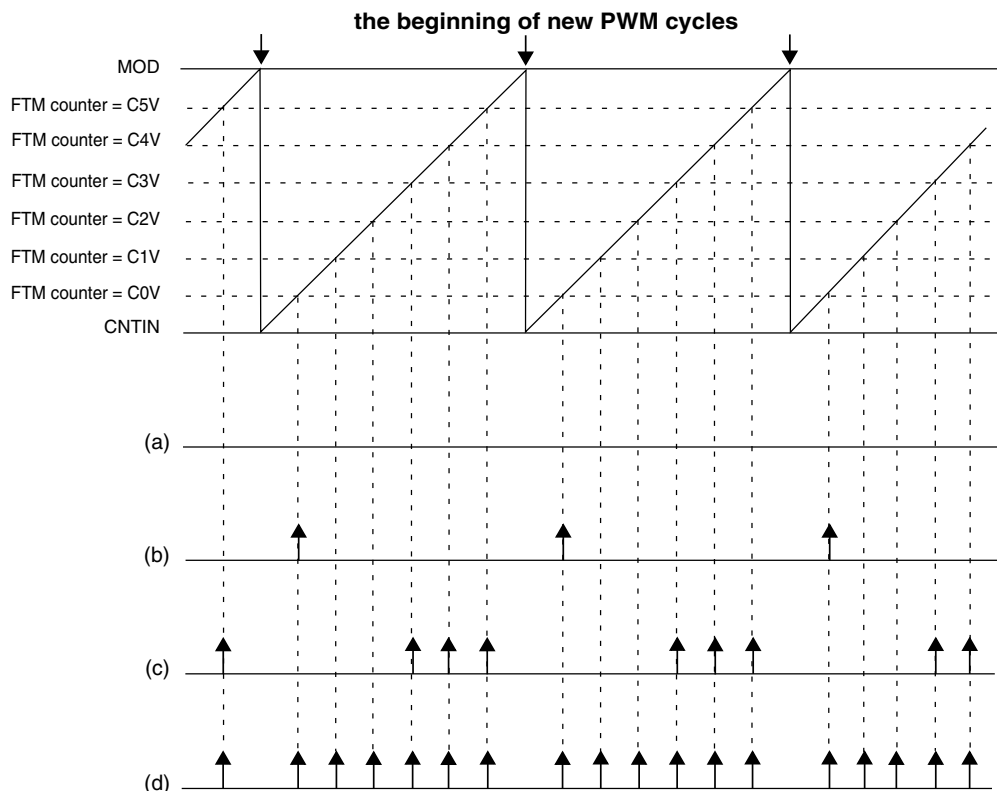
The **Initialization** feature must not be used with **Inverting** and **Software output control** features.

38.4.20 Channel trigger output

If $CH_jTRIG = 1$, where $j = 0, 1, 2, 3, 4$, or 5 , then the FTM generates a trigger when the channel (j) match occurs (FTM counter = $C(j)V$).

The channel trigger output provides a trigger signal that is used for on-chip modules.

The FTM is able to generate multiple triggers in one PWM period. Because each trigger is generated for a specific channel, several channels are required to implement this functionality. This behavior is described in the following figure.



NOTE

- (a) CH0TRIG = 0, CH1TRIG = 0, CH2TRIG = 0, CH3TRIG = 0, CH4TRIG = 0, CH5TRIG = 0
- (b) CH0TRIG = 1, CH1TRIG = 0, CH2TRIG = 0, CH3TRIG = 0, CH4TRIG = 0, CH5TRIG = 0
- (c) CH0TRIG = 0, CH1TRIG = 0, CH2TRIG = 0, CH3TRIG = 1, CH4TRIG = 1, CH5TRIG = 1
- (d) CH0TRIG = 1, CH1TRIG = 1, CH2TRIG = 1, CH3TRIG = 1, CH4TRIG = 1, CH5TRIG = 1

Figure 38-238. Channel match trigger

38.4.21 Initialization trigger

If INITTRIGEN = 1, then the FTM generates a trigger when the FTM counter is updated with the CNTIN register value in the following cases.

- The FTM counter is automatically updated with the CNTIN register value by the selected counting mode.
- When there is a write to CNT register.

functional description

- When there is the **FTM counter synchronization**.
- If (CNT = CNTIN), (CLKS[1:0] = 0:0), and a value different from zero is written to CLKS[1:0] bits.

The following figures show these cases.

CNTIN = 0x0000
MOD = 0x000F
CPWMS = 0

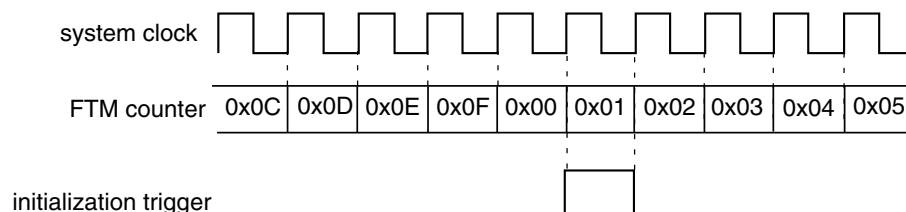


Figure 38-239. Initialization trigger is generated when the FTM counting achieves the CNTIN register value

CNTIN = 0x0000
MOD = 0x000F
CPWMS = 0

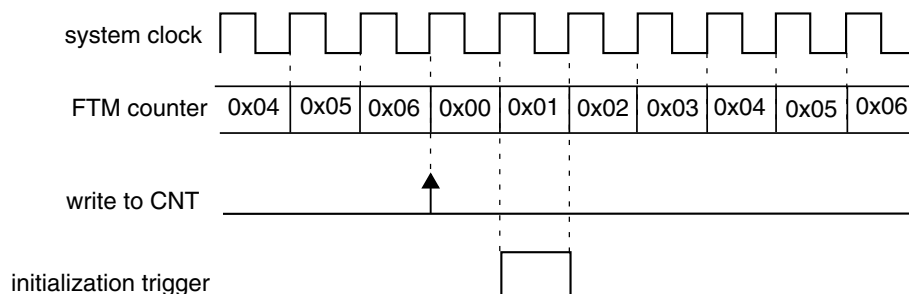


Figure 38-240. Initialization trigger is generated when there is a write to CNT register

CNTIN = 0x0000
MOD = 0x000F
CPWMS = 0

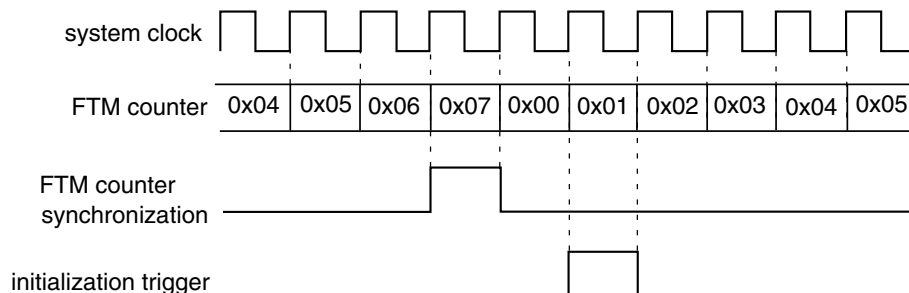


Figure 38-241. Initialization trigger is generated when there is the FTM counter synchronization

CNTIN = 0x0000
MOD = 0x000F
CPWMS = 0

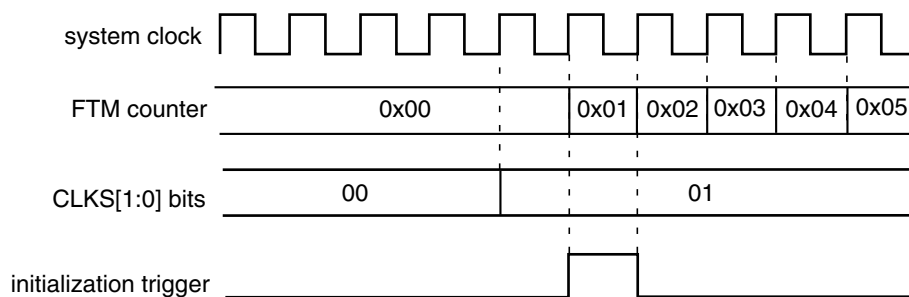


Figure 38-242. Initialization trigger is generated if (CNT = CNTIN), (CLKS[1:0] = 0:0), and a value different from zero is written to CLKS[1:0] bits

The initialization trigger output provides a trigger signal that is used for on-chip modules.

38.4.22 Capture Test mode

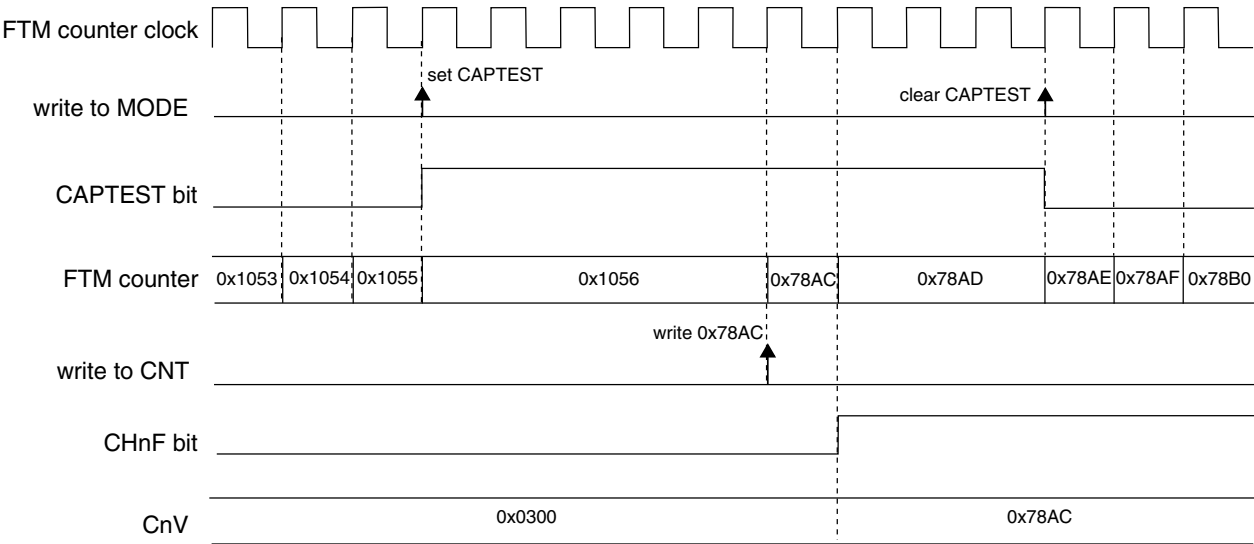
The Capture Test mode allows to test the CnV registers, the FTM counter and the interconnection logic between the FTM counter and CnV registers.

In this test mode, all channels must be configured for [Input Capture mode](#) and FTM counter must be configured to the [Up counting](#).

When the Capture Test mode is enabled (CAPTEST = 1), the FTM counter is frozen and any write to CNT register updates directly the FTM counter; see the following figure. After it was written, all CnV registers are updated with the written value to CNT register and CHnF bits are set. Therefore, the FTM counter is updated with its next value according to its configuration. Its next value depends on CNTIN, MOD, and the written value to FTM counter.

The next reads of CnV registers return the written value to the FTM counter and the next reads of CNT register return FTM counter next value.

functional description



NOTE

- FTM counter configuration: (FTMEN = 1), (QUADEN = 0), (CAPTEST = 1), (CPWMS = 0), (CNTIN = 0x0000), and (MOD = 0xFFFF)
- FTM channel n configuration: input capture mode - (DECAPEN = 0), (COMBINE = 0), and (MSnB:MSnA = 0:0)

Figure 38-243. Capture Test mode

38.4.23 DMA

The channel generates a DMA transfer request according to DMA and CHnIE bits. See the following table.

Table 38-251. Channel DMA transfer request

| DMA | CHnIE | Channel DMA Transfer Request | Channel Interrupt |
|-----|-------|--|---|
| 0 | 0 | The channel DMA transfer request is not generated. | The channel interrupt is not generated. |
| 0 | 1 | The channel DMA transfer request is not generated. | The channel interrupt is generated if (CHnF = 1). |
| 1 | 0 | The channel DMA transfer request is not generated. | The channel interrupt is not generated. |
| 1 | 1 | The channel DMA transfer request is generated if (CHnF = 1). | The channel interrupt is not generated. |

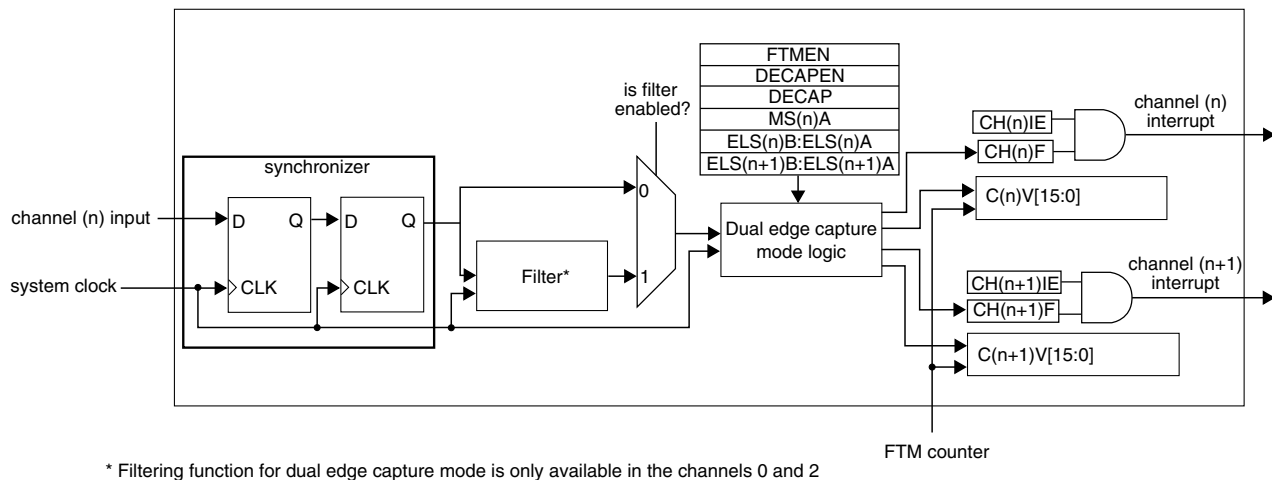
If DMA = 1, the CHnF bit is cleared either by channel DMA transfer done or reading CnSC while CHnF is set and then writing a zero to CHnF bit according to CHnIE bit. See the following table.

Table 38-252. Clear CHnF bit when DMA = 1

| CHnIE | How CHnF Bit Can Be Cleared |
|-------|---|
| 0 | CHnF bit is cleared either when the channel DMA transfer is done or by reading CnSC while CHnF is set and then writing a 0 to CHnF bit. |
| 1 | CHnF bit is cleared when the channel DMA transfer is done. |

38.4.24 Dual Edge Capture mode

The Dual Edge Capture mode is selected if DECAPEN = 1. This mode allows to measure a pulse width or period of the signal on the input of channel (n) of a channel pair. The channel (n) filter can be active in this mode when n is 0 or 2.


Figure 38-244. Dual Edge Capture mode block diagram

The MS(n)A bit defines if the Dual Edge Capture mode is one-shot or continuous.

The ELS(n)B:ELS(n)A bits select the edge that is captured by channel (n), and ELS(n+1)B:ELS(n+1)A bits select the edge that is captured by channel (n+1). If both ELS(n)B:ELS(n)A and ELS(n+1)B:ELS(n+1)A bits select the same edge, then it is the period measurement. If these bits select different edges, then it is a pulse width measurement.

In the Dual Edge Capture mode, only channel (n) input is used and channel (n+1) input is ignored.

If the selected edge by channel (n) bits is detected at channel (n) input, then CH(n)F bit is set and the channel (n) interrupt is generated (if CH(n)IE = 1). If the selected edge by channel (n+1) bits is detected at channel (n) input and (CH(n)F = 1), then CH(n+1)F bit is set and the channel (n+1) interrupt is generated (if CH(n+1)IE = 1).

The C(n)V register stores the value of FTM counter when the selected edge by channel (n) is detected at channel (n) input. The C(n+1)V register stores the value of FTM counter when the selected edge by channel (n+1) is detected at channel (n) input.

In this mode, a coherency mechanism ensures coherent data when the C(n)V and C(n+1)V registers are read. The only requirement is that C(n)V must be read before C(n+1)V.

Note

- The CH(n)F, CH(n)IE, MS(n)A, ELS(n)B, and ELS(n)A bits are channel (n) bits.
- The CH(n+1)F, CH(n+1)IE, MS(n+1)A, ELS(n+1)B, and ELS(n+1)A bits are channel (n+1) bits.
- The Dual Edge Capture mode must be used with ELS(n)B:ELS(n)A = 0:1 or 1:0, ELS(n+1)B:ELS(n+1)A = 0:1 or 1:0 and the FTM counter in [Free running counter](#).

38.4.24.1 One-Shot Capture mode

The One-Shot Capture mode is selected when (DECAPEN = 1), and (MS(n)A = 0). In this capture mode, only one pair of edges at the channel (n) input is captured. The ELS(n)B:ELS(n)A bits select the first edge to be captured, and ELS(n+1)B:ELS(n+1)A bits select the second edge to be captured.

The edge captures are enabled while DECAP bit is set. For each new measurement in One-Shot Capture mode, first the CH(n)F and CH(n+1) bits must be cleared, and then the DECAP bit must be set.

In this mode, the DECAP bit is automatically cleared by FTM when the edge selected by channel (n+1) is captured. Therefore, while DECAP bit is set, the one-shot capture is in process. When this bit is cleared, both edges were captured and the captured values are ready for reading in the C(n)V and C(n+1)V registers.

Similarly, when the CH(n+1)F bit is set, both edges were captured and the captured values are ready for reading in the C(n)V and C(n+1)V registers.

38.4.24.2 Continuous Capture mode

The Continuous Capture mode is selected when (DECAPEN = 1), and (MS(n)A = 1). In this capture mode, the edges at the channel (n) input are captured continuously. The ELS(n)B:ELS(n)A bits select the initial edge to be captured, and ELS(n+1)B:ELS(n+1)A bits select the final edge to be captured.

The edge captures are enabled while DECAP bit is set. For the initial use, first the CH(n)F and CH(n+1)F bits must be cleared, and then DECAP bit must be set to start the continuous measurements.

When the CH(n+1)F bit is set, both edges were captured and the captured values are ready for reading in the C(n)V and C(n+1)V registers. The latest captured values are always available in these registers even after the DECAP bit is cleared.

In this mode, it is possible to clear only the CH(n+1)F bit. Therefore, when the CH(n+1)F bit is set again, the latest captured values are available in C(n)V and C(n+1)V registers.

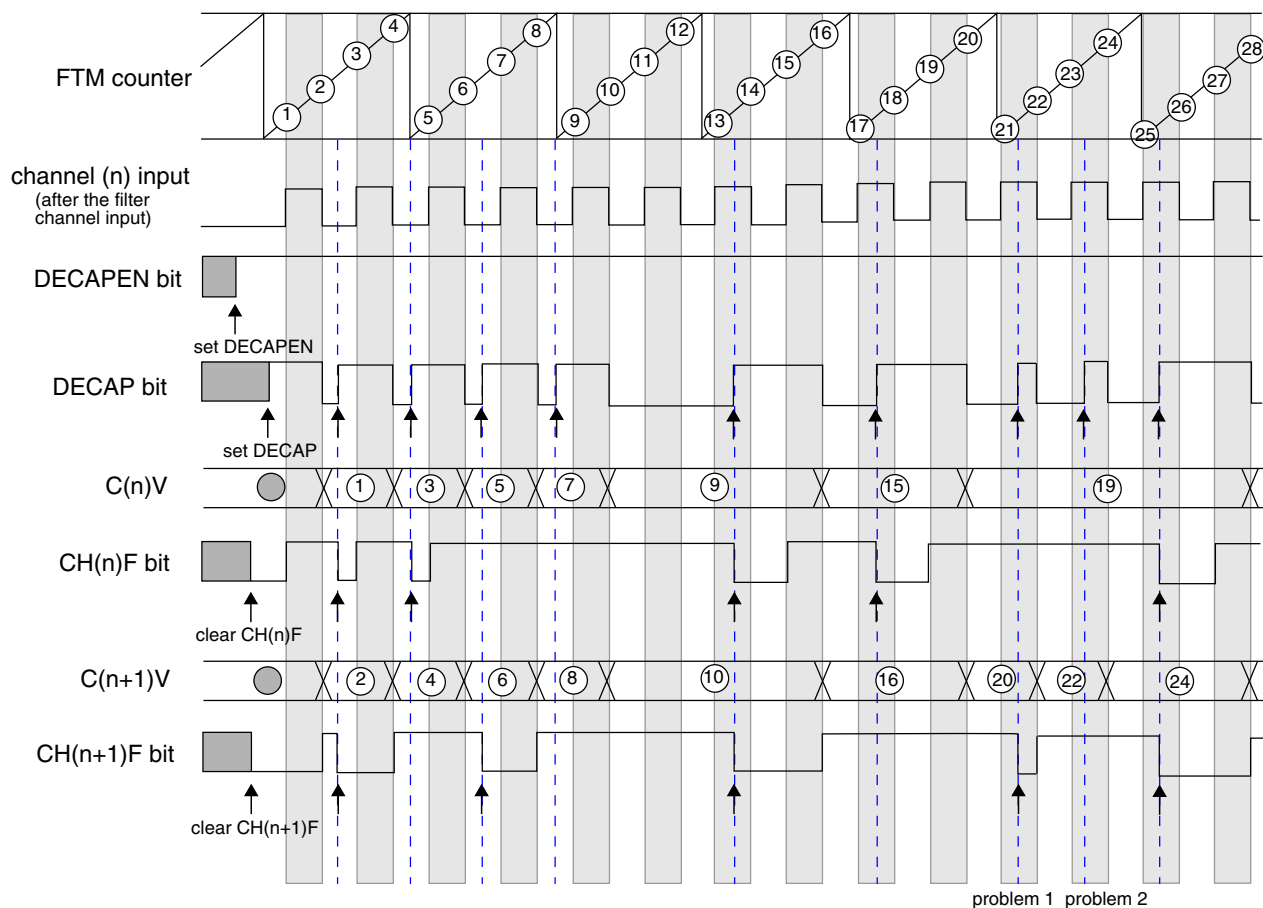
For a new sequence of the measurements in the Dual Edge Capture – Continuous mode, clear the CH(n)F and CH(n+1)F bits to start new measurements.

38.4.24.3 Pulse width measurement

If the channel (n) is configured to capture rising edges (ELS(n)B:ELS(n)A = 0:1) and the channel (n+1) to capture falling edges (ELS(n+1)B:ELS(n+1)A = 1:0), then the positive polarity pulse width is measured. If the channel (n) is configured to capture falling edges (ELS(n)B:ELS(n)A = 1:0) and the channel (n+1) to capture rising edges (ELS(n+1)B:ELS(n+1)A = 0:1), then the negative polarity pulse width is measured.

The pulse width measurement can be made in [One-Shot Capture mode](#) or [Continuous Capture mode](#).

The following figure shows an example of the Dual Edge Capture – One-Shot mode used to measure the positive polarity pulse width. The DECAPEN bit selects the Dual Edge Capture mode, so it remains set. The DECAP bit is set to enable the measurement of next positive polarity pulse width. The CH(n)F bit is set when the first edge of this pulse is detected, that is, the edge selected by ELS(n)B:ELS(n)A bits. The CH(n+1)F bit is set and DECAP bit is cleared when the second edge of this pulse is detected, that is, the edge selected by ELS(n+1)B:ELS(n+1)A bits. Both DECAP and CH(n+1)F bits indicate when two edges of the pulse were captured and the C(n)V and C(n+1)V registers are ready for reading.

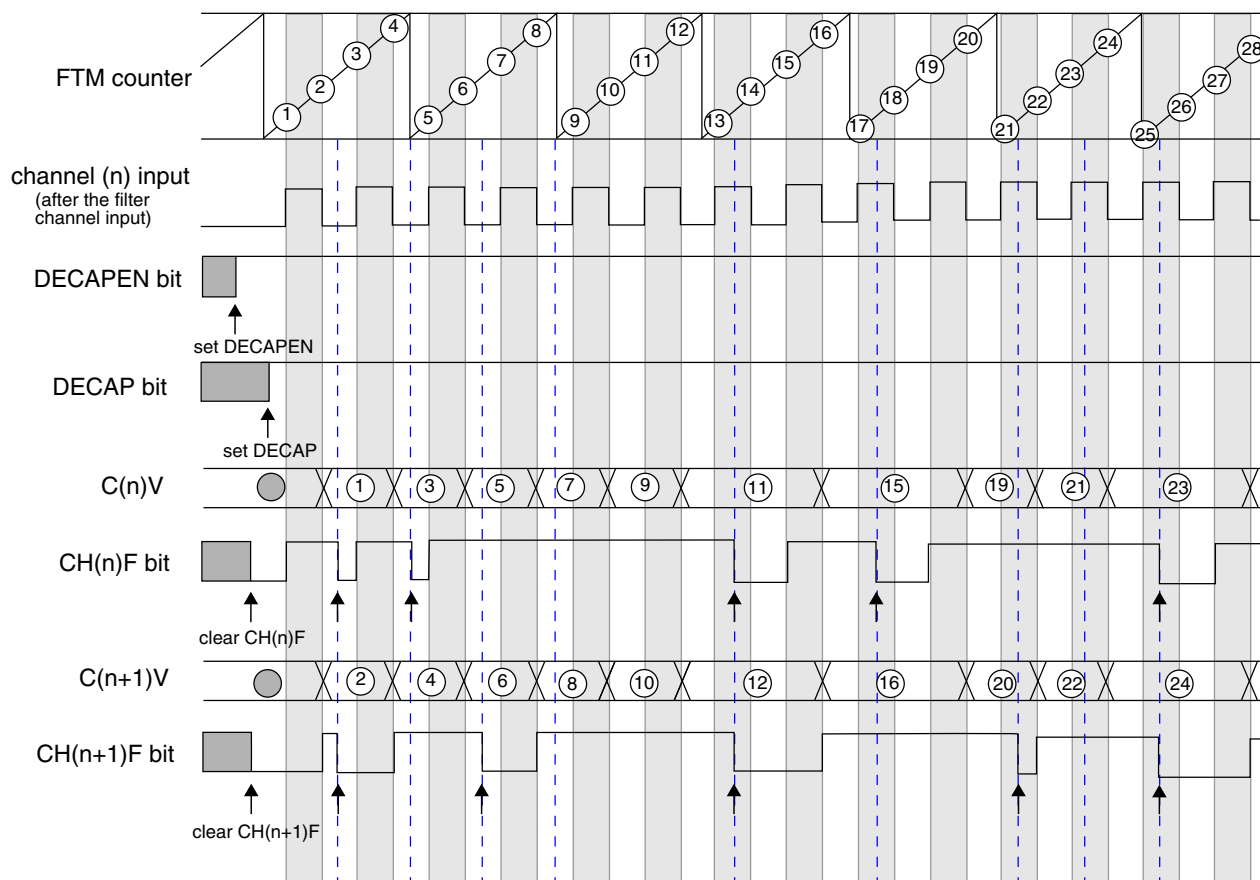


Note

- The commands set DECAPEN, set DECAP, clear CH(n)F, and clear CH(n+1)F are made by the user.
- Problem 1: channel (n) input = 1, set DECAP, not clear CH(n)F, and clear CH(n+1)F.
- Problem 2: channel (n) input = 1, set DECAP, not clear CH(n)F, and not clear CH(n+1)F.

Figure 38-245. Dual Edge Capture – One-Shot mode for positive polarity pulse width measurement

The following figure shows an example of the Dual Edge Capture – Continuous mode used to measure the positive polarity pulse width. The DECAPEN bit selects the Dual Edge Capture mode, so it remains set. While the DECAP bit is set the configured measurements are made. The CH(n)F bit is set when the first edge of the positive polarity pulse is detected, that is, the edge selected by ELS(n)B:ELS(n)A bits. The CH(n+1)F bit is set when the second edge of this pulse is detected, that is, the edge selected by ELS(n+1)B:ELS(n+1)A bits. The CH(n+1)F bit indicates when two edges of the pulse were captured and the C(n)V and C(n+1)V registers are ready for reading.



Note

- The commands set DECAPEN, set DECAP, clear CH(n)F, and clear CH(n+1)F are made by the user.

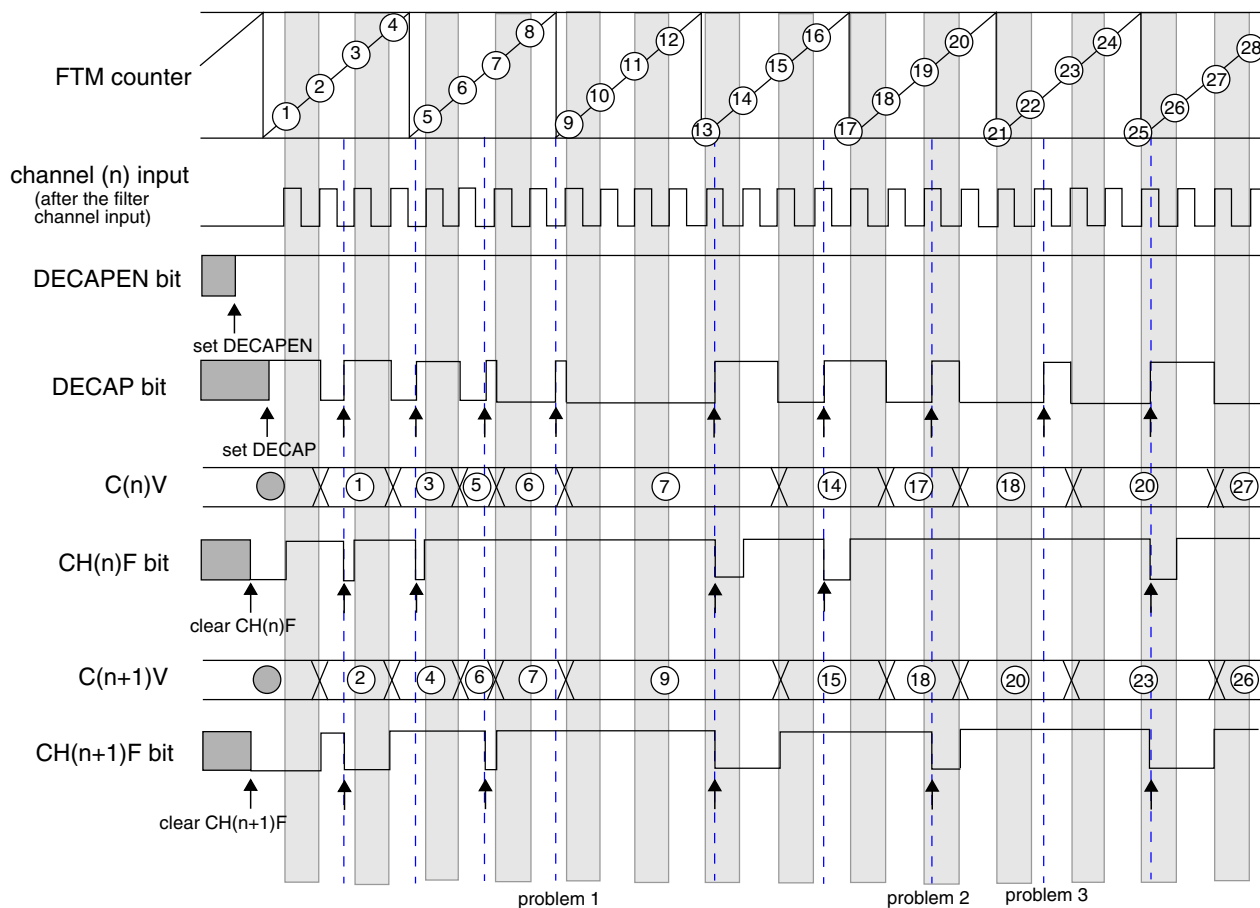
Figure 38-246. Dual Edge Capture – Continuous mode for positive polarity pulse width measurement

38.4.24.4 Period measurement

If the channels (n) and (n+1) are configured to capture consecutive edges of the same polarity, then the period of the channel (n) input signal is measured. If both channels (n) and (n+1) are configured to capture rising edges ($ELS(n)B:ELS(n)A = 0:1$ and $ELS(n+1)B:ELS(n+1)A = 0:1$), then the period between two consecutive rising edges is measured. If both channels (n) and (n+1) are configured to capture falling edges ($ELS(n)B:ELS(n)A = 1:0$ and $ELS(n+1)B:ELS(n+1)A = 1:0$), then the period between two consecutive falling edges is measured.

The period measurement can be made in [One-Shot Capture mode](#) or [Continuous Capture mode](#).

The following figure shows an example of the Dual Edge Capture – One-Shot mode used to measure the period between two consecutive rising edges. The DECAPEN bit selects the Dual Edge Capture mode, so it remains set. The DECAP bit is set to enable the measurement of next period. The CH(n)F bit is set when the first rising edge is detected, that is, the edge selected by ELS(n)B:ELS(n)A bits. The CH(n+1)F bit is set and DECAP bit is cleared when the second rising edge is detected, that is, the edge selected by ELS(n+1)B:ELS(n+1)A bits. Both DECAP and CH(n+1)F bits indicate when two selected edges were captured and the C(n)V and C(n+1)V registers are ready for reading.



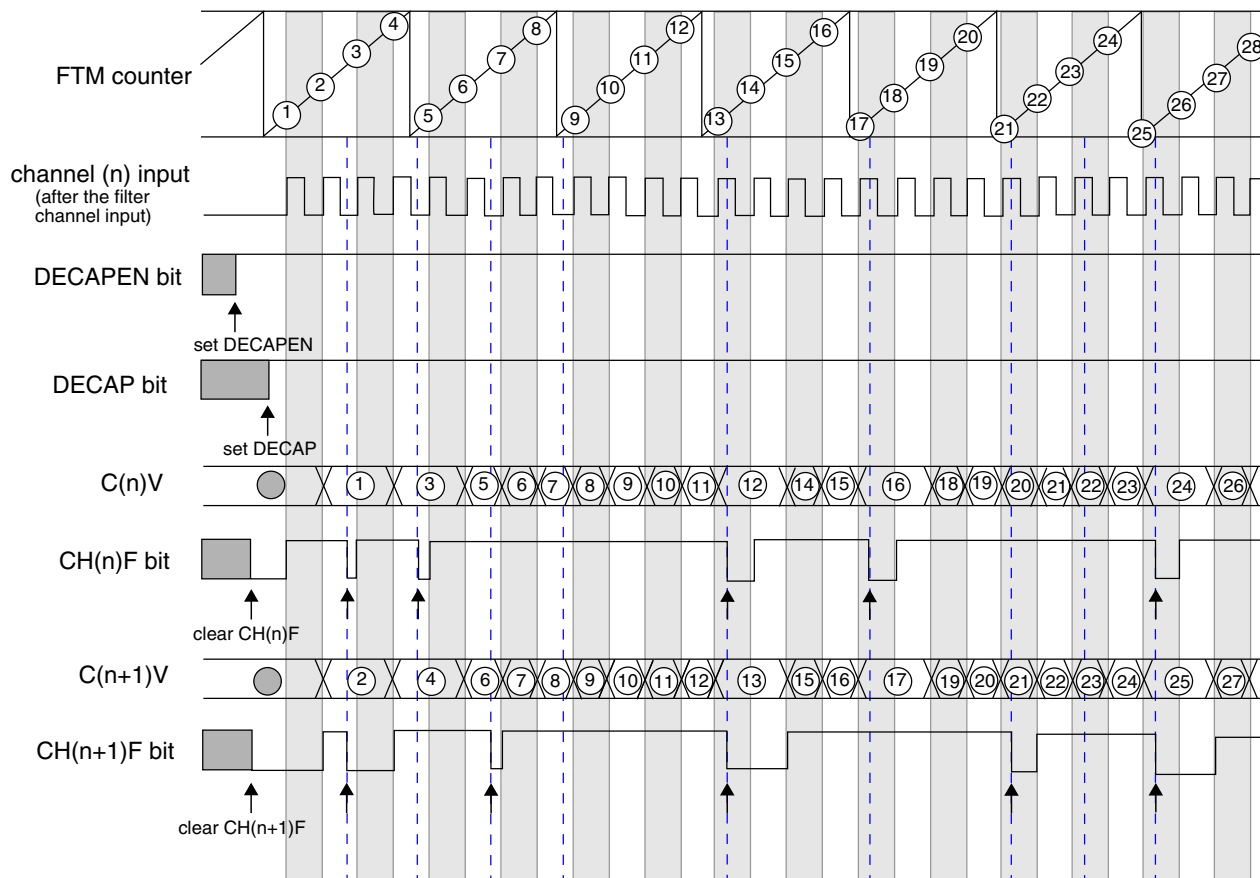
Note

- The commands set DECAPEN, set DECAP, clear CH(n)F, and clear CH(n+1)F are made by the user.
- Problem 1: channel (n) input = 0, set DECAP, not clear CH(n)F, and not clear CH(n+1)F.
- Problem 2: channel (n) input = 1, set DECAP, not clear CH(n)F, and clear CH(n+1)F.
- Problem 3: channel (n) input = 1, set DECAP, not clear CH(n)F, and not clear CH(n+1)F.

Figure 38-247. Dual Edge Capture – One-Shot mode to measure of the period between two consecutive rising edges

The following figure shows an example of the Dual Edge Capture – Continuous mode used to measure the period between two consecutive rising edges. The DECAPEN bit selects the Dual Edge Capture mode, so it remains set. While the DECAP bit is set the configured measurements are made. The CH(n)F bit is set when the first rising edge is detected, that is, the edge selected by ELS(n)B:ELS(n)A bits. The CH(n+1)F bit is set

when the second rising edge is detected, that is, the edge selected by $ELS(n+1)B:ELS(n+1)A$ bits. The $CH(n+1)F$ bit indicates when two edges of the period were captured and the $C(n)V$ and $C(n+1)V$ registers are ready for reading.



Note

- The commands set DECAPEN, set DECAP, clear $CH(n)F$, and clear $CH(n+1)F$ are made by the user.

Figure 38-248. Dual Edge Capture – Continuous mode to measure of the period between two consecutive rising edges

38.4.24.5 Read coherency mechanism

The Dual Edge Capture mode implements a read coherency mechanism between the FTM counter value captured in $C(n)V$ and $C(n+1)V$ registers. The read coherency mechanism is illustrated in the following figure. In this example, the channels (n) and (n+1) are in Dual Edge Capture – Continuous mode for positive polarity pulse width measurement. Thus, the channel (n) is configured to capture the FTM counter value when there is a rising edge at channel (n) input signal, and channel (n+1) to capture the FTM counter value when there is a falling edge at channel (n) input signal.

When a rising edge occurs in the channel (n) input signal, the FTM counter value is captured into channel (n) capture buffer. The channel (n) capture buffer value is transferred to C(n)V register when a falling edge occurs in the channel (n) input signal. C(n)V register has the FTM counter value when the previous rising edge occurred, and the channel (n) capture buffer has the FTM counter value when the last rising edge occurred.

When a falling edge occurs in the channel (n) input signal, the FTM counter value is captured into channel (n+1) capture buffer. The channel (n+1) capture buffer value is transferred to C(n+1)V register when the C(n)V register is read.

In the following figure, the read of C(n)V returns the FTM counter value when the event 1 occurred and the read of C(n+1)V returns the FTM counter value when the event 2 occurred.

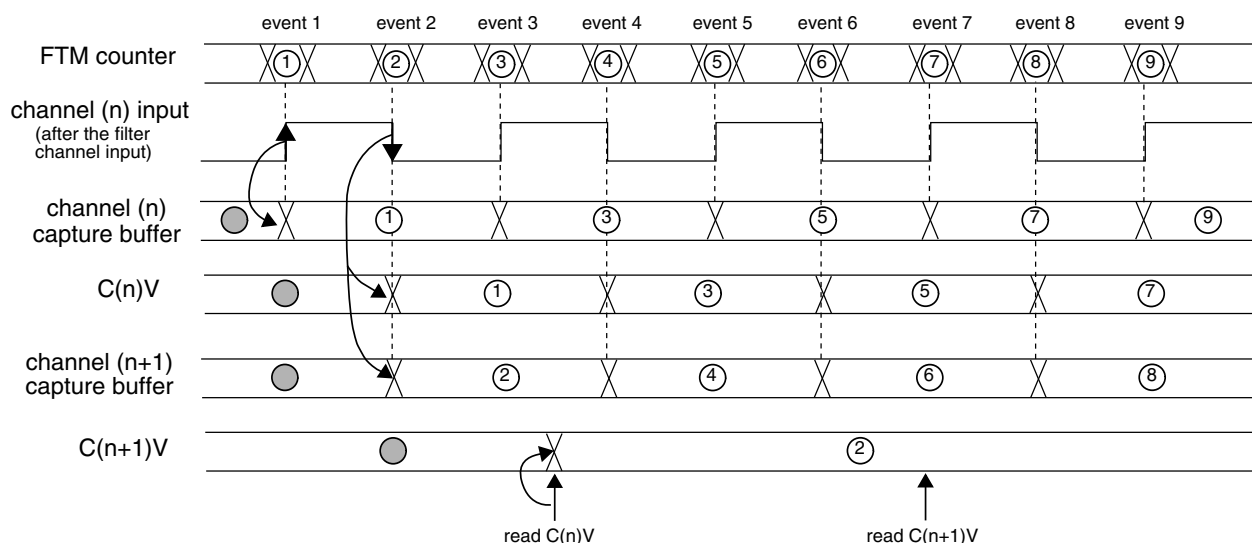


Figure 38-249. Dual Edge Capture mode read coherency mechanism

C(n)V register must be read prior to C(n+1)V register in dual edge capture one-shot and continuous modes for the read coherency mechanism works properly.

38.4.25 Quadrature Decoder mode

The Quadrature Decoder mode is selected if (QUADEN = 1). The Quadrature Decoder mode uses the input signals phase A and B to control the FTM counter increment and decrement. The following figure shows the quadrature decoder block diagram.

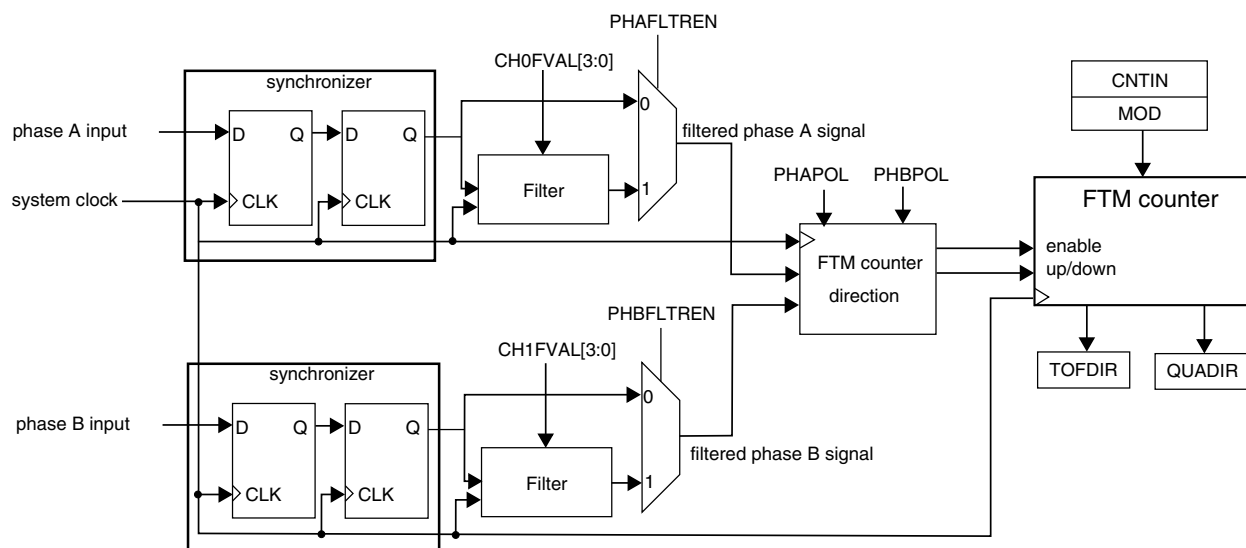


Figure 38-250. Quadrature Decoder block diagram

Each one of input signals phase A and B has a filter that is equivalent to the filter used in the channels input; [Filter for Input Capture mode](#). The phase A input filter is enabled by PHAFLTREN bit and this filter's value is defined by CH0FVAL[3:0] bits (CH(n)FVAL[3:0] bits in FILTER0 register). The phase B input filter is enabled by PHBFLTREN bit and this filter's value is defined by CH1FVAL[3:0] bits (CH(n+1)FVAL[3:0] bits in FILTER0 register).

Except for CH0FVAL[3:0] and CH1FVAL[3:0] bits, no channel logic is used in Quadrature Decoder mode.

Note

Notice that the FTM counter is clocked by the phase A and B input signals when quadrature decoder mode is selected. Therefore it is expected that the Quadrature Decoder be used only with the FTM channels in input capture or output compare modes.

Note

An edge at phase A must not occur together an edge at phase B and vice-versa.

The PHAPOL bit selects the polarity of the phase A input, and the PHBPOL bit selects the polarity of the phase B input.

The QUADM0DE selects the encoding mode used in the Quadrature Decoder mode. If QUADM0DE = 1, then the count and direction encoding mode is enabled; see the following figure. In this mode, the phase B input value indicates the counting direction, and the phase A input defines the counting rate. The FTM counter is updated when there is a rising edge at phase A input signal.

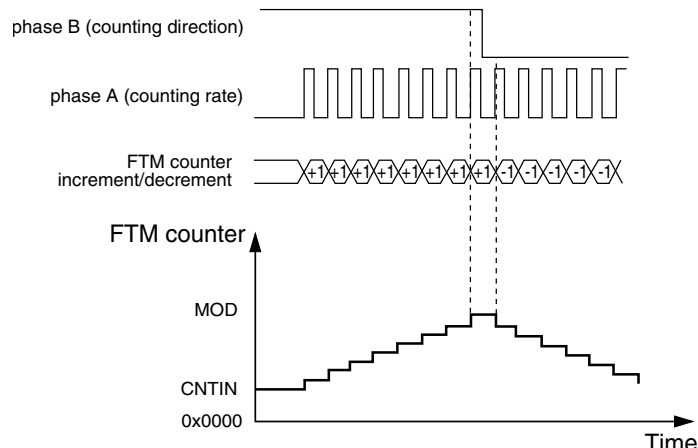


Figure 38-251. Quadrature Decoder – Count and Direction Encoding mode

If QUADM0DE = 0, then the Phase A and Phase B Encoding mode is enabled; see the following figure. In this mode, the relationship between phase A and B signals indicates the counting direction, and phase A and B signals define the counting rate. The FTM counter is updated when there is an edge either at the phase A or phase B signals.

If PHAPOL = 0 and PHBPOL = 0, then the FTM counter increment happens when:

- there is a rising edge at phase A signal and phase B signal is at logic zero;
- there is a rising edge at phase B signal and phase A signal is at logic one;
- there is a falling edge at phase B signal and phase A signal is at logic zero;
- there is a falling edge at phase A signal and phase B signal is at logic one;

and the FTM counter decrement happens when:

- there is a falling edge at phase A signal and phase B signal is at logic zero;
- there is a falling edge at phase B signal and phase A signal is at logic one;
- there is a rising edge at phase B signal and phase A signal is at logic zero;
- there is a rising edge at phase A signal and phase B signal is at logic one.

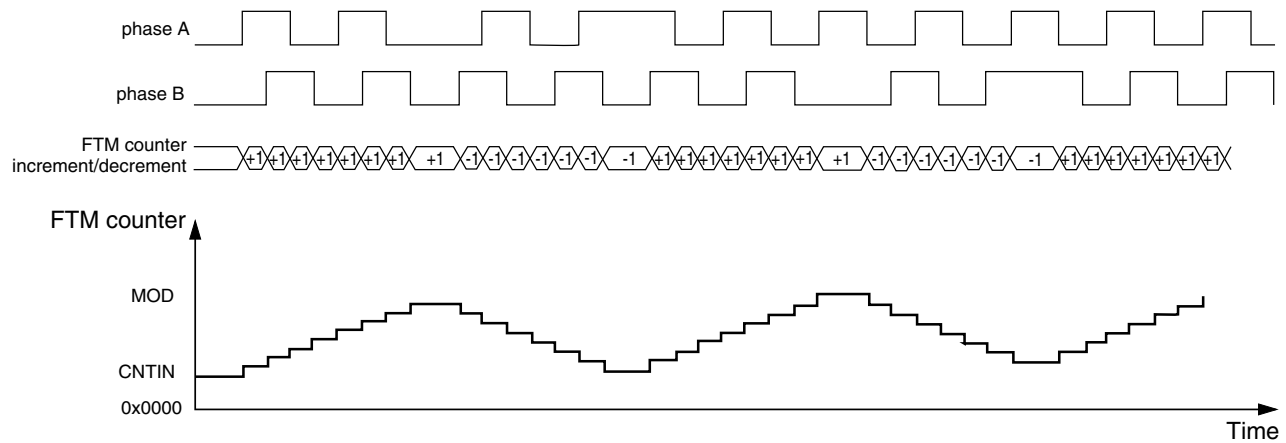


Figure 38-252. Quadrature Decoder – Phase A and Phase B Encoding mode

The following figure shows the FTM counter overflow in up counting. In this case, when the FTM counter changes from MOD to CNTIN, TOF and TOFDIR bits are set. TOF bit indicates the FTM counter overflow occurred. TOFDIR indicates the counting was up when the FTM counter overflow occurred.

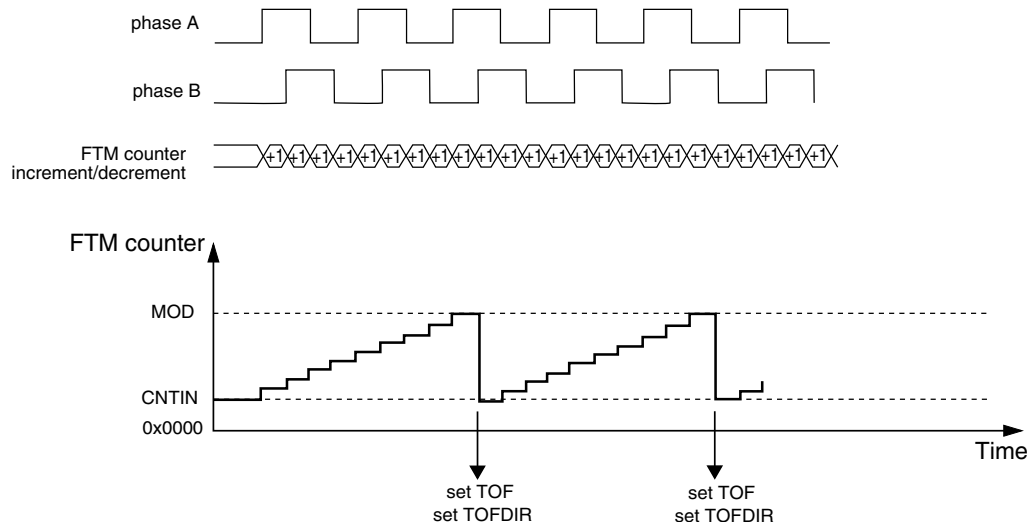


Figure 38-253. FTM Counter overflow in up counting for Quadrature Decoder mode

The following figure shows the FTM counter overflow in down counting. In this case, when the FTM counter changes from CNTIN to MOD, TOF bit is set and TOFDIR bit is cleared. TOF bit indicates the FTM counter overflow occurred. TOFDIR indicates the counting was down when the FTM counter overflow occurred.

functional description

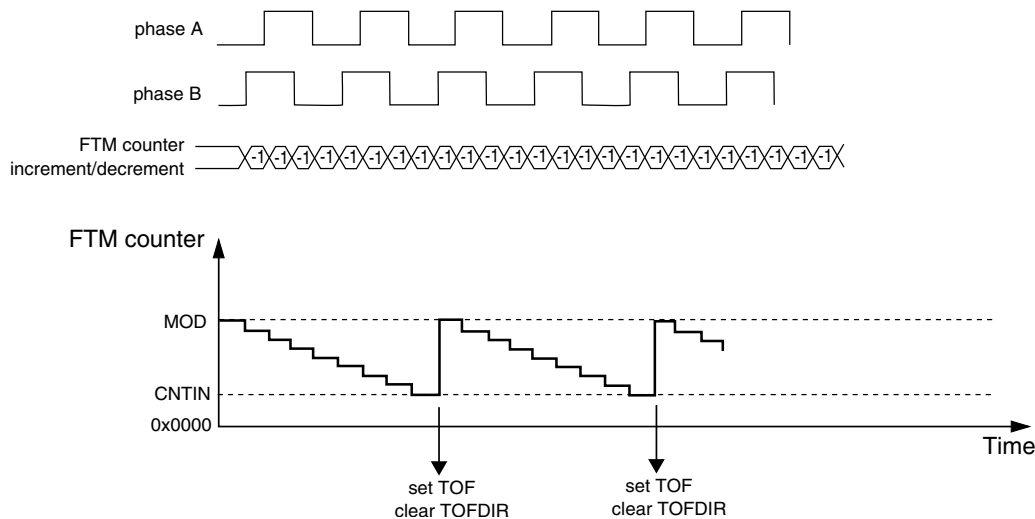


Figure 38-254. FTM counter overflow in down counting for Quadrature Decoder mode

38.4.25.1 Quadrature Decoder boundary conditions

The following figures show the FTM counter responding to motor jittering typical in motor position control applications.

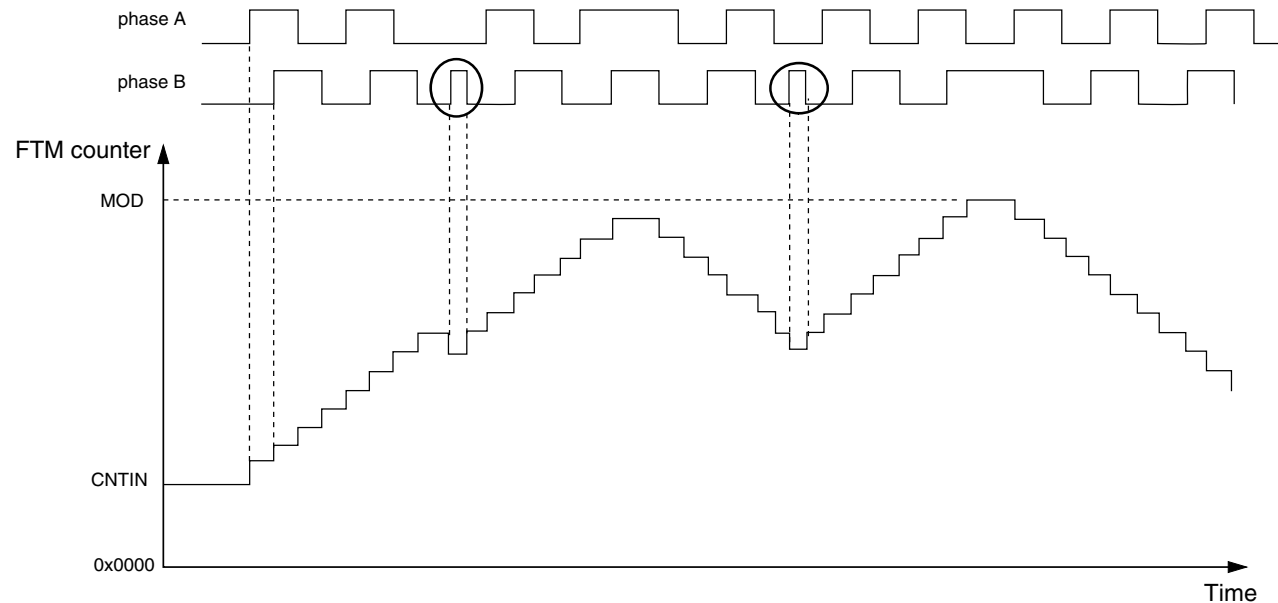


Figure 38-255. Motor position jittering in a mid count value

The following figure shows motor jittering produced by the phase B and A pulses respectively:

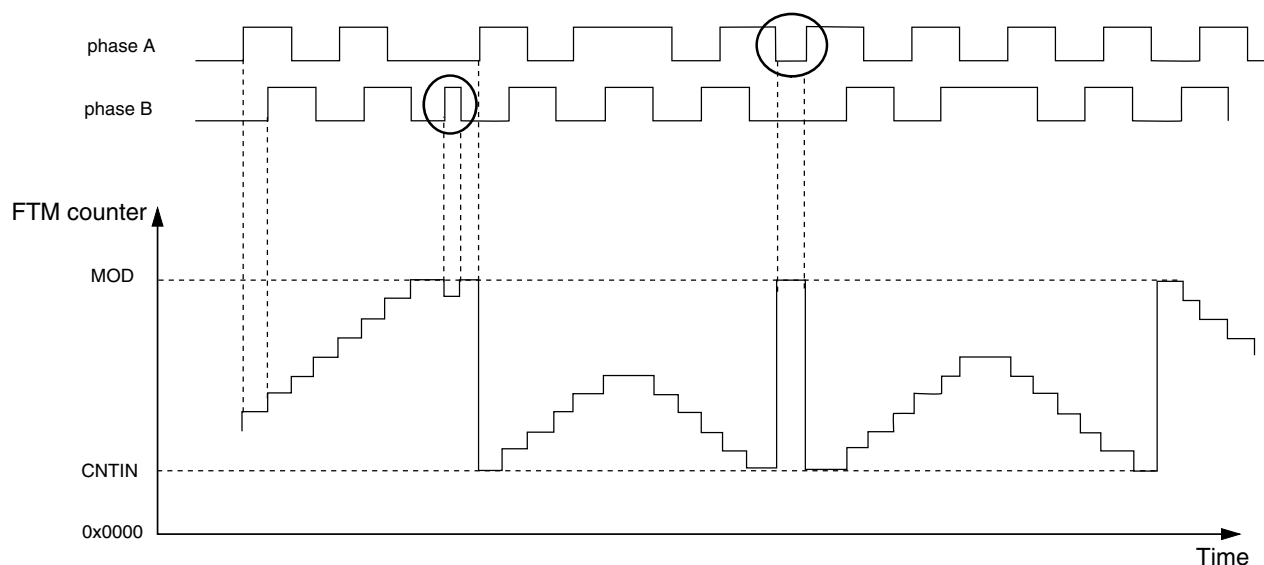


Figure 38-256. Motor position jittering near maximum and minimum count value

The first highlighted transition causes a jitter on the FTM counter value near the maximum count value (MOD). The second indicated transition occurs on phase A and causes the FTM counter transition between the maximum and minimum count values which are defined by MOD and CNTIN registers.

The appropriate settings of the phase A and phase B input filters are important to avoid glitches that may cause oscillation on the FTM counter value. The preceding figures show examples of oscillations that can be caused by poor input filter setup. Thus, it is important to guarantee a minimum pulse width to avoid these oscillations.

38.4.26 BDM mode

When the chip is in BDM mode, the BDMMODE[1:0] bits select the behavior of the FTM counter, the CH(n)F bit, the channels output, and the writes to the MOD, CNTIN, and C(n)V registers according to the following table.

Table 38-253. FTM behavior when the chip is in BDM mode

| BDMMODE | FTM Counter | CH(n)F Bit | FTM Channels Output | Writes to MOD, CNTIN, and C(n)V Registers |
|---------|-------------|------------|---|--|
| 00 | Stopped | can be set | Functional mode | Writes to these registers bypass the registers buffers |
| 01 | Stopped | is not set | The channels outputs are forced to their safe value according to POLn bit | Writes to these registers bypass the registers buffers |
| 10 | Stopped | is not set | The channels outputs are frozen when the chip enters in BDM mode | Writes to these registers bypass the registers buffers |

Table continues on the next page...

Table 38-253. FTM behavior when the chip is in BDM mode (continued)

| BDMMODE | FTM Counter | CH(n)F Bit | FTM Channels Output | Writes to MOD, CNTIN, and C(n)V Registers |
|---------|-----------------|------------|---------------------|---|
| 11 | Functional mode | can be set | Functional mode | Functional mode |

Note that if BDMMODE[1:0] = 2'b00 then the channels outputs remain at the value when the chip enters in BDM mode, because the FTM counter is stopped. However, the following situations modify the channels outputs in this BDM mode.

- Write any value to CNT register; see [Counter reset](#). In this case, the FTM counter is updated with the CNTIN register value and the channels outputs are updated to the initial value – except for those channels set to Output Compare mode.
- FTM counter is reset by PWM Synchronization mode; see [FTM counter synchronization](#). In this case, the FTM counter is updated with the CNTIN register value and the channels outputs are updated to the initial value – except for channels in Output Compare mode.
- In the channels outputs initialization, the channel (n) output is forced to the CH(n)OI bit value when the value 1 is written to INIT bit. See [Initialization](#).

Note

The BDMMODE[1:0] = 2'b00 must not be used with the [Fault control](#). Even if the fault control is enabled and a fault condition exists, the channels outputs values are updated as above.

Note

If CLKS[1:0] = 2'b00 in BDM, a non-zero value is written to CLKS in BDM, and CnV = CNTIN when the BDM is disabled, then the CHnF bit is set (since if the channel is a 0% EPWM signal) when the BDM is disabled.

38.4.27 Intermediate load

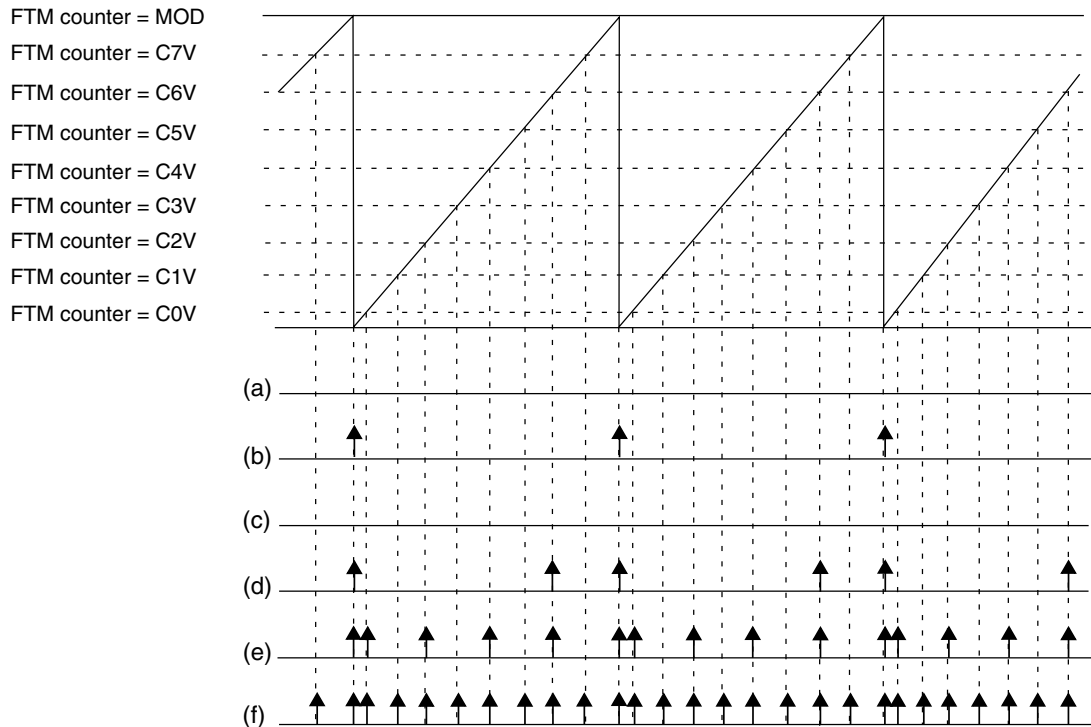
The PWMLOAD register allows to update the MOD, CNTIN, and C(n)V registers with the content of the register buffer at a defined load point. In this case, it is not required to use the PWM synchronization.

There are multiple possible loading points for intermediate load:

Table 38-254. When possible loading points are enabled

| Loading point | Enabled |
|--|-----------------|
| When the FTM counter wraps from MOD value to CNTIN value | Always |
| At the channel (j) match (FTM counter = C(j)V) | When CHjSEL = 1 |

The following figure shows some examples of enabled loading points.


NOTE

- (a) LDOK = 0, CH0SEL = 0, CH1SEL = 0, CH2SEL = 0, CH3SEL = 0, CH4SEL = 0, CH5SEL = 0, CH6SEL = 0, CH7SEL = 0
(b) LDOK = 1, CH0SEL = 0, CH1SEL = 0, CH2SEL = 0, CH3SEL = 0, CH4SEL = 0, CH5SEL = 0, CH6SEL = 0, CH7SEL = 0
(c) LDOK = 0, CH0SEL = 0, CH1SEL = 0, CH2SEL = 0, CH3SEL = 1, CH4SEL = 0, CH5SEL = 0, CH6SEL = 0, CH7SEL = 0
(d) LDOK = 1, CH0SEL = 0, CH1SEL = 0, CH2SEL = 0, CH3SEL = 0, CH4SEL = 0, CH5SEL = 0, CH6SEL = 1, CH7SEL = 0
(e) LDOK = 1, CH0SEL = 1, CH1SEL = 0, CH2SEL = 1, CH3SEL = 0, CH4SEL = 1, CH5SEL = 0, CH6SEL = 1, CH7SEL = 0
(f) LDOK = 1, CH0SEL = 1, CH1SEL = 1, CH2SEL = 1, CH3SEL = 1, CH4SEL = 1, CH5SEL = 1, CH6SEL = 1, CH7SEL = 1

Figure 38-257. Loading points for intermediate load

After enabling the loading points, the LDOK bit must be set for the load to occur. In this case, the load occurs at the next enabled loading point according to the following conditions:

Table 38-255. Conditions for loads occurring at the next enabled loading point

| When a new value was written | Then |
|------------------------------|--|
| To the MOD register | The MOD register is updated with its write buffer value. |

Table continues on the next page...

Table 38-255. Conditions for loads occurring at the next enabled loading point (continued)

| When a new value was written | Then |
|---|--|
| To the CNTIN register and CNTINC = 1 | The CNTIN register is updated with its write buffer value. |
| To the C(n)V register and SYNCENm = 1 – where m indicates the pair channels (n) and (n+1) | The C(n)V register is updated with its write buffer value. |
| To the C(n+1)V register and SYNCENm = 1 – where m indicates the pair channels (n) and (n+1) | The C(n+1)V register is updated with its write buffer value. |

NOTE

- If ELSjB and ELSjA bits are different from zero, then the channel (j) output signal is generated according to the configured output mode. If ELSjB and ELSjA bits are zero, then the generated signal is not available on channel (j) output.
- If CHjIE = 1, then the channel (j) interrupt is generated when the channel (j) match occurs.
- At the intermediate load neither the channels outputs nor the FTM counter are changed. Software must set the intermediate load at a safe point in time.

38.4.28 Global time base (GTB)

The global time base (GTB) is a FTM function that allows the synchronization of multiple FTM modules on a chip. The following figure shows an example of the GTB feature used to synchronize two FTM modules. In this case, the FTM A and B channels can behave as if just one FTM module was used, that is, a global time base.

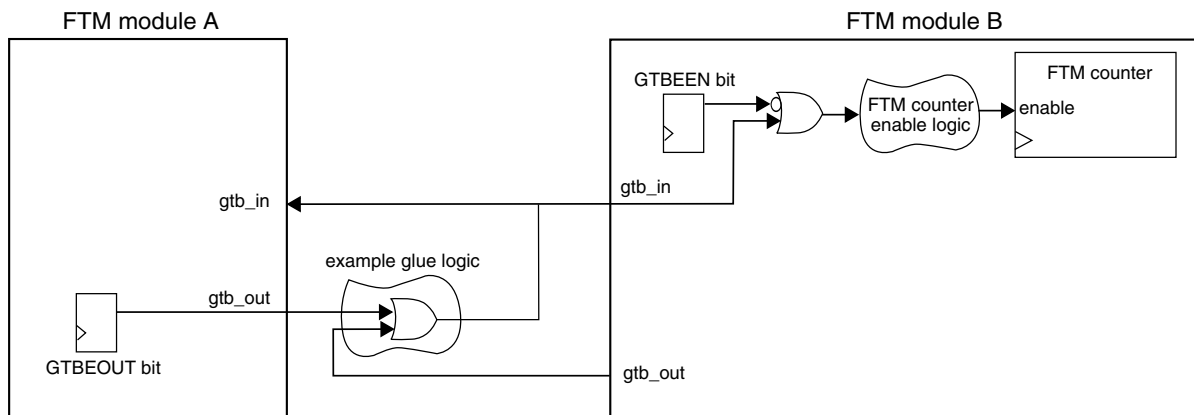


Figure 38-258. Global time base (GTB) block diagram

The GTB functionality is implemented by the GTBEEN and GTBEOUT bits in the CONF register, the input signal *gtb_in*, and the output signal *gtb_out*. The GTBEEN bit enables *gtb_in* to control the FTM counter enable signal:

- If GTBEEN = 0, each one of FTM modules works independently according to their configured mode.
- If GTBEEN = 1, the FTM counter update is enabled only when *gtb_in* is 1.

In the configuration described in the preceding figure, FTM modules A and B have their FTM counters enabled if at least one of the *gtb_out* signals from one of the FTM modules is 1. There are several possible configurations for the interconnection of the *gtb_in* and *gtb_out* signals, represented by the example glue logic shown in the figure. Note that these configurations are chip-dependent and implemented outside of the FTM modules. See the chip-specific FTM information for the chip's specific implementation.

NOTE

- In order to use the GTB signals to synchronize the FTM counter of different FTM modules, the configuration of each FTM module should guarantee that its FTM counter starts counting as soon as the *gtb_in* signal is 1.
- The GTB feature does not provide continuous synchronization of FTM counters, meaning that the FTM counters may lose synchronization during FTM operation. The GTB feature only allows the FTM counters to *start* their operation synchronously.

38.4.28.1 Enabling the global time base (GTB)

To enable the GTB feature, follow these steps for each participating FTM module:

1. Stop the FTM counter: Write 00b to SC[CLKS].
2. Program the FTM to the intended configuration. The FTM counter mode needs to be consistent across all participating modules.
3. Write 1 to CONF[GTBEEN] and write 0 to CONF[GTBEOUT] at the same time.
4. Select the intended FTM counter clock source in SC[CLKS]. The clock source needs to be consistent across all participating modules.
5. Reset the FTM counter: Write any value to the CNT register.

To initiate the GTB feature in the configuration described in the preceding figure, write 1 to CONF[GTBEOUT] in the FTM module used as the time base.

38.5 Reset overview

The FTM is reset whenever any chip reset occurs.

When the FTM exits from reset:

- the FTM counter and the prescaler counter are zero and are stopped (CLKS[1:0] = 00b);
- the timer overflow interrupt is zero, see [Timer Overflow Interrupt](#);
- the channels interrupts are zero, see [Channel \(n\) Interrupt](#);
- the fault interrupt is zero, see [Fault Interrupt](#);
- the channels are in input capture mode, see [Input Capture mode](#);
- the channels outputs are zero;
- the channels pins are not controlled by FTM (ELS(n)B:ELS(n)A = 0:0) (See the table in the description of CnSC register).

The following figure shows the FTM behavior after the reset. At the reset (item 1), the FTM counter is disabled (see the description of the CLKS field in the Status and Control register), its value is updated to zero and the pins are not controlled by FTM (See the table in the description of CnSC register).

After the reset, the FTM should be configured (item 2). It is necessary to define the FTM counter mode, the FTM counting limits (MOD and CNTIN registers value), the channels mode and CnV registers value according to the channels mode.

Thus, it is recommended to write any value to CNT register (item 3). This write updates the FTM counter with the CNTIN register value and the channels output with its initial value (except for channels in output compare mode) ([Counter reset](#)).

The next step is to select the FTM counter clock by the CLKS[1:0] bits (item 4). It is important to highlight that the pins are only controlled by FTM when CLKS[1:0] bits are different from zero (See the table in the description of CnSC register).

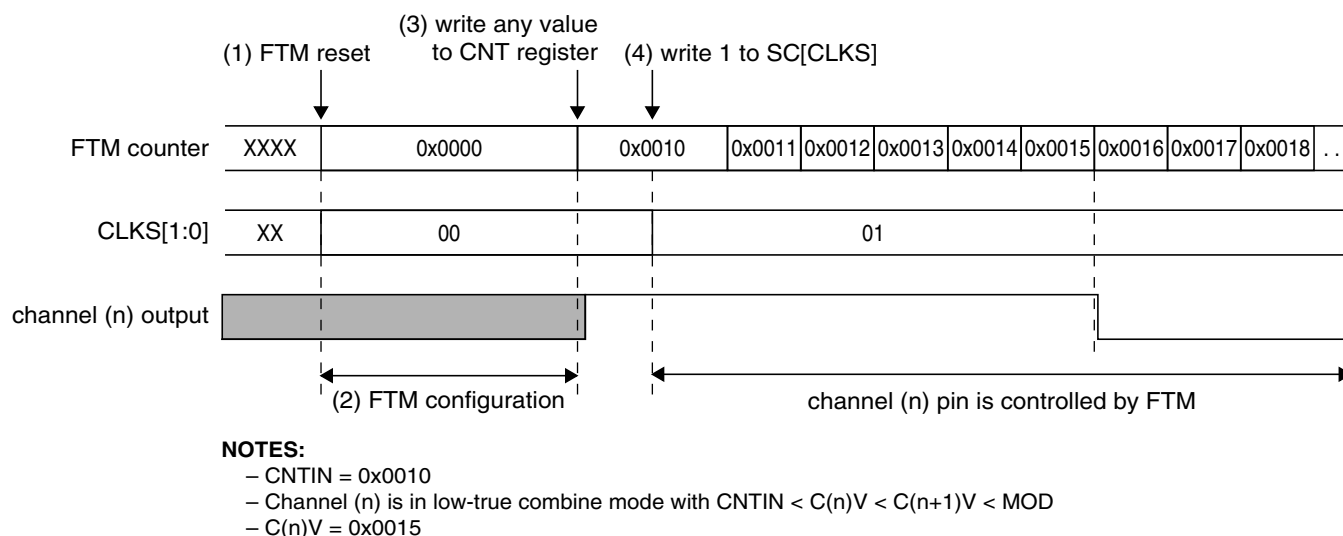


Figure 38-259. FTM behavior after reset when the channel (n) is in Combine mode

The following figure shows an example when the channel (n) is in Output Compare mode and the channel (n) output is toggled when there is a match. In the Output Compare mode, the channel output is not updated to its initial value when there is a write to CNT register (item 3). In this case, use the software output control ([Software output control](#)) or the initialization ([Initialization](#)) to update the channel output to the selected value (item 4).

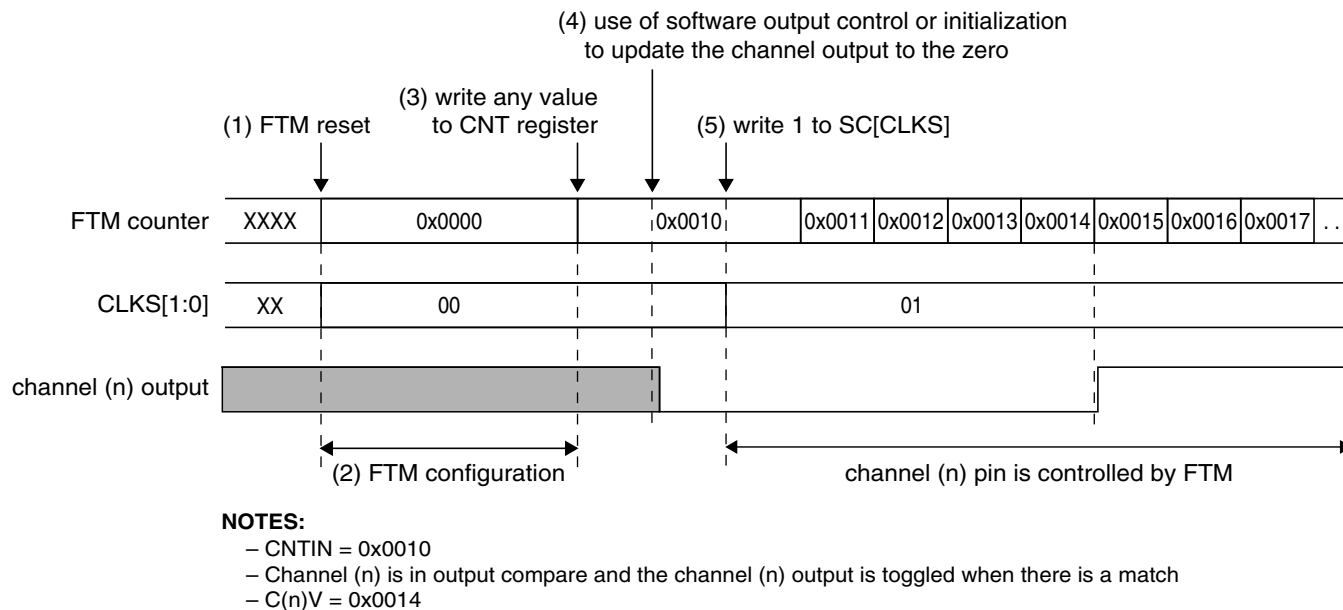


Figure 38-260. FTM behavior after reset when the channel (n) is in Output Compare mode

38.6 FTM Interrupts

38.6.1 Timer Overflow Interrupt

The timer overflow interrupt is generated when (TOIE = 1) and (TOF = 1).

38.6.2 Channel (n) Interrupt

The channel (n) interrupt is generated when (CHnIE = 1) and (CHnF = 1).

38.6.3 Fault Interrupt

The fault interrupt is generated when (FAULTIE = 1) and (FAULTF = 1).

38.7 Initialization Procedure

The following initialization procedure is recommended to configure the FlexTimer operation. This procedure can also be used to do a new configuration of the FlexTimer operation.

- Define the POL bits.
- Mask the channels outputs using SYNCHOM = 0. Two clocks after the write to OUTMASK, the channels output are in the safe value.
- (Re)Configuration FTM counter and channels to generation of periodic signals - Disable the clock. If the selected mode is Quadrature Decoder, then disable this mode. Examples of the (re)configuration:
 - Write to MOD.
 - Write to CNTIN.
 - Select OC, EPWM, CPWM, Combine, Complement modes for all channels that will be used
 - Select the high-true and low-true channels modes.
 - Write to CnV for all channels that will be used .
 - (Re)Configure deadtime and fault control.
 - Do not use the SWOC without SW synchronization (see item 6).
 - Do not use the Inverting without SW synchronization (see item 6).
 - Do not use the Initialization.
 - Do not change the polarity control.
 - Do not configure the HW synchronization

- Write any value to CNT. The FTM Counter is reset and the channels output are updated according to new configuration.
- Enable the clock. Write to CLKS[1:0] bits a value different from zero. If in the Quadrature Decoder mode, enable this mode.
- Configure the SW synchronization for SWOC (if it is necessary), Inverting (if it is necessary) and Output Mask (always)
 - Select synchronization for Output Mask Write to SYNC (SWSYNC = 0, TRIG2 = 0, TRIG1 = 0, TRIG0 = 0, SYNCHOM = 1, REINIT = 0, CNTMAX = 0, CNTMIN = 0)
 - Write to SYNCONF.
 - HW Synchronization can not be enabled (HWSOC = 0, HWINVC = 0, HWOM = 0, HWWRBUF = 0, HWRSTCNT = 0, HWTRIGMODE = 0).
 - SW Synchronization for SWOC (if it is necessary): SWSOC = [0/1] and SWOC = [0/1].
 - SW Synchronization for Inverting (if it is necessary): SWINVC = [0/1] and INVC = [0/1].
 - SW Synchronization for SWOM (always): SWOM = 1. No enable the SW Synchronization for write buffers (because the writes to registers with write buffer are done using CLKS[1:0] = 2'b00): SWWRBUF = 0 and CNTINC = 0 .
 - SW Synchronization for counter reset (always): SWRSTCNT = 1.
 - Enhanced synchronization (always): SYNCMODE = 1
 - If the SWOC is used (SWSOC = 1 and SWOC = 1), then write to SWOCTRL register.
 - If the Inverting is used (SWINVC = 1 and INVC = 1), then write to INVCTRL register.
 - Write to OUTMASK to enable the masked channels.
- Generate the Software Trigger Write to SYNC (SWSYNC = 1, TRIG2 = 0, TRIG1 = 0, TRIG0 = 0, SYNCHOM = 1, REINIT = 0, CNTMAX = 0, CNTMIN = 0)



Chapter 39

Periodic Interrupt Timer (PIT)

39.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The PIT module is an array of timers that can be used to raise interrupts and trigger DMA channels.

39.1.1 Block diagram

The following figure shows the block diagram of the PIT module.

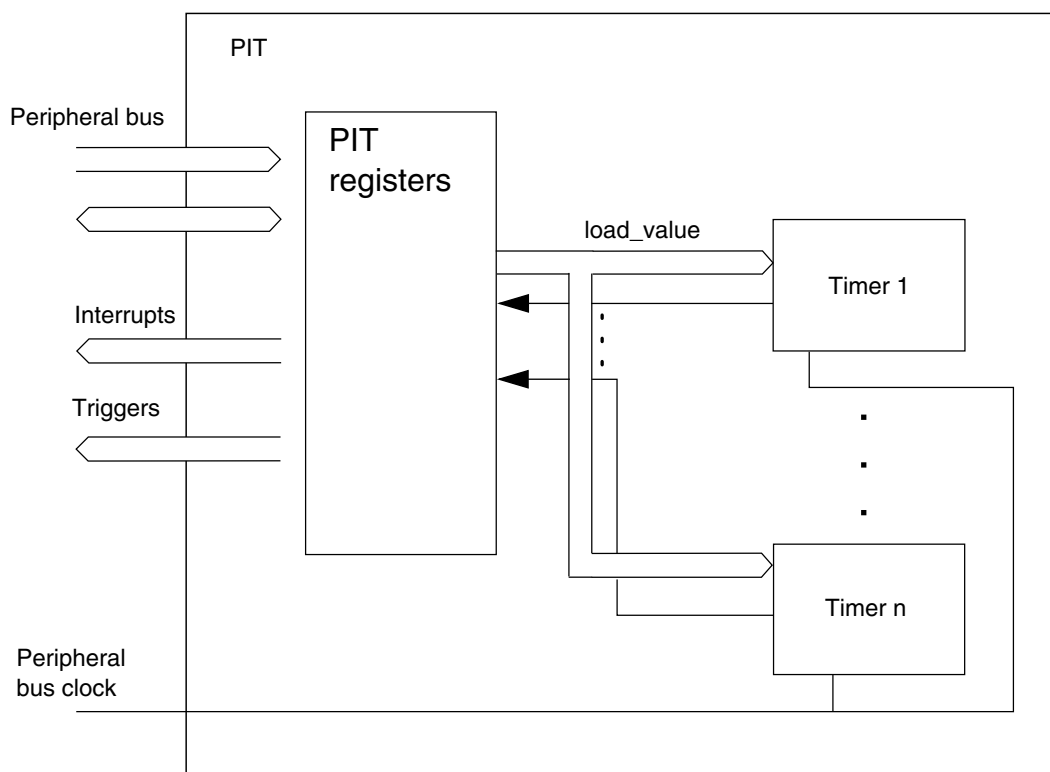


Figure 39-1. Block diagram of the PIT

NOTE

See the chip-specific PIT information for the number of PIT channels used in this MCU.

39.1.2 Features

The main features of this block are:

- Ability of timers to generate DMA trigger pulses
- Ability of timers to generate interrupts
- Maskable interrupts
- Independent timeout periods for each timer

39.2 Signal description

The PIT module has no external pins.

39.3 Memory map/register description

This section provides a detailed description of all registers accessible in the PIT module.

- Reserved registers will read as 0, writes will have no effect.
- See the chip-specific PIT information for the number of PIT channels used in this MCU.

PIT memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|--|-----------------|--------|-------------|----------------------------|
| 4003_7000 | PIT Module Control Register (PIT_MCR) | 32 | R/W | 0000_0006h | 39.3.1/905 |
| 4003_7100 | Timer Load Value Register (PIT_LDVAL0) | 32 | R/W | 0000_0000h | 39.3.2/907 |
| 4003_7104 | Current Timer Value Register (PIT_CVAL0) | 32 | R | 0000_0000h | 39.3.3/907 |
| 4003_7108 | Timer Control Register (PIT_TCTRL0) | 32 | R/W | 0000_0000h | 39.3.4/908 |
| 4003_710C | Timer Flag Register (PIT_TFLG0) | 32 | R/W | 0000_0000h | 39.3.5/908 |
| 4003_7110 | Timer Load Value Register (PIT_LDVAL1) | 32 | R/W | 0000_0000h | 39.3.2/907 |
| 4003_7114 | Current Timer Value Register (PIT_CVAL1) | 32 | R | 0000_0000h | 39.3.3/907 |
| 4003_7118 | Timer Control Register (PIT_TCTRL1) | 32 | R/W | 0000_0000h | 39.3.4/908 |
| 4003_711C | Timer Flag Register (PIT_TFLG1) | 32 | R/W | 0000_0000h | 39.3.5/908 |
| 4003_7120 | Timer Load Value Register (PIT_LDVAL2) | 32 | R/W | 0000_0000h | 39.3.2/907 |
| 4003_7124 | Current Timer Value Register (PIT_CVAL2) | 32 | R | 0000_0000h | 39.3.3/907 |
| 4003_7128 | Timer Control Register (PIT_TCTRL2) | 32 | R/W | 0000_0000h | 39.3.4/908 |
| 4003_712C | Timer Flag Register (PIT_TFLG2) | 32 | R/W | 0000_0000h | 39.3.5/908 |
| 4003_7130 | Timer Load Value Register (PIT_LDVAL3) | 32 | R/W | 0000_0000h | 39.3.2/907 |
| 4003_7134 | Current Timer Value Register (PIT_CVAL3) | 32 | R | 0000_0000h | 39.3.3/907 |
| 4003_7138 | Timer Control Register (PIT_TCTRL3) | 32 | R/W | 0000_0000h | 39.3.4/908 |
| 4003_713C | Timer Flag Register (PIT_TFLG3) | 32 | R/W | 0000_0000h | 39.3.5/908 |

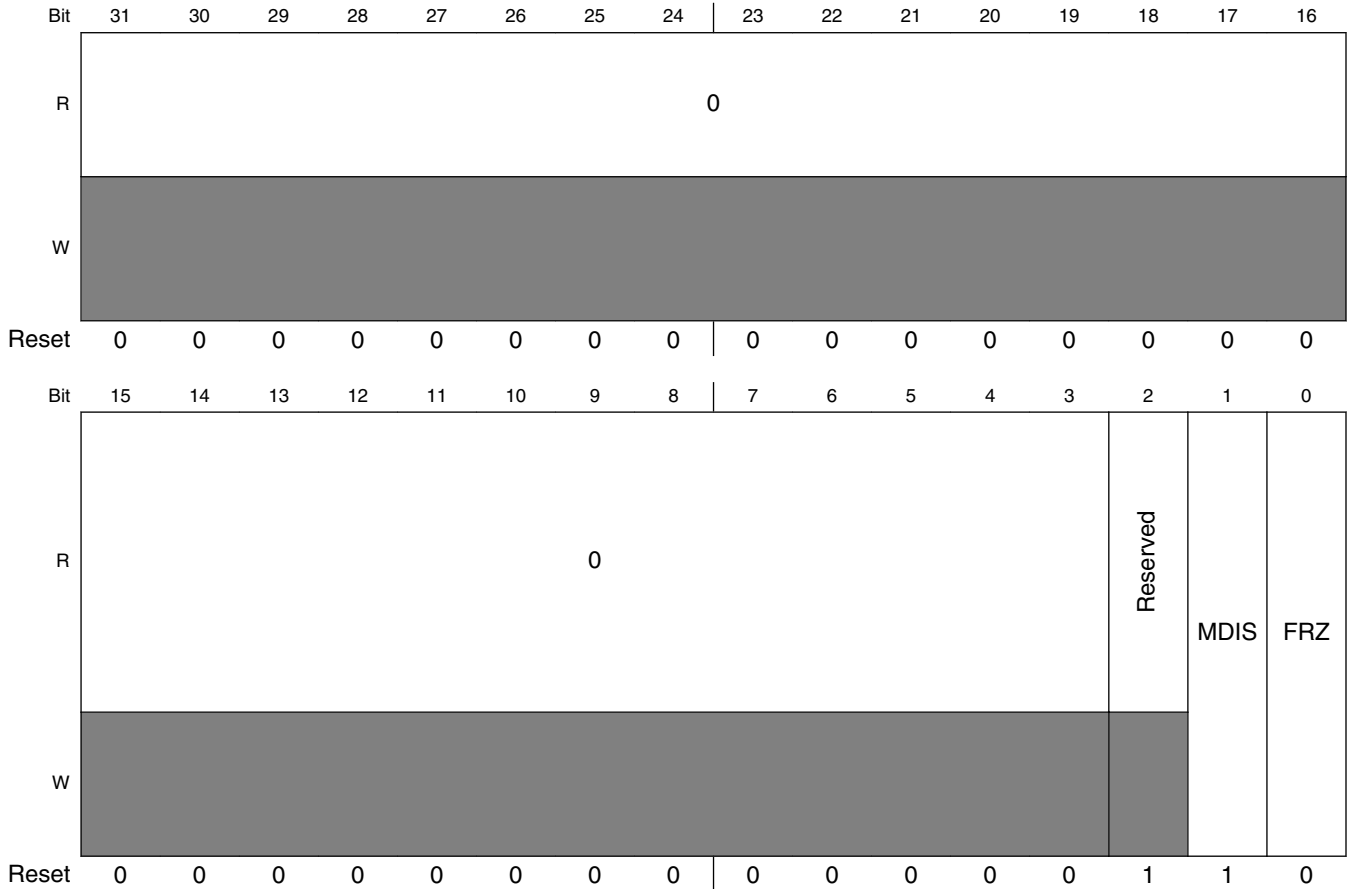
39.3.1 PIT Module Control Register (PIT_MCR)

This register enables or disables the PIT timer clocks and controls the timers when the PIT enters the Debug mode.

Access: User read/write

memory map/register description

Address: 4003_7000h base + 0h offset = 4003_7000h



PIT_MCR field descriptions

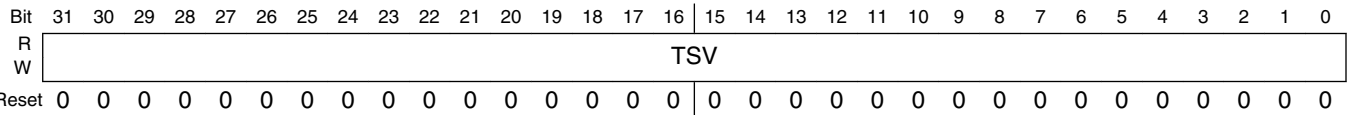
| Field | Description |
|------------------|---|
| 31–3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 Reserved | This field is reserved. |
| 1 MDIS | Module Disable - (PIT section) Disables the standard timers. This field must be enabled before any other setup is done. 0 Clock for standard PIT timers is enabled. 1 Clock for standard PIT timers is disabled. |
| 0 FRZ | Freeze Allows the timers to be stopped when the device enters the Debug mode. 0 Timers continue to run in Debug mode. 1 Timers are stopped in Debug mode. |

39.3.2 Timer Load Value Register (PIT_LDVALn)

These registers select the timeout period for the timer interrupts.

Access: User read/write

Address: 4003_7000h base + 100h offset + (16d × i), where i=0d to 3d



PIT_LDVALn field descriptions

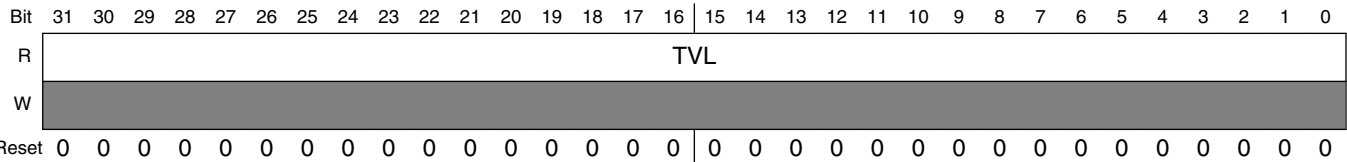
| Field | Description |
|-------------|---|
| 31–0 TSV | <p>Timer Start Value</p> <p>Sets the timer start value. The timer will count down until it reaches 0, then it will generate an interrupt and load this register value again. Writing a new value to this register will not restart the timer; instead the value will be loaded after the timer expires. To abort the current cycle and start a timer period with the new value, the timer must be disabled and enabled again.</p> |

39.3.3 Current Timer Value Register (PIT_CVALn)

These registers indicate the current timer position.

Access: User read only

Address: 4003_7000h base + 104h offset + (16d × i), where i=0d to 3d



PIT_CVALn field descriptions

| Field | Description |
|-------------|---|
| 31–0 TVL | <p>Current Timer Value</p> <p>Represents the current timer value, if the timer is enabled.</p> <p>NOTE:</p> <ul style="list-style-type: none"> If the timer is disabled, do not use this field as its value is unreliable. The timer uses a downcounter. The timer values are frozen in Debug mode if MCR[FRZ] is set. |

39.3.4 Timer Control Register (PIT_TCTRLn)

These registers contain the control bits for each timer.

Access: User read/write

Address: 4003_7000h base + 108h offset + (16d × i), where i=0d to 3d

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|-----|-----|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | CHN | TIE |
| W | | | | | | | | | | | | | | | | TEN |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PIT_TCTRLn field descriptions

| Field | Description |
|------------------|---|
| 31–3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 CHN | Chain Mode When activated, Timer n-1 needs to expire before timer n can decrement by 1. Timer 0 cannot be chained. 0 Timer is not chained. 1 Timer is chained to previous timer. For example, for Channel 2, if this field is set, Timer 2 is chained to Timer 1. |
| 1 TIE | Timer Interrupt Enable When an interrupt is pending, or, TFLGn[TIF] is set, enabling the interrupt will immediately cause an interrupt event. To avoid this, the associated TFLGn[TIF] must be cleared first. 0 Interrupt requests from Timer n are disabled. 1 Interrupt will be requested whenever TIF is set. |
| 0 TEN | Timer Enable Enables or disables the timer. 0 Timer n is disabled. 1 Timer n is enabled. |

39.3.5 Timer Flag Register (PIT_TFLGn)

These registers hold the PIT interrupt flags.

Access: User read/write

Address: 4003_7000h base + 10Ch offset + (16d × i), where i=0d to 3d

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | TIF |
| W | | | | | | | | | | | | | | | | w1c |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PIT_TFLGn field descriptions

| Field | Description |
|------------------|---|
| 31–1 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 0 TIF | Timer Interrupt Flag Sets to 1 at the end of the timer period. Writing 1 to this flag clears it. Writing 0 has no effect. If enabled, or, when TCTRLn[TIE] = 1, TIF causes an interrupt request. 0 Timeout has not yet occurred. 1 Timeout has occurred. |

39.4 Functional description

This section provides the functional description of the module.

39.4.1 General operation

This section gives detailed information on the internal operation of the module. Each timer can be used to generate trigger pulses and interrupts. Each interrupt is available on a separate interrupt line.

39.4.1.1 Timers

The timers generate triggers at periodic intervals, when enabled. The timers load the start values as specified in their LDVAL registers, count down to 0 and then load the respective start value again. Each time a timer reaches 0, it will generate a trigger pulse and set the interrupt flag.

All interrupts can be enabled or masked by setting TCTRLn[TIE]. A new interrupt can be generated only after the previous one is cleared.

If desired, the current counter value of the timer can be read via the CVAL registers.

The counter period can be restarted, by first disabling, and then enabling the timer with TCTRLn[TEN]. See the following figure.

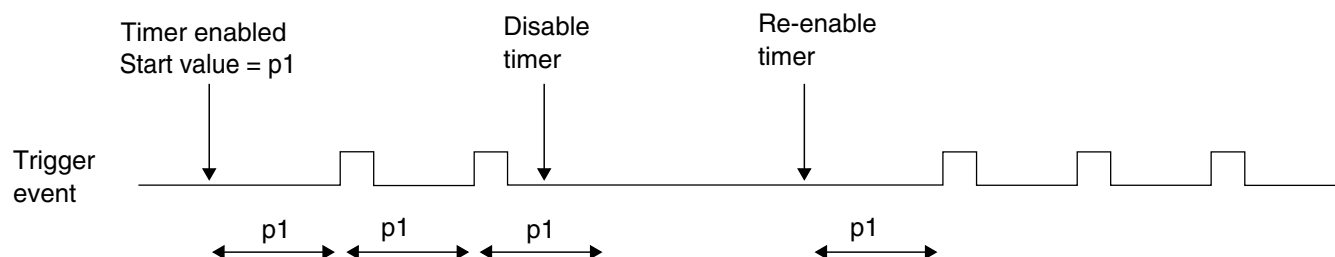


Figure 39-23. Stopping and starting a timer

The counter period of a running timer can be modified, by first disabling the timer, setting a new load value, and then enabling the timer again. See the following figure.

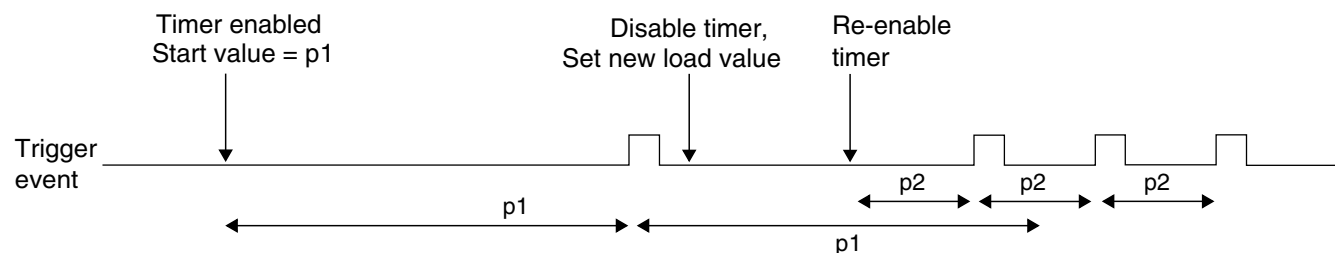


Figure 39-24. Modifying running timer period

It is also possible to change the counter period without restarting the timer by writing LDVAL with the new load value. This value will then be loaded after the next trigger event. See the following figure.

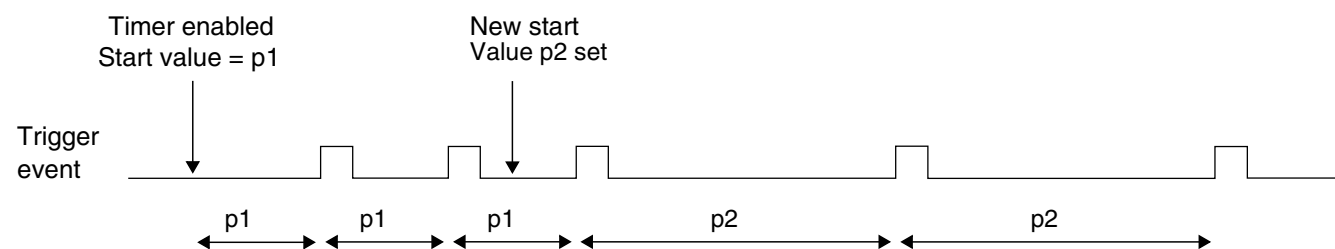


Figure 39-25. Dynamically setting a new load value

39.4.1.2 Debug mode

In Debug mode, the timers will be frozen based on MCR[FRZ]. This is intended to aid software development, allowing the developer to halt the processor, investigate the current state of the system, for example, the timer values, and then continue the operation.

39.4.2 Interrupts

All the timers support interrupt generation. See the MCU specification for related vector addresses and priorities.

Timer interrupts can be enabled by setting TCTRLn[TIE]. TFLGn[TIF] are set to 1 when a timeout occurs on the associated timer, and are cleared to 0 by writing a 1 to the corresponding TFLGn[TIF].

39.4.3 Chained timers

When a timer has chain mode enabled, it will only count after the previous timer has expired. So if timer n-1 has counted down to 0, counter n will decrement the value by one. This allows to chain some of the timers together to form a longer timer. The first timer (timer 0) cannot be chained to any other timer.

39.5 Initialization and application information

In the example configuration:

- The PIT clock has a frequency of 50 MHz.
- Timer 1 creates an interrupt every 5.12 ms.
- Timer 3 creates a trigger event every 30 ms.

The PIT module must be activated by writing a 0 to MCR[MDIS].

The 50 MHz clock frequency equates to a clock period of 20 ns. Timer 1 needs to trigger every $5.12 \text{ ms} / 20 \text{ ns} = 256,000$ cycles and Timer 3 every $30 \text{ ms} / 20 \text{ ns} = 1,500,000$ cycles. The value for the LDVAL register trigger is calculated as:

$\text{LDVAL trigger} = (\text{period} / \text{clock period}) - 1$

This means LDVAL1 and LDVAL3 must be written with 0x0003E7FF and 0x0016E35F respectively.

The interrupt for Timer 1 is enabled by setting TCTRL1[TIE]. The timer is started by writing 1 to TCTRL1[TEN].

Timer 3 shall be used only for triggering. Therefore, Timer 3 is started by writing a 1 to TCTRL3[TEN]. TCTRL3[TIE] stays at 0.

The following example code matches the described setup:

```
// turn on PIT
PIT_MCR = 0x00;

// Timer 1
PIT_LDVAL1 = 0x0003E7FF; // setup timer 1 for 256000 cycles
PIT_TCTRL1 = TIE; // enable Timer 1 interrupts
PIT_TCTRL1 |= TEN; // start Timer 1

// Timer 3
PIT_LDVAL3 = 0x0016E35F; // setup timer 3 for 1500000 cycles
PIT_TCTRL3 |= TEN; // start Timer 3
```

39.6 Example configuration for chained timers

In the example configuration:

- The PIT clock has a frequency of 100 MHz.
- Timers 1 and 2 are available.
- An interrupt shall be raised every 1 minute.

The PIT module needs to be activated by writing a 0 to MCR[MDIS].

The 100 MHz clock frequency equates to a clock period of 10 ns, so the PIT needs to count for 6000 million cycles, which is more than a single timer can do. So, Timer 1 is set up to trigger every 6 s (600 million cycles). Timer 2 is chained to Timer 1 and programmed to trigger 10 times.

The value for the LDVAL register trigger is calculated as number of cycles-1, so LDVAL1 receives the value 0x23C345FF and LDVAL2 receives the value 0x00000009.

The interrupt for Timer 2 is enabled by setting TCTRL2[TIE], the Chain mode is activated by setting TCTRL2[CHN], and the timer is started by writing a 1 to TCTRL2[TEN]. TCTRL1[TEN] needs to be set, and TCTRL1[CHN] and TCTRL1[TIE] are cleared.

The following example code matches the described setup:

```
// turn on PIT
PIT_MCR = 0x00;

// Timer 2
PIT_LDVAL2 = 0x00000009; // setup Timer 2 for 10 counts
PIT_TCTRL2 = TIE; // enable Timer 2 interrupt
PIT_TCTRL2 |= CHN; // chain Timer 2 to Timer 1
PIT_TCTRL2 |= TEN; // start Timer 2

// Timer 1
PIT_LDVAL1 = 0x23C345FF; // setup Timer 1 for 600 000 000 cycles
PIT_TCTRL1 = TEN; // start Timer 1
```



Chapter 40

Low-Power Timer (LPTMR)

40.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The low-power timer (LPTMR) can be configured to operate as a time counter with optional prescaler, or as a pulse counter with optional glitch filter, across all power modes, including the low-leakage modes. It can also continue operating through most system reset events, allowing it to be used as a time of day counter.

40.1.1 Features

The features of the LPTMR module include:

- 16-bit time counter or pulse counter with compare
 - Optional interrupt can generate asynchronous wakeup from any low-power mode
 - Hardware trigger output
 - Counter supports free-running mode or reset on compare
- Configurable clock source for prescaler/glitch filter
- Configurable input source for pulse counter
 - Rising-edge or falling-edge

40.1.2 Modes of operation

The following table describes the operation of the LPTMR module in various modes.

Table 40-1. Modes of operation

| Modes | Description |
|-------------|--|
| Run | The LPTMR operates normally. |
| Wait | The LPTMR continues to operate normally and may be configured to exit the low-power mode by generating an interrupt request. |
| Stop | The LPTMR continues to operate normally and may be configured to exit the low-power mode by generating an interrupt request. |
| Low-Leakage | The LPTMR continues to operate normally and may be configured to exit the low-power mode by generating an interrupt request. |
| Debug | The LPTMR operates normally. |

40.2 LPTMR signal descriptions

Table 40-2. LPTMR signal descriptions

| Signal | I/O | Description |
|------------|-----|-------------------------|
| LPTMR_ALTx | I | Pulse Counter Input pin |

40.2.1 Detailed signal descriptions

Table 40-3. LPTMR interface—detailed signal descriptions

| Signal | I/O | Description | |
|------------|-----|---|---|
| LPTMR_ALTx | I | Pulse Counter Input The LPTMR can select one of the input pins to be used in Pulse Counter mode. | |
| | | State meaning | Assertion—If configured for pulse counter mode with active-high input, then assertion causes the CNR to increment. Deassertion—If configured for pulse counter mode with active-low input, then deassertion causes the CNR to increment. |
| | | Timing | Assertion or deassertion may occur at any time; input may assert asynchronously to the bus clock. |

40.3 Memory map and register definition

NOTE

The LPTMR registers are reset only on a POR or LVD event.
See [LPTMR power and reset](#) for more details.

LPTMR memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|----------------------------|
| 4004_0000 | Low Power Timer Control Status Register (LPTMR0_CSR) | 32 | R/W | 0000_0000h | 40.3.1/917 |
| 4004_0004 | Low Power Timer Prescale Register (LPTMR0_PSR) | 32 | R/W | 0000_0000h | 40.3.2/919 |
| 4004_0008 | Low Power Timer Compare Register (LPTMR0_CMR) | 32 | R/W | 0000_0000h | 40.3.3/920 |
| 4004_000C | Low Power Timer Counter Register (LPTMR0_CNR) | 32 | R | 0000_0000h | 40.3.4/921 |

40.3.1 Low Power Timer Control Status Register (LPTMRx_CSR)

Address: 4004_0000h base + 0h offset = 4004_0000h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | TCF | | | | | | | |
| W | | | | | | | | | w1c | TIE | TPS | TPP | TFC | TMS | TEN | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LPTMRx_CSR field descriptions

| Field | Description |
|------------------|--|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 TCF | Timer Compare Flag TCF is set when the LPTMR is enabled and the CNR equals the CMR and increments. TCF is cleared when the LPTMR is disabled or a logic 1 is written to it. 0 The value of CNR is not equal to CMR and increments. 1 The value of CNR is equal to CMR and increments. |
| 6 TIE | Timer Interrupt Enable When TIE is set, the LPTMR Interrupt is generated whenever TCF is also set. |

Table continues on the next page...

LPTMRx_CSR field descriptions (continued)

| Field | Description |
|------------|--|
| | <p>0 Timer interrupt disabled.</p> <p>1 Timer interrupt enabled.</p> |
| 5–4 TPS | <p>Timer Pin Select</p> <p>Configures the input source to be used in Pulse Counter mode. TPS must be altered only when the LPTMR is disabled. The input connections vary by device. See the chip configuration details for information on the connections to these inputs.</p> <p>00 Pulse counter input 0 is selected.</p> <p>01 Pulse counter input 1 is selected.</p> <p>10 Pulse counter input 2 is selected.</p> <p>11 Pulse counter input 3 is selected.</p> |
| 3 TPP | <p>Timer Pin Polarity</p> <p>Configures the polarity of the input source in Pulse Counter mode. TPP must be changed only when the LPTMR is disabled.</p> <p>0 Pulse Counter input source is active-high, and the CNR will increment on the rising-edge.</p> <p>1 Pulse Counter input source is active-low, and the CNR will increment on the falling-edge.</p> |
| 2 TFC | <p>Timer Free-Running Counter</p> <p>When clear, TFC configures the CNR to reset whenever TCF is set. When set, TFC configures the CNR to reset on overflow. TFC must be altered only when the LPTMR is disabled.</p> <p>0 CNR is reset whenever TCF is set.</p> <p>1 CNR is reset on overflow.</p> |
| 1 TMS | <p>Timer Mode Select</p> <p>Configures the mode of the LPTMR. TMS must be altered only when the LPTMR is disabled.</p> <p>0 Time Counter mode.</p> <p>1 Pulse Counter mode.</p> |
| 0 TEN | <p>Timer Enable</p> <p>When TEN is clear, it resets the LPTMR internal logic, including the CNR and TCF. When TEN is set, the LPTMR is enabled. While writing 1 to this field, CSR[5:1] must not be altered.</p> <p>0 LPTMR is disabled and internal logic is reset.</p> <p>1 LPTMR is enabled.</p> |

40.3.2 Low Power Timer Prescale Register (LPTMRx_PSR)

Address: 4004_0000h base + 4h offset = 4004_0004h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|----------|---|---|---|------|---|-----|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | PRESCALE | | | | PBYP | | PCS | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LPTMRx_PSR field descriptions

| Field | Description |
|------------------|--|
| 31–7 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 6–3 PRESCALE | <p>Prescale Value</p> <p>Configures the size of the Prescaler in Time Counter mode or width of the glitch filter in Pulse Counter mode. PRESCALE must be altered only when the LPTMR is disabled.</p> <p>0000 Prescaler divides the prescaler clock by 2; glitch filter does not support this configuration.</p> <p>0001 Prescaler divides the prescaler clock by 4; glitch filter recognizes change on input pin after 2 rising clock edges.</p> <p>0010 Prescaler divides the prescaler clock by 8; glitch filter recognizes change on input pin after 4 rising clock edges.</p> <p>0011 Prescaler divides the prescaler clock by 16; glitch filter recognizes change on input pin after 8 rising clock edges.</p> <p>0100 Prescaler divides the prescaler clock by 32; glitch filter recognizes change on input pin after 16 rising clock edges.</p> <p>0101 Prescaler divides the prescaler clock by 64; glitch filter recognizes change on input pin after 32 rising clock edges.</p> <p>0110 Prescaler divides the prescaler clock by 128; glitch filter recognizes change on input pin after 64 rising clock edges.</p> <p>0111 Prescaler divides the prescaler clock by 256; glitch filter recognizes change on input pin after 128 rising clock edges.</p> <p>1000 Prescaler divides the prescaler clock by 512; glitch filter recognizes change on input pin after 256 rising clock edges.</p> <p>1001 Prescaler divides the prescaler clock by 1024; glitch filter recognizes change on input pin after 512 rising clock edges.</p> <p>1010 Prescaler divides the prescaler clock by 2048; glitch filter recognizes change on input pin after 1024 rising clock edges.</p> <p>1011 Prescaler divides the prescaler clock by 4096; glitch filter recognizes change on input pin after 2048 rising clock edges.</p> <p>1100 Prescaler divides the prescaler clock by 8192; glitch filter recognizes change on input pin after 4096 rising clock edges.</p> <p>1101 Prescaler divides the prescaler clock by 16,384; glitch filter recognizes change on input pin after 8192 rising clock edges.</p> |

Table continues on the next page...

LPTMRx_PSR field descriptions (continued)

| Field | Description |
|------------|---|
| | <p>1110 Prescaler divides the prescaler clock by 32,768; glitch filter recognizes change on input pin after 16,384 rising clock edges.</p> <p>1111 Prescaler divides the prescaler clock by 65,536; glitch filter recognizes change on input pin after 32,768 rising clock edges.</p> |
| 2 PBYP | <p>Prescaler Bypass</p> <p>When PBYP is set, the selected prescaler clock in Time Counter mode or selected input source in Pulse Counter mode directly clocks the CNR. When PBYP is clear, the CNR is clocked by the output of the prescaler/glitch filter. PBYP must be altered only when the LPTMR is disabled.</p> <p>0 Prescaler/glitch filter is enabled.</p> <p>1 Prescaler/glitch filter is bypassed.</p> |
| 1–0 PCS | <p>Prescaler Clock Select</p> <p>Selects the clock to be used by the LPTMR prescaler/glitch filter. PCS must be altered only when the LPTMR is disabled. The clock connections vary by device.</p> <p>NOTE: See the chip configuration details for information on the connections to these inputs.</p> <p>00 Prescaler/glitch filter clock 0 selected.</p> <p>01 Prescaler/glitch filter clock 1 selected.</p> <p>10 Prescaler/glitch filter clock 2 selected.</p> <p>11 Prescaler/glitch filter clock 3 selected.</p> |

40.3.3 Low Power Timer Compare Register (LPTMRx_CMRR)

Address: 4004_0000h base + 8h offset = 4004_0008h

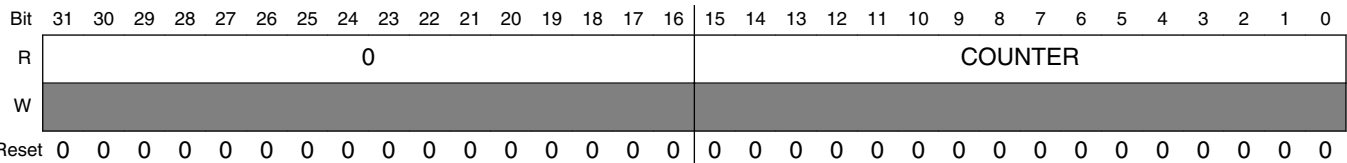
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---------|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | COMPARE | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

LPTMRx_CMRR field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 15–0 COMPARE | <p>Compare Value</p> <p>When the LPTMR is enabled and the CNR equals the value in the CMR and increments, TCF is set and the hardware trigger asserts until the next time the CNR increments. If the CMR is 0, the hardware trigger will remain asserted until the LPTMR is disabled. If the LPTMR is enabled, the CMR must be altered only when TCF is set.</p> |

40.3.4 Low Power Timer Counter Register (LPTMRx_CNR)

Address: 4004_0000h base + Ch offset = 4004_000Ch



LPTMRx_CNR field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 COUNTER | Counter Value |

40.4 Functional description

40.4.1 LPTMR power and reset

The LPTMR remains powered in all power modes, including low-leakage modes. If the LPTMR is not required to remain operating during a low-power mode, then it must be disabled before entering the mode.

The LPTMR is reset only on global Power On Reset (POR) or Low Voltage Detect (LVD). When configuring the LPTMR registers, the CSR must be initially written with the timer disabled, before configuring the PSR and CMR. Then, CSR[TIE] must be set as the last step in the initialization. This ensures the LPTMR is configured correctly and the LPTMR counter is reset to zero following a warm reset.

40.4.2 LPTMR clocking

The LPTMR prescaler/glitch filter can be clocked by one of the four clocks. The clock source must be enabled before the LPTMR is enabled.

NOTE

The clock source selected may need to be configured to remain enabled in low-power modes, otherwise the LPTMR will not operate during low-power modes.

In Pulse Counter mode with the prescaler/glitch filter bypassed, the selected input source directly clocks the CNR and no other clock source is required. To minimize power in this case, configure the prescaler clock source for a clock that is not toggling.

NOTE

The clock source or pulse input source selected for the LPTMR should not exceed the frequency f_{LPTMR} defined in the device datasheet.

40.4.3 LPTMR prescaler/glitch filter

The LPTMR prescaler and glitch filter share the same logic which operates as a prescaler in Time Counter mode and as a glitch filter in Pulse Counter mode.

NOTE

The prescaler/glitch filter configuration must not be altered when the LPTMR is enabled.

40.4.3.1 Prescaler enabled

In Time Counter mode, when the prescaler is enabled, the output of the prescaler directly clocks the CNR. When the LPTMR is enabled, the CNR will increment every 2^2 to 2^{16} prescaler clock cycles. After the LPTMR is enabled, the first increment of the CNR will take an additional one or two prescaler clock cycles due to synchronization logic.

40.4.3.2 Prescaler bypassed

In Time Counter mode, when the prescaler is bypassed, the selected prescaler clock increments the CNR on every clock cycle. When the LPTMR is enabled, the first increment will take an additional one or two prescaler clock cycles due to synchronization logic.

40.4.3.3 Glitch filter

In Pulse Counter mode, when the glitch filter is enabled, the output of the glitch filter directly clocks the CNR. When the LPTMR is first enabled, the output of the glitch filter is asserted, that is, logic 1 for active-high and logic 0 for active-low. The following table shows the change in glitch filter output with the selected input source.

| If | Then |
|--|--|
| The selected input source remains deasserted for at least 2^1 to 2^{15} consecutive prescaler clock rising edges | The glitch filter output will also deassert. |
| The selected input source remains asserted for at least 2^1 to 2^{15} consecutive prescaler clock rising-edges | The glitch filter output will also assert. |

NOTE

The input is only sampled on the rising clock edge.

The CNR will increment each time the glitch filter output asserts. In Pulse Counter mode, the maximum rate at which the CNR can increment is once every 2^2 to 2^{16} prescaler clock edges. When first enabled, the glitch filter will wait an additional one or two prescaler clock edges due to synchronization logic.

40.4.3.4 Glitch filter bypassed

In Pulse Counter mode, when the glitch filter is bypassed, the selected input source increments the CNR every time it asserts. Before the LPTMR is first enabled, the selected input source is forced to be asserted. This prevents the CNR from incrementing if the selected input source is already asserted when the LPTMR is first enabled.

40.4.4 LPTMR compare

When the CNR equals the value of the CMR and increments, the following events occur:

- CSR[TCF] is set.
- LPTMR interrupt is generated if CSR[TIE] is also set.
- LPTMR hardware trigger is generated.
- CNR is reset if CSR[TFC] is clear.

When the LPTMR is enabled, the CMR can be altered only when CSR[TCF] is set. When updating the CMR, the CMR must be written and CSR[TCF] must be cleared before the LPTMR counter has incremented past the new LPTMR compare value.

40.4.5 LPTMR counter

The CNR increments by one on every:

- Prescaler clock in Time Counter mode with prescaler bypassed
- Prescaler output in Time Counter mode with prescaler enabled
- Input source assertion in Pulse Counter mode with glitch filter bypassed
- Glitch filter output in Pulse Counter mode with glitch filter enabled

The CNR is reset when the LPTMR is disabled or if the counter register overflows. If CSR[TFC] is cleared, then the CNR is also reset whenever CSR[TCF] is set.

The CNR continues incrementing when the core is halted in Debug mode.

The CNR cannot be initialized, but can be read at any time. On each read of the CNR, software must first write to the CNR with any value. This will synchronize and register the current value of the CNR into a temporary register. The contents of the temporary register are returned on each read of the CNR.

When reading the CNR, the bus clock must be at least two times faster than the rate at which the LPTMR counter is incrementing, otherwise incorrect data may be returned.

40.4.6 LPTMR hardware trigger

The LPTMR hardware trigger asserts at the same time the CSR[TCF] is set and can be used to trigger hardware events in other peripherals without software intervention. The hardware trigger is always enabled.

| When | Then |
|---|--|
| The CMR is set to 0 with CSR[TFC] clear | The LPTMR hardware trigger will assert on the first compare and does not deassert. |
| The CMR is set to a nonzero value, or, if CSR[TFC] is set | The LPTMR hardware trigger will assert on each compare and deassert on the following increment of the CNR. |

40.4.7 LPTMR interrupt

The LPTMR interrupt is generated whenever CSR[TIE] and CSR[TCF] are set. CSR[TCF] is cleared by disabling the LPTMR or by writing a logic 1 to it.

CSR[TIE] can be altered and CSR[TCF] can be cleared while the LPTMR is enabled.

The LPTMR interrupt is generated asynchronously to the system clock and can be used to generate a wakeup from any low-power mode, including the low-leakage modes, provided the LPTMR is enabled as a wakeup source.



Chapter 41

Carrier Modulator Transmitter (CMT)

41.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The carrier modulator transmitter (CMT) module provides the means to generate the protocol timing and carrier signals for a wide variety of encoding schemes. The CMT incorporates hardware to off-load the critical and/or lengthy timing requirements associated with signal generation from the CPU, releasing much of its bandwidth to handle other tasks such as:

- Code data generation
- Data decompression, or,
- Keyboard scanning

. The CMT does not include dedicated hardware configurations for specific protocols, but is intended to be sufficiently programmable in its function to handle the timing requirements of most protocols with minimal CPU intervention.

When the modulator is disabled, certain CMT registers can be used to change the state of the infrared output (IRO) signal directly. This feature allows for the generation of future protocol timing signals not readily producible by the current architecture.

41.2 Features

The features of this module include:

- Four modes of operation:
 - Time; with independent control of high and low times

Block diagram

- Baseband
- Frequency-shift key (FSK)
- Direct software control of the IRO signal
- Extended space operation in Time, Baseband, and FSK modes
- Selectable input clock divider
- Interrupt on end-of-cycle
 - Ability to disable the IRO signal and use as timer interrupt

41.3 Block diagram

The following figure presents the block diagram of the CMT module.

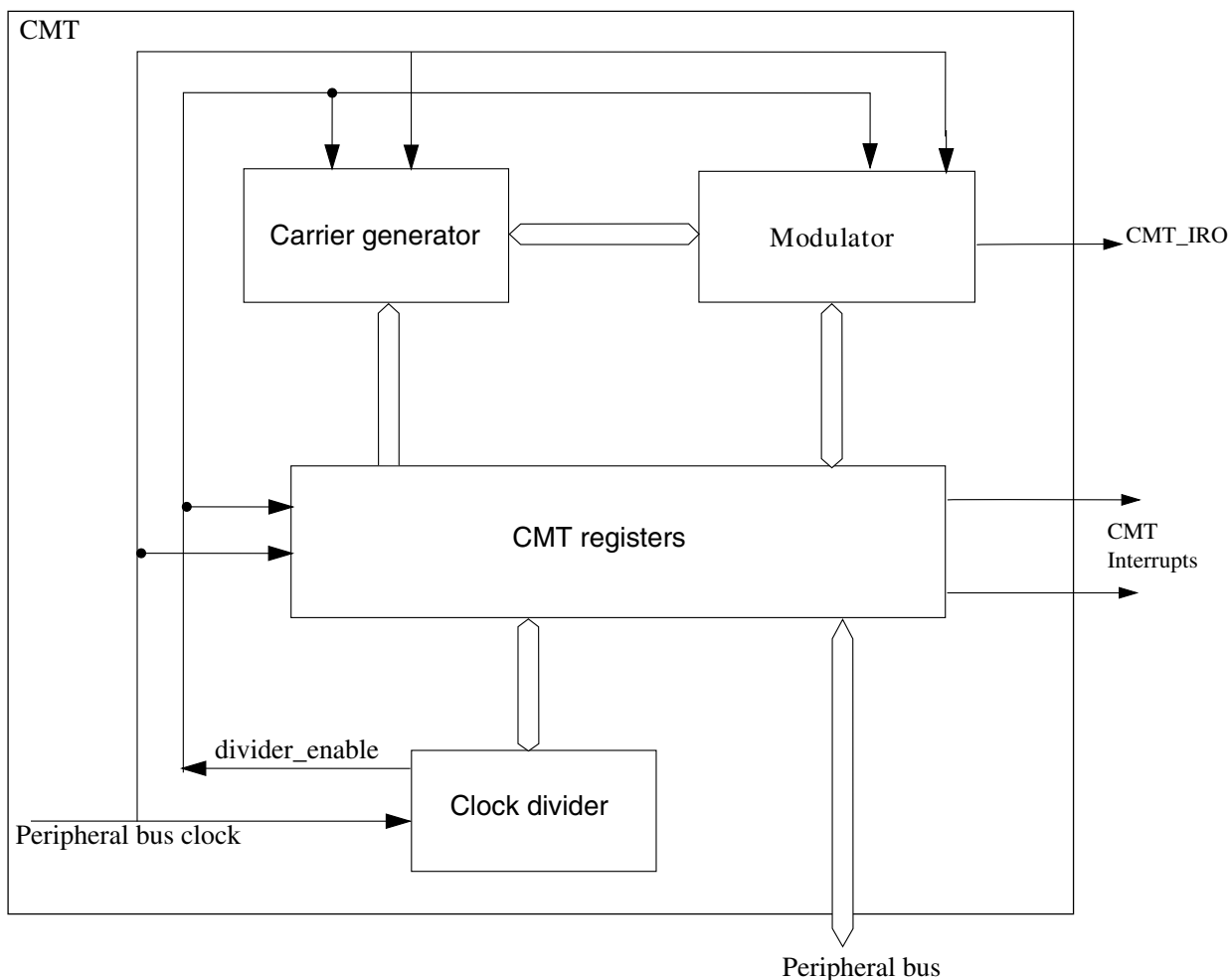


Figure 41-1. CMT module block diagram

41.4 Modes of operation

The following table describes the operation of the CMT module operates in various modes.

Table 41-1. Modes of operation

| Modes | Description |
|----------|--|
| Time | In Time mode, the user independently defines the high and low times of the carrier signal to determine both period and duty cycle |
| Baseband | When MSC[BASE] is set, the carrier output (f_{cg}) to the modulator is held high continuously to allow for the generation of baseband protocols. |

Table continues on the next page...

Table 41-1. Modes of operation (continued)

| Modes | Description |
|---------------------|--|
| Frequency-shift key | This mode allows the carrier generator to alternate between two sets of high and low times. When operating in FSK mode, the generator will toggle between the two sets when instructed by the modulator, allowing the user to dynamically switch between two carrier frequencies without CPU intervention. |

The following table summarizes the modes of operation of the CMT module.

Table 41-2. CMT modes of operation

| Mode | MSC[MCGEN] ¹ | MSC[BASE] ² | MSC[FSK] ² | MSC[EXSPC] | Comment |
|----------------|-------------------------|------------------------|-----------------------|------------|---|
| Time | 1 | 0 | 0 | 0 | f_{cg} controlled by primary high and low registers. f_{cg} transmitted to the IRO signal when modulator gate is open. |
| Baseband | 1 | 1 | X | 0 | f_{cg} is always high. The IRO signal is high when the modulator gate is open. |
| FSK | 1 | 0 | 1 | 0 | f_{cg} control alternates between primary high/low registers and secondary high/low registers. f_{cg} transmitted to the IRO signal when modulator gate is open. |
| Extended Space | 1 | X | X | 1 | Setting MSC[EXSPC] causes subsequent modulator cycles to be spaces (modulator out not asserted) for the duration of the modulator period (mark and space times). |
| IRO Latch | 0 | X | X | X | OC[IROL] controls the state of the IRO signal. |

1. To prevent spurious operation, initialize all data and control registers before beginning a transmission when MSC[MCGEN]=1.
2. This field is not double-buffered and must not be changed during a transmission while MSC[MCGEN]=1.

NOTE

The assignment of module modes to core modes is chip-specific. For module-to-core mode assignments, see the chapter that describes how modules are configured.

41.4.1 Wait mode operation

During Wait mode, the CMT if enabled, will continue to operate normally. However, there is no change in operating modes of CMT during Wait mode, because the CPU is not operating.

41.4.2 Stop mode operation

This section describes the CMT Stop mode operations.

41.4.2.1 Normal Stop mode operation

During Normal Stop mode, clocks to the CMT module are halted. No registers are affected.

The CMT module will resume upon exit from Normal Stop mode because the clocks are halted. Software must ensure that the Normal Stop mode is not entered while the modulator is still in operation so as to prevent the IRO signal from being asserted while in Normal Stop mode. This may require a timeout period from the time that MSC[MCGEN] is cleared to allow the last modulator cycle to complete.

41.4.2.2 Low-Power Stop mode operation

During Low-Power Stop mode, the CMT module is completely powered off internally and the IRO signal state is latched and held at the time when the CMT enters this mode. To prevent the IRO signal from being asserted during Low-Power Stop mode, the software must assure that the signal is not active when entering Low-Power Stop mode. Upon wakeup from Low-Power Stop mode, the CMT module will be in the reset state.

41.5 CMT external signal descriptions

The following table shows the description of the external signal.

Table 41-3. CMT signal description

| Signal | Description | I/O |
|---------|-----------------|-----|
| CMT_IRO | Infrared Output | O |

41.5.1 CMT_IRO — Infrared Output

This output signal is driven by the modulator output when MSC[MCGEN] and OC[IROPEN] are set. The IRO signal starts a valid transmission with a delay, after MSC[MCGEN] bit be asserted to high, that can be calculated based on two register bits. [Table 41-5](#) shows how to calculate this delay.

The following table describes conditions for the IRO signal to be active.

| If | Then |
|---|--|
| MSC[MCGEN] is cleared and OC[IROPEN] is set | The signal is driven by OC[IROL] . This enables user software to directly control the state of the IRO signal by writing to OC[IROL] . |
| OC[IROPEN] is cleared | The signal is disabled and is not driven by the CMT module. Therefore, CMT can be configured as a modulo timer for generating periodic interrupts without causing signal activity. |

Table 41-5. CMT_IRO signal delay calculation

| Condition | Delay (bus clock cycles) |
|-----------------|--------------------------|
| MSC[CMTDIV] = 0 | PPS[PPSDIV] + 2 |
| MSC[CMTDIV] > 0 | (PPS[PPSDIV] *2) + 3 |

41.6 Memory map/register definition

The following registers control and monitor the CMT operation.

The address of a register is the sum of a base address and an address offset. The base address is defined at the chip level. The address offset is defined at the module level.

CMT memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|----------------------------|
| 4006_2000 | CMT Carrier Generator High Data Register 1 (CMT_CGH1) | 8 | R/W | Undefined | 41.6.1/933 |
| 4006_2001 | CMT Carrier Generator Low Data Register 1 (CMT_CGL1) | 8 | R/W | Undefined | 41.6.2/934 |
| 4006_2002 | CMT Carrier Generator High Data Register 2 (CMT_CGH2) | 8 | R/W | Undefined | 41.6.3/934 |
| 4006_2003 | CMT Carrier Generator Low Data Register 2 (CMT_CGL2) | 8 | R/W | Undefined | 41.6.4/935 |
| 4006_2004 | CMT Output Control Register (CMT_OC) | 8 | R/W | 00h | 41.6.5/935 |
| 4006_2005 | CMT Modulator Status and Control Register (CMT_MSC) | 8 | R/W | 00h | 41.6.6/936 |
| 4006_2006 | CMT Modulator Data Register Mark High (CMT_CMD1) | 8 | R/W | Undefined | 41.6.7/938 |

Table continues on the next page...

CMT memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-------------|-----------------------------|
| 4006_2007 | CMT Modulator Data Register Mark Low (CMT_CMD2) | 8 | R/W | Undefined | 41.6.8/939 |
| 4006_2008 | CMT Modulator Data Register Space High (CMT_CMD3) | 8 | R/W | Undefined | 41.6.9/939 |
| 4006_2009 | CMT Modulator Data Register Space Low (CMT_CMD4) | 8 | R/W | Undefined | 41.6.10/940 |
| 4006_200A | CMT Primary Prescaler Register (CMT_PPS) | 8 | R/W | 00h | 41.6.11/940 |
| 4006_200B | CMT Direct Memory Access Register (CMT_DMA) | 8 | R/W | 00h | 41.6.12/941 |

41.6.1 CMT Carrier Generator High Data Register 1 (CMT_CGH1)

This data register contains the primary high value for generating the carrier output.

Address: 4006_2000h base + 0h offset = 4006_2000h

| | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | | | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

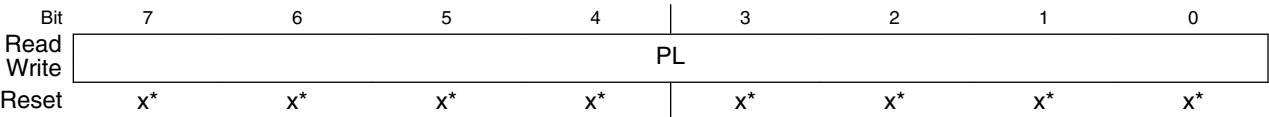
CMT_CGH1 field descriptions

| Field | Description |
|-----------|---|
| 7–0 PH | <p>Primary Carrier High Time Data Value</p> <p>Contains the number of input clocks required to generate the carrier high time period. When operating in Time mode, this register is always selected. When operating in FSK mode, this register and the secondary register pair are alternately selected under the control of the modulator. The primary carrier high time value is undefined out of reset. This register must be written to nonzero values before the carrier generator is enabled to avoid spurious results.</p> |

41.6.2 CMT Carrier Generator Low Data Register 1 (CMT_CGL1)

This data register contains the primary low value for generating the carrier output.

Address: 4006_2000h base + 1h offset = 4006_2001h



- * Notes:
- x = Undefined at reset.

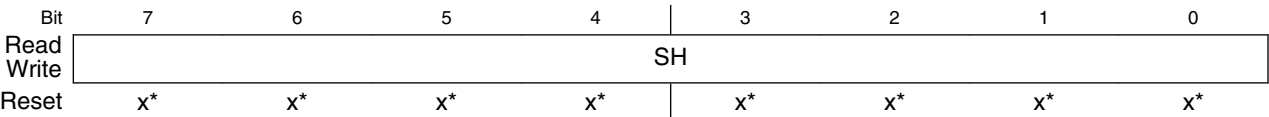
CMT_CGL1 field descriptions

| Field | Description |
|-----------|--|
| 7–0 PL | <p>Primary Carrier Low Time Data Value</p> <p>Contains the number of input clocks required to generate the carrier low time period. When operating in Time mode, this register is always selected. When operating in FSK mode, this register and the secondary register pair are alternately selected under the control of the modulator. The primary carrier low time value is undefined out of reset. This register must be written to nonzero values before the carrier generator is enabled to avoid spurious results.</p> |

41.6.3 CMT Carrier Generator High Data Register 2 (CMT_CGH2)

This data register contains the secondary high value for generating the carrier output.

Address: 4006_2000h base + 2h offset = 4006_2002h



- * Notes:
- x = Undefined at reset.

CMT_CGH2 field descriptions

| Field | Description |
|-----------|--|
| 7–0 SH | <p>Secondary Carrier High Time Data Value</p> <p>Contains the number of input clocks required to generate the carrier high time period. When operating in Time mode, this register is never selected. When operating in FSK mode, this register and the primary register pair are alternately selected under control of the modulator.</p> |

CMT_CGH2 field descriptions (continued)

| Field | Description |
|-------|--|
| | The secondary carrier high time value is undefined out of reset. This register must be written to nonzero values before the carrier generator is enabled when operating in FSK mode. |

41.6.4 CMT Carrier Generator Low Data Register 2 (CMT_CGL2)

This data register contains the secondary low value for generating the carrier output.

Address: 4006_2000h base + 3h offset = 4006_2003h

| | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | SL | | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

CMT_CGL2 field descriptions

| Field | Description |
|-----------|--|
| 7–0 SL | <p>Secondary Carrier Low Time Data Value</p> <p>Contains the number of input clocks required to generate the carrier low time period. When operating in Time mode, this register is never selected. When operating in FSK mode, this register and the primary register pair are alternately selected under the control of the modulator. The secondary carrier low time value is undefined out of reset. This register must be written to nonzero values before the carrier generator is enabled when operating in FSK mode.</p> |

41.6.5 CMT Output Control Register (CMT_OC)

This register is used to control the IRO signal of the CMT module.

Address: 4006_2000h base + 4h offset = 4006_2004h

| | | | | | | | | |
|-------|------|--------|--------|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | IROL | CMTPOL | IROPEN | 0 | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CMT_OC field descriptions

| Field | Description |
|-----------------|---|
| 7 IROL | IRO Latch Control Reads the state of the IRO latch. Writing to IROL changes the state of the IRO signal when MSC[MCGEN] is cleared and IROPEN is set. |
| 6 CMTPOL | CMT Output Polarity Controls the polarity of the IRO signal. 0 The IRO signal is active-low. 1 The IRO signal is active-high. |
| 5 IROPEN | IRO Pin Enable Enables and disables the IRO signal. When the IRO signal is enabled, it is an output that drives out either the CMT transmitter output or the state of IROL depending on whether MSC[MCGEN] is set or not. Also, the state of output is either inverted or non-inverted, depending on the state of CMTPOL. When the IRO signal is disabled, it is in a high-impedance state and is unable to draw any current. This signal is disabled during reset. 0 The IRO signal is disabled. 1 The IRO signal is enabled as output. |
| 4–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

41.6.6 CMT Modulator Status and Control Register (CMT_MSC)

This register contains the modulator and carrier generator enable (MCGEN), end of cycle interrupt enable (EOCIE), FSK mode select (FSK), baseband enable (BASE), extended space (EXSPC), prescaler (CMTDIV) bits, and the end of cycle (EOCF) status bit.

Address: 4006_2000h base + 5h offset = 4006_2005h

| | | | | | | | | | |
|-------|------|--------|---|---|-------|------|-----|-------|-------|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |
| Read | EOCF | CMTDIV | | | EXSPC | BASE | FSK | EOCIE | MCGEN |
| Write | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CMT_MSC field descriptions

| Field | Description |
|-----------|--|
| 7 EOCF | End Of Cycle Status Flag Sets when: |

Table continues on the next page...

CMT_MSC field descriptions (continued)

| Field | Description |
|---------------|---|
| | <ul style="list-style-type: none"> The modulator is not currently active and MCGEN is set to begin the initial CMT transmission. At the end of each modulation cycle while MCGEN is set. This is recognized when a match occurs between the contents of the space period register and the down counter. At this time, the counter is initialized with, possibly new contents of the mark period buffer, CMD1 and CMD2, and the space period register is loaded with, possibly new contents of the space period buffer, CMD3 and CMD4. <p>This flag is cleared by reading MSC followed by an access of CMD2 or CMD4, or by the DMA transfer.</p> <p>0 End of modulation cycle has not occurred since the flag last cleared. 1 End of modulator cycle has occurred.</p> |
| 6–5 CMTDIV | <p>CMT Clock Divide Prescaler</p> <p>Causes the CMT to be clocked at the IF signal frequency, or the IF frequency divided by 2, 4, or 8. This field must not be changed during a transmission because it is not double-buffered.</p> <p>00 IF ÷ 1 01 IF ÷ 2 10 IF ÷ 4 11 IF ÷ 8</p> |
| 4 EXSPC | <p>Extended Space Enable</p> <p>Enables the extended space operation.</p> <p>0 Extended space is disabled. 1 Extended space is enabled.</p> |
| 3 BASE | <p>Baseband Enable</p> <p>When set, BASE disables the carrier generator and forces the carrier output high for generation of baseband protocols. When BASE is cleared, the carrier generator is enabled and the carrier output toggles at the frequency determined by values stored in the carrier data registers. This field is cleared by reset. This field is not double-buffered and must not be written to during a transmission.</p> <p>0 Baseband mode is disabled. 1 Baseband mode is enabled.</p> |
| 2 FSK | <p>FSK Mode Select</p> <p>Enables FSK operation.</p> <p>0 The CMT operates in Time or Baseband mode. 1 The CMT operates in FSK mode.</p> |
| 1 EOCIE | <p>End of Cycle Interrupt Enable</p> <p>Requests to enable a CPU interrupt when EOCF is set if EOCIE is high.</p> |

Table continues on the next page...

CMT_MSC field descriptions (continued)

| Field | Description |
|------------|---|
| | 0 CPU interrupt is disabled. 1 CPU interrupt is enabled. |
| 0 MCGEN | <p>Modulator and Carrier Generator Enable</p> <p>Setting MCGEN will initialize the carrier generator and modulator and will enable all clocks. When enabled, the carrier generator and modulator will function continuously. When MCGEN is cleared, the current modulator cycle will be allowed to expire before all carrier and modulator clocks are disabled to save power and the modulator output is forced low.</p> <p>NOTE: To prevent spurious operation, the user should initialize all data and control registers before enabling the system.</p> <p>0 Modulator and carrier generator disabled 1 Modulator and carrier generator enabled</p> |

41.6.7 CMT Modulator Data Register Mark High (CMT_CMD1)

The contents of this register are transferred to the modulator down counter upon the completion of a modulation period.

Address: 4006_2000h base + 6h offset = 4006_2006h

| | | | | | | | | |
|-------|----------|----|----|----|----|----|----|----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | MB[15:8] | | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

CMT_CMD1 field descriptions

| Field | Description |
|-----------------|--|
| 7–0 MB[15:8] | <p>MB[15:8]</p> <p>Controls the upper mark periods of the modulator for all modes.</p> |

41.6.8 CMT Modulator Data Register Mark Low (CMT_CMD2)

The contents of this register are transferred to the modulator down counter upon the completion of a modulation period.

Address: 4006_2000h base + 7h offset = 4006_2007h

| | | | | | | | | |
|-------|---------|----|----|----|----|----|----|----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | MB[7:0] | | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

CMT_CMD2 field descriptions

| Field | Description |
|----------------|--|
| 7-0 MB[7:0] | MB[7:0] Controls the lower mark periods of the modulator for all modes. |

41.6.9 CMT Modulator Data Register Space High (CMT_CMD3)

The contents of this register are transferred to the space period register upon the completion of a modulation period.

Address: 4006_2000h base + 8h offset = 4006_2008h

| | | | | | | | | |
|-------|----------|----|----|----|----|----|----|----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | SB[15:8] | | | | | | | |
| Write | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* |

* Notes:

- x = Undefined at reset.

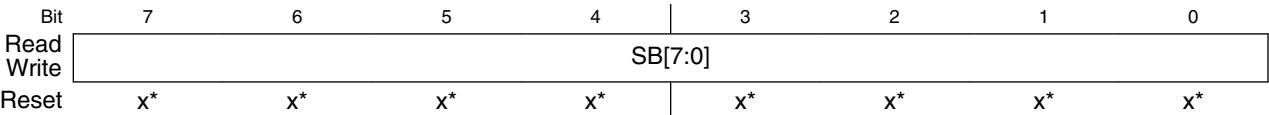
CMT_CMD3 field descriptions

| Field | Description |
|-----------------|--|
| 7-0 SB[15:8] | SB[15:8] Controls the upper space periods of the modulator for all modes. |

41.6.10 CMT Modulator Data Register Space Low (CMT_CMD4)

The contents of this register are transferred to the space period register upon the completion of a modulation period.

Address: 4006_2000h base + 9h offset = 4006_2009h



- * Notes:
- x = Undefined at reset.

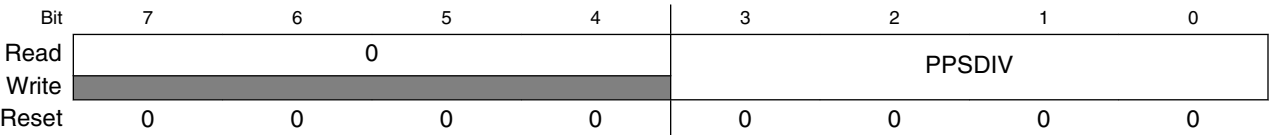
CMT_CMD4 field descriptions

| Field | Description |
|----------------|---|
| 7–0 SB[7:0] | SB[7:0] Controls the lower space periods of the modulator for all modes. |

41.6.11 CMT Primary Prescaler Register (CMT_PPS)

This register is used to set the Primary Prescaler Divider field (PPSDIV).

Address: 4006_2000h base + Ah offset = 4006_200Ah



CMT_PPS field descriptions

| Field | Description |
|-----------------|--|
| 7–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3–0 PPSDIV | Primary Prescaler Divider Divides the CMT clock to generate the Intermediate Frequency clock enable to the secondary prescaler. 0000 Bus clock ÷ 1 0001 Bus clock ÷ 2 0010 Bus clock ÷ 3 |

Table continues on the next page...

CMT_PPS field descriptions (continued)

| Field | Description |
|-------|----------------|
| 0011 | Bus clock ÷ 4 |
| 0100 | Bus clock ÷ 5 |
| 0101 | Bus clock ÷ 6 |
| 0110 | Bus clock ÷ 7 |
| 0111 | Bus clock ÷ 8 |
| 1000 | Bus clock ÷ 9 |
| 1001 | Bus clock ÷ 10 |
| 1010 | Bus clock ÷ 11 |
| 1011 | Bus clock ÷ 12 |
| 1100 | Bus clock ÷ 13 |
| 1101 | Bus clock ÷ 14 |
| 1110 | Bus clock ÷ 15 |
| 1111 | Bus clock ÷ 16 |

41.6.12 CMT Direct Memory Access Register (CMT_DMA)

This register is used to enable/disable direct memory access (DMA).

Address: 4006_2000h base + Bh offset = 4006_200Bh

| | | | | | | | | |
|-------|---|---|---|---|---|---|---|-----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | | | | DMA |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CMT_DMA field descriptions

| Field | Description |
|-----------------|--|
| 7–1 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 0 DMA | DMA Enable Enables the DMA protocol. 0 DMA transfer request and done are disabled. 1 DMA transfer request and done are enabled. |

41.7 Functional description

The CMT module primarily consists of clock divider, carrier generator, and modulator.

41.7.1 Clock divider

The CMT was originally designed to be based on an 8 MHz bus clock that could be divided by 1, 2, 4, or 8 according to the specification. To be compatible with higher bus frequency, the primary prescaler (PPS) was developed to receive a higher frequency and generate a clock enable signal called intermediate frequency (IF). This IF must be approximately equal to 8 MHz and will work as a clock enable to the secondary prescaler. The following figure shows the clock divider block diagram.

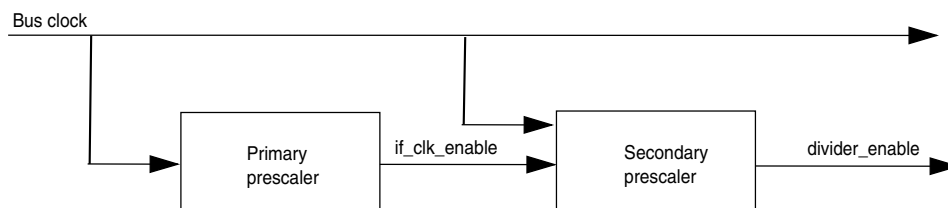


Figure 41-14. Clock divider block diagram

For compatibility with previous versions of CMT, when bus clock = 8 MHz, the PPS must be configured to zero. The PPS counter is selected according to the bus clock to generate an intermediate frequency approximately equal to 8 MHz.

41.7.2 Carrier generator

The carrier generator resolution is 125 ns when operating with an 8 MHz intermediate frequency signal and the secondary prescaler is set to divide by 1, or, when $MSC[CMTDIV] = 00$. The carrier generator can generate signals with periods between 250 ns (4 MHz) and 127.5 μs (7.84 kHz) in steps of 125 ns. The following table shows the relationship between the clock divide bits and the carrier generator resolution, minimum carrier generator period, and minimum modulator period.

Table 41-19. Clock divider

| Bus clock (MHz) | MSC[CMTDIV] | Carrier generator resolution (μs) | Min. carrier generator period (μs) | Min. modulator period (μs) |
|-----------------|-------------|-----------------------------------|------------------------------------|----------------------------|
| 8 | 00 | 0.125 | 0.25 | 1.0 |
| 8 | 01 | 0.25 | 0.5 | 2.0 |
| 8 | 10 | 0.5 | 1.0 | 4.0 |
| 8 | 11 | 1.0 | 2.0 | 8.0 |

The possible duty cycle options depend upon the number of counts required to complete the carrier period. For example, 1.6 MHz signal has a period of 625 ns and will therefore require 5 x 125 ns counts to generate. These counts may be split between high and low times, so the duty cycles available will be:

- 20% with one high and four low times
- 40% with two high and three low times
- 60% with three high and two low times, and
- 80% with four high and one low time

.

For low-frequency signals with large periods, high-resolution duty cycles as a percentage of the total period, are possible.

The carrier signal is generated by counting a register-selected number of input clocks (125 ns for an 8 MHz bus) for both the carrier high time and the carrier low time. The period is determined by the total number of clocks counted. The duty cycle is determined by the ratio of high-time clocks to total clocks counted. The high and low time values are user-programmable and are held in two registers.

An alternate set of high/low count values is held in another set of registers to allow the generation of dual-frequency FSK protocols without CPU intervention.

Note

Only nonzero data values are allowed. The carrier generator will not work if any of the count values are equal to zero.

MSC[MCGEN] must be set and MSC[BASE] must be cleared to enable carrier generator clocks. When MSC[BASE] is set, the carrier output to the modulator is held high continuously. The following figure represents the block diagram of the clock generator.

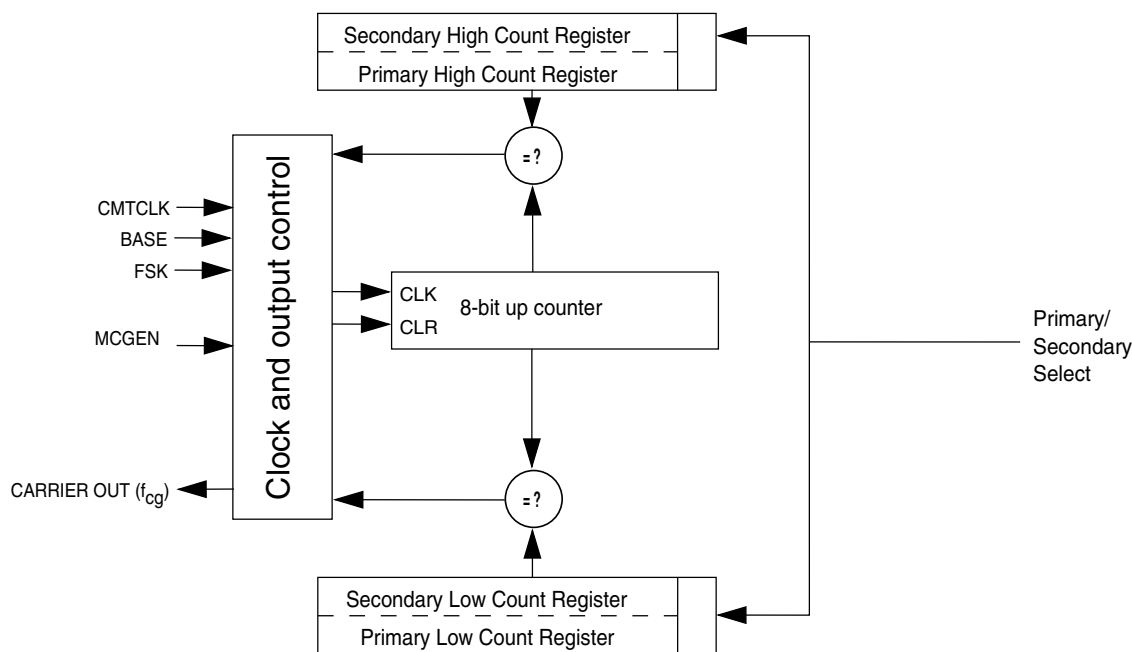


Figure 41-15. Carrier generator block diagram

The high/low time counter is an 8-bit up counter. After each increment, the contents of the counter are compared with the appropriate high or low count value register. When the compare value is reached, the counter is reset to a value of 0x01, and the compare is redirected to the other count value register.

Assuming that the high time count compare register is currently active, a valid compare will cause the carrier output to be driven low. The counter will continue to increment starting at the reset value of 0x01. When the value stored in the selected low count value register is reached, the counter will again be reset and the carrier output will be driven high.

The cycle repeats, automatically generating a periodic signal which is directed to the modulator. The lower frequency with maximum period, f_{\max} , and highest frequency with minimum period, f_{\min} , which can be generated, are defined as:

$$f_{\max} = f_{\text{CMTCLK}} \div (2 * 1) \text{ Hz}$$

$$f_{\min} = f_{\text{CMTCLK}} \div (2 * (2^8 - 1)) \text{ Hz}$$

In the general case, the carrier generator output frequency is:

$$f_{\text{cg}} = f_{\text{CMTCLK}} \div (\text{High count} + \text{Low count}) \text{ Hz}$$

Where: $0 < \text{High count} < 256$ and

$$0 < \text{Low count} < 256$$

The duty cycle of the carrier signal is controlled by varying the ratio of high time to low + high time. As the input clock period is fixed, the duty cycle resolution will be proportional to the number of counts required to generate the desired carrier period.

$$\text{DutyCycle} = \frac{\text{Highcount}}{\text{Highcount} + \text{Lowcount}}$$

41.7.3 Modulator

The modulator block controls the state of the infrared out signal (IRO). The modulator output is gated on to the IRO signal when the modulator/carrier generator is enabled. . When the modulator/carrier generator is disabled, the IRO signal is controlled by the state of the IRO latch. OC[CMTPOL] enables the IRO signal to be active-high or active-low.

The following table describes the functions of the modulators in different modes:

Table 41-20. Mode functions

| Mode | Function |
|----------|--|
| Time | The modulator can gate the carrier onto the modulator output. |
| Baseband | The modulator can control the logic level of the modulator output. |
| FSK | The modulator can count carrier periods and instruct the carrier generator to alternate between two carrier frequencies whenever a modulation period consisting of mark and space counts, expires. |

The modulator provides a simple method to control protocol timing. The modulator has a minimum resolution of 1.0 μs with an 8 MHz. It can count bus clocks to provide real-time control, or carrier clocks for self-clocked protocols.

The modulator includes a 17-bit down counter with underflow detection. The counter is loaded from the 16-bit modulation mark period buffer registers, CMD1 and CMD2. The most significant bit is loaded with a logic 0 and serves as a sign bit.

| When | Then |
|------------------------------------|---|
| The counter holds a positive value | The modulator gate is open and the carrier signal is driven to the transmitter block. |
| The counter underflows | The modulator gate is closed and a 16-bit comparator is enabled which compares the logical complement of the value of the down counter with the contents of the modulation space period register which has been loaded from the registers, CMD3 and CMD4. |

When a match is obtained, the cycle repeats by opening the modulator gate, reloading the counter with the contents of CMD1 and CMD2, and reloading the modulation space period register with the contents of CMD3 and CMD4.

The modulation space period is activated when the carrier signal is low to prohibit cutting off the high pulse of a carrier signal. If the carrier signal is high, the modulator extends the mark period until the carrier signal becomes low. To deassert the space period and assert the mark period, the carrier signal must have gone low to ensure that a space period is not erroneously shortened.

If the contents of the modulation space period register are all zeroes, the match will be immediate and no space period will be generated, for instance, for FSK protocols that require successive bursts of different frequencies).

MSC[MCGEN] must be set to enable the modulator timer.

The following figure presents the block diagram of the modulator.

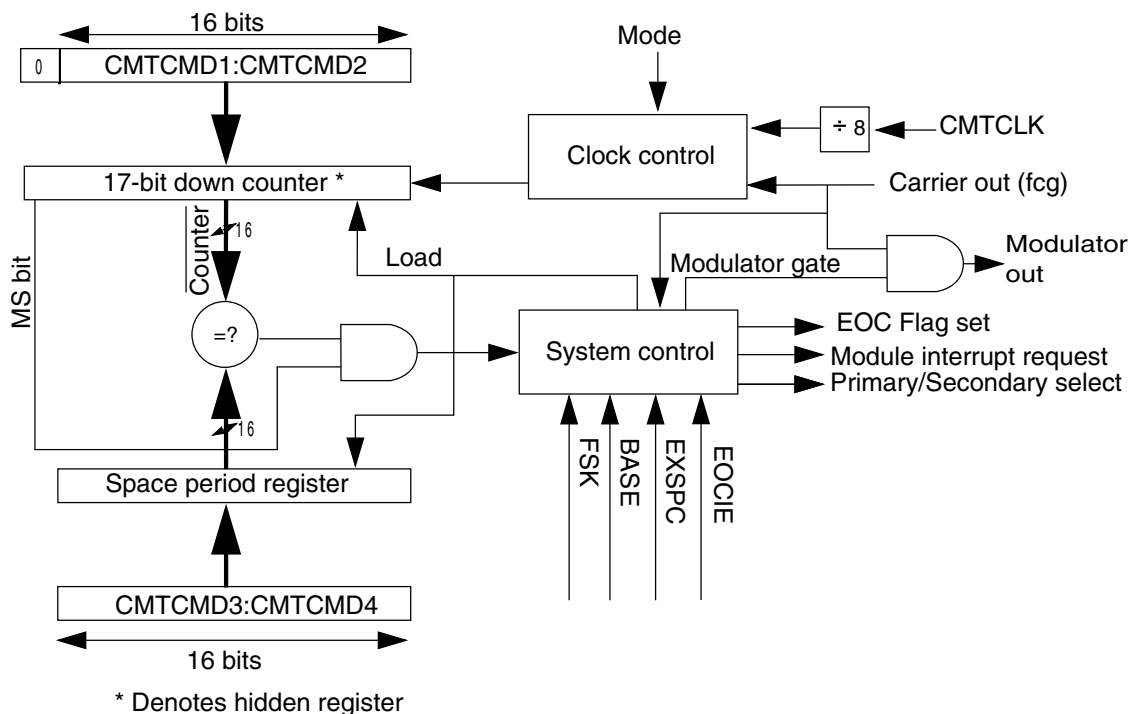


Figure 41-16. Modulator block diagram

41.7.3.1 Time mode

When the modulator operates in Time mode, or, when MSC[MCGEN] is set, and MSC[BASE] and MSC[FSK] are cleared:

- The modulation mark period consists of an integer number of $(\text{CMTCLK} \div 8)$ clock periods.
- The modulation space period consists of 0 or an integer number of $(\text{CMTCLK} \div 8)$ clock periods.

With an 8 MHz IF and $\text{MSC}[\text{CMTDIV}] = 00$, the modulator resolution is 1 μs and has a maximum mark and space period of about 65.535 μs each. See Figure 41-17 for an example of the Time and Baseband mode outputs.

The mark and space time equations for Time and Baseband mode are:

$$t_{\text{mark}} = (\text{CMD1}:\text{CMD2} + 1) \div (f_{\text{CMTCLK}} \div 8)$$

$$t_{\text{space}} = \text{CMD3}:\text{CMD4} \div (f_{\text{CMTCLK}} \div 8)$$

where $\text{CMD1}:\text{CMD2}$ and $\text{CMD3}:\text{CMD4}$ are the decimal values of the concatenated registers.

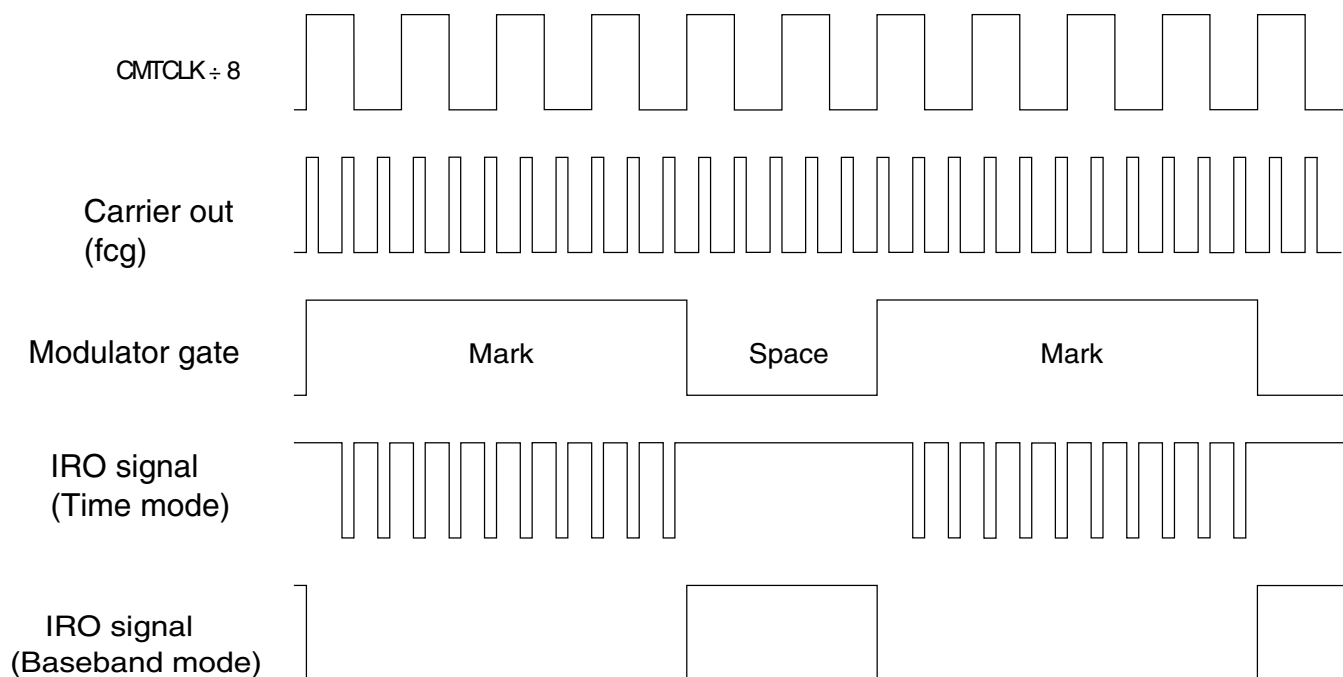


Figure 41-17. Example: CMT output in Time and Baseband modes with $\text{OC}[\text{CMTPOL}] = 0$

41.7.3.2 Baseband mode

Baseband mode, that is, when $\text{MSC}[\text{MCGEN}]$ and $\text{MSC}[\text{BASE}]$ are set, is a derivative of Time mode, where the mark and space period is based on $(\text{CMTCLK} \div 8)$ counts. The mark and space calculations are the same as in Time mode.

In this mode, the modulator output will be at a logic 1 for the duration of the mark period and at a logic 0 for the duration of a space period. See [Figure 41-17](#) for an example of the output for both Baseband and Time modes. In the example, the carrier out frequency (f_{cg}) is generated with a high count of 0x01 and a low count of 0x02 that results in a divide of 3 of CMTCLK with a 33% duty cycle. The modulator down counter was loaded with the value 0x0003 and the space period register with 0x0002.

Note

The waveforms in [Figure 41-17](#) and [Figure 41-18](#) are for the purpose of conceptual illustration and are not meant to represent precise timing relationships between the signals shown.

41.7.3.3 FSK mode

When the modulator operates in FSK mode, that is, when MSC[MCGEN] and MSC[FSK] are set, and MSC[BASE] is cleared:

- The modulation mark and space periods consist of an integer number of carrier clocks (space period can be zero).
- When the mark period expires, the space period is transparently started as in Time mode.
- The carrier generator toggles between primary and secondary data register values whenever the modulator space period expires.

The space period provides an interpulse gap (no carrier). If CMD3:CMD4 = 0x0000, then the modulator and carrier generator will switch between carrier frequencies without a gap or any carrier glitches (zero space).

Using timing data for carrier burst and interpulse gap length calculated by the CPU, FSK mode can automatically generate a phase-coherent, dual-frequency FSK signal with programmable burst and interburst gaps.

The mark and space time equations for FSK mode are:

$$t_{\text{mark}} = (\text{CMD1:CMD2} + 1) \div f_{cg}$$

$$t_{\text{space}} = (\text{CMD3:CMD4}) \div f_{cg}$$

Where f_{cg} is the frequency output from the carrier generator. The example in [Figure 41-18](#) shows what the IRO signal looks like in FSK mode with the following values:

- CMD1:CMD2 = 0x0003
- CMD3:CMD4 = 0x0002
- Primary carrier high count = 0x01
- Primary carrier low count = 0x02

- Secondary carrier high count = 0x03
- Secondary carrier low count = 0x01

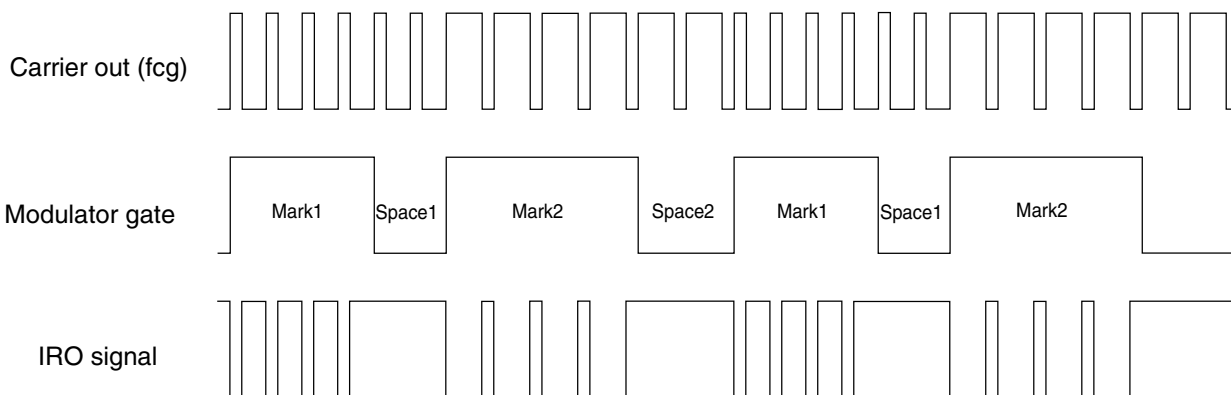


Figure 41-18. Example: CMT output in FSK mode

41.7.4 Extended space operation

In either Time, Baseband, or FSK mode, the space period can be made longer than the maximum possible value of the space period register. Setting MSC[EXSPC] will force the modulator to treat the next modulation period beginning with the next load of the counter and space period register, as a space period equal in length to the mark and space counts combined. Subsequent modulation periods will consist entirely of these extended space periods with no mark periods. Clearing MSC[EXSPC] will return the modulator to standard operation at the beginning of the next modulation period.

41.7.4.1 EXSPC operation in Time mode

To calculate the length of an extended space in Time or Baseband mode, add the mark and space times and multiply by the number of modulation periods when MSC[EXSPC] is set.

$$t_{\text{exspace}} = (t_{\text{mark}} + t_{\text{space}}) * (\text{number of modulation periods})$$

For an example of extended space operation, see [Figure 41-19](#).

Note

The extended space enable feature can be used to emulate a zero mark event.

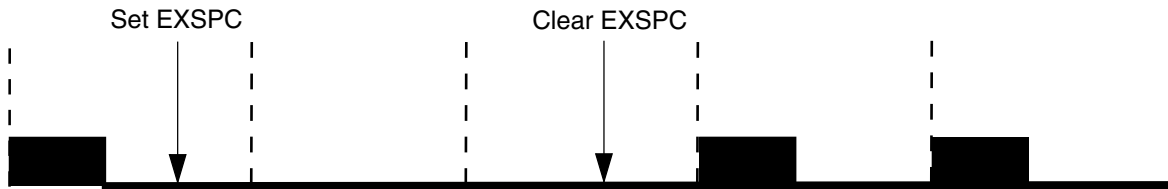


Figure 41-19. Extended space operation

41.7.4.2 EXSPC operation in FSK mode

In FSK mode, the modulator continues to count carrier out clocks, alternating between the primary and secondary registers at the end of each modulation period.

To calculate the length of an extended space in FSK mode, it is required to know whether MSC[EXSPC] was set on a primary or secondary modulation period, and the total number of both primary and secondary modulation periods completed while MSC[EXSPC] is high. A status bit for the current modulation is not accessible to the CPU. If necessary, software must maintain tracking of the current primary or secondary modulation cycle. The extended space period ends at the completion of the space period time of the modulation period during which MSC[EXSPC] is cleared.

The following table depicts the equations which can be used to calculate the extended space period depending on when MSC[EXSPC] is set.

| If | Then |
|--|--|
| MSC[EXSPC] was set during a primary modulation cycle | Use the equation: $t_{\text{exspace}} = (t_{\text{space}})_p + (t_{\text{mark}} + t_{\text{space}})_s + (t_{\text{mark}} + t_{\text{space}})_p + \dots$ |
| MSC[EXSPC] bit was set during a secondary modulation cycle | Use the equation: $t_{\text{exspace}} = (t_{\text{space}})_s + (t_{\text{mark}} + t_{\text{space}})_p + (t_{\text{mark}} + t_{\text{space}})_s + \dots$ |

Where the subscripts p and s refer to mark and space times for the primary and secondary modulation cycles.

41.8 CMT interrupts and DMA

The CMT generates an interrupt request or a DMA transfer request according to MSC[EOCIE], MSC[EOCF], DMA[DMA] bits.

Table 41-23. DMA transfer request x CMT interrupt request

| MSC[EOCF] | DMA[DMA] | MSC[EOCIE] | DMA transfer request | CMT interrupt request |
|-----------|----------|------------|----------------------|-----------------------|
| 0 | X | X | 0 | 0 |
| 1 | X | 0 | 0 | 0 |
| 1 | 0 | 1 | 0 | 1 |
| 1 | 1 | 1 | 1 | 0 |

MSC[EOCF] is set:

- When the modulator is not currently active and MSC[MCGEN] is set to begin the initial CMT transmission.
- At the end of each modulation cycle when the counter is reloaded from CMD1:CMD2, while MSC[MCGEN] is set.

When MSC[MCGEN] is cleared and then set before the end of the modulation cycle, MSC[EOCF] will not be set when MSC[MCGEN] is set, but will become set at the end of the current modulation cycle.

When MSC[MCGEN] becomes disabled, the CMT module does not set MSC[EOCF] at the end of the last modulation cycle.

If MSC[EOCIE] is high when MSC[EOCF] is set, the CMT module will generate an interrupt request or a DMA transfer request.

MSC[EOCF] must be cleared to prevent from being generated by another event like interrupt or DMA request, after exiting the service routine. See the following table.

Table 41-24. How to clear MSC[EOCF]

| DMA[DMA] | MSC[EOCIE] | Description |
|----------|------------|--|
| 0 | X | MSC[EOCF] is cleared by reading MSC followed by an access of CMD2 or CMD4. |
| 1 | X | MSC[EOCF] is cleared by the CMT DMA transfer done. |

The EOC interrupt is coincident with:

- Loading the down-counter with the contents of CMD1:CMD2
- Loading the space period register with the contents of CMD3:CMD4

The EOC interrupt provides a means for the user to reload new mark/space values into the modulator data registers. Modulator data register updates will take effect at the end of the current modulation cycle.

NOTE

The down-counter and space period register are updated at the end of every modulation cycle, irrespective of interrupt handling and the state of MSC[EOCF].

Chapter 42

Real Time Clock (RTC)

42.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

42.1.1 Features

The RTC module features include:

- Independent power supply, POR, and 32 kHz crystal oscillator
- 32-bit seconds counter with roll-over protection and 32-bit alarm
- 16-bit prescaler with compensation that can correct errors between 0.12 ppm and 3906 ppm
- Register write protection
 - Lock register requires VBAT POR or software reset to enable write access
 - Access control registers require system reset to enable read and/or write access
- 1 Hz square wave output
- 64-bit monotonic counter with roll-over protection
- Tamper time seconds register that records when the time was invalidated

42.1.2 Modes of operation

The RTC remains functional in all low power modes and can generate an interrupt to exit any low power mode. It operates in one of two modes of operation: chip power-up and chip power-down.

During chip power-down, RTC is powered from the backup power supply (VBAT) and is electrically isolated from the rest of the chip but continues to increment the time counter (if enabled) and retain the state of the RTC registers. The RTC registers are not accessible.

During chip power-up, RTC remains powered from the backup power supply (VBAT). All RTC registers are accessible by software and all functions are operational. If enabled, the 32.768 kHz clock can be supplied to the rest of the chip.

42.1.3 RTC signal descriptions

Table 42-1. RTC signal descriptions

| Signal | Description | I/O |
|------------|------------------------------|-----|
| EXTAL32 | 32.768 kHz oscillator input | I |
| XTAL32 | 32.768 kHz oscillator output | O |
| RTC_CLKOUT | 1 Hz square-wave output | O |

42.1.3.1 RTC clock output

The clock to the seconds counter is available on the RTC_CLKOUT signal. It is a 1 Hz square wave output.

42.2 Register definition

All registers must be accessed using 32-bit writes and all register accesses incur three wait states.

Write accesses to any register and read accesses to tamper and monotonic registers by non-supervisor mode software, when the supervisor access bit in the control register is clear, will terminate with a bus error.

Read accesses to other registers by non-supervisor mode software complete as normal.

Writing to a register protected by the write access register or lock register does not generate a bus error, but the write will not complete.

Reading a register protected by the read access register does not generate a bus error, but the register will read zero.

RTC memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|--|-----------------|--------|-------------|-----------------------------|
| 4003_D000 | RTC Time Seconds Register (RTC_TSR) | 32 | R/W | 0000_0000h | 42.2.1/955 |
| 4003_D004 | RTC Time Prescaler Register (RTC_TPR) | 32 | R/W | 0000_0000h | 42.2.2/956 |
| 4003_D008 | RTC Time Alarm Register (RTC_TAR) | 32 | R/W | 0000_0000h | 42.2.3/956 |
| 4003_D00C | RTC Time Compensation Register (RTC_TCR) | 32 | R/W | 0000_0000h | 42.2.4/957 |
| 4003_D010 | RTC Control Register (RTC_CR) | 32 | R/W | 0000_0000h | 42.2.5/958 |
| 4003_D014 | RTC Status Register (RTC_SR) | 32 | R/W | 0000_0001h | 42.2.6/960 |
| 4003_D018 | RTC Lock Register (RTC_LR) | 32 | R/W | 0000_FFFFh | 42.2.7/961 |
| 4003_D01C | RTC Interrupt Enable Register (RTC_IER) | 32 | R/W | 0000_0007h | 42.2.8/963 |
| 4003_D020 | RTC Tamper Time Seconds Register (RTC_TTSR) | 32 | R | Undefined | 42.2.9/964 |
| 4003_D024 | RTC Monotonic Enable Register (RTC_MER) | 32 | R/W | 0000_0000h | 42.2.10/964 |
| 4003_D028 | RTC Monotonic Counter Low Register (RTC_MCLR) | 32 | R/W | 0000_0000h | 42.2.11/965 |
| 4003_D02C | RTC Monotonic Counter High Register (RTC_MCHR) | 32 | R/W | 0000_0000h | 42.2.12/965 |
| 4003_D800 | RTC Write Access Register (RTC_WAR) | 32 | R/W | 0000_FFFFh | 42.2.13/966 |
| 4003_D804 | RTC Read Access Register (RTC_RAR) | 32 | R/W | 0000_FFFFh | 42.2.14/968 |

42.2.1 RTC Time Seconds Register (RTC_TSR)

Address: 4003_D000h base + 0h offset = 4003_D000h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

RTC_TSR field descriptions

| Field | Description |
|-------------|---|
| 31–0 TSR | Time Seconds Register When the time counter is enabled, the TSR is read only and increments once a second provided SR[TOF] or SR[TIF] are not set. The time counter will read as zero when SR[TOF] or SR[TIF] are set. When the time counter is disabled, the TSR can be read or written. Writing to the TSR when the time counter is disabled will clear the SR[TOF] and/or the SR[TIF]. Writing to TSR with zero is supported, but not |

RTC_TSR field descriptions (continued)

| Field | Description |
|-------|---|
| | recommended because TSR will read as zero when SR[TIF] or SR[TOF] are set (indicating the time is invalid). |

42.2.2 RTC Time Prescaler Register (RTC_TPR)

Address: 4003_D000h base + 4h offset = 4003_D004h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | TPR | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | TPR | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

RTC_TPR field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 TPR | Time Prescaler Register When the time counter is enabled, the TPR is read only and increments every 32.768 kHz clock cycle. The time counter will read as zero when SR[TOF] or SR[TIF] are set. When the time counter is disabled, the TPR can be read or written. The TSR[TSR] increments when bit 14 of the TPR transitions from a logic one to a logic zero. |

42.2.3 RTC Time Alarm Register (RTC_TAR)

Address: 4003_D000h base + 8h offset = 4003_D008h

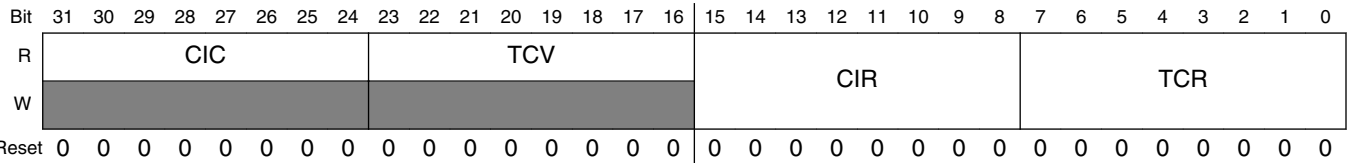
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | TAR | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

RTC_TAR field descriptions

| Field | Description |
|-------------|---|
| 31–0 TAR | Time Alarm Register When the time counter is enabled, the SR[TAF] is set whenever the TAR[TAR] equals the TSR[TSR] and the TSR[TSR] increments. Writing to the TAR clears the SR[TAF]. |

42.2.4 RTC Time Compensation Register (RTC_TCR)

Address: 4003_D000h base + Ch offset = 4003_D00Ch

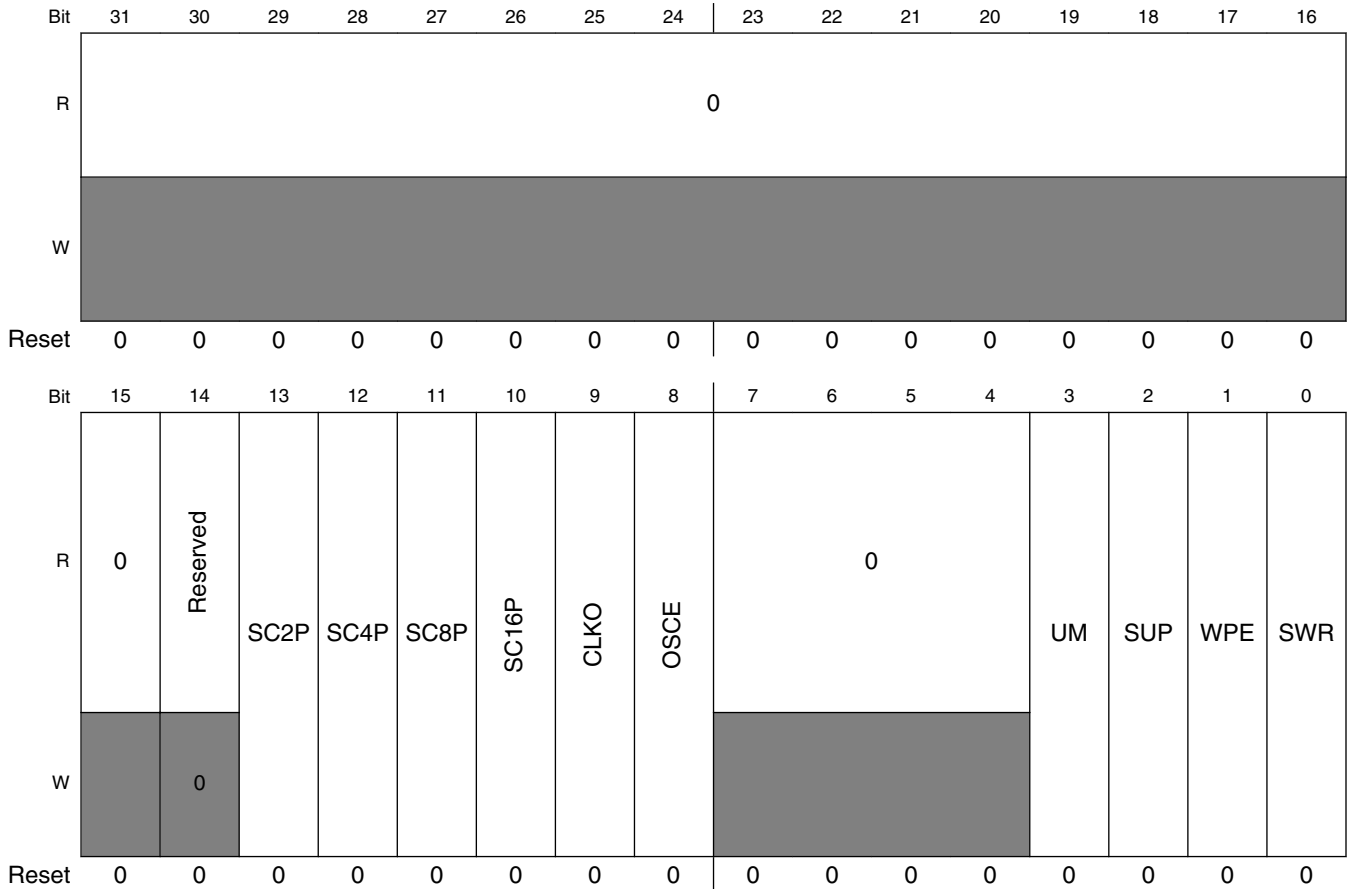


RTC_TCR field descriptions

| Field | Description |
|--------------|---|
| 31–24 CIC | <p>Compensation Interval Counter</p> <p>Current value of the compensation interval counter. If the compensation interval counter equals zero then it is loaded with the contents of the CIR. If the CIC does not equal zero then it is decremented once a second.</p> |
| 23–16 TCV | <p>Time Compensation Value</p> <p>Current value used by the compensation logic for the present second interval. Updated once a second if the CIC equals 0 with the contents of the TCR field. If the CIC does not equal zero then it is loaded with zero (compensation is not enabled for that second increment).</p> |
| 15–8 CIR | <p>Compensation Interval Register</p> <p>Configures the compensation interval in seconds from 1 to 256 to control how frequently the TCR should adjust the number of 32.768 kHz cycles in each second. The value written should be one less than the number of seconds. For example, write zero to configure for a compensation interval of one second. This register is double buffered and writes do not take affect until the end of the current compensation interval.</p> |
| 7–0 TCR | <p>Time Compensation Register</p> <p>Configures the number of 32.768 kHz clock cycles in each second. This register is double buffered and writes do not take affect until the end of the current compensation interval.</p> <p>80h Time Prescaler Register overflows every 32896 clock cycles. ... FFh Time Prescaler Register overflows every 32769 clock cycles. 00h Time Prescaler Register overflows every 32768 clock cycles. 01h Time Prescaler Register overflows every 32767 clock cycles. ... 7Fh Time Prescaler Register overflows every 32641 clock cycles.</p> |

42.2.5 RTC Control Register (RTC_CR)

Address: 4003_D000h base + 10h offset = 4003_D010h



RTC_CR field descriptions

| Field | Description |
|-------------------|---|
| 31–15 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 14 Reserved | This field is reserved. It must always be written to 0. |
| 13 SC2P | Oscillator 2pF Load Configure 0 Disable the load. 1 Enable the additional load. |
| 12 SC4P | Oscillator 4pF Load Configure 0 Disable the load. 1 Enable the additional load. |
| 11 SC8P | Oscillator 8pF Load Configure |

Table continues on the next page...

RTC_CR field descriptions (continued)

| Field | Description |
|-----------------|---|
| | 0 Disable the load. 1 Enable the additional load. |
| 10 SC16P | Oscillator 16pF Load Configure 0 Disable the load. 1 Enable the additional load. |
| 9 CLKO | Clock Output 0 The 32 kHz clock is output to other peripherals. 1 The 32 kHz clock is not output to other peripherals. |
| 8 OSCE | Oscillator Enable 0 32.768 kHz oscillator is disabled. 1 32.768 kHz oscillator is enabled. After setting this bit, wait the oscillator startup time before enabling the time counter to allow the 32.768 kHz clock time to stabilize. |
| 7–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3 UM | Update Mode Allows SR[TCE] to be written even when the Status Register is locked. When set, the SR[TCE] can always be written if the SR[TIF] or SR[TOF] are set or if the SR[TCE] is clear. Allows the monotonic enable register to be written when it is locked. When set, the monotonic enable register can always be written if the SR[TIF] or SR[MOF] are set or if the montonic counter enable is clear. 0 Registers cannot be written when locked. 1 Registers can be written when locked under limited conditions. |
| 2 SUP | Supervisor Access Configures non-supervisor mode write access to all RTC registers and non-supervisor mode read access to RTC tamper/monotonic registers 0 Non-supervisor mode write accesses are not supported and generate a bus error. 1 Non-supervisor mode write accesses are supported. |
| 1 WPE | Wakeup Pin Enable The wakeup pin is optional and not available on all devices. 0 Wakeup pin is disabled. 1 Wakeup pin is enabled and wakeup pin asserts if the RTC interrupt asserts or the wakeup pin is turned on. |
| 0 SWR | Software Reset 0 No effect. 1 Resets all RTC registers except for the SWR bit and the RTC_WAR and RTC_RAR registers . The SWR bit is cleared by VBAT POR and by software explicitly clearing it. |

42.2.6 RTC Status Register (RTC_SR)

Address: 4003_D000h base + 14h offset = 4003_D014h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|-----|----|----|----|-----|-----|-----|-----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | MOF | TAF | TOF | TIF |
| W | | | | | | | | | TCE | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

RTC_SR field descriptions

| Field | Description |
|------------------|---|
| 31–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 TCE | Time Counter Enable When time counter is disabled the TSR register and TPR register are writeable, but do not increment. When time counter is enabled the TSR register and TPR register are not writeable, but increment. 0 Time counter is disabled. 1 Time counter is enabled. |
| 3 MOF | Monotonic Overflow Flag Monotonic overflow flag is set when the monotonic counter is enabled and the monotonic counter high overflows. The monotonic counter does not increment and will read as zero when this bit is set. This bit is cleared by writing the monotonic counter high register when the monotonic counter is disabled. 0 Monotonic counter overflow has not occurred. 1 Monotonic counter overflow has occurred and monotonic counter is read as zero. |
| 2 TAF | Time Alarm Flag Time alarm flag is set when the TAR[TAR] equals the TSR[TSR] and the TSR[TSR] increments. This bit is cleared by writing the TAR register. 0 Time alarm has not occurred. 1 Time alarm has occurred. |
| 1 TOF | Time Overflow Flag Time overflow flag is set when the time counter is enabled and overflows. The TSR and TPR do not increment and read as zero when this bit is set. This bit is cleared by writing the TSR register when the time counter is disabled. 0 Time overflow has not occurred. 1 Time overflow has occurred and time counter is read as zero. |

Table continues on the next page...

RTC_SR field descriptions (continued)

| Field | Description |
|----------|--|
| 0 TIF | <p>Time Invalid Flag</p> <p>The time invalid flag is set on VBAT POR or software reset. The TSR and TPR do not increment and read as zero when this bit is set. This bit is cleared by writing the TSR register when the time counter is disabled.</p> <p>The monotonic counter register is held in reset whenever the time invalid flag is set.</p> <p>0 Time is valid. 1 Time is invalid and time counter is read as zero.</p> |

42.2.7 RTC Lock Register (RTC_LR)

Address: 4003_D000h base + 18h offset = 4003_D018h

| | | | | | | | | | | | | | | | | |
|-------|----------|----|----|----|------|------|-----|------|----|-----|-----|-----|-----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | Reserved | | | | | | | | 1 | | | | | | 1 | |
| W | 1 | | | | MCHL | MCLL | MEL | TTSL | | LRL | SRL | CRL | TCL | | | |
| Reset | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

RTC_LR field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–12 Reserved | This field is reserved. |
| 11 MCHL | <p>Monotonic Counter High Lock</p> <p>After being cleared, this bit can be set only by VBAT POR or software reset.</p> |

Table continues on the next page...

RTC_LR field descriptions (continued)

| Field | Description |
|-----------------|--|
| | <p>0 Monotonic Counter High Register is locked and writes are ignored.</p> <p>1 Monotonic Counter High Register is not locked and writes complete as normal.</p> |
| 10 MCLL | <p>Monotonic Counter Low Lock</p> <p>After being cleared, this bit can be set only by VBAT POR or software reset.</p> <p>0 Monotonic Counter Low Register is locked and writes are ignored.</p> <p>1 Monotonic Counter Low Register is not locked and writes complete as normal.</p> |
| 9 MEL | <p>Monotonic Enable Lock</p> <p>After being cleared, this bit can be set only by VBAT POR or software reset.</p> <p>0 Monotonic Enable Register is locked and writes are ignored.</p> <p>1 Monotonic Enable Register is not locked and writes complete as normal.</p> |
| 8 TTSL | <p>Tamper Time Seconds Lock</p> <p>After being cleared, this bit can be set only by VBAT POR or software reset.</p> <p>0 Tamper Time Seconds Register is locked and writes are ignored.</p> <p>1 Tamper Time Seconds Register is not locked and writes complete as normal.</p> |
| 7 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 1.</p> |
| 6 LRL | <p>Lock Register Lock</p> <p>After being cleared, this bit can be set only by VBAT POR or software reset.</p> <p>0 Lock Register is locked and writes are ignored.</p> <p>1 Lock Register is not locked and writes complete as normal.</p> |
| 5 SRL | <p>Status Register Lock</p> <p>After being cleared, this bit can be set only by VBAT POR or software reset.</p> <p>0 Status Register is locked and writes are ignored.</p> <p>1 Status Register is not locked and writes complete as normal.</p> |
| 4 CRL | <p>Control Register Lock</p> <p>After being cleared, this bit can only be set by VBAT POR.</p> <p>0 Control Register is locked and writes are ignored.</p> <p>1 Control Register is not locked and writes complete as normal.</p> |
| 3 TCL | <p>Time Compensation Lock</p> <p>After being cleared, this bit can be set only by VBAT POR or software reset.</p> <p>0 Time Compensation Register is locked and writes are ignored.</p> <p>1 Time Compensation Register is not locked and writes complete as normal.</p> |
| 2-0 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 1.</p> |

42.2.8 RTC Interrupt Enable Register (RTC_IER)

Address: 4003_D000h base + 1Ch offset = 4003_D01Ch

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|------|----------|----|------|------|------|------|------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | WPON | Reserved | | TSIE | MOIE | TAIE | TOIE | TIIE |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |

RTC_IER field descriptions

| Field | Description |
|------------------|---|
| 31–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7 WPON | Wakeup Pin On The wakeup pin is optional and not available on all devices. Whenever the wakeup pin is enabled and this bit is set, the wakeup pin will assert. 0 No effect. 1 If the wakeup pin is enabled, then the wakeup pin will assert. |
| 6–5 Reserved | This field is reserved. |
| 4 TSIE | Time Seconds Interrupt Enable The seconds interrupt is an edge-sensitive interrupt with a dedicated interrupt vector. It is generated once a second and requires no software overhead (there is no corresponding status flag to clear). 0 Seconds interrupt is disabled. 1 Seconds interrupt is enabled. |
| 3 MOIE | Monotonic Overflow Interrupt Enable 0 Monotonic overflow flag does not generate an interrupt. 1 Monotonic overflow flag does generate an interrupt. |
| 2 TAIE | Time Alarm Interrupt Enable 0 Time alarm flag does not generate an interrupt. 1 Time alarm flag does generate an interrupt. |
| 1 TOIE | Time Overflow Interrupt Enable |

Table continues on the next page...

RTC_IER field descriptions (continued)

| Field | Description |
|-----------|---|
| | 0 Time overflow flag does not generate an interrupt. 1 Time overflow flag does generate an interrupt. |
| 0 TIIE | Time Invalid Interrupt Enable 0 Time invalid flag does not generate an interrupt. 1 Time invalid flag does generate an interrupt. |

42.2.9 RTC Tamper Time Seconds Register (RTC_TTSR)

Address: 4003_D000h base + 20h offset = 4003_D020h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | TTS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | x* | |

* Notes:

- x = Undefined at reset.

RTC_TTSR field descriptions

| Field | Description |
|-------------|---|
| 31–0 TTS | Tamper Time Seconds If the time invalid flag is set then reading this register returns the contents of the time seconds register at the point at which the time invalid flag was set. If the time invalid flag is clear then reading this register returns zero. Writing the tamper time seconds register with any value will set the time invalid flag. |

42.2.10 RTC Monotonic Enable Register (RTC_MER)

Address: 4003_D000h base + 24h offset = 4003_D024h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|-----|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | MCE | | 0 | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

RTC_MER field descriptions

| Field | Description |
|------------------|--|
| 31–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 MCE | Monotonic Counter Enable 0 Writes to the monotonic counter load the counter with the value written. 1 Writes to the monotonic counter increment the counter. |
| 3–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

42.2.11 RTC Monotonic Counter Low Register (RTC_MCLR)

Address: 4003_D000h base + 28h offset = 4003_D028h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | MCL | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

RTC_MCLR field descriptions

| Field | Description |
|-------------|---|
| 31–0 MCL | Monotonic Counter Low When the time invalid flag is set, the monotonic counter is held in reset. When the monotonic counter enable is clear, a write to this register will load the counter with the value written. When the monotonic counter enable is set, a write to this register will cause it to increment. A write to monotonic counter low that causes it to overflow will also increment monotonic counter high. |

42.2.12 RTC Monotonic Counter High Register (RTC_MCHR)

Address: 4003_D000h base + 2Ch offset = 4003_D02Ch

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | <div>MCH</div> | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

RTC_MCHR field descriptions

| Field | Description |
|-------------|--|
| 31–0 MCH | Monotonic Counter High When the time invalid flag is set, the monotonic counter is held in reset. When the monotonic counter enable is clear, a write to this register will load the counter with the value written. When the monotonic counter enable is set, a write to this register will cause it to increment. A write to monotonic counter low that causes it to overflow will also increment monotonic counter high. |

42.2.13 RTC Write Access Register (RTC_WAR)

Address: 4003_D000h base + 800h offset = 4003_D800h

| | | | | | | | | | | | | | | | | |
|-------|----------|----|----|----|------|------|------|------|------|-----|-----|-----|------|------|------|------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | Reserved | | | | | | | | | | | | | | | |
| W | 1 | | | | MCHW | MCLW | MERW | TTSW | IERW | LRW | SRW | CRW | TCRW | TARW | TPRW | TSRW |
| Reset | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

RTC_WAR field descriptions

| Field | Description |
|-------------------|---|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–12 Reserved | This field is reserved. |
| 11 MCHW | Monotonic Counter High Write After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset. 0 Writes to the Monotonic Counter High Register are ignored. 1 Writes to the Monotonic Counter High Register complete as normal. |
| 10 MCLW | Monotonic Counter Low Write After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset. 0 Writes to the Monotonic Counter Low Register are ignored. 1 Writes to the Monotonic Counter Low Register complete as normal. |
| 9 MERW | Monotonic Enable Register Write After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset. |

Table continues on the next page...

RTC_WAR field descriptions (continued)

| Field | Description |
|-----------|--|
| | <p>0 Writes to the Monotonic Enable Register are ignored.</p> <p>1 Writes to the Monotonic Enable Register complete as normal.</p> |
| 8 TTSW | <p>Tamper Time Seconds Write</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Writes to the Tamper Time Seconds Register are ignored.</p> <p>1 Writes to the Tamper Time Seconds Register complete as normal.</p> |
| 7 IERW | <p>Interrupt Enable Register Write</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Writes to the Interrupt Enable Register are ignored.</p> <p>1 Writes to the Interrupt Enable Register complete as normal.</p> |
| 6 LRW | <p>Lock Register Write</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Writes to the Lock Register are ignored.</p> <p>1 Writes to the Lock Register complete as normal.</p> |
| 5 SRW | <p>Status Register Write</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Writes to the Status Register are ignored.</p> <p>1 Writes to the Status Register complete as normal.</p> |
| 4 CRW | <p>Control Register Write</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Writes to the Control Register are ignored.</p> <p>1 Writes to the Control Register complete as normal.</p> |
| 3 TCRW | <p>Time Compensation Register Write</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Writes to the Time Compensation Register are ignored.</p> <p>1 Writes to the Time Compensation Register complete as normal.</p> |
| 2 TARW | <p>Time Alarm Register Write</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Writes to the Time Alarm Register are ignored.</p> <p>1 Writes to the Time Alarm Register complete as normal.</p> |
| 1 TPRW | <p>Time Prescaler Register Write</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Writes to the Time Prescaler Register are ignored.</p> <p>1 Writes to the Time Prescaler Register complete as normal.</p> |

Table continues on the next page...

RTC_WAR field descriptions (continued)

| Field | Description |
|-----------|--|
| 0 TSRW | Time Seconds Register Write After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset. 0 Writes to the Time Seconds Register are ignored. 1 Writes to the Time Seconds Register complete as normal. |

42.2.14 RTC Read Access Register (RTC_RAR)

Address: 4003_D000h base + 804h offset = 4003_D804h

| | | | | | | | | | | | | | | | | |
|-------|----------|----|----|----|------|------|------|------|------|-----|-----|-----|------|------|------|------|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | Reserved | | | | MCHR | MCLR | MERR | TTSR | IERR | LRR | SRR | CRR | TCRR | TARR | TPRR | TSRR |
| W | 1 | | | | | | | | | | | | | | | |
| Reset | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

RTC_RAR field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–12 Reserved | This field is reserved. |
| 11 MCHR | Monotonic Counter High Read After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset. 0 Reads to the Monotonic Counter High Register are ignored. 1 Reads to the Monotonic Counter High Register complete as normal. |

Table continues on the next page...

RTC_RAR field descriptions (continued)

| Field | Description |
|------------|---|
| 10 MCLR | <p>Monotonic Counter Low Read</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Reads to the Monotonic Counter Low Register are ignored. 1 Reads to the Monotonic Counter Low Register complete as normal.</p> |
| 9 MERR | <p>Monotonic Enable Register Read</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Reads to the Monotonic Enable Register are ignored. 1 Reads to the Monotonic Enable Register complete as normal.</p> |
| 8 TTSR | <p>Tamper Time Seconds Read</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Reads to the Tamper Time Seconds Register are ignored. 1 Reads to the Tamper Time Seconds Register complete as normal.</p> |
| 7 IERR | <p>Interrupt Enable Register Read</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Reads to the Interrupt Enable Register are ignored. 1 Reads to the Interrupt Enable Register complete as normal.</p> |
| 6 LRR | <p>Lock Register Read</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Reads to the Lock Register are ignored. 1 Reads to the Lock Register complete as normal.</p> |
| 5 SRR | <p>Status Register Read</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Reads to the Status Register are ignored. 1 Reads to the Status Register complete as normal.</p> |
| 4 CRR | <p>Control Register Read</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Reads to the Control Register are ignored. 1 Reads to the Control Register complete as normal.</p> |
| 3 TCRR | <p>Time Compensation Register Read</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> <p>0 Reads to the Time Compensation Register are ignored. 1 Reads to the Time Compensation Register complete as normal.</p> |
| 2 TARR | <p>Time Alarm Register Read</p> <p>After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset.</p> |

Table continues on the next page...

RTC_RAR field descriptions (continued)

| Field | Description |
|-----------|--|
| | 0 Reads to the Time Alarm Register are ignored. 1 Reads to the Time Alarm Register complete as normal. |
| 1 TPRR | Time Prescaler Register Read After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset. 0 Reads to the Time Pprescaler Register are ignored. 1 Reads to the Time Prescaler Register complete as normal. |
| 0 TSRR | Time Seconds Register Read After being cleared, this bit is set only by system reset. It is not affected by VBAT POR or software reset. 0 Reads to the Time Seconds Register are ignored. 1 Reads to the Time Seconds Register complete as normal. |

42.3 Functional description

42.3.1 Power, clocking, and reset

The RTC is an always powered block that remains active in all low power modes and is powered by the battery power supply (VBAT). The battery power supply ensures that the RTC registers retain their state during chip power-down and that the RTC time counter remains operational.

The time counter within the RTC is clocked by a 32.768 kHz clock and can supply this clock to other peripherals. The 32.768 kHz clock can only be sourced from an external crystal using the oscillator that is part of the RTC module.

The RTC includes its own analog POR block, which generates a VBAT power-on-reset signal whenever the RTC module is powered up and initializes all RTC registers to their default state. A software reset bit can also initialize all RTC registers. The RTC also monitors the chip power supply and electrically isolates itself when the rest of the chip is powered down.

NOTE

An attempt to access an RTC register, except the access control registers, results in a bus error when:

- VBAT is powered down,
- the RTC is electrically isolated, or
- VBAT POR is asserted.

42.3.1.1 Oscillator control

The 32.768 kHz crystal oscillator is disabled at VBAT POR and must be enabled by software. After enabling the crystal oscillator, wait the oscillator startup time before setting SR[TCE] or using the oscillator clock external to the RTC.

The crystal oscillator includes tunable capacitors that can be configured by software. Do not change the capacitance unless the oscillator is disabled.

42.3.1.2 Software reset

Writing 1 to CR[SWR] forces the equivalent of a VBAT POR to the rest of the RTC module. CR[SWR] is not affected by the software reset and must be cleared by software. The access control registers are not affected by either VBAT POR or the software reset; they are reset by the chip reset.

42.3.1.3 Supervisor access

When the supervisor access control bit is clear, only supervisor mode software can write to the RTC registers or read the RTC tamper and monotonic registers, non-supervisor mode software will generate a bus error. Both supervisor and non-supervisor mode software can always read the other RTC registers.

42.3.2 Time counter

The time counter consists of a 32-bit seconds counter that increments once every second and a 16-bit prescaler register that increments once every 32.768 kHz clock cycle.

Reading the time counter (either seconds or prescaler) while it is incrementing may return invalid data due to synchronization of the read data bus. If it is necessary for software to read the prescaler or seconds counter when they could be incrementing, it is recommended that two read accesses are performed and that software verifies that the same data was returned for both reads.

The time seconds register and time prescaler register can be written only when SR[TCE] is clear. Always write to the prescaler register before writing to the seconds register, because the seconds register increments on the falling edge of bit 14 of the prescaler register.

The time prescaler register increments provided SR[TCE] is set, SR[TIF] is clear, SR[TOF] is clear, and the 32.768 kHz clock source is present. After enabling the oscillator, wait the oscillator startup time before setting SR[TCE] to allow time for the oscillator clock output to stabilize.

If the time seconds register overflows then the SR[TOF] will set and the time prescaler register will stop incrementing. Clear SR[TOF] by initializing the time seconds register. The time seconds register and time prescaler register read as zero whenever SR[TOF] is set.

SR[TIF] is set on VBAT POR and software reset and is cleared by initializing the time seconds register. The time seconds register and time prescaler register read as zero whenever SR[TIF] is set.

42.3.3 Compensation

The compensation logic provides an accurate and wide compensation range and can correct errors as high as 3906 ppm and as low as 0.12 ppm. The compensation factor must be calculated externally to the RTC and supplied by software to the compensation register. The RTC itself does not calculate the amount of compensation that is required, although the 1 Hz clock is output to an external pin in support of external calibration logic.

Crystal compensation can be supported by using firmware and crystal characteristics to determine the compensation amount. Temperature compensation can be supported by firmware that periodically measures the external temperature via ADC and updates the compensation register based on a look-up table that specifies the change in crystal frequency over temperature.

The compensation logic alters the number of 32.768 kHz clock cycles it takes for the prescaler register to overflow and increment the time seconds counter. The time compensation value is used to adjust the number of clock cycles between -127 and +128. Cycles are added or subtracted from the prescaler register when the prescaler register equals 0x3FFF and then increments. The compensation interval is used to adjust the frequency at which the time compensation value is used, that is, from once a second to once every 256 seconds.

Updates to the time compensation register will not take effect until the next time the time seconds register increments and provided the previous compensation interval has expired. When the compensation interval is set to other than once a second then the compensation is applied in the first second interval and the remaining second intervals receive no compensation.

Compensation is disabled by configuring the time compensation register to zero.

42.3.4 Time alarm

The Time Alarm register (TAR), SR[TAF], and IER[TAIE] allow the RTC to generate an interrupt at a predefined time. The 32-bit TAR is compared with the 32-bit Time Seconds register (TSR) each time it increments. SR[TAF] will set when TAR equals TSR and TSR increments.

SR[TAF] is cleared by writing TAR. This will usually be the next alarm value, although writing a value that is less than TSR, such as 0, will prevent SR[TAF] from setting again. SR[TAF] cannot otherwise be disabled, although the interrupt it generates is enabled or disabled by IER[TAIE].

42.3.5 Update mode

The Update Mode field in the Control register (CR[UM]) configures software write access to the Time Counter Enable (SR[TCE]) field. When CR[UM] is clear, SR[TCE] can be written only when LR[SRL] is set. When CR[UM] is set, SR[TCE] can also be written when SR[TCE] is clear or when SR[TIF] or SR[TOF] are set. This allows the time seconds and prescaler registers to be initialized whenever time is invalidated, while preventing the time seconds and prescaler registers from being changed on the fly. When LR[SRL] is set, CR[UM] has no effect on SR[TCE].

CR[UM] also configures software write access to the Monotonic Counter Enable (MER[MCE]) bit. When CR[UM] is clear, MER[MCE] can be written only when LR[MEL] is set. When CR[UM] is set, MER[MCE] can also be written when MER[MCE] is clear or when SR[TIF] or SR[MOF] are set. This allows the monotonic counter register to be initialized whenever the monotonic counter is invalid, while preventing the monotonic counter from being changed on the fly. When LR[MEL] is set, CR[UM] has no effect on MCR[MCE].

42.3.6 Monotonic counter

The 64-bit Monotonic Counter is a counter that cannot be exhausted or return to any previous value, once it has been initialized. If the monotonic overflow flag is set, the monotonic counter returns zero and does not increment.

Depending on the value of the monotonic counter enable bit, writing to the monotonic counter either initializes the register with the value written, or increments the register by one (and the value written is ignored).

When the monotonic counter is enabled, the monotonic counter high increments on either a write to the monotonic counter high register or if the monotonic counter low register overflows (due to a write to the monotonic counter low register). The monotonic overflow flag sets when the monotonic counter high register overflows and is cleared by writing the monotonic counter high register when the monotonic counter is disabled.

The monotonic counter is held in reset whenever the time invalid flag is set. Always clear the time invalid flag before initializing the monotonic counter.

42.3.7 Register lock

The Lock register (LR) can be used to block write accesses to certain registers until the next VBAT POR or software reset. Locking the Control register (CR) will disable the software reset. Locking LR will block future updates to LR.

Write accesses to a locked register are ignored and do not generate a bus error.

42.3.8 Access control

The read access and write access registers are implemented in the chip power domain and reset on the chip reset. They are not affected by the VBAT POR or the software reset. They are used to block read or write accesses to each register until the next chip system reset. When accesses are blocked, the bus access is not seen in the VBAT power supply and does not generate a bus error.

42.3.9 Interrupt

The RTC interrupt is asserted whenever a status flag and the corresponding interrupt enable bit are both set. It is always asserted on VBAT POR, and software reset, and when the VBAT power supply is powered down. The RTC interrupt is enabled at the chip level by enabling the chip-specific RTC clock gate control bit. The RTC interrupt can be used to wakeup the chip from any low-power mode.

The optional RTC seconds interrupt is an edge-sensitive interrupt with a dedicated interrupt vector that is generated once a second and requires no software overhead (there is no corresponding status flag to clear). It is enabled in the RTC by the time seconds interrupt enable bit and enabled at the chip level by setting the chip-specific RTC clock gate control bit. This interrupt is optional and may not be implemented on all devices.



Chapter 43

Serial Peripheral Interface (SPI)

43.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The serial peripheral interface (SPI) module provides a synchronous serial bus for communication between an MCU and an external peripheral device.

43.1.1 Block Diagram

The block diagram of this module is as follows:

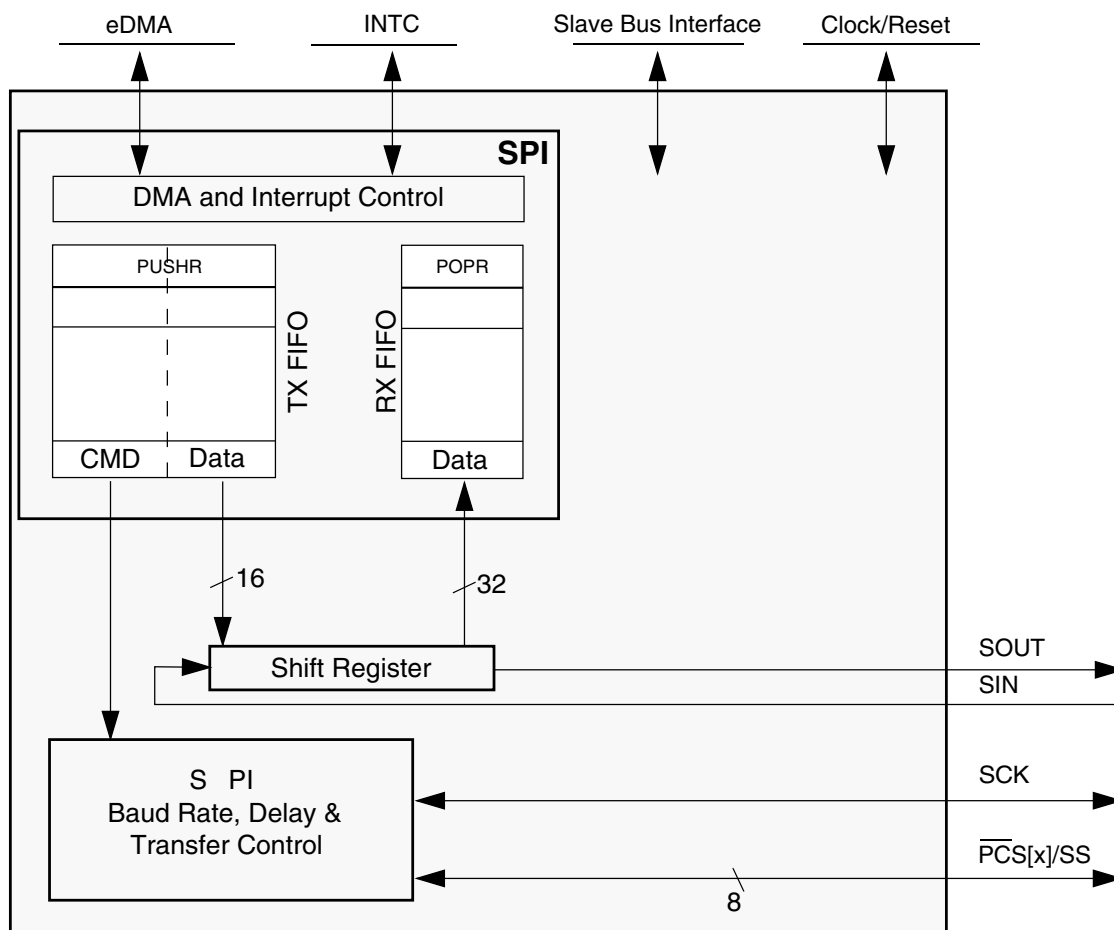


Figure 43-1. SPI Block Diagram

43.1.2 Features

The module supports the following features:

- Full-duplex, three-wire synchronous transfers
- Master mode
- Slave mode
- Data streaming operation in Slave mode with continuous slave selection
- Buffered transmit operation using the transmit first in first out (TX FIFO) with depth of 4 entries
- Buffered receive operation using the receive FIFO (RX FIFO) with depth of 4 entries
- Asynchronous clocking scheme for Register and Protocol Interfaces

- TX and RX FIFOs can be disabled individually for low-latency updates to SPI queues
- Visibility into TX and RX FIFOs for ease of debugging
- Programmable transfer attributes on a per-frame basis:
 - two transfer attribute registers
 - Serial clock (SCK) with programmable polarity and phase
 - Various programmable delays
 - Programmable serial frame size: 4 to 16 bits
 - SPI frames longer than 16 bits can be supported using the continuous selection format.
 - Continuously held chip select capability
- 5 peripheral chip selects (PCSEs), expandable to 32 with external demultiplexer
- Deglitching support for up to 16 peripheral chip selects (PCSEs) with external demultiplexer
- DMA support for adding entries to TX FIFO and removing entries from RX FIFO:
 - TX FIFO is not full (TFFF)
 - RX FIFO is not empty (RFDF)
- Interrupt conditions:
 - End of Queue reached (EOQF)
 - TX FIFO is not full (TFFF)
 - Transfer of current frame complete (TCF)
 - Attempt to transmit with an empty Transmit FIFO (TFUF)
 - RX FIFO is not empty (RFDF)
 - Frame received while Receive FIFO is full (RFOF)
- Global interrupt request line
- Modified SPI transfer formats for communication with slower peripheral devices
- Power-saving architectural features:

- Support for Stop mode
- Support for Doze mode

43.1.3 Interface configurations

43.1.3.1 SPI configuration

The Serial Peripheral Interface (SPI) configuration allows the module to send and receive serial data. This configuration allows the module to operate as a basic SPI block with internal FIFOs supporting external queue operation. Transmitted data and received data reside in separate FIFOs. The host CPU or a DMA controller read the received data from the Receive FIFO and write transmit data to the Transmit FIFO.

For queued operations, the SPI queues can reside in system RAM, external to the module. Data transfers between the queues and the module FIFOs are accomplished by a DMA controller or host CPU. The following figure shows a system example with DMA, SPI, and external queues in system RAM.

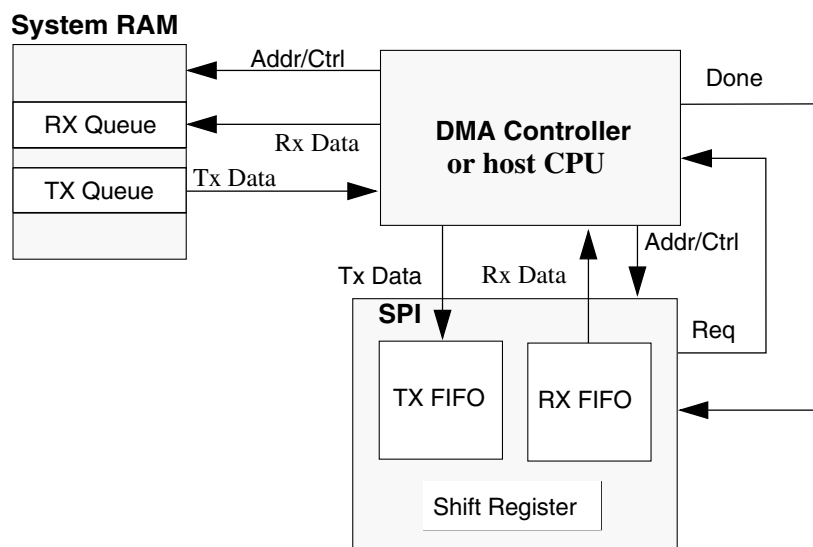


Figure 43-2. SPI with queues and DMA

43.1.4 Modes of Operation

The module supports the following modes of operation that can be divided into two categories:

- Module-specific modes:

- Master mode
- Slave mode
- Module Disable mode
- MCU-specific modes:
 - External Stop mode
 - Debug mode

The module enters module-specific modes when the host writes a module register. The MCU-specific modes are controlled by signals external to the module. The MCU-specific modes are modes that an MCU may enter in parallel to the block-specific modes.

43.1.4.1 Master Mode

Master mode allows the module to initiate and control serial communication. In this mode, these signals are controlled by the module and configured as outputs:

- SCK
- SOUT
- PCS[x]

43.1.4.2 Slave Mode

Slave mode allows the module to communicate with SPI bus masters. In this mode, the module responds to externally controlled serial transfers. The SCK signal and the PCS[0]/ $\overline{\text{SS}}$ signals are configured as inputs and driven by an SPI bus master.

43.1.4.3 Module Disable Mode

The Module Disable mode can be used for MCU power management. The clock to the non-memory mapped logic in the module can be stopped while in the Module Disable mode.

43.1.4.4 External Stop Mode

External Stop mode is used for MCU power management. The module supports the Peripheral Bus Stop mode mechanism. When a request is made to enter External Stop mode, it acknowledges the request and completes the transfer that is in progress. When the module reaches the frame boundary, it signals that the protocol clock to the module may be shut off.

43.1.4.5 Debug Mode

Debug mode is used for system development and debugging. The MCR[FRZ] bit controls module behavior in the Debug mode:

- If the bit is set, the module stops all serial transfers, when the MCU is in debug mode.
- If the bit is cleared, the MCU debug mode has no effect on the module.

43.2 Module signal descriptions

This table describes the signals on the boundary of the module that may connect off chip (in alphabetical order).

Table 43-1. Module signal descriptions

| Signal | Master mode | Slave mode | I/O |
|-----------------------|------------------------------|------------------|-----|
| PCS0/ \overline{SS} | Peripheral Chip Select 0 (O) | Slave Select (I) | I/O |
| PCS[1:3] | Peripheral Chip Selects 1–3 | (Unused) | O |
| PCS4 | Peripheral Chip Select 4 | (Unused) | O |
| SCK | Serial Clock (O) | Serial Clock (I) | I/O |
| SIN | Serial Data In | Serial Data In | I |
| SOUT | Serial Data Out | Serial Data Out | O |

43.2.1 PCS0/ \overline{SS} —Peripheral Chip Select/Slave Select

Master mode: Peripheral Chip Select 0 (O)—Selects an SPI slave to receive data transmitted from the module.

Slave mode: Slave Select (I)—Selects the module to receive data transmitted from an SPI master.

43.2.2 PCS1–PCS3—Peripheral Chip Selects 1–3

Master mode: Peripheral Chip Selects 1–3 (O)—Select an SPI slave to receive data transmitted by the module.

Slave mode: Unused

43.2.3 PCS4—Peripheral Chip Select 4

Master mode: Peripheral Chip Select 4 (O)—Selects an SPI slave to receive data transmitted by the module.

Slave mode: Unused

43.2.4 SCK—Serial Clock

Master mode: Serial Clock (O)—Supplies a clock signal from the module to SPI slaves.

Slave mode: Serial Clock (I)—Supplies a clock signal to the module from an SPI master.

43.2.5 SIN—Serial Input

Master mode: Serial Input (I)—Receives serial data.

Slave mode: Serial Input (I)—Receives serial data.

NOTE

Serial Data Out output buffers are controlled through SIU (or SIUL) and cannot be controlled through the module.

43.2.6 SOUT—Serial Output

Master mode: Serial Output (O)—Transmits serial data.

Slave mode: Serial Output (O)—Transmits serial data.

NOTE

Serial Data Out output buffers are controlled through SIU (or SIUL) and cannot be controlled through the module.

43.3 Memory Map/Register Definition

Register accesses to memory addresses that are reserved or undefined result in a transfer error. Write access to the POPR also results in a transfer error.

SPI memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-----------------------------|------------------------------|
| 4002_C000 | Module Configuration Register (SPI0_MCR) | 32 | R/W | 0000_4001h | 43.3.1/986 |
| 4002_C008 | Transfer Count Register (SPI0_TCR) | 32 | R/W | 0000_0000h | 43.3.2/989 |
| 4002_C00C | Clock and Transfer Attributes Register (In Master Mode) (SPI0_CTAR0) | 32 | R/W | 7800_0000h | 43.3.3/990 |
| 4002_C00C | Clock and Transfer Attributes Register (In Slave Mode) (SPI0_CTAR0_SLAVE) | 32 | R/W | 7800_0000h | 43.3.4/994 |
| 4002_C010 | Clock and Transfer Attributes Register (In Master Mode) (SPI0_CTAR1) | 32 | R/W | 7800_0000h | 43.3.3/990 |
| 4002_C02C | Status Register (SPI0_SR) | 32 | R/W | See section | 43.3.5/996 |
| 4002_C030 | DMA/Interrupt Request Select and Enable Register (SPI0_RSER) | 32 | R/W | 0000_0000h | 43.3.6/999 |
| 4002_C034 | PUSH TX FIFO Register In Master Mode (SPI0_PUSHR) | 32 | R/W | 0000_0000h | 43.3.7/1001 |
| 4002_C034 | PUSH TX FIFO Register In Slave Mode (SPI0_PUSHR_SLAVE) | 32 | R/W | 0000_0000h | 43.3.8/1002 |
| 4002_C038 | POP RX FIFO Register (SPI0_POPR) | 32 | R | 0000_0000h | 43.3.9/1003 |
| 4002_C03C | Transmit FIFO Registers (SPI0_TXFR0) | 32 | R | 0000_0000h | 43.3.10/1004 |
| 4002_C040 | Transmit FIFO Registers (SPI0_TXFR1) | 32 | R | 0000_0000h | 43.3.10/1004 |
| 4002_C044 | Transmit FIFO Registers (SPI0_TXFR2) | 32 | R | 0000_0000h | 43.3.10/1004 |
| 4002_C048 | Transmit FIFO Registers (SPI0_TXFR3) | 32 | R | 0000_0000h | 43.3.10/1004 |
| 4002_C07C | Receive FIFO Registers (SPI0_RXFR0) | 32 | R | 0000_0000h | 43.3.11/1004 |
| 4002_C080 | Receive FIFO Registers (SPI0_RXFR1) | 32 | R | 0000_0000h | 43.3.11/1004 |
| 4002_C084 | Receive FIFO Registers (SPI0_RXFR2) | 32 | R | 0000_0000h | 43.3.11/1004 |
| 4002_C088 | Receive FIFO Registers (SPI0_RXFR3) | 32 | R | 0000_0000h | 43.3.11/1004 |
| 4002_D000 | Module Configuration Register (SPI1_MCR) | 32 | R/W | 0000_4001h | 43.3.1/986 |
| 4002_D008 | Transfer Count Register (SPI1_TCR) | 32 | R/W | 0000_0000h | 43.3.2/989 |
| 4002_D00C | Clock and Transfer Attributes Register (In Master Mode) (SPI1_CTAR0) | 32 | R/W | 7800_0000h | 43.3.3/990 |

Table continues on the next page...

SPI memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|--------|-----------------------------|------------------------------|
| 4002_D00C | Clock and Transfer Attributes Register (In Slave Mode) (SPI1_CTAR0_SLAVE) | 32 | R/W | 7800_0000h | 43.3.4/994 |
| 4002_D010 | Clock and Transfer Attributes Register (In Master Mode) (SPI1_CTAR1) | 32 | R/W | 7800_0000h | 43.3.3/990 |
| 4002_D02C | Status Register (SPI1_SR) | 32 | R/W | See section | 43.3.5/996 |
| 4002_D030 | DMA/Interrupt Request Select and Enable Register (SPI1_RSER) | 32 | R/W | 0000_0000h | 43.3.6/999 |
| 4002_D034 | PUSH TX FIFO Register In Master Mode (SPI1_PUSHR) | 32 | R/W | 0000_0000h | 43.3.7/1001 |
| 4002_D034 | PUSH TX FIFO Register In Slave Mode (SPI1_PUSHR_SLAVE) | 32 | R/W | 0000_0000h | 43.3.8/1002 |
| 4002_D038 | POP RX FIFO Register (SPI1_POPR) | 32 | R | 0000_0000h | 43.3.9/1003 |
| 4002_D03C | Transmit FIFO Registers (SPI1_TXFR0) | 32 | R | 0000_0000h | 43.3.10/1004 |
| 4002_D040 | Transmit FIFO Registers (SPI1_TXFR1) | 32 | R | 0000_0000h | 43.3.10/1004 |
| 4002_D044 | Transmit FIFO Registers (SPI1_TXFR2) | 32 | R | 0000_0000h | 43.3.10/1004 |
| 4002_D048 | Transmit FIFO Registers (SPI1_TXFR3) | 32 | R | 0000_0000h | 43.3.10/1004 |
| 4002_D07C | Receive FIFO Registers (SPI1_RXFR0) | 32 | R | 0000_0000h | 43.3.11/1004 |
| 4002_D080 | Receive FIFO Registers (SPI1_RXFR1) | 32 | R | 0000_0000h | 43.3.11/1004 |
| 4002_D084 | Receive FIFO Registers (SPI1_RXFR2) | 32 | R | 0000_0000h | 43.3.11/1004 |
| 4002_D088 | Receive FIFO Registers (SPI1_RXFR3) | 32 | R | 0000_0000h | 43.3.11/1004 |

43.3.1 Module Configuration Register (SPlx_MCR)

Contains bits to configure various attributes associated with the module operations. The HALT and MDIS bits can be changed at any time, but the effect takes place only on the next frame boundary. Only the HALT and MDIS bits in the MCR can be changed, while the module is in the Running state.

Address: Base address + 0h offset

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| R | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

SPIx_MCR field descriptions

| Field | Description |
|-------------------|--|
| 31 MSTR | <p>Master/Slave Mode Select</p> <p>Enables either Master mode (if supported) or Slave mode (if supported) operation.</p> <p>0 Enables Slave mode 1 Enables Master mode</p> |
| 30 CONT_SCKE | <p>Continuous SCK Enable</p> <p>Enables the Serial Communication Clock (SCK) to run continuously.</p> <p>0 Continuous SCK disabled. 1 Continuous SCK enabled.</p> |
| 29–28 DCONF | <p>SPI Configuration.</p> <p>Selects among the different configurations of the module.</p> <p>00 SPI 01 Reserved 10 Reserved 11 Reserved</p> |
| 27 FRZ | <p>Freeze</p> <p>Enables transfers to be stopped on the next frame boundary when the device enters Debug mode.</p> <p>0 Do not halt serial transfers in Debug mode. 1 Halt serial transfers in Debug mode.</p> |
| 26 MTFE | <p>Modified Timing Format Enable</p> <p>Enables a modified transfer format to be used.</p> <p>0 Modified SPI transfer format disabled. 1 Modified SPI transfer format enabled.</p> |
| 25 Reserved | This field is reserved. |
| 24 ROOE | <p>Receive FIFO Overflow Overwrite Enable</p> <p>In the RX FIFO overflow condition, configures the module to ignore the incoming serial data or overwrite existing data. If the RX FIFO is full and new data is received, the data from the transfer, generating the overflow, is ignored or shifted into the shift register.</p> <p>0 Incoming data is ignored. 1 Incoming data is shifted into the shift register.</p> |
| 23–21 Reserved | <p>Reserved.</p> <p>This field is reserved.</p> |
| 20–16 PCSIS | <p>Peripheral Chip Select x Inactive State</p> <p>Determines the inactive state of PCSx.</p> <p>0 The inactive state of PCSx is low. 1 The inactive state of PCSx is high.</p> |

Table continues on the next page...

SPIx_MCR field descriptions (continued)

| Field | Description |
|----------------|--|
| 15 DOZE | <p>Doze Enable</p> <p>Provides support for an externally controlled Doze mode power-saving mechanism.</p> <p>0 Doze mode has no effect on the module. 1 Doze mode disables the module.</p> |
| 14 MDIS | <p>Module Disable</p> <p>Allows the clock to be stopped to the non-memory mapped logic in the module effectively putting it in a software-controlled power-saving state. The reset value of the MDIS bit is parameterized, with a default reset value of 0. When the module is used in Slave Mode, it is recommended to leave this bit 0, because a slave doesn't have control over master transactions.</p> <p>0 Enables the module clocks. 1 Allows external logic to disable the module clocks.</p> |
| 13 DIS_TXF | <p>Disable Transmit FIFO</p> <p>When the TX FIFO is disabled, the transmit part of the module operates as a simplified double-buffered SPI. This bit can be written only when the MDIS bit is cleared.</p> <p>0 TX FIFO is enabled. 1 TX FIFO is disabled.</p> |
| 12 DIS_RXF | <p>Disable Receive FIFO</p> <p>When the RX FIFO is disabled, the receive part of the module operates as a simplified double-buffered SPI. This bit can only be written when the MDIS bit is cleared.</p> <p>0 RX FIFO is enabled. 1 RX FIFO is disabled.</p> |
| 11 CLR_TXF | <p>Clear TX FIFO</p> <p>Flushes the TX FIFO. Writing a 1 to CLR_TXF clears the TX FIFO Counter. The CLR_TXF bit is always read as zero.</p> <p>0 Do not clear the TX FIFO counter. 1 Clear the TX FIFO counter.</p> |
| 10 CLR_RXF | <p>CLR_RXF</p> <p>Flushes the RX FIFO. Writing a 1 to CLR_RXF clears the RX Counter. The CLR_RXF bit is always read as zero.</p> <p>0 Do not clear the RX FIFO counter. 1 Clear the RX FIFO counter.</p> |
| 9–8 SMPL_PT | <p>Sample Point</p> <p>Controls when the module master samples SIN in Modified Transfer Format. This field is valid only when CPHA bit in CTARn[CPHA] is 0.</p> <p>00 0 protocol clock cycles between SCK edge and SIN sample 01 1 protocol clock cycle between SCK edge and SIN sample 10 2 protocol clock cycles between SCK edge and SIN sample 11 Reserved</p> |

Table continues on the next page...

SPIx_MCR field descriptions (continued)

| Field | Description |
|-----------------|--|
| 7–3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 Reserved | This field is reserved. |
| 1 Reserved | This field is reserved. |
| 0 HALT | Halt The HALT bit starts and stops frame transfers. See Start and Stop of Module transfers 0 Start transfers. 1 Stop transfers. |

43.3.2 Transfer Count Register (SPIx_TCR)

TCR contains a counter that indicates the number of SPI transfers made. The transfer counter is intended to assist in queue management. Do not write the TCR when the module is in the Running state.

Address: Base address + 8h offset

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SPIx_TCR field descriptions

| Field | Description |
|-------------------|--|
| 31–16 SPI_TCNT | SPI Transfer Counter Counts the number of SPI transfers the module makes. The SPI_TCNT field increments every time the last bit of an SPI frame is transmitted. A value written to SPI_TCNT presets the counter to that value. SPI_TCNT is reset to zero at the beginning of the frame when the CTCNT field is set in the executing SPI command. The Transfer Counter wraps around; incrementing the counter past 65535 resets the counter to zero. |
| 15–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

43.3.3 Clock and Transfer Attributes Register (In Master Mode) (SPIx_CTARn)

CTAR registers are used to define different transfer attributes. Do not write to the CTAR registers while the module is in the Running state.

In Master mode, the CTAR registers define combinations of transfer attributes such as frame size, clock phase and polarity, data bit ordering, baud rate, and various delays. In slave mode, a subset of the bitfields in CTAR0 are used to set the slave transfer attributes.

When the module is configured as an SPI master, the CTAS field in the command portion of the TX FIFO entry selects which of the CTAR registers is used. When the module is configured as an SPI bus slave, it uses the CTAR0 register.

Address: Base address + Ch offset + (4d × i), where i=0d to 1d

| | | | | | | | | | | | | | | | | | |
|-------|-----|----|------|----|----|----|------|------|-------|--------|----|------|----|-----|----|-----|--|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | |
| R | DBR | | FMSZ | | | | CPOL | CPHA | LSBFE | PCSSCK | | PASC | | PDT | | PBR | |
| W | | | | | | | | | | | | | | | | | |
| Reset | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

| | | | | | | | | | | | | | | | | |
|-------|-------|----|----|----|----|-----|---|---|----|---|---|---|----|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | CSSCK | | | | | ASC | | | DT | | | | BR | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SPIx_CTARn field descriptions

| Field | Description | | | | | | | | | | | | | | | | | | | | |
|-----------|---|-----|----------------|-----|----------------|---|-----|-----|-------|---|---|----|-------|---|---|----|-------|---|---|----|-------|
| 31 DBR | <p>Double Baud Rate</p> <p>Doubles the effective baud rate of the Serial Communications Clock (SCK). This field is used only in master mode. It effectively halves the Baud Rate division ratio, supporting faster frequencies, and odd division ratios for the Serial Communications Clock (SCK). When the DBR bit is set, the duty cycle of the Serial Communications Clock (SCK) depends on the value in the Baud Rate Prescaler and the Clock Phase bit as listed in the following table. See the BR field description for details on how to compute the baud rate.</p> <p>Table 43-40. SPI SCK Duty Cycle</p> <table><tr><th>DBR</th><th>CPHA</th><th>PBR</th><th>SCK Duty Cycle</th></tr><tr><td>0</td><td>any</td><td>any</td><td>50/50</td></tr><tr><td>1</td><td>0</td><td>00</td><td>50/50</td></tr><tr><td>1</td><td>0</td><td>01</td><td>33/66</td></tr><tr><td>1</td><td>0</td><td>10</td><td>40/60</td></tr></table> | DBR | CPHA | PBR | SCK Duty Cycle | 0 | any | any | 50/50 | 1 | 0 | 00 | 50/50 | 1 | 0 | 01 | 33/66 | 1 | 0 | 10 | 40/60 |
| DBR | CPHA | PBR | SCK Duty Cycle | | | | | | | | | | | | | | | | | | |
| 0 | any | any | 50/50 | | | | | | | | | | | | | | | | | | |
| 1 | 0 | 00 | 50/50 | | | | | | | | | | | | | | | | | | |
| 1 | 0 | 01 | 33/66 | | | | | | | | | | | | | | | | | | |
| 1 | 0 | 10 | 40/60 | | | | | | | | | | | | | | | | | | |

Table continues on the next page...

SPIx_CTARn field descriptions (continued)

| Field | Description | | | | | | | | | | | | | | | | | | | | | | | | |
|-----------------|--|-----|----------------|-----|----------------|---|---|----|-------|---|---|----|-------|---|---|----|-------|---|---|----|-------|---|---|----|-------|
| | <div>Table 43-40. SPI SCK Duty Cycle (continued)</div> <table><tr><th>DBR</th><th>CPHA</th><th>PBR</th><th>SCK Duty Cycle</th></tr><tr><td>1</td><td>0</td><td>11</td><td>43/57</td></tr><tr><td>1</td><td>1</td><td>00</td><td>50/50</td></tr><tr><td>1</td><td>1</td><td>01</td><td>66/33</td></tr><tr><td>1</td><td>1</td><td>10</td><td>60/40</td></tr><tr><td>1</td><td>1</td><td>11</td><td>57/43</td></tr></table> <div><div>0</div><div>The baud rate is computed normally with a 50/50 duty cycle.</div></div> <div><div>1</div><div>The baud rate is doubled with the duty cycle depending on the Baud Rate Prescaler.</div></div> | DBR | CPHA | PBR | SCK Duty Cycle | 1 | 0 | 11 | 43/57 | 1 | 1 | 00 | 50/50 | 1 | 1 | 01 | 66/33 | 1 | 1 | 10 | 60/40 | 1 | 1 | 11 | 57/43 |
| DBR | CPHA | PBR | SCK Duty Cycle | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 0 | 11 | 43/57 | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 1 | 00 | 50/50 | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 1 | 01 | 66/33 | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 1 | 10 | 60/40 | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 1 | 11 | 57/43 | | | | | | | | | | | | | | | | | | | | | | |
| 30–27 FMSZ | <div>Frame Size</div> <div>The number of bits transferred per frame is equal to the FMSZ value plus 1. Regardless of the transmission mode, the minimum valid frame size value is 4.</div> | | | | | | | | | | | | | | | | | | | | | | | | |
| 26 CPOL | <div>Clock Polarity</div> <div>Selects the inactive state of the Serial Communications Clock (SCK). This bit is used in both master and slave mode. For successful communication between serial devices, the devices must have identical clock polarities. When the Continuous Selection Format is selected, switching between clock polarities without stopping the module can cause errors in the transfer due to the peripheral device interpreting the switch of clock polarity as a valid clock edge.</div> <div>NOTE: In case of Continuous SCK mode, when the module goes in low power mode(disabled), inactive state of SCK is not guaranteed.</div> <div><div>0</div><div>The inactive state value of SCK is low.</div></div> <div><div>1</div><div>The inactive state value of SCK is high.</div></div> | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 CPHA | <div>Clock Phase</div> <div>Selects which edge of SCK causes data to change and which edge causes data to be captured. This bit is used in both master and slave mode. For successful communication between serial devices, the devices must have identical clock phase settings. In Continuous SCK mode, the bit value is ignored and the transfers are done as if the CPHA bit is set to 1.</div> <div><div>0</div><div>Data is captured on the leading edge of SCK and changed on the following edge.</div></div> <div><div>1</div><div>Data is changed on the leading edge of SCK and captured on the following edge.</div></div> | | | | | | | | | | | | | | | | | | | | | | | | |
| 24 LSBFE | <div>LSB First</div> <div>Specifies whether the LSB or MSB of the frame is transferred first.</div> <div><div>0</div><div>Data is transferred MSB first.</div></div> <div><div>1</div><div>Data is transferred LSB first.</div></div> | | | | | | | | | | | | | | | | | | | | | | | | |
| 23–22 PCSSCK | <div>PCS to SCK Delay Prescaler</div> <div>Selects the prescaler value for the delay between assertion of PCS and the first edge of the SCK. See the CSSCK field description for information on how to compute the PCS to SCK Delay. Refer PCS to SCK Delay (t_{CSC}) for more details.</div> | | | | | | | | | | | | | | | | | | | | | | | | |

Table continues on the next page...

SPIx_CTARn field descriptions (continued)

| Field | Description | | | | | | | | |
|----------------|--|-------------|--------------------|------|---|------|---|------|---|
| | <p>00 PCS to SCK Prescaler value is 1.</p> <p>01 PCS to SCK Prescaler value is 3.</p> <p>10 PCS to SCK Prescaler value is 5.</p> <p>11 PCS to SCK Prescaler value is 7.</p> | | | | | | | | |
| 21–20 PASC | <p>After SCK Delay Prescaler</p> <p>Selects the prescaler value for the delay between the last edge of SCK and the negation of PCS. See the ASC field description for information on how to compute the After SCK Delay. Refer After SCK Delay (t_{ASC}) for more details.</p> <p>00 Delay after Transfer Prescaler value is 1.</p> <p>01 Delay after Transfer Prescaler value is 3.</p> <p>10 Delay after Transfer Prescaler value is 5.</p> <p>11 Delay after Transfer Prescaler value is 7.</p> | | | | | | | | |
| 19–18 PDT | <p>Delay after Transfer Prescaler</p> <p>Selects the prescaler value for the delay between the negation of the PCS signal at the end of a frame and the assertion of PCS at the beginning of the next frame. The PDT field is only used in master mode. See the DT field description for details on how to compute the Delay after Transfer. Refer Delay after Transfer (t_{DT}) for more details.</p> <p>00 Delay after Transfer Prescaler value is 1.</p> <p>01 Delay after Transfer Prescaler value is 3.</p> <p>10 Delay after Transfer Prescaler value is 5.</p> <p>11 Delay after Transfer Prescaler value is 7.</p> | | | | | | | | |
| 17–16 PBR | <p>Baud Rate Prescaler</p> <p>Selects the prescaler value for the baud rate. This field is used only in master mode. The baud rate is the frequency of the SCK. The protocol clock is divided by the prescaler value before the baud rate selection takes place. See the BR field description for details on how to compute the baud rate.</p> <p>00 Baud Rate Prescaler value is 2.</p> <p>01 Baud Rate Prescaler value is 3.</p> <p>10 Baud Rate Prescaler value is 5.</p> <p>11 Baud Rate Prescaler value is 7.</p> | | | | | | | | |
| 15–12 CSSCK | <p>PCS to SCK Delay Scaler</p> <p>Selects the scaler value for the PCS to SCK delay. This field is used only in master mode. The PCS to SCK Delay is the delay between the assertion of PCS and the first edge of the SCK. The delay is a multiple of the protocol clock period, and it is computed according to the following equation:</p> $t_{CSC} = (1/f_P) \times PCSSCK \times CSSCK.$ <p>The following table lists the delay scaler values.</p> <p style="text-align: center;">Table 43-39. Delay Scaler Encoding</p> <table> <tr> <th>Field Value</th><th>Delay Scaler Value</th></tr> <tr> <td>0000</td><td>2</td></tr> <tr> <td>0001</td><td>4</td></tr> <tr> <td>0010</td><td>8</td></tr> </table> | Field Value | Delay Scaler Value | 0000 | 2 | 0001 | 4 | 0010 | 8 |
| Field Value | Delay Scaler Value | | | | | | | | |
| 0000 | 2 | | | | | | | | |
| 0001 | 4 | | | | | | | | |
| 0010 | 8 | | | | | | | | |

Table continues on the next page...

SPIx_CTARn field descriptions (continued)

| Field | Description | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|--|--------------------|--------------------|------|----|------|----|------|----|------|-----|------|-----|------|-----|------|------|------|------|------|------|------|------|------|-------|------|-------|------|-------|
| | Table 43-39. Delay Scaler Encoding (continued) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | <table><tr><th>Field Value</th><th>Delay Scaler Value</th></tr><tr><td>0011</td><td>16</td></tr><tr><td>0100</td><td>32</td></tr><tr><td>0101</td><td>64</td></tr><tr><td>0110</td><td>128</td></tr><tr><td>0111</td><td>256</td></tr><tr><td>1000</td><td>512</td></tr><tr><td>1001</td><td>1024</td></tr><tr><td>1010</td><td>2048</td></tr><tr><td>1011</td><td>4096</td></tr><tr><td>1100</td><td>8192</td></tr><tr><td>1101</td><td>16384</td></tr><tr><td>1110</td><td>32768</td></tr><tr><td>1111</td><td>65536</td></tr></table> | Field Value | Delay Scaler Value | 0011 | 16 | 0100 | 32 | 0101 | 64 | 0110 | 128 | 0111 | 256 | 1000 | 512 | 1001 | 1024 | 1010 | 2048 | 1011 | 4096 | 1100 | 8192 | 1101 | 16384 | 1110 | 32768 | 1111 | 65536 |
| | Field Value | Delay Scaler Value | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 0011 | 16 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 0100 | 32 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 0101 | 64 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 0110 | 128 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 0111 | 256 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1000 | 512 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1001 | 1024 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1010 | 2048 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1011 | 4096 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1100 | 8192 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1101 | 16384 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1110 | 32768 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 1111 | 65536 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Refer PCS to SCK Delay (t_{CSC}) for more details. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11–8 ASC | <p>After SCK Delay Scaler</p> <p>Selects the scaler value for the After SCK Delay. This field is used only in master mode. The After SCK Delay is the delay between the last edge of SCK and the negation of PCS. The delay is a multiple of the protocol clock period, and it is computed according to the following equation:</p> $t_{ASC} = (1/f_P) \times PASC \times ASC$ <p>See Delay Scaler Encoding table in CTARn[CSSCK] bit field description for scaler values. Refer After SCK Delay (t_{ASC}) for more details.</p> | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7–4 DT | <p>Delay After Transfer Scaler</p> <p>Selects the Delay after Transfer Scaler. This field is used only in master mode. The Delay after Transfer is the time between the negation of the PCS signal at the end of a frame and the assertion of PCS at the beginning of the next frame.</p> <p>In the Continuous Serial Communications Clock operation, the DT value is fixed to one SCK clock period, The Delay after Transfer is a multiple of the protocol clock period, and it is computed according to the following equation:</p> $t_{DT} = (1/f_P) \times PDT \times DT$ <p>See Delay Scaler Encoding table in CTARn[CSSCK] bit field description for scaler values.</p> | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3–0 BR | <p>Baud Rate Scaler</p> <p>Selects the scaler value for the baud rate. This field is used only in master mode. The prescaled protocol clock is divided by the Baud Rate Scaler to generate the frequency of the SCK. The baud rate is computed according to the following equation:</p> $SCK \text{ baud rate} = (f_P /PBR) \times [(1+DBR)/BR]$ <p>The following table lists the baud rate scaler values.</p> | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Table continues on the next page...

SPIx_CTARn field descriptions (continued)

| Field | Description | |
|-------|-------------------------------|------------------------|
| | Table 43-38. Baud Rate Scaler | |
| | CTARn[BR] | Baud Rate Scaler Value |
| | 0000 | 2 |
| | 0001 | 4 |
| | 0010 | 6 |
| | 0011 | 8 |
| | 0100 | 16 |
| | 0101 | 32 |
| | 0110 | 64 |
| | 0111 | 128 |
| | 1000 | 256 |
| | 1001 | 512 |
| | 1010 | 1024 |
| | 1011 | 2048 |
| | 1100 | 4096 |
| | 1101 | 8192 |
| | 1110 | 16384 |
| | 1111 | 32768 |

43.3.4 Clock and Transfer Attributes Register (In Slave Mode) (SPIx_CTARn_SLAVE)

When the module is configured as an SPI bus slave, the CTAR0 register is used.

Address: Base address + Ch offset + (0d × i), where i=0d to 0d

| | | | | | | | | | | | | | | | | |
|-------|----------|----|----|----|----|------|------|----|----|----------|----------|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | FMSZ | | | | | CPOL | CPHA | 0 | | Reserved | Reserved | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | Reserved | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SPIx_CTARn_SLAVE field descriptions

| Field | Description |
|-------------------|--|
| 31–27 FMSZ | <p>Frame Size</p> <p>The number of bits transferred per frame is equal to the FMSZ field value plus 1. Note that the minimum valid value of frame size is 4.</p> |
| 26 CPOL | <p>Clock Polarity</p> <p>Selects the inactive state of the Serial Communications Clock (SCK).</p> <p>NOTE: In case of Continuous SCK mode, when the module goes in low power mode(disabled), inactive state of SCK is not guaranteed.</p> <p>0 The inactive state value of SCK is low. 1 The inactive state value of SCK is high.</p> |
| 25 CPHA | <p>Clock Phase</p> <p>Selects which edge of SCK causes data to change and which edge causes data to be captured. This bit is used in both master and slave mode. For successful communication between serial devices, the devices must have identical clock phase settings. In Continuous SCK mode, the bit value is ignored and the transfers are done as if the CPHA bit is set to 1.</p> <p>0 Data is captured on the leading edge of SCK and changed on the following edge. 1 Data is changed on the leading edge of SCK and captured on the following edge.</p> |
| 24–23 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 22 Reserved | <p>This field is reserved.</p> |
| 21–0 Reserved | <p>This field is reserved.</p> |

43.3.5 Status Register (SPIx_SR)

SR contains status and flag bits. The bits reflect the status of the module and indicate the occurrence of events that can generate interrupt or DMA requests. Software can clear flag bits in the SR by writing a 1 to them. Writing a 0 to a flag bit has no effect. This register may not be writable in Module Disable mode due to the use of power saving mechanisms.

Address: Base address + 2Ch offset

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|-----|-------|----|------|------|----|------|----|----|----|----|----|------|----|------|----|
| R | TCF | TXRXS | 0 | EOQF | TFUF | 0 | TFFF | 0 | 0 | 0 | 0 | 0 | RFOF | 0 | RFDF | 0 |
| W | w1c | w1c | | w1c | w1c | | w1c | | | | | | w1c | | w1c | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|----|----|----|----------|----|---|---|-------|---|---|---|-----------|---|---|---|
| R | TXCTR | | | | TXNXTPTR | | | | RXCTR | | | | POPNXTPTR | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SPIx_SR field descriptions

| Field | Description |
|----------------|---|
| 31 TCF | Transfer Complete Flag Indicates that all bits in a frame have been shifted out. TCF remains set until it is cleared by writing a 1 to it. 0 Transfer not complete. 1 Transfer complete. |
| 30 TXRXS | TX and RX Status Reflects the run status of the module. 0 Transmit and receive operations are disabled (The module is in Stopped state). 1 Transmit and receive operations are enabled (The module is in Running state). |
| 29 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

Table continues on the next page...

SPIx_SR field descriptions (continued)

| Field | Description |
|----------------|---|
| 28 EOQF | <p>End of Queue Flag</p> <p>Indicates that the last entry in a queue has been transmitted when the module is in Master mode. The EOQF bit is set when the TX FIFO entry has the EOQ bit set in the command halfword and the end of the transfer is reached. The EOQF bit remains set until cleared by writing a 1 to it. When the EOQF bit is set, the TXRXS bit is automatically cleared.</p> <p>0 EOQ is not set in the executing command. 1 EOQ is set in the executing SPI command.</p> |
| 27 TFUF | <p>Transmit FIFO Underflow Flag</p> <p>Indicates an underflow condition in the TX FIFO. The transmit underflow condition is detected only for SPI blocks operating in Slave mode and SPI configuration. TFUF is set when the TX FIFO of the module operating in SPI Slave mode is empty and an external SPI master initiates a transfer. The TFUF bit remains set until cleared by writing 1 to it.</p> <p>0 No TX FIFO underflow. 1 TX FIFO underflow has occurred.</p> |
| 26 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 25 TFFF | <p>Transmit FIFO Fill Flag</p> <p>Provides a method for the module to request more entries to be added to the TX FIFO. The TFFF bit is set while the TX FIFO is not full. The TFFF bit can be cleared by writing 1 to it or by acknowledgement from the DMA controller to the TX FIFO full request.</p> <p>0 TX FIFO is full. 1 TX FIFO is not full.</p> |
| 24 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 23 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 22 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 21 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 20 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 19 RFOF | <p>Receive FIFO Overflow Flag</p> <p>Indicates an overflow condition in the RX FIFO. The field is set when the RX FIFO and shift register are full and a transfer is initiated. The bit remains set until it is cleared by writing a 1 to it.</p> <p>0 No Rx FIFO overflow. 1 Rx FIFO overflow has occurred.</p> |
| 18 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 17 RFDF | <p>Receive FIFO Drain Flag</p> |

Table continues on the next page...

SPIx_SR field descriptions (continued)

| Field | Description |
|------------------|--|
| | Provides a method for the module to request that entries be removed from the RX FIFO. The bit is set while the RX FIFO is not empty. The RFDF bit can be cleared by writing 1 to it or by acknowledgement from the DMA controller when the RX FIFO is empty. 0 RX FIFO is empty. 1 RX FIFO is not empty. |
| 16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–12 TXCTR | TX FIFO Counter Indicates the number of valid entries in the TX FIFO. The TXCTR is incremented every time the PUSHX is written. The TXCTR is decremented every time an SPI command is executed and the SPI data is transferred to the shift register. |
| 11–8 TXNXTPTR | Transmit Next Pointer Indicates which TX FIFO entry is transmitted during the next transfer. The TXNXTPTR field is updated every time SPI data is transferred from the TX FIFO to the shift register. |
| 7–4 RXCTR | RX FIFO Counter Indicates the number of entries in the RX FIFO. The RXCTR is decremented every time the POPR is read. The RXCTR is incremented every time data is transferred from the shift register to the RX FIFO. |
| 3–0 POPXTPTR | Pop Next Pointer Contains a pointer to the RX FIFO entry to be returned when the POPR is read. The POPXTPTR is updated when the POPR is read. |

43.3.6 DMA/Interrupt Request Select and Enable Register (SPIx_RSER)

RSER controls DMA and interrupt requests. Do not write to the RSER while the module is in the Running state.

Address: Base address + 30h offset

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|--------|----|----------|---------|---------|----------|---------|-----------|----|----------|----------|----------|---------|----|---------|-----------|
| R | TCF_RE | 0 | Reserved | EOQF_RE | TFUF_RE | Reserved | TFFF_RE | TFFF_DIRS | 0 | Reserved | Reserved | Reserved | RFOF_RE | 0 | RFDF_RE | RFDF_DIRS |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | 0 | 0 | 0 | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SPIx_RSER field descriptions

| Field | Description |
|----------------|--|
| 31 TCF_RE | Transmission Complete Request Enable Enables TCF flag in the SR to generate an interrupt request. 0 TCF interrupt requests are disabled. 1 TCF interrupt requests are enabled. |
| 30 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 29 Reserved | This field is reserved. |
| 28 EOQF_RE | Finished Request Enable Enables the EOQF flag in the SR to generate an interrupt request. 0 EOQF interrupt requests are disabled. 1 EOQF interrupt requests are enabled. |
| 27 TFUF_RE | Transmit FIFO Underflow Request Enable Enables the TFUF flag in the SR to generate an interrupt request. 0 TFUF interrupt requests are disabled. 1 TFUF interrupt requests are enabled. |

Table continues on the next page...

SPIx_RSER field descriptions (continued)

| Field | Description |
|-----------------|--|
| 26 Reserved | This field is reserved. |
| 25 TFFF_RE | Transmit FIFO Fill Request Enable Enables the TFFF flag in the SR to generate a request. The TFFF_DIRS bit selects between generating an interrupt request or a DMA request. 0 TFFF interrupts or DMA requests are disabled. 1 TFFF interrupts or DMA requests are enabled. |
| 24 TFFF_DIRS | Transmit FIFO Fill DMA or Interrupt Request Select Selects between generating a DMA request or an interrupt request. When SR[TFFF] and RSER[TFFF_RE] are set, this field selects between generating an interrupt request or a DMA request. 0 TFFF flag generates interrupt requests. 1 TFFF flag generates DMA requests. |
| 23 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 22 Reserved | This field is reserved. |
| 21 Reserved | This field is reserved. |
| 20 Reserved | This field is reserved. |
| 19 RFOF_RE | Receive FIFO Overflow Request Enable Enables the RFOF flag in the SR to generate an interrupt request. 0 RFOF interrupt requests are disabled. 1 RFOF interrupt requests are enabled. |
| 18 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 17 RFDF_RE | Receive FIFO Drain Request Enable Enables the RFDF flag in the SR to generate a request. The RFDF_DIRS bit selects between generating an interrupt request or a DMA request. 0 RFDF interrupt or DMA requests are disabled. 1 RFDF interrupt or DMA requests are enabled. |
| 16 RFDF_DIRS | Receive FIFO Drain DMA or Interrupt Request Select Selects between generating a DMA request or an interrupt request. When the RFDF flag bit in the SR is set, and the RFDF_RE bit in the RSER is set, the RFDF_DIRS bit selects between generating an interrupt request or a DMA request. 0 Interrupt request. 1 DMA request. |
| 15 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

Table continues on the next page...

SPIx_RSER field descriptions (continued)

| Field | Description |
|------------------|---|
| 14 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 13–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

43.3.7 PUSH TX FIFO Register In Master Mode (SPIx_PUSHR)

Specifies data to be transferred to the TX FIFO. An 8- or 16-bit write access transfers all 32 bits to the TX FIFO. In Master mode, the register transfers 16 bits of data and 16 bits of command information. In Slave mode, all 32 bits can be used as data, supporting up to 32-bit frame operation.

A read access of PUSHR returns the topmost TX FIFO entry.

When the module is disabled, writing to this register does not update the FIFO. Therefore, any reads performed while the module is disabled return the last PUSHR write performed while the module was still enabled.

Address: Base address + 34h offset

| | | | | | | | | | | | | | | | | |
|-------|--------|------|----|----|----|-------|----|----|----|----|-----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | CONT | CTAS | | | | CTCNT | 0 | | 0 | | PCS | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | TXDATA | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

SPIx_PUSHR field descriptions

| Field | Description |
|------------|--|
| 31 CONT | Continuous Peripheral Chip Select Enable Selects a continuous selection format. The bit is used in SPI Master mode. The bit enables the selected PCS signals to remain asserted between transfers. 0 Return PCSn signals to their inactive state between transfers. 1 Keep PCSn signals asserted between transfers. |

Table continues on the next page...

SPIx_PUSHR field descriptions (continued)

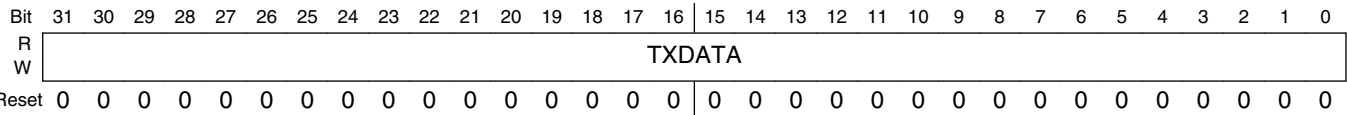
| Field | Description |
|-------------------|---|
| 30–28 CTAS | <p>Clock and Transfer Attributes Select</p> <p>Selects which CTAR to use in master mode to specify the transfer attributes for the associated SPI frame. In SPI Slave mode, CTAR0 is used. See the chip configuration details to determine how many CTARs this device has. You should not program a value in this field for a register that is not present.</p> <p>000 CTAR0 001 CTAR1 010 Reserved 011 Reserved 100 Reserved 101 Reserved 110 Reserved 111 Reserved</p> |
| 27 EOQ | <p>End Of Queue</p> <p>Host software uses this bit to signal to the module that the current SPI transfer is the last in a queue. At the end of the transfer, the EOQF bit in the SR is set.</p> <p>0 The SPI data is not the last data to transfer. 1 The SPI data is the last data to transfer.</p> |
| 26 CTCNT | <p>Clear Transfer Counter</p> <p>Clears the TCNT field in the TCR register. The TCNT field is cleared before the module starts transmitting the current SPI frame.</p> <p>0 Do not clear the TCR[TCNT] field. 1 Clear the TCR[TCNT] field.</p> |
| 25–24 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 23–21 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 20–16 PCS | <p>Select which PCS signals are to be asserted for the transfer. Refer to the chip configuration details for the number of PCS signals used in this MCU.</p> <p>0 Negate the PCS[x] signal. 1 Assert the PCS[x] signal.</p> |
| 15–0 TXDATA | <p>Transmit Data</p> <p>Holds SPI data to be transferred according to the associated SPI command.</p> |

43.3.8 PUSH TX FIFO Register In Slave Mode (SPIx_PUSHR_SLAVE)

Specifies data to be transferred to the TX FIFO. An 8- or 16-bit write access to PUSHR transfers all 32 bits to the TX FIFO.

In master mode, the register transfers 16 bits of data and 16 bits of command information to the TX FIFO. In slave mode, all 32 register bits can be used as data, supporting up to 32-bit SPI Frame operation.

Address: Base address + 34h offset



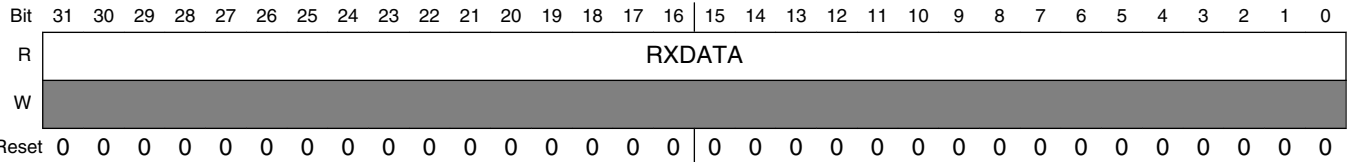
SPIx_PUSHR_SLAVE field descriptions

| Field | Description |
|----------------|--|
| 31–0 TXDATA | Transmit Data Holds SPI data to be transferred according to the associated SPI command. |

43.3.9 POP RX FIFO Register (SPIx_POPR)

POPR is used to read the RX FIFO. Eight- or sixteen-bit read accesses to the POPR have the same effect on the RX FIFO as 32-bit read accesses. A write to this register will generate a Transfer Error.

Address: Base address + 38h offset



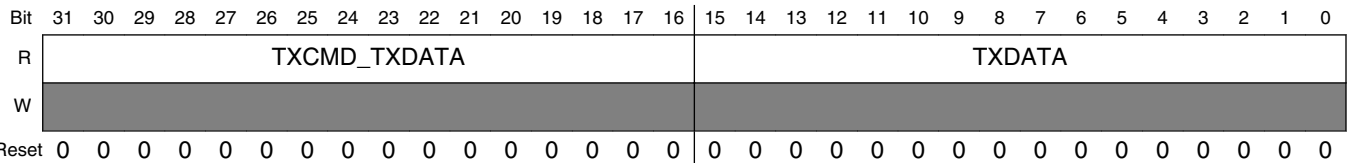
SPIx_POPR field descriptions

| Field | Description |
|----------------|--|
| 31–0 RXDATA | Received Data Contains the SPI data from the RX FIFO entry to which the Pop Next Data Pointer points. |

43.3.10 Transmit FIFO Registers (SPIx_TXFRn)

TXFRn registers provide visibility into the TX FIFO for debugging purposes. Each register is an entry in the TX FIFO. The registers are read-only and cannot be modified. Reading the TXFRx registers does not alter the state of the TX FIFO.

Address: Base address + 3Ch offset + (4d × i), where i=0d to 3d



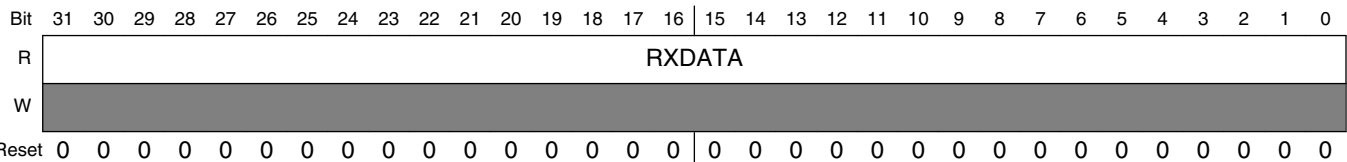
SPIx_TXFRn field descriptions

| Field | Description |
|---------------------------|--|
| 31–16 TXCMD_ TXDATA | Transmit Command or Transmit Data In Master mode the TXCMD field contains the command that sets the transfer attributes for the SPI data. In Slave mode, the TXDATA contains 16 MSB bits of the SPI data to be shifted out. |
| 15–0 TXDATA | Transmit Data Contains the SPI data to be shifted out. |

43.3.11 Receive FIFO Registers (SPIx_RXFRn)

RXFRn provide visibility into the RX FIFO for debugging purposes. Each register is an entry in the RX FIFO. The RXFR registers are read-only. Reading the RXFRx registers does not alter the state of the RX FIFO.

Address: Base address + 7Ch offset + (4d × i), where i=0d to 3d



SPIx_RXFRn field descriptions

| Field | Description |
|----------------|---|
| 31–0 RXDATA | Receive Data Contains the received SPI data. |

SPIx_RXFRn field descriptions (continued)

| Field | Description |
|-------|-------------|
|-------|-------------|

43.4 Functional description

The module supports full-duplex, synchronous serial communications between MCUs and peripheral devices. The SPI configuration transfers data serially using a shift register and a selection of programmable transfer attributes.

The module has the following configurations

- The SPI Configuration in which the module operates as a basic SPI or a queued SPI.
- When Master mode is enabled, the module also supports CSI Configuration, which combines the functionality of the SPI and DSI configurations.

The DCONF field in the Module Configuration Register (MCR) determines the module Configuration. SPI configuration is selected when DCONF within SPIx_MCR is 0b00.

The CTARn registers hold clock and transfer attributes. The SPI configuration allows to select which CTAR to use on a frame by frame basis by setting a field in the SPI command.

See [Clock and Transfer Attributes Register \(In Master Mode\) \(SPI_CTARn\)](#) for information on the fields of CTAR registers.

Typical master to slave connections are shown in the following figure. When a data transfer operation is performed, data is serially shifted a predetermined number of bit positions. Because the modules are linked, data is exchanged between the master and the slave. The data that was in the master shift register is now in the shift register of the slave, and vice versa. At the end of a transfer, the Transfer Control Flag(TCF) bit in the Shift Register(SR) is set to indicate a completed frame transfer.

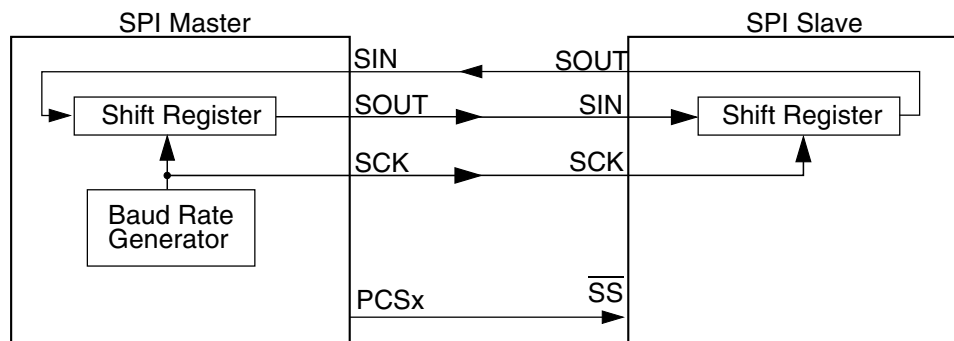


Figure 43-69. Serial protocol overview

Generally, more than one slave device can be connected to the module master. 5 Peripheral Chip Select (PCS) signals of the module masters can be used to select which of the slaves to communicate with. Refer to the chip configuration details for the number of PCS signals used in this MCU.

The SPI configuration shares transfer protocol and timing properties which are described independently of the configuration in [Transfer formats](#). The transfer rate and delay settings are described in [Module baud rate and clock delay generation](#).

43.4.1 Start and Stop of module transfers

The module has two operating states: Stopped and Running. Both the states are independent of it's configuration. The default state of the module is Stopped. In the Stopped state, no serial transfers are initiated in Master mode and no transfers are responded to in Slave mode. The Stopped state is also a safe state for writing the various configuration registers of the module without causing undetermined results. In the Running state serial transfers take place.

The TXRXS bit in the SR indicates the state of module. The bit is set if the module is in Running state.

The module starts or transitions to Running when all of the following conditions are true:

- SR[EOQF] bit is clear
- MCU is not in the Debug mode or the MCR[FRZ] bit is clear
- MCR[HALT] bit is clear

The module stops or transitions from Running to Stopped after the current frame when any one of the following conditions exist:

- SR[EOQF] bit is set
- MCU in the Debug mode and the MCR[FRZ] bit is set
- MCR[HALT] bit is set

State transitions from Running to Stopped occur on the next frame boundary if a transfer is in progress, or immediately if no transfers are in progress.

43.4.2 Serial Peripheral Interface (SPI) configuration

The SPI configuration transfers data serially using a shift register and a selection of programmable transfer attributes. The module is in SPI configuration when the DCONF field in the MCR is 0b00. The SPI frames can be 32 bits long. The host CPU or a DMA controller transfers the SPI data from the external to the module RAM queues to a TX FIFO buffer. The received data is stored in entries in the RX FIFO buffer. The host CPU or the DMA controller transfers the received data from the RX FIFO to memory external to the module. The operation of FIFO buffers is described in the following sections:

- [Transmit First In First Out \(TX FIFO\) buffering mechanism](#)
- [Transmit First In First Out \(TX FIFO\) buffering mechanism](#)
- [Receive First In First Out \(RX FIFO\) buffering mechanism](#)

The interrupt and DMA request conditions are described in [Interrupts/DMA requests](#).

The SPI configuration supports two block-specific modes—Master mode and Slave mode. In Master mode the module initiates and controls the transfer according to the fields of the executing SPI Command. In Slave mode, the module responds only to transfers initiated by a bus master external to it and the SPI command field space is reserved.

43.4.2.1 Master mode

In SPI Master mode, the module initiates the serial transfers by controlling the SCK and the PCS signals. The executing SPI Command determines which CTARs will be used to set the transfer attributes and which PCS signals to assert. The command field also contains various bits that help with queue management and transfer protocol. See [PUSH TX FIFO Register In Master Mode \(SPI_PUSHR\)](#) for details on the SPI command fields. The data in the executing TX FIFO entry is loaded into the shift register and shifted out on the Serial Out (SOUT) pin. In SPI Master mode, each SPI frame to be transmitted has a command associated with it, allowing for transfer attribute control on a frame by frame basis.

43.4.2.2 Slave mode

In SPI Slave mode the module responds to transfers initiated by an SPI bus master. It does not initiate transfers. Certain transfer attributes such as clock polarity, clock phase, and frame size must be set for successful communication with an SPI master. The SPI Slave mode transfer attributes are set in the CTAR0. The data is shifted out with MSB first. Shifting out of LSB is not supported in this mode.

43.4.2.3 FIFO disable operation

The FIFO disable mechanisms allow SPI transfers without using the TX FIFO or RX FIFO. The module operates as a double-buffered simplified SPI when the FIFOs are disabled. The Transmit and Receive side of the FIFOs are disabled separately. Setting the MCR[DIS_TXF] bit disables the TX FIFO, and setting the MCR[DIS_RXF] bit disables the RX FIFO.

The FIFO disable mechanisms are transparent to the user and to host software. Transmit data and commands are written to the PUSHHR and received data is read from the POPR.

When the TX FIFO is disabled:

- SR[TFFF], SR[TFUF] and SR[TXCTR] behave as if there is a one-entry FIFO
- The contents of TXFRs, SR[TXNXTPTR] are undefined

Similarly, when the RX FIFO is disabled, the RFDF, RFOF, and RXCTR fields in the SR behave as if there is a one-entry FIFO, but the contents of the RXFR registers and POPNXTPTR are undefined.

43.4.2.4 Transmit First In First Out (TX FIFO) buffering mechanism

The TX FIFO functions as a buffer of SPI data for transmission. The TX FIFO holds 4 words, each consisting of SPI data. The number of entries in the TX FIFO is device-specific. SPI data is added to the TX FIFO by writing to the Data Field of module PUSH FIFO Register (PUSHHR). TX FIFO entries can only be removed from the TX FIFO by being shifted out or by flushing the TX FIFO.

The TX FIFO Counter field (TXCTR) in the module Status Register (SR) indicates the number of valid entries in the TX FIFO. The TXCTR is updated every time a 8- or 16-bit write takes place to PUSHHR[TXDATA] or SPI data is transferred into the shift register from the TX FIFO.

The TXNXTPTR field indicates the TX FIFO Entry that will be transmitted during the next transfer. The TXNXTPTR field is incremented every time SPI data is transferred from the TX FIFO to the shift register. The maximum value of the field is equal to the maximum implemented TXFR number and it rolls over after reaching the maximum.

43.4.2.4.1 Filling the TX FIFO

Host software or other intelligent blocks can add (push) entries to the TX FIFO by writing to the PUSHHR. When the TX FIFO is not full, the TX FIFO Fill Flag (TFFF) in the SR is set. The TFFF bit is cleared when TX FIFO is full and the DMA controller

indicates that a write to PUSHHR is complete. Writing a '1' to the TFFF bit also clears it. The TFFF can generate a DMA request or an interrupt request. See [Transmit FIFO Fill Interrupt or DMA Request](#) for details.

The module ignores attempts to push data to a full TX FIFO, and the state of the TX FIFO does not change and no error condition is indicated.

43.4.2.4.2 Draining the TX FIFO

The TX FIFO entries are removed (drained) by shifting SPI data out through the shift register. Entries are transferred from the TX FIFO to the shift register and shifted out as long as there are valid entries in the TX FIFO. Every time an entry is transferred from the TX FIFO to the shift register, the TX FIFO Counter decrements by one. At the end of a transfer, the TCF bit in the SR is set to indicate the completion of a transfer. The TX FIFO is flushed by writing a '1' to the CLR_TXF bit in MCR.

If an external bus master initiates a transfer with a module slave while the slave's TX FIFO is empty, the Transmit FIFO Underflow Flag (TFUF) in the slave's SR is set. See [Transmit FIFO Underflow Interrupt Request](#) for details.

43.4.2.5 Receive First In First Out (RX FIFO) buffering mechanism

The RX FIFO functions as a buffer for data received on the SIN pin. The RX FIFO holds 4 received SPI data frames. The number of entries in the RX FIFO is device-specific. SPI data is added to the RX FIFO at the completion of a transfer when the received data in the shift register is transferred into the RX FIFO. SPI data are removed (popped) from the RX FIFO by reading the module POP RX FIFO Register (POPR). RX FIFO entries can only be removed from the RX FIFO by reading the POPR or by flushing the RX FIFO.

The RX FIFO Counter field (RXCTR) in the module's Status Register (SR) indicates the number of valid entries in the RX FIFO. The RXCTR is updated every time the POPR is read or SPI data is copied from the shift register to the RX FIFO.

The POPNXTPTR field in the SR points to the RX FIFO entry that is returned when the POPR is read. The POPNXTPTR contains the positive offset from RXFR0 in a number of 32-bit registers. For example, POPNXTPTR equal to two means that the RXFR2 contains the received SPI data that will be returned when the POPR is read. The POPNXTPTR field is incremented every time the POPR is read. The maximum value of the field is equal to the maximum implemented RXFR number and it rolls over after reaching the maximum.

43.4.2.5.1 Filling the RX FIFO

The RX FIFO is filled with the received SPI data from the shift register. While the RX FIFO is not full, SPI frames from the shift register are transferred to the RX FIFO. Every time an SPI frame is transferred to the RX FIFO, the RX FIFO Counter is incremented by one.

If the RX FIFO and shift register are full and a transfer is initiated, the RFOF bit in the SR is set indicating an overflow condition. Depending on the state of the ROOE bit in the MCR, the data from the transfer that generated the overflow is either ignored or shifted in to the shift register. If the ROOE bit is set, the incoming data is shifted in to the shift register. If the ROOE bit is cleared, the incoming data is ignored.

43.4.2.5.2 Draining the RX FIFO

Host CPU or a DMA can remove (pop) entries from the RX FIFO by reading the module POP RX FIFO Register (POPR). A read of the POPR decrements the RX FIFO Counter by one. Attempts to pop data from an empty RX FIFO are ignored and the RX FIFO Counter remains unchanged. The data, read from the empty RX FIFO, is undetermined.

When the RX FIFO is not empty, the RX FIFO Drain Flag (RFDF) in the SR is set. The RFDF bit is cleared when the RX_FIFO is empty and the DMA controller indicates that a read from POPR is complete or by writing a 1 to it.

43.4.3 Module baud rate and clock delay generation

The SCK frequency and the delay values for serial transfer are generated by dividing the protocol clock frequency by a prescaler and a scaler with the option for doubling the baud rate. The following figure shows conceptually how the SCK signal is generated.

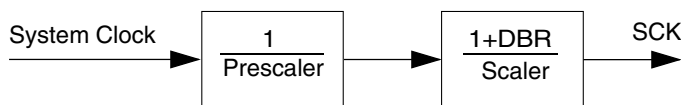


Figure 43-70. Communications clock prescalers and scalers

43.4.3.1 Baud rate generator

The baud rate is the frequency of the SCK. The protocol clock is divided by a prescaler (PBR) and scaler (BR) to produce SCK with the possibility of halving the scaler division. The DBR, PBR, and BR fields in the CTARs select the frequency of SCK by the formula in the BR field description. The following table shows an example of how to compute the baud rate.

Table 43-98. Baud rate computation example

| f_p | PBR | Prescaler | BR | Scaler | DBR | Baud rate |
|---------|------|-----------|--------|--------|-----|-----------|
| 100 MHz | 0b00 | 2 | 0b0000 | 2 | 0 | 25 Mb/s |
| 20 MHz | 0b00 | 2 | 0b0000 | 2 | 1 | 10 Mb/s |

NOTE

The clock frequencies mentioned in the preceding table are given as an example. Refer to the clocking chapter for the frequency used to drive this module in the device.

43.4.3.2 PCS to SCK Delay (t_{csc})

The PCS to SCK delay is the length of time from assertion of the PCS signal to the first SCK edge. See [Figure 43-71](#) for an illustration of the PCS to SCK delay. The PCSSCK and CSSCK fields in the CTAR_x registers select the PCS to SCK delay by the formula in the CSSCK field description. The following table shows an example of how to compute the PCS to SCK delay.

Table 43-99. PCS to SCK delay computation example

| f_{sys} | PCSSCK | Prescaler | CSSCK | Scaler | PCS to SCK Delay |
|-----------|--------|-----------|--------|--------|------------------|
| 100 MHz | 0b01 | 3 | 0b0100 | 32 | 0.96 μ s |

NOTE

The clock frequency mentioned in the preceding table is given as an example. Refer to the clocking chapter for the frequency used to drive this module in the device.

43.4.3.3 After SCK Delay (t_{ASC})

The After SCK Delay is the length of time between the last edge of SCK and the negation of PCS. See [Figure 43-71](#) and [Figure 43-72](#) for illustrations of the After SCK delay. The PASC and ASC fields in the CTAR_x registers select the After SCK Delay by the formula in the ASC field description. The following table shows an example of how to compute the After SCK delay.

Table 43-100. After SCK Delay computation example

| f_p | PASC | Prescaler | ASC | Scaler | After SCK Delay |
|---------|------|-----------|--------|--------|-----------------|
| 100 MHz | 0b01 | 3 | 0b0100 | 32 | 0.96 μ s |

NOTE

The clock frequency mentioned in the preceding table is given as an example. Refer to the clocking chapter for the frequency used to drive this module in the device.

43.4.3.4 Delay after Transfer (t_{DT})

The Delay after Transfer is the minimum time between negation of the PCS signal for a frame and the assertion of the PCS signal for the next frame. See [Figure 43-71](#) for an illustration of the Delay after Transfer. The PDT and DT fields in the CTAR_x registers select the Delay after Transfer by the formula in the DT field description. The following table shows an example of how to compute the Delay after Transfer.

Table 43-101. Delay after Transfer computation example

| f_p | PDT | Prescaler | DT | Scaler | Delay after Transfer |
|---------|------|-----------|--------|--------|----------------------|
| 100 MHz | 0b01 | 3 | 0b1110 | 32768 | 0.98 ms |

NOTE

The clock frequency mentioned in the preceding table is given as an example. Refer to the clocking chapter for the frequency used to drive this module in the device.

When in Non-Continuous Clock mode the t_{DT} delay is configured according to the equation specified in the CTAR[DT] field description. When in Continuous Clock mode, the delay is fixed at 1 SCK period.

43.4.4 Transfer formats

The SPI serial communication is controlled by the Serial Communications Clock (SCK) signal and the PCS signals. The SCK signal provided by the master device synchronizes shifting and sampling of the data on the SIN and SOUT pins. The PCS signals serve as enable signals for the slave devices.

In Master mode, the CPOL and CPHA bits in the Clock and Transfer Attributes Registers (CTARn) select the polarity and phase of the serial clock, SCK.

- CPOL - Selects the idle state polarity of the SCK
- CPHA - Selects if the data on SOUT is valid before or on the first SCK edge

Even though the bus slave does not control the SCK signal, in Slave mode the values of CPOL and CPHA must be identical to the master device settings to ensure proper transmission. In SPI Slave mode, only CTAR0 is used.

The module supports four different transfer formats:

- Classic SPI with CPHA=0
- Classic SPI with CPHA=1
- Modified Transfer Format with CPHA = 0
- Modified Transfer Format with CPHA = 1

A modified transfer format is supported to allow for high-speed communication with peripherals that require longer setup times. The module can sample the incoming data later than halfway through the cycle to give the peripheral more setup time. The MTFE bit in the MCR selects between Classic SPI Format and Modified Transfer Format.

In the interface configurations, the module provides the option of keeping the PCS signals asserted between frames. See [Continuous Selection Format](#) for details.

43.4.4.1 Classic SPI Transfer Format (CPHA = 0)

The transfer format shown in following figure is used to communicate with peripheral SPI slave devices where the first data bit is available on the first clock edge. In this format, the master and slave sample their SIN pins on the odd-numbered SCK edges and change the data on their SOUT pins on the even-numbered SCK edges.

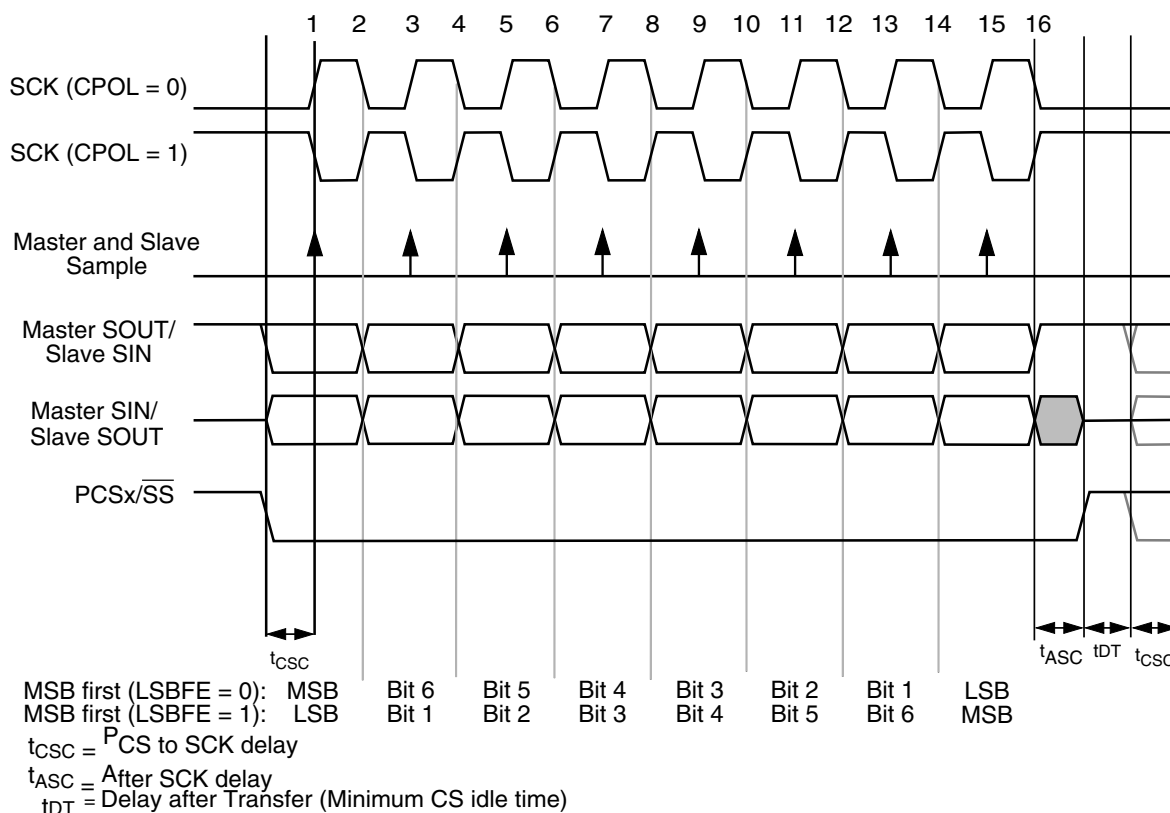


Figure 43-71. Module transfer timing diagram (MTFE=0, CPHA=0, FMSZ=8)

The master initiates the transfer by placing its first data bit on the SOUT pin and asserting the appropriate peripheral chip select signals to the slave device. The slave responds by placing its first data bit on its SOUT pin. After the t_{ASC} delay elapses, the master outputs the first edge of SCK. The master and slave devices use this edge to sample the first input data bit on their serial data input signals. At the second edge of the SCK, the master and slave devices place their second data bit on their serial data output signals. For the rest of the frame the master and the slave sample their SIN pins on the odd-numbered clock edges and changes the data on their SOUT pins on the even-numbered clock edges. After the last clock edge occurs, a delay of t_{ASC} is inserted before the master negates the PCS signals. A delay of t_{DT} is inserted before a new frame transfer can be initiated by the master.

43.4.4.2 Classic SPI Transfer Format (CPHA = 1)

This transfer format shown in the following figure is used to communicate with peripheral SPI slave devices that require the first SCK edge before the first data bit becomes available on the slave SOUT pin. In this format, the master and slave devices change the data on their SOUT pins on the odd-numbered SCK edges and sample the data on their SIN pins on the even-numbered SCK edges.

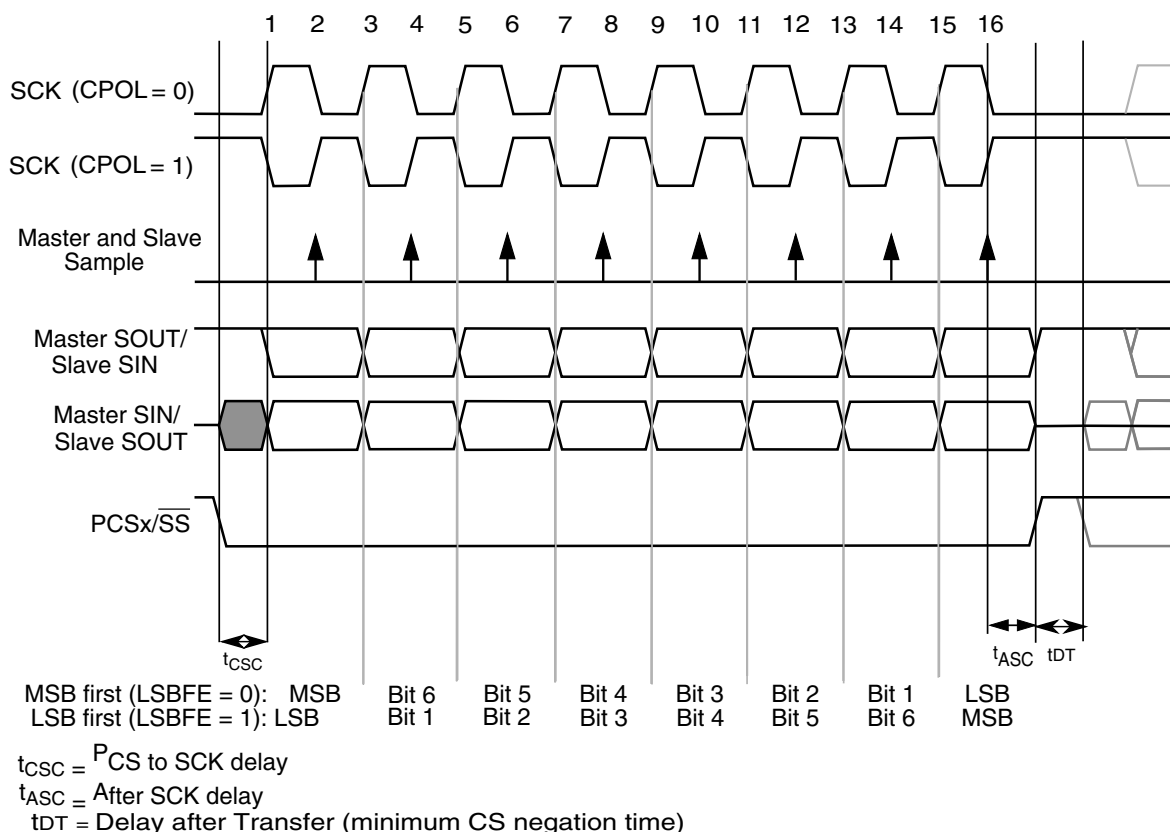


Figure 43-72. Module transfer timing diagram (MTFE=0, CPHA=1, FMSZ=8)

The master initiates the transfer by asserting the PCS signal to the slave. After the t_{CSC} delay has elapsed, the master generates the first SCK edge and at the same time places valid data on the master SOUT pin. The slave responds to the first SCK edge by placing its first data bit on its slave SOUT pin.

At the second edge of the SCK the master and slave sample their SIN pins. For the rest of the frame the master and the slave change the data on their SOUT pins on the odd-numbered clock edges and sample their SIN pins on the even-numbered clock edges. After the last clock edge occurs, a delay of t_{ASC} is inserted before the master negates the PCS signal. A delay of t_{DT} is inserted before a new frame transfer can be initiated by the master.

43.4.4.3 Modified SPI/DSI Transfer Format (MTFE = 1, CPHA = 0)

In this Modified Transfer Format both the master and the slave sample later in the SCK period than in Classic SPI mode to allow the logic to tolerate more delays in device pads and board traces. These delays become a more significant fraction of the SCK period as the SCK period decreases with increasing baud rates.

The master and the slave place data on the SOUT pins at the assertion of the PCS signal. After the PCS to SCK delay has elapsed the first SCK edge is generated. The slave samples the master SOUT signal on every odd numbered SCK edge. The DSPI in the slave mode when the MTFE bit is set also places new data on the slave SOUT on every odd numbered clock edge. Regular external slave, configured with CPHA=0 format drives its SOUT output at every even numbered SCK clock edge.

The DSPI master places its second data bit on the SOUT line one protocol clock after odd numbered SCK edge if the protocol clock frequency to SCK frequency ratio is higher than three. If this ratio is below four the master changes SOUT at odd numbered SCK edge. The point where the master samples the SIN is selected by the DSPI_MCR[SMPL_PT] field. The master sample point can be delayed by one or two protocol clock cycles. The SMPL_PT field should be set to 0 if the protocol to SCK frequency ratio is less than 4. However if this ratio is less than 4, the actual sample point is delayed by one protocol clock cycle automatically by the design.

The following timing diagrams illustrate the DSPI operation with MTFE=1. Timing delays shown are:

- T_{csc} - PCS to SCK assertion delay
- T_{acs} - After SCK PCS negation delay
- $T_{su_{ms}}$ - master SIN setup time
- $T_{hd_{ms}}$ - master SIN hold time
- $T_{vd_{sl}}$ - slave data output valid time, time between slave data output SCK driving edge and data becomes valid.
- $T_{su_{sl}}$ - data setup time on slave data input
- $T_{hd_{sl}}$ - data hold time on slave data input
- T_{sys} - protocol clock period.

The following figure shows the modified transfer format for CPHA = 0 and Fsys/Fsck = 4. Only the condition where CPOL = 0 is illustrated. Solid triangles show the data sampling clock edges. The two possible slave behavior are shown.

- Signal, marked "SOUT of Ext Slave", presents regular SPI slave serial output.
- Signal, marked "SOUT of DSPI Slave", presents DSPI in the slave mode with MTFE bit set.

Other MTFE = 1 diagrams show DSPI SIN input as being driven by a regular external SPI slave, configured according DSPI master CPHA programming.

Note

In the following diagrams, f_{sys} represents the protocol clock frequency from which the Baud frequency f_{sck} is derived.

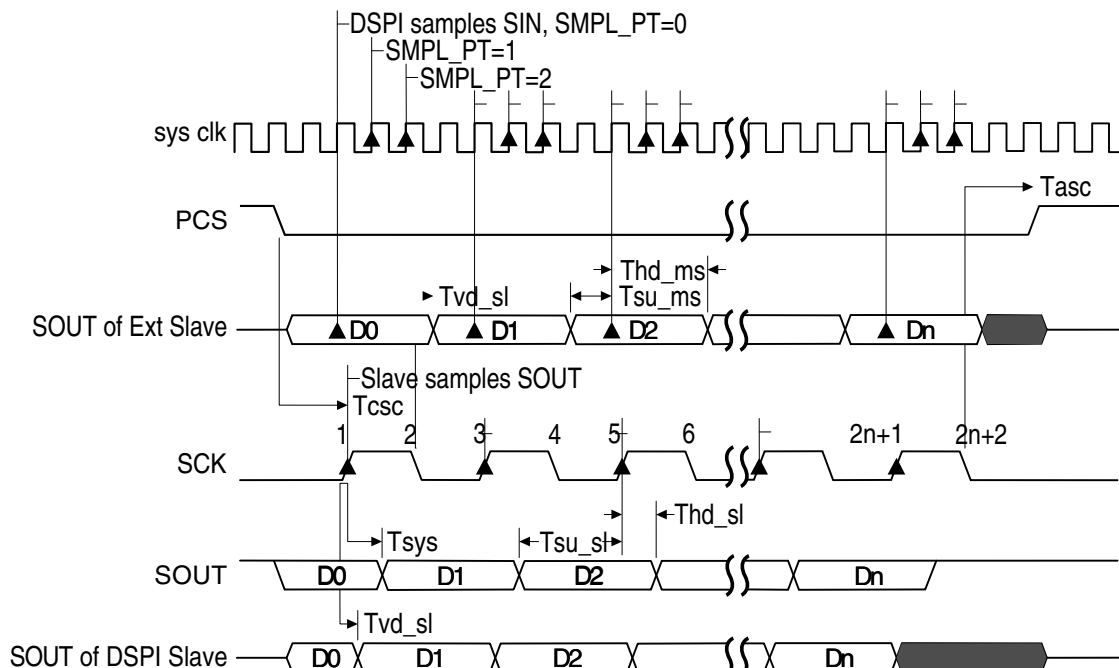


Figure 43-73. DSPI Modified Transfer Format (MTFE=1, CPHA=0, $f_{sck} = f_{sys}/4$)

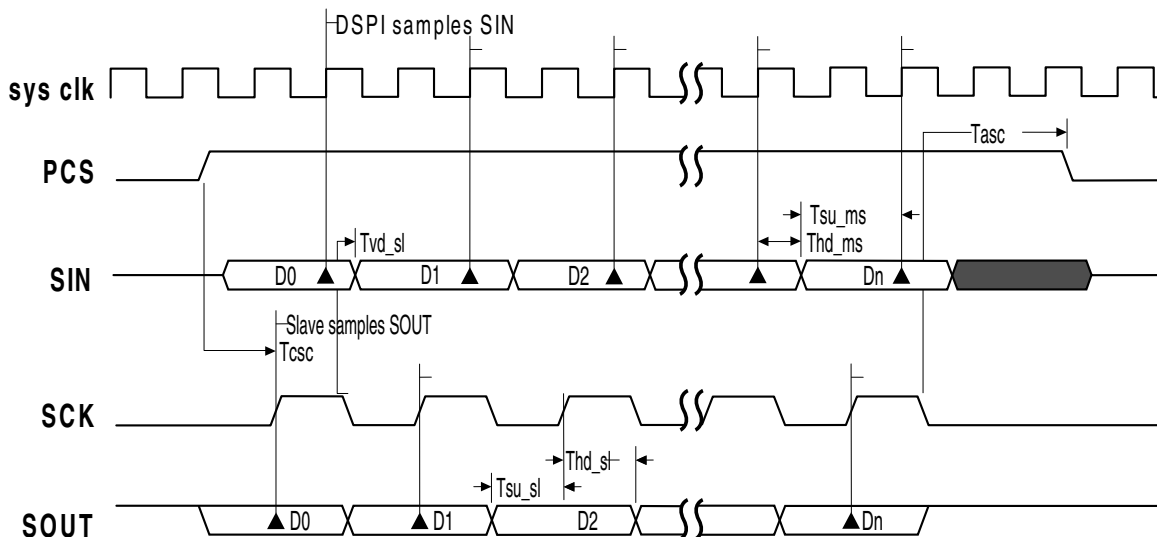


Figure 43-74. DSPI Modified Transfer Format (MTFE=1, CPHA=0, $f_{sck} = f_{sys}/2$)

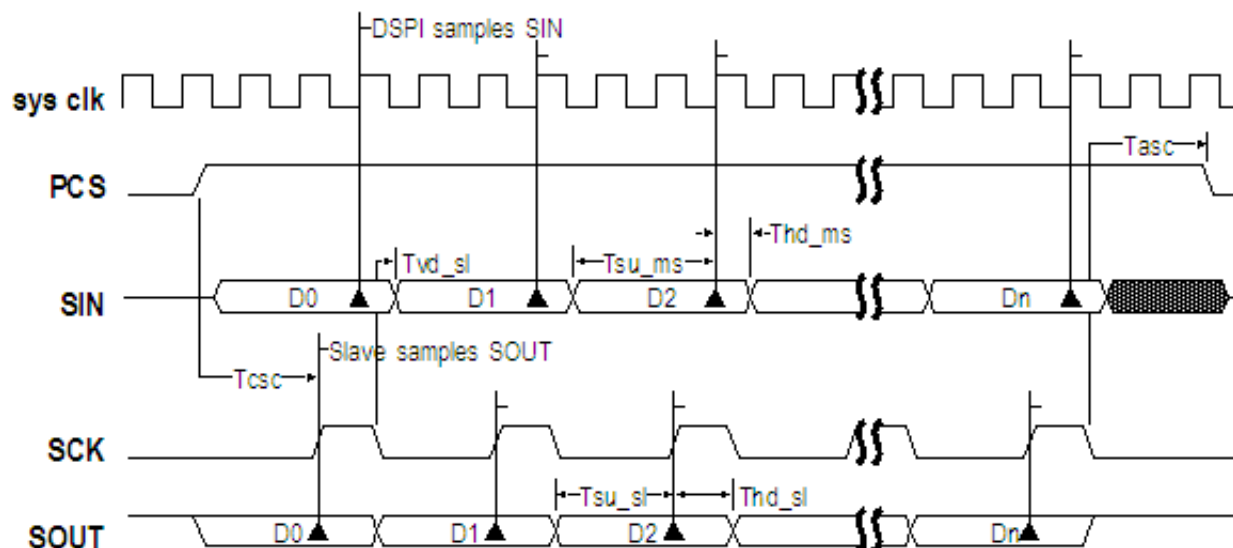


Figure 43-75. DSPI Modified Transfer Format (MTFE=1, CPHA=0, $f_{sck} = f_{sys}/3$)

43.4.4.4 Modified SPI/DSI Transfer Format (MTFE = 1, CPHA = 1)

The following figures show the Modified Transfer Format for CPHA = 1. Only the condition, where CPOL = 0 is shown. At the start of a transfer the DSPI asserts the PCS signal to the slave device. After the PCS to SCK delay has elapsed the master and the slave put data on their SOUT pins at the first edge of SCK. The slave samples the master SOUT signal on the even numbered edges of SCK. The master samples the slave SOUT signal on the odd numbered SCK edges starting with the third SCK edge. The slave samples the last bit on the last edge of the SCK. The master samples the last slave SOUT bit one half SCK cycle after the last edge of SCK. No clock edge will be visible on the master SCK pin during the sampling of the last bit. **The SCK to PCS delay and the After SCK delay must be greater or equal to half of the SCK period.**

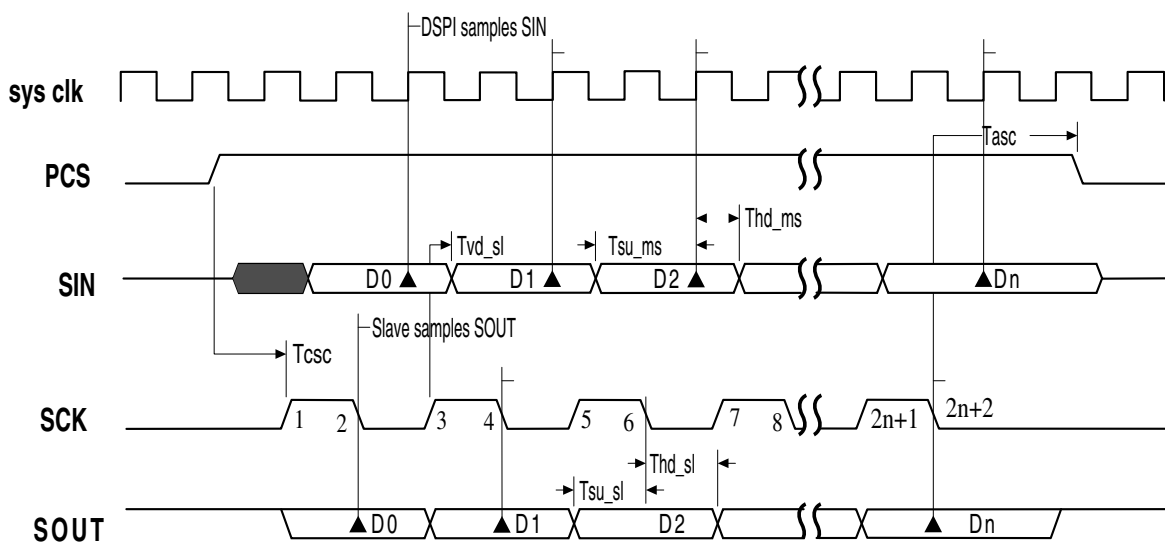


Figure 43-76. DSPI Modified Transfer Format (MTFE=1, CPHA=1, $f_{sck} = f_{sys}/2$)

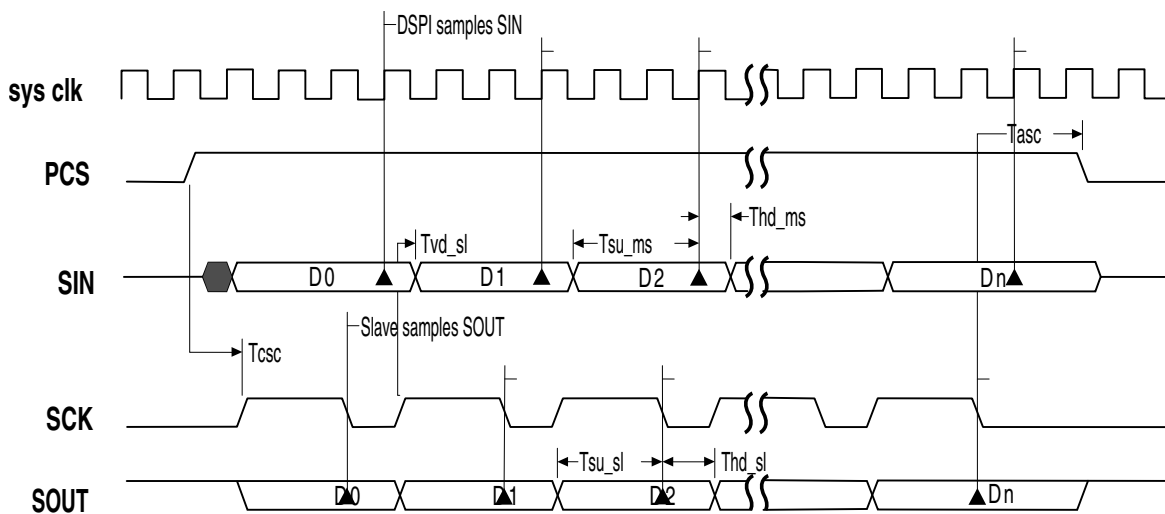


Figure 43-77. DSPI Modified Transfer Format (MTFE=1, CPHA=1, $f_{sck} = f_{sys}/3$)

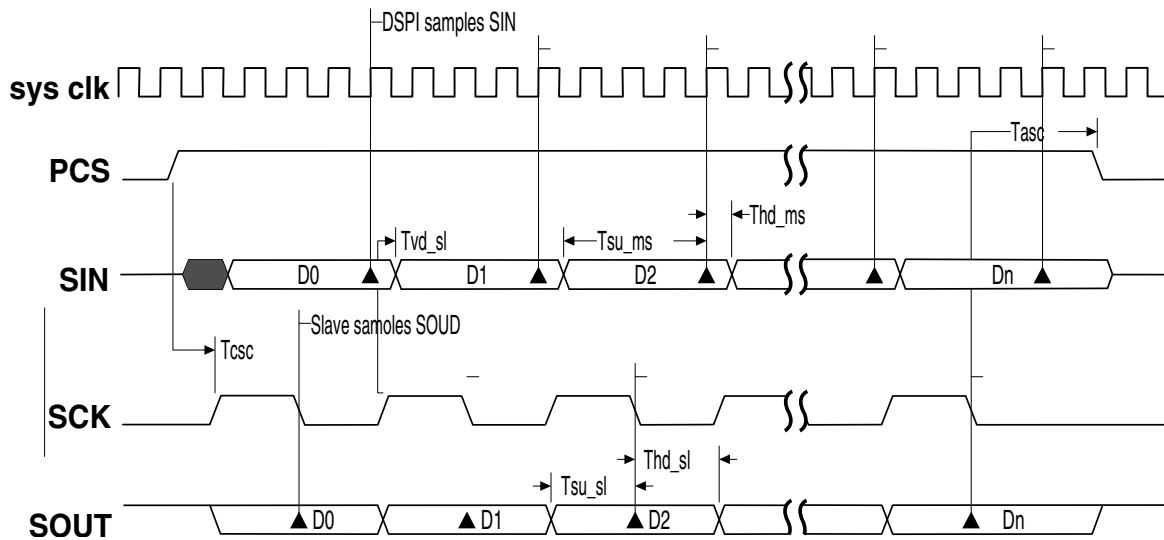


Figure 43-78. DSPI Modified Transfer Format (MTFE=1, CPHA=1, $f_{sck} = f_{sys}/4$)

43.4.4.5 Continuous Selection Format

Some peripherals must be deselected between every transfer. Other peripherals must remain selected between several sequential serial transfers. The Continuous Selection Format provides the flexibility to handle the following case. The Continuous Selection Format is enabled for the SPI configuration by setting the CONT bit in the SPI command.

When the CONT bit = 0, the module drives the asserted Chip Select signals to their idle states in between frames. The idle states of the Chip Select signals are selected by the PCSISn bits in the MCR. The following timing diagram is for two four-bit transfers with CPHA = 1 and CONT = 0.

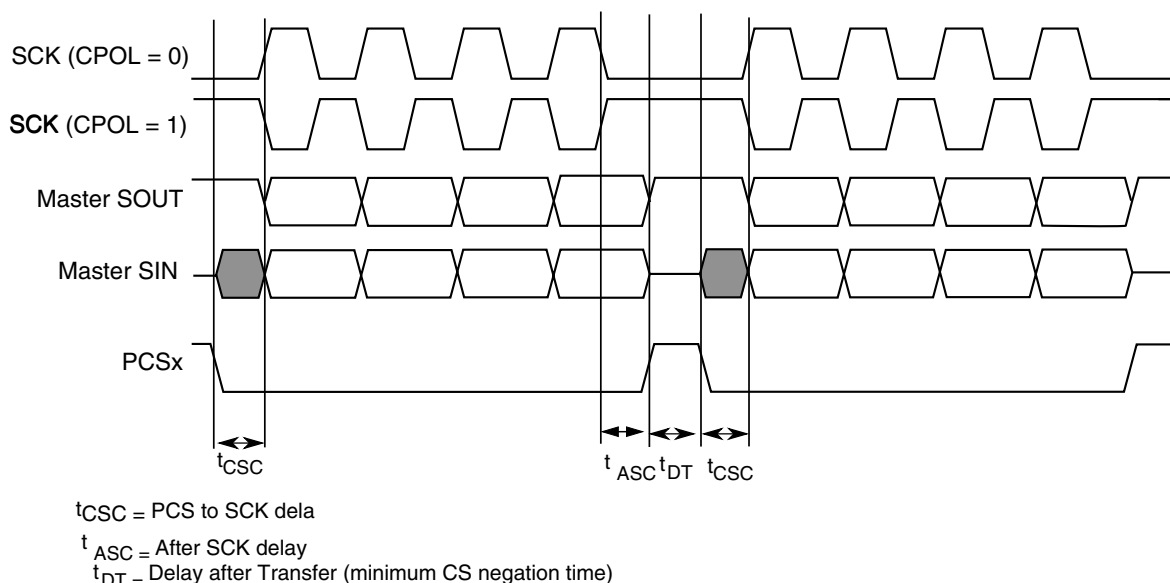


Figure 43-79. Example of non-continuous format (CPHA=1, CONT=0)

When the CONT bit = 1, the PCS signal remains asserted for the duration of the two transfers. The Delay between Transfers (t_{DT}) is not inserted between the transfers. The following figure shows the timing diagram for two four-bit transfers with CPHA = 1 and CONT = 1.

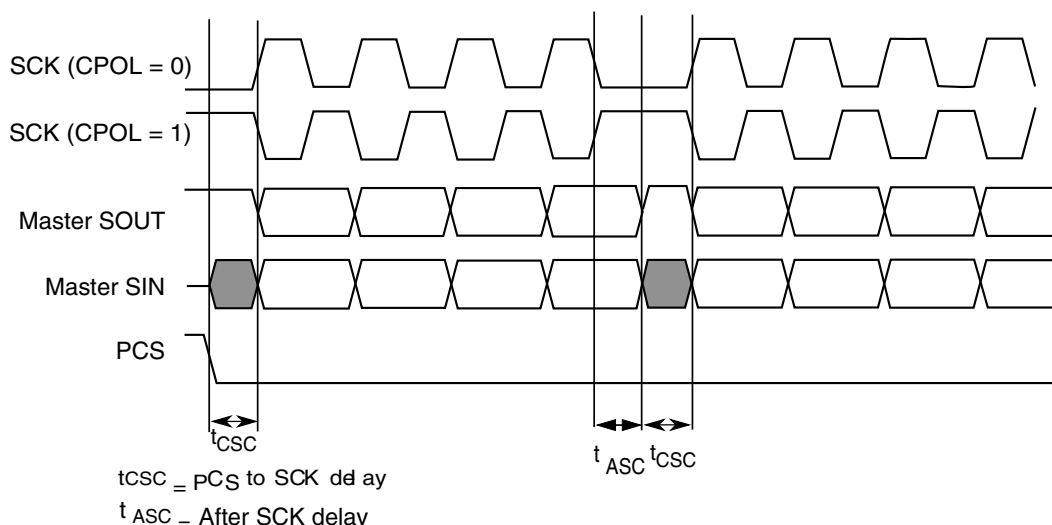


Figure 43-80. Example of continuous transfer (CPHA=1, CONT=1)

When using the module with continuous selection follow these rules:

- All transmit commands must have the same PCSn bits programming.
- The CTARs, selected by transmit commands, must be programmed with the same transfer attributes. Only FMSZ field can be programmed differently in these CTARs.

- When transmitting multiple frames in this mode, the user software must ensure that the last frame has the PUSHHR[CONT] bit deasserted in Master mode and the user software must provide sufficient frames in the TX_FIFO to be sent out in Slave mode and the master deasserts the PCSn at end of transmission of the last frame.
- PUSHHR[CONT] must be deasserted before asserting MCR[HALT] in master mode. This will make sure that the PCSn signals are deasserted. Asserting MCR[HALT] during continuous transfer will cause the PCSn signals to remain asserted and hence Slave Device cannot transition from Running to Stopped state.

NOTE

User must fill the TX FIFO with the number of entries that will be concatenated together under one PCS assertion for both master and slave before the TX FIFO becomes empty.

When operating in Slave mode, ensure that when the last entry in the TX FIFO is completely transmitted, that is, the corresponding TCF flag is asserted and TXFIFO is empty, the slave is deselected for any further serial communication; otherwise, an underflow error occurs.

43.4.5 Continuous Serial Communications Clock

The module provides the option of generating a Continuous SCK signal for slave peripherals that require a continuous clock.

Continuous SCK is enabled by setting the CONT_SCKE bit in the MCR. Enabling this bit generates the Continuous SCK regardless of the MCR[HALT] bit status. Continuous SCK is valid in all configurations.

Continuous SCK is only supported for CPHA=1. Clearing CPHA is ignored if the CONT_SCKE bit is set. Continuous SCK is supported for Modified Transfer Format.

Clock and transfer attributes for the Continuous SCK mode are set according to the following rules:

- When the module is in SPI configuration, CTAR0 is used initially. At the start of each SPI frame transfer, the CTAR specified by the CTAS for the frame is used.
- In all configurations, the currently selected CTAR remains in use until the start of a frame with a different CTAR specified, or the Continuous SCK mode is terminated.

It is recommended to keep the baud rate the same while using the Continuous SCK. Switching clock polarity between frames while using Continuous SCK can cause errors in the transfer. Continuous SCK operation is not guaranteed if the module is put into the External Stop mode or Module Disable mode.

Enabling Continuous SCK disables the PCS to SCK delay and the Delay after Transfer (t_{DT}) is fixed to one SCK cycle. The following figure is the timing diagram for Continuous SCK format with Continuous Selection disabled.

NOTE

In Continuous SCK mode, for the SPI transfer CTAR0 should always be used, and the TX FIFO must be cleared using the MCR[CLR_TXF] field before initiating transfer.

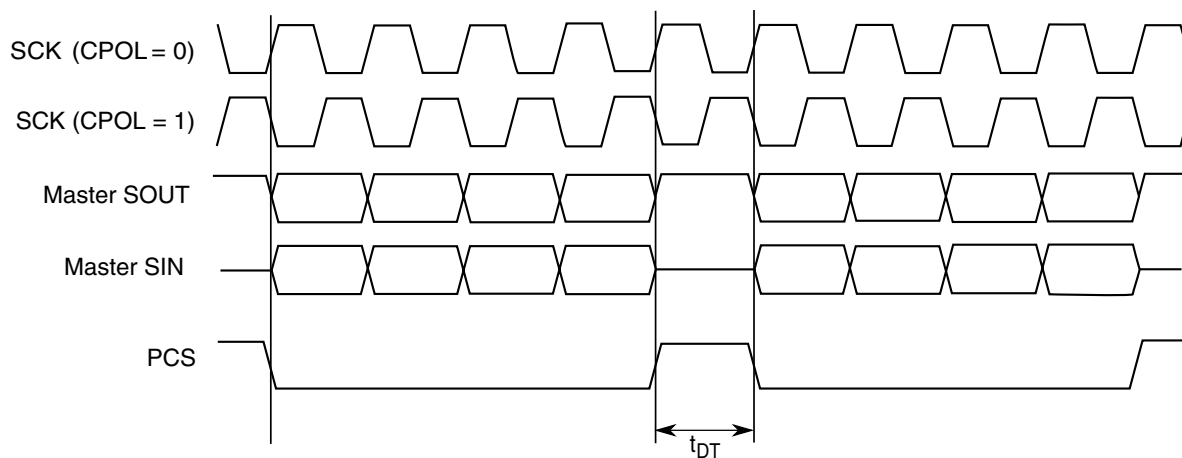


Figure 43-81. Continuous SCK Timing Diagram (CONT=0)

If the CONT bit in the TX FIFO entry is set, PCS remains asserted between the transfers. Under certain conditions, SCK can continue with PCS asserted, but with no data being shifted out of SOUT, that is, SOUT pulled high. This can cause the slave to receive incorrect data. Those conditions include:

- Continuous SCK with CONT bit set, but no data in the TX FIFO.
- Continuous SCK with CONT bit set and entering Stopped state (refer to [Start and Stop of module transfers](#)).
- Continuous SCK with CONT bit set and entering Stop mode or Module Disable mode.

The following figure shows timing diagram for Continuous SCK format with Continuous Selection enabled.

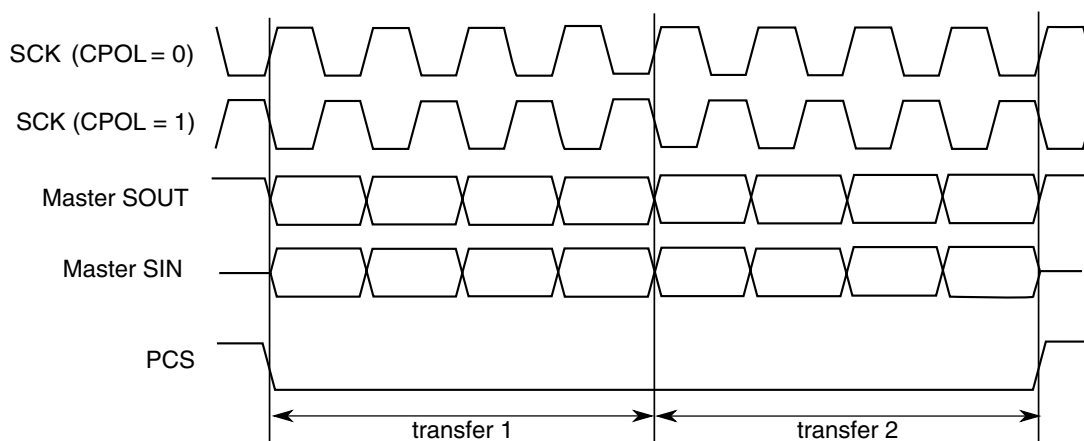


Figure 43-82. Continuous SCK timing diagram (CONT=1)

43.4.6 Slave Mode Operation Constraints

Slave mode logic shift register is buffered. This allows data streaming operation, when the module is permanently selected and data is shifted in with a constant rate.

The transmit data is transferred at second SCK clock edge of the each frame to the shift register if the \overline{SS} signal is asserted and any time when transmit data is ready and \overline{SS} signal is negated.

Received data is transferred to the receive buffer at last SCK edge of each frame, defined by frame size programmed to the CTAR0/1 register. Then the data from the buffer is transferred to the RXFIFO or DDR register.

If the \overline{SS} negates before that last SCK edge, the data from shift register is lost.

43.4.7 Interrupts/DMA requests

The module has several conditions that can generate only interrupt requests and two conditions that can generate interrupt or DMA requests. The following table lists these conditions.

Table 43-102. Interrupt and DMA request conditions

| Condition | Flag | Interrupt | DMA |
|--------------------|------|-----------|-----|
| End of Queue (EOQ) | EOQF | Yes | - |
| TX FIFO Fill | TFFF | Yes | Yes |
| Transfer Complete | TCF | Yes | - |
| TX FIFO Underflow | TFUF | Yes | - |

Table continues on the next page...

Table 43-102. Interrupt and DMA request conditions (continued)

| Condition | Flag | Interrupt | DMA |
|------------------|------|-----------|-----|
| RX FIFO Drain | RFDF | Yes | Yes |
| RX FIFO Overflow | RFOF | Yes | - |

Each condition has a flag bit in the module Status Register (SR) and a Request Enable bit in the DMA/Interrupt Request Select and Enable Register (RSER). Certain flags (as shown in above table) generate interrupt requests or DMA requests depending on configuration of RSER register.

The module also provides a global interrupt request line, which is asserted when any of individual interrupt requests lines is asserted.

43.4.7.1 End Of Queue interrupt request

The End Of Queue (EOQ) interrupt request indicates that the end of a transmit queue is reached. The module generates the interrupt request when EOQ interrupt requests are enabled (RSER[EOQF_RE]) and the EOQ bit in the executing SPI command is 1.

The module generates the interrupt request when the last bit of the SPI frame with EOQ bit set is transmitted.

43.4.7.2 Transmit FIFO Fill Interrupt or DMA Request

The Transmit FIFO Fill Request indicates that the TX FIFO is not full. The Transmit FIFO Fill Request is generated when the number of entries in the TX FIFO is less than the maximum number of possible entries, and the TFFF_RE bit in the RSER is set. The TFFF_DIRS bit in the RSER selects whether a DMA request or an interrupt request is generated.

NOTE

TFFF flag clears automatically when DMA is used to fill TX FIFO.

To clear TFFF when not using DMA, follow these steps for every PUSH performed using CPU to fill TX FIFO:

1. Wait until TFFF = 1.
2. Write data to PUSHR using CPU.
3. Clear TFFF by writing a 1 to its location. If TX FIFO is not full, this flag will not clear.

43.4.7.3 Transfer Complete Interrupt Request

The Transfer Complete Request indicates the end of the transfer of a serial frame. The Transfer Complete Request is generated at the end of each frame transfer when the TCF_RE bit is set in the RSER.

43.4.7.4 Transmit FIFO Underflow Interrupt Request

The Transmit FIFO Underflow Request indicates that an underflow condition in the TX FIFO has occurred. The transmit underflow condition is detected only for the module operating in Slave mode and SPI configuration . The TFUF bit is set when the TX FIFO of the module is empty, and a transfer is initiated from an external SPI master. If the TFUF bit is set while the TFUF_RE bit in the RSER is set, an interrupt request is generated.

43.4.7.5 Receive FIFO Drain Interrupt or DMA Request

The Receive FIFO Drain Request indicates that the RX FIFO is not empty. The Receive FIFO Drain Request is generated when the number of entries in the RX FIFO is not zero, and the RFDF_RE bit in the RSER is set. The RFDF_DIRS bit in the RSER selects whether a DMA request or an interrupt request is generated.

43.4.7.6 Receive FIFO Overflow Interrupt Request

The Receive FIFO Overflow Request indicates that an overflow condition in the RX FIFO has occurred. A Receive FIFO Overflow request is generated when RX FIFO and shift register are full and a transfer is initiated. The RFOF_RE bit in the RSER must be set for the interrupt request to be generated.

Depending on the state of the ROOE bit in the MCR, the data from the transfer that generated the overflow is either ignored or shifted in to the shift register. If the ROOE bit is set, the incoming data is shifted in to the shift register. If the ROOE bit is cleared, the incoming data is ignored.

43.4.8 Power saving features

The module supports following power-saving strategies:

- External Stop mode
- Module Disable mode – Clock gating of non-memory mapped logic

43.4.8.1 Stop mode (External Stop mode)

This module supports the Stop mode protocol. When a request is made to enter External Stop mode, the module acknowledges the request. If a serial transfer is in progress, then this module waits until it reaches the frame boundary before it is ready to have its clocks shut off. While the clocks are shut off, this module's memory-mapped logic is not accessible. This also puts the module in STOPPED state. The SR[TXRXS] bit is cleared to indicate STOPPED state. The states of the interrupt and DMA request signals cannot be changed while in External Stop mode.

43.4.8.2 Module Disable mode

Module Disable mode is a block-specific mode that the module can enter to save power. Host CPU can initiate the Module Disable mode by setting the MDIS bit in the MCR. The Module Disable mode can also be initiated by hardware.

When the MDIS bit is set, the module negates the Clock Enable signal at the next frame boundary. Once the Clock Enable signal is negated, it is said to have entered Module Disable Mode. This also puts the module in STOPPED state. The SR[TXRXS] bit is cleared to indicate STOPPED state. If implemented, the Clock Enable signal can stop the clock to the non-memory mapped logic. When Clock Enable is negated, the module is in a dormant state, but the memory mapped registers are still accessible. Certain read or write operations have a different effect when the module is in the Module Disable mode. Reading the RX FIFO Pop Register does not change the state of the RX FIFO. Similarly, writing to the PUSHR Register does not change the state of the TX FIFO. Clearing either of the FIFOs has no effect in the Module Disable mode. Changes to the DIS_TXF and DIS_RXF fields of the MCR have no effect in the Module Disable mode. In the Module Disable mode, all status bits and register flags in the module return the correct values when read, but writing to them has no effect. Writing to the TCR during Module Disable mode has no effect. Interrupt and DMA request signals cannot be cleared while in the Module Disable mode.

43.5 Initialization/application information

This section describes how to initialize the module.

43.5.1 How to manage queues

The queues are not part of the module, but it includes features in support of queue management. Queues are primarily supported in SPI configuration.

1. When module executes last command word from a queue, the EOQ bit in the command word is set to indicate it that this is the last entry in the queue.
2. At the end of the transfer, corresponding to the command word with EOQ set is sampled, the EOQ flag (EOQF) in the SR is set.
3. The setting of the EOQF flag disables serial transmission and reception of data, putting the module in the Stopped state. The TXRXS bit is cleared to indicate the Stopped state.
4. The DMA can continue to fill TX FIFO until it is full or step 5 occurs.
5. Disable DMA transfers by disabling the DMA enable request for the DMA channel assigned to TX FIFO and RX FIFO. This is done by clearing the corresponding DMA enable request bits in the DMA Controller.
6. Ensure all received data in RX FIFO has been transferred to memory receive queue by reading the RXCNT in SR or by checking RFDF in the SR after each read operation of the POPR.
7. Modify DMA descriptor of TX and RX channels for new queues
8. Flush TX FIFO by writing a 1 to the CLR_TXF bit in the MCR. Flush RX FIFO by writing a '1' to the CLR_RXF bit in the MCR.
9. Clear transfer count either by setting CTCNT bit in the command word of the first entry in the new queue or via CPU writing directly to SPI_TCNT field in the TCR.
10. Enable DMA channel by enabling the DMA enable request for the DMA channel assigned to the module TX FIFO, and RX FIFO by setting the corresponding DMA set enable request bit.
11. Enable serial transmission and serial reception of data by clearing the EOQF bit.

43.5.2 Switching Master and Slave mode

When changing modes in the module, follow the steps below to guarantee proper operation.

1. Halt it by setting MCR[HALT].
2. Clear the transmit and receive FIFOs by writing a 1 to the CLR_TXF and CLR_RXF bits in MCR.
3. Set the appropriate mode in MCR[MSTR] and enable it by clearing MCR[HALT].

43.5.3 Initializing Module in Master/Slave Modes

Once the appropriate mode in MCR[MSTR] is configured, the module is enabled by clearing MCR[HALT]. It should be ensured that module Slave is enabled before enabling it's Master. This ensures the Slave is ready to be communicated with, before Master initializes communication.

43.5.4 Baud rate settings

The following table shows the baud rate that is generated based on the combination of the baud rate prescaler PBR and the baud rate scaler BR in the CTARs. The values calculated assume a 100 MHz protocol frequency and the double baud rate DBR bit is cleared.

NOTE

The clock frequency mentioned above is given as an example in this chapter. See the clocking chapter for the frequency used to drive this module in the device.

Table 43-103. Baud rate values (bps)

| | | Baud rate divider prescaler values | | | |
|-------------------------|-------|------------------------------------|-------|-------|-------|
| | | 2 | 3 | 5 | 7 |
| Baud Rate Scaler Values | 2 | 25.0M | 16.7M | 10.0M | 7.14M |
| | 4 | 12.5M | 8.33M | 5.00M | 3.57M |
| | 6 | 8.33M | 5.56M | 3.33M | 2.38M |
| | 8 | 6.25M | 4.17M | 2.50M | 1.79M |
| | 16 | 3.12M | 2.08M | 1.25M | 893k |
| | 32 | 1.56M | 1.04M | 625k | 446k |
| | 64 | 781k | 521k | 312k | 223k |
| | 128 | 391k | 260k | 156k | 112k |
| | 256 | 195k | 130k | 78.1k | 55.8k |
| | 512 | 97.7k | 65.1k | 39.1k | 27.9k |
| | 1024 | 48.8k | 32.6k | 19.5k | 14.0k |
| | 2048 | 24.4k | 16.3k | 9.77k | 6.98k |
| | 4096 | 12.2k | 8.14k | 4.88k | 3.49k |
| | 8192 | 6.10k | 4.07k | 2.44k | 1.74k |
| | 16384 | 3.05k | 2.04k | 1.22k | 872 |
| | 32768 | 1.53k | 1.02k | 610 | 436 |

43.5.5 Delay settings

The following table shows the values for the Delay after Transfer (t_{DT}) and CS to SCK Delay (T_{CSC}) that can be generated based on the prescaler values and the scaler values set in the CTARs. The values calculated assume a 100 MHz protocol frequency.

NOTE

The clock frequency mentioned above is given as an example in this chapter. See the clocking chapter for the frequency used to drive this module in the device.

Table 43-104. Delay values

| | | Delay prescaler values | | | |
|---------------------|-------|------------------------|---------------|---------------|---------------|
| | | 1 | 3 | 5 | 7 |
| Delay scaler values | 2 | 20.0 ns | 60.0 ns | 100.0 ns | 140.0 ns |
| | 4 | 40.0 ns | 120.0 ns | 200.0 ns | 280.0 ns |
| | 8 | 80.0 ns | 240.0 ns | 400.0 ns | 560.0 ns |
| | 16 | 160.0 ns | 480.0 ns | 800.0 ns | 1.1 μ s |
| | 32 | 320.0 ns | 960.0 ns | 1.6 μ s | 2.2 μ s |
| | 64 | 640.0 ns | 1.9 μ s | 3.2 μ s | 4.5 μ s |
| | 128 | 1.3 μ s | 3.8 μ s | 6.4 μ s | 9.0 μ s |
| | 256 | 2.6 μ s | 7.7 μ s | 12.8 μ s | 17.9 μ s |
| | 512 | 5.1 μ s | 15.4 μ s | 25.6 μ s | 35.8 μ s |
| | 1024 | 10.2 μ s | 30.7 μ s | 51.2 μ s | 71.7 μ s |
| | 2048 | 20.5 μ s | 61.4 μ s | 102.4 μ s | 143.4 μ s |
| | 4096 | 41.0 μ s | 122.9 μ s | 204.8 μ s | 286.7 μ s |
| | 8192 | 81.9 μ s | 245.8 μ s | 409.6 μ s | 573.4 μ s |
| | 16384 | 163.8 μ s | 491.5 μ s | 819.2 μ s | 1.1 ms |
| | 32768 | 327.7 μ s | 983.0 μ s | 1.6 ms | 2.3 ms |
| | 65536 | 655.4 μ s | 2.0 ms | 3.3 ms | 4.6 ms |

43.5.6 Calculation of FIFO pointer addresses

Complete visibility of the FIFO contents is available through the FIFO registers, and valid entries can be identified through a memory-mapped pointer and counter for each FIFO. The pointer to the first-in entry in each FIFO is memory mapped. For the TX FIFO the first-in pointer is the Transmit Next Pointer (TXNXTPTR). For the RX FIFO the first-in pointer is the Pop Next Pointer (POPNXTPTR). The following figure illustrates the concept of first-in and last-in FIFO entries along with the FIFO Counter. The TX FIFO is chosen for the illustration, but the concepts carry over. See [Transmit First In First Out \(TX FIFO\) buffering mechanism](#) and [Receive First In First Out \(RX FIFO\) buffering mechanism](#) for details on the FIFO operation.

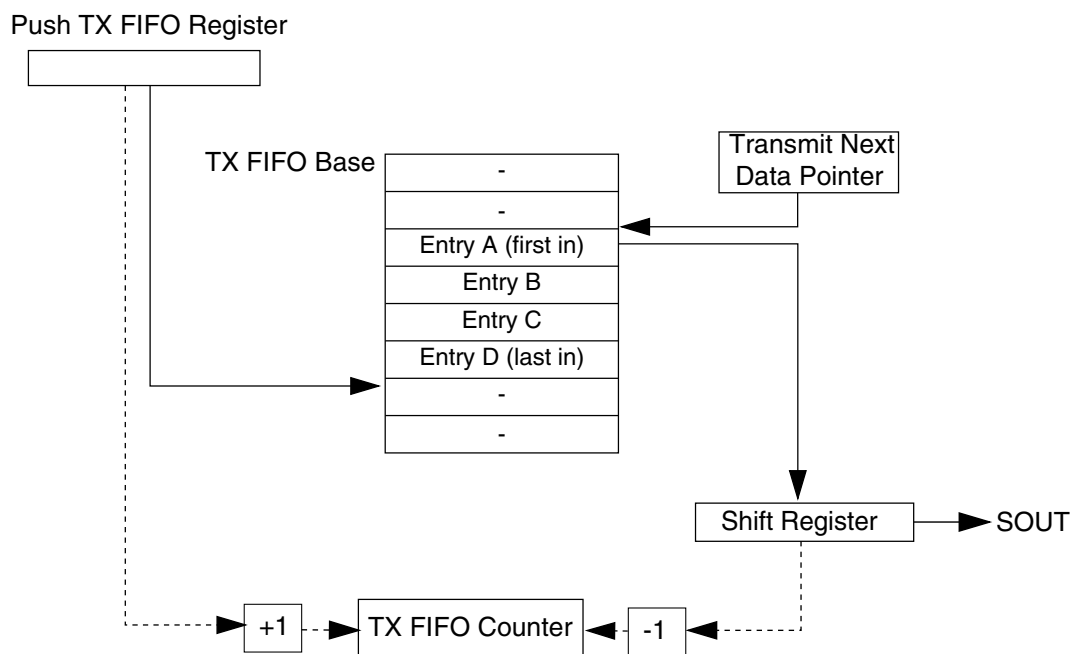


Figure 43-83. TX FIFO pointers and counter

43.5.6.1 Address Calculation for the First-in Entry and Last-in Entry in the TX FIFO

The memory address of the first-in entry in the TX FIFO is computed by the following equation:

$$\text{First-in EntryAddress} = \text{TXFIFOBase} + (4 \times \text{TXNXTPTR})$$

The memory address of the last-in entry in the TX FIFO is computed by the following equation:

$$\text{Last-inEntryaddress} = \text{TXFIFOBase} + 4 \times (\text{TXCTR} + \text{TXNXTPTR} - 1) \bmod (\text{TXFIFOdepth})$$

TX FIFO Base - Base address of TX FIFO

TXCTR - TX FIFO Counter

TXNXTPTR - Transmit Next Pointer

TX FIFO Depth - Transmit FIFO depth, implementation specific

43.5.6.2 Address Calculation for the First-in Entry and Last-in Entry in the RX FIFO

The memory address of the first-in entry in the RX FIFO is computed by the following equation:

$$\text{First-in EntryAddress} = \text{RX FIFOBase} + (4 \times \text{POPNextPTR})$$

The memory address of the last-in entry in the RX FIFO is computed by the following equation:

$$\text{Last-inEntryaddress} = \text{RX FIFO Base} + 4 \times (\text{RXCTR} + \text{POPNextPTR} - 1) \bmod (\text{RXFIFOdepth})$$

RX FIFO Base - Base address of RX FIFO

RXCTR - RX FIFO counter

POPNextPTR - Pop Next Pointer

RX FIFO Depth - Receive FIFO depth, implementation specific



Chapter 44

Inter-Integrated Circuit (I2C)

44.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The inter-integrated circuit (I²C, I2C, or IIC) module provides a method of communication between a number of devices.

The interface is designed to operate up to 100 kbit/s with maximum bus loading and timing. The I2C device is capable of operating at higher baud rates, up to a maximum of clock/20, with reduced bus loading. The maximum communication length and the number of devices that can be connected are limited by a maximum bus capacitance of 400 pF. The I2C module also complies with the *System Management Bus (SMBus) Specification, version 2*.

44.1.1 Features

The I2C module has the following features:

- Compatible with *The I²C-Bus Specification*
- Multimaster operation
- Software programmable for one of 64 different serial clock frequencies
- Software-selectable acknowledge bit
- Interrupt-driven byte-by-byte data transfer
- Arbitration-lost interrupt with automatic mode switching from master to slave
- Calling address identification interrupt
- START and STOP signal generation and detection
- Repeated START signal generation and detection
- Acknowledge bit generation and detection

- Bus busy detection
- General call recognition
- 10-bit address extension
- Support for *System Management Bus (SMBus) Specification, version 2*
- Programmable input glitch filter
- Low power mode wakeup on slave address match
- Range slave address support
- DMA support

44.1.2 Modes of operation

The I2C module's operation in various low power modes is as follows:

- Run mode: This is the basic mode of operation. To conserve power in this mode, disable the module.
- Wait mode: The module continues to operate when the core is in Wait mode and can provide a wakeup interrupt.
- Stop mode: The module is inactive in Stop mode for reduced power consumption, except that address matching is enabled in Stop mode. The STOP instruction does not affect the I2C module's register states.

44.1.3 Block diagram

The following figure is a functional block diagram of the I2C module.

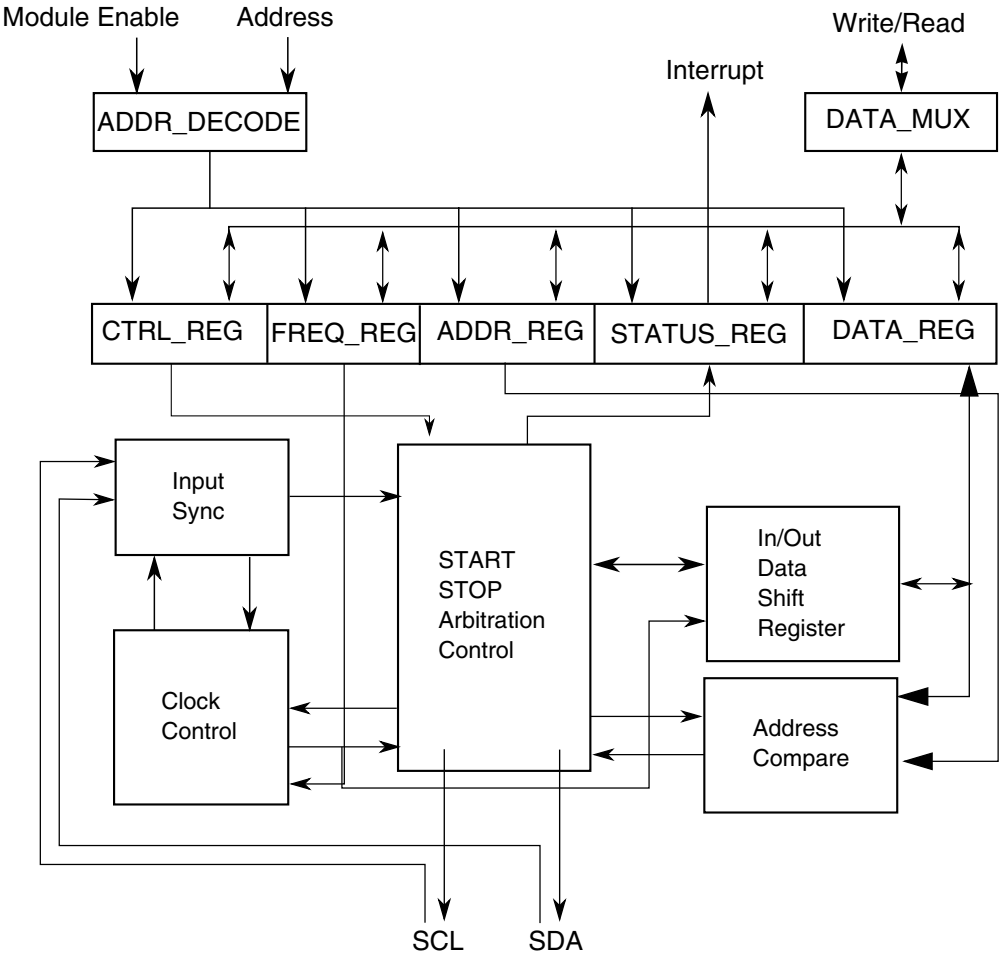


Figure 44-1. I2C Functional block diagram

44.2 I²C signal descriptions

The signal properties of I²C are shown in the table found here.

Table 44-1. I²C signal descriptions

| Signal | Description | I/O |
|--------|---|-----|
| SCL | Bidirectional serial clock line of the I ² C system. | I/O |
| SDA | Bidirectional serial data line of the I ² C system. | I/O |

44.3 Memory map/register definition

This section describes in detail all I2C registers accessible to the end user.

I2C memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|------------------------------|
| 4006_6000 | I2C Address Register 1 (I2C0_A1) | 8 | R/W | 00h | 44.3.1/1039 |
| 4006_6001 | I2C Frequency Divider register (I2C0_F) | 8 | R/W | 00h | 44.3.2/1039 |
| 4006_6002 | I2C Control Register 1 (I2C0_C1) | 8 | R/W | 00h | 44.3.3/1040 |
| 4006_6003 | I2C Status register (I2C0_S) | 8 | R/W | 80h | 44.3.4/1042 |
| 4006_6004 | I2C Data I/O register (I2C0_D) | 8 | R/W | 00h | 44.3.5/1044 |
| 4006_6005 | I2C Control Register 2 (I2C0_C2) | 8 | R/W | 00h | 44.3.6/1044 |
| 4006_6006 | I2C Programmable Input Glitch Filter Register (I2C0_FLT) | 8 | R/W | 00h | 44.3.7/1045 |
| 4006_6007 | I2C Range Address register (I2C0_RA) | 8 | R/W | 00h | 44.3.8/1046 |
| 4006_6008 | I2C SMBus Control and Status register (I2C0_SMB) | 8 | R/W | 00h | 44.3.9/1046 |
| 4006_6009 | I2C Address Register 2 (I2C0_A2) | 8 | R/W | C2h | 44.3.10/1048 |
| 4006_600A | I2C SCL Low Timeout Register High (I2C0_SLTH) | 8 | R/W | 00h | 44.3.11/1048 |
| 4006_600B | I2C SCL Low Timeout Register Low (I2C0_SLTL) | 8 | R/W | 00h | 44.3.12/1049 |
| 4006_7000 | I2C Address Register 1 (I2C1_A1) | 8 | R/W | 00h | 44.3.1/1039 |
| 4006_7001 | I2C Frequency Divider register (I2C1_F) | 8 | R/W | 00h | 44.3.2/1039 |
| 4006_7002 | I2C Control Register 1 (I2C1_C1) | 8 | R/W | 00h | 44.3.3/1040 |
| 4006_7003 | I2C Status register (I2C1_S) | 8 | R/W | 80h | 44.3.4/1042 |
| 4006_7004 | I2C Data I/O register (I2C1_D) | 8 | R/W | 00h | 44.3.5/1044 |
| 4006_7005 | I2C Control Register 2 (I2C1_C2) | 8 | R/W | 00h | 44.3.6/1044 |
| 4006_7006 | I2C Programmable Input Glitch Filter Register (I2C1_FLT) | 8 | R/W | 00h | 44.3.7/1045 |
| 4006_7007 | I2C Range Address register (I2C1_RA) | 8 | R/W | 00h | 44.3.8/1046 |
| 4006_7008 | I2C SMBus Control and Status register (I2C1_SMB) | 8 | R/W | 00h | 44.3.9/1046 |
| 4006_7009 | I2C Address Register 2 (I2C1_A2) | 8 | R/W | C2h | 44.3.10/1048 |
| 4006_700A | I2C SCL Low Timeout Register High (I2C1_SLTH) | 8 | R/W | 00h | 44.3.11/1048 |
| 4006_700B | I2C SCL Low Timeout Register Low (I2C1_SLTL) | 8 | R/W | 00h | 44.3.12/1049 |

44.3.1 I2C Address Register 1 (I2Cx_A1)

This register contains the slave address to be used by the I2C module.

Address: Base address + 0h offset

| | | | | | | | | |
|-------|---------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | AD[7:1] | | | | | | | 0 |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Cx_A1 field descriptions

| Field | Description |
|----------------|---|
| 7–1 AD[7:1] | Address Contains the primary slave address used by the I2C module when it is addressed as a slave. This field is used in the 7-bit address scheme and the lower seven bits in the 10-bit address scheme. |
| 0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

44.3.2 I2C Frequency Divider register (I2Cx_F)

Address: Base address + 1h offset

| | | | | | | | | |
|-------|------|---|-----|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | MULT | | ICR | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Cx_F field descriptions

| Field | Description |
|-------------|---|
| 7–6 MULT | Multiplier Factor Defines the multiplier factor (mul). This factor is used along with the SCL divider to generate the I2C baud rate. 00 mul = 1 01 mul = 2 10 mul = 4 11 Reserved |
| 5–0 ICR | ClockRate Prescales the I2C module clock for bit rate selection. This field and the MULT field determine the I2C baud rate, the SDA hold time, the SCL start hold time, and the SCL stop hold time. For a list of values corresponding to each ICR setting, see I2C divider and hold values . The SCL divider multiplied by multiplier factor (mul) determines the I2C baud rate. $\text{I2C baud rate} = \text{I2C module clock speed (Hz)} / (\text{mul} \times \text{SCL divider})$ |

Table continues on the next page...

I2Cx_F field descriptions (continued)

| Field | Description | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|---|-------|-----------|-----------------|--|--|-----|-----------|----------|----|-----|-------|-------|-------|----|-----|-------|-------|-------|----|-----|-------|-------|-------|----|-----|-------|-------|-------|----|-----|-------|-------|-------|
| | <p>The SDA hold time is the delay from the falling edge of SCL (I2C clock) to the changing of SDA (I2C data).</p> <p>$\text{SDA hold time} = \text{I2C module clock period (s)} \times \text{mul} \times \text{SDA hold value}$</p> <p>The SCL start hold time is the delay from the falling edge of SDA (I2C data) while SCL is high (start condition) to the falling edge of SCL (I2C clock).</p> <p>$\text{SCL start hold time} = \text{I2C module clock period (s)} \times \text{mul} \times \text{SCL start hold value}$</p> <p>The SCL stop hold time is the delay from the rising edge of SCL (I2C clock) to the rising edge of SDA (I2C data) while SCL is high (stop condition).</p> <p>$\text{SCL stop hold time} = \text{I2C module clock period (s)} \times \text{mul} \times \text{SCL stop hold value}$</p> <p>For example, if the I2C module clock speed is 8 MHz, the following table shows the possible hold time values with different ICR and MULT selections to achieve an I²C baud rate of 100 kbit/s.</p> <table><tr><th rowspan="2">MULT</th><th rowspan="2">ICR</th><th colspan="3">Hold times (μs)</th></tr><tr><th>SDA</th><th>SCL Start</th><th>SCL Stop</th></tr><tr><td>2h</td><td>00h</td><td>3.500</td><td>3.000</td><td>5.500</td></tr><tr><td>1h</td><td>07h</td><td>2.500</td><td>4.000</td><td>5.250</td></tr><tr><td>1h</td><td>0Bh</td><td>2.250</td><td>4.000</td><td>5.250</td></tr><tr><td>0h</td><td>14h</td><td>2.125</td><td>4.250</td><td>5.125</td></tr><tr><td>0h</td><td>18h</td><td>1.125</td><td>4.750</td><td>5.125</td></tr></table> | MULT | ICR | Hold times (μs) | | | SDA | SCL Start | SCL Stop | 2h | 00h | 3.500 | 3.000 | 5.500 | 1h | 07h | 2.500 | 4.000 | 5.250 | 1h | 0Bh | 2.250 | 4.000 | 5.250 | 0h | 14h | 2.125 | 4.250 | 5.125 | 0h | 18h | 1.125 | 4.750 | 5.125 |
| MULT | ICR | | | Hold times (μs) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | SDA | SCL Start | SCL Stop | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2h | 00h | 3.500 | 3.000 | 5.500 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1h | 07h | 2.500 | 4.000 | 5.250 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1h | 0Bh | 2.250 | 4.000 | 5.250 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0h | 14h | 2.125 | 4.250 | 5.125 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0h | 18h | 1.125 | 4.750 | 5.125 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

44.3.3 I2C Control Register 1 (I2Cx_C1)

Address: Base address + 2h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|-------|-----|----|------|------|------|-------|
| Read | IICEN | IICIE | MST | TX | TXAK | 0 | WUEN | DMAEN |
| Write | | | | | | RSTA | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Cx_C1 field descriptions

| Field | Description |
|------------|--|
| 7 IICEN | <p>I2C Enable</p> <p>Enables I2C module operation.</p> <p>0 Disabled 1 Enabled</p> |
| 6 IICIE | <p>I2C Interrupt Enable</p> <p>Enables I2C interrupt requests.</p> |

Table continues on the next page...

I2Cx_C1 field descriptions (continued)

| Field | Description |
|------------|--|
| | 0 Disabled 1 Enabled |
| 5 MST | Master Mode Select When MST is changed from 0 to 1, a START signal is generated on the bus and master mode is selected. When this bit changes from 1 to 0, a STOP signal is generated and the mode of operation changes from master to slave. 0 Slave mode 1 Master mode |
| 4 TX | Transmit Mode Select Selects the direction of master and slave transfers. In master mode this bit must be set according to the type of transfer required. Therefore, for address cycles, this bit is always set. When addressed as a slave this bit must be set by software according to the SRW bit in the status register. 0 Receive 1 Transmit |
| 3 TXAK | Transmit Acknowledge Enable Specifies the value driven onto the SDA during data acknowledge cycles for both master and slave receivers. The value of SMB[FAK] affects NACK/ACK generation. NOTE: SCL is held low until TXAK is written. 0 An acknowledge signal is sent to the bus on the following receiving byte (if FACK is cleared) or the current receiving byte (if FACK is set). 1 No acknowledge signal is sent to the bus on the following receiving data byte (if FACK is cleared) or the current receiving data byte (if FACK is set). |
| 2 RSTA | Repeat START Writing 1 to this bit generates a repeated START condition provided it is the current master. This bit will always be read as 0. Attempting a repeat at the wrong time results in loss of arbitration. |
| 1 WUEN | Wakeup Enable The I2C module can wake the MCU from low power mode with no peripheral bus running when slave address matching occurs. 0 Normal operation. No interrupt generated when address matching in low power mode. 1 Enables the wakeup function in low power mode. |
| 0 DMAEN | DMA Enable Enables or disables the DMA function. 0 All DMA signalling disabled. 1 DMA transfer is enabled. While SMB[FAK] = 0, the following conditions trigger the DMA request: <ul style="list-style-type: none"> a data byte is received, and either address or data is transmitted. (ACK/NACK is automatic) the first byte received matches the A1 register or is a general call address. |

Table continues on the next page...

I2Cx_C1 field descriptions (continued)

| Field | Description |
|-------|---|
| | <p>If any address matching occurs, S[IAAS] and S[TCF] are set. If the direction of transfer is known from master to slave, then it is not required to check S[SRW]. With this assumption, DMA can also be used in this case. In other cases, if the master reads data from the slave, then it is required to rewrite the C1 register operation. With this assumption, DMA cannot be used.</p> <p>When FACK = 1, an address or a data byte is transmitted.</p> |

44.3.4 I2C Status register (I2Cx_S)

Address: Base address + 3h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-----|------|------|------|-----|-----|-------|------|
| Read | TCF | IAAS | BUSY | ARBL | RAM | SRW | IICIF | RXAK |
| Write | | | | w1c | | | w1c | |
| Reset | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Cx_S field descriptions

| Field | Description |
|-----------|---|
| 7 TCF | <p>Transfer Complete Flag</p> <p>Acknowledges a byte transfer; TCF is set on the completion of a byte transfer. This bit is valid only during or immediately following a transfer to or from the I2C module. TCF is cleared by reading the I2C data register in receive mode or by writing to the I2C data register in transmit mode.</p> <p>0 Transfer in progress 1 Transfer complete</p> |
| 6 IAAS | <p>Addressed As A Slave</p> <p>This bit is set by one of the following conditions:</p> <ul style="list-style-type: none"> The calling address matches the programmed primary slave address in the A1 register, or matches the range address in the RA register (which must be set to a nonzero value and under the condition I2C_C2[RMEN] = 1). C2[GCAEN] is set and a general call is received. SMB[SIICAEN] is set and the calling address matches the second programmed slave address. ALERTEN is set and an SMBus alert response address is received RMEN is set and an address is received that is within the range between the values of the A1 and RA registers. <p>IAAS sets before the ACK bit. The CPU must check the SRW bit and set TX/RX accordingly. Writing the C1 register with any value clears this bit.</p> <p>0 Not addressed 1 Addressed as a slave</p> |
| 5 BUSY | <p>Bus Busy</p> <p>Indicates the status of the bus regardless of slave or master mode. This bit is set when a START signal is detected and cleared when a STOP signal is detected.</p> |

Table continues on the next page...

I2Cx_S field descriptions (continued)

| Field | Description |
|------------|---|
| | 0 Bus is idle 1 Bus is busy |
| 4 ARBL | <p>Arbitration Lost</p> <p>This bit is set by hardware when the arbitration procedure is lost. The ARBL bit must be cleared by software, by writing 1 to it.</p> 0 Standard bus operation. 1 Loss of arbitration. |
| 3 RAM | <p>Range Address Match</p> <p>This bit is set to 1 by any of the following conditions, if I2C_C2[RMEN] = 1:</p> <ul style="list-style-type: none"> Any nonzero calling address is received that matches the address in the RA register. The calling address is within the range of values of the A1 and RA registers. <p>NOTE: For the RAM bit to be set to 1 correctly, C1[IICIE] must be set to 1.</p> <p>Writing the C1 register with any value clears this bit to 0.</p> 0 Not addressed 1 Addressed as a slave |
| 2 SRW | <p>Slave Read/Write</p> <p>When addressed as a slave, SRW indicates the value of the R/W command bit of the calling address sent to the master.</p> 0 Slave receive, master writing to slave 1 Slave transmit, master reading from slave |
| 1 IICIF | <p>Interrupt Flag</p> <p>This bit sets when an interrupt is pending. This bit must be cleared by software by writing 1 to it, such as in the interrupt routine. One of the following events can set this bit:</p> <ul style="list-style-type: none"> One byte transfer, including ACK/NACK bit, completes if FACK is 0. An ACK or NACK is sent on the bus by writing 0 or 1 to TXAK after this bit is set in receive mode. One byte transfer, excluding ACK/NACK bit, completes if FACK is 1. Match of slave address to calling address including primary slave address, range slave address, alert response address, second slave address, or general call address. Arbitration lost In SMBus mode, any timeouts except SCL and SDA high timeouts 0 No interrupt pending 1 Interrupt pending |
| 0 RXAK | <p>Receive Acknowledge</p> 0 Acknowledge signal was received after the completion of one byte of data transmission on the bus 1 No acknowledge signal detected |

44.3.5 I2C Data I/O register (I2Cx_D)

Address: Base address + 4h offset

| | | | | | | | | |
|-------|------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | DATA | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Cx_D field descriptions

| Field | Description |
|-------------|---|
| 7-0 DATA | <p>Data</p> <p>In master transmit mode, when data is written to this register, a data transfer is initiated. The most significant bit is sent first. In master receive mode, reading this register initiates receiving of the next byte of data.</p> <p>NOTE: When making the transition out of master receive mode, switch the I2C mode before reading the Data register to prevent an inadvertent initiation of a master receive data transfer.</p> <p>In slave mode, the same functions are available after an address match occurs.</p> <p>The C1[TX] bit must correctly reflect the desired direction of transfer in master and slave modes for the transmission to begin. For example, if the I2C module is configured for master transmit but a master receive is desired, reading the Data register does not initiate the receive.</p> <p>Reading the Data register returns the last byte received while the I2C module is configured in master receive or slave receive mode. The Data register does not reflect every byte that is transmitted on the I2C bus, and neither can software verify that a byte has been written to the Data register correctly by reading it back.</p> <p>In master transmit mode, the first byte of data written to the Data register following assertion of MST (start bit) or assertion of RSTA (repeated start bit) is used for the address transfer and must consist of the calling address (in bits 7-1) concatenated with the required R/W bit (in position bit 0).</p> |

44.3.6 I2C Control Register 2 (I2Cx_C2)

Address: Base address + 5h offset

| | | | | | | | | |
|-------|-------|-------|------|------|------|----------|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | GCAEN | ADEXT | HDRS | SBRC | RMEN | AD[10:8] | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Cx_C2 field descriptions

| Field | Description |
|------------|--|
| 7 GCAEN | <p>General Call Address Enable</p> <p>Enables general call address.</p> <p>0 Disabled</p> <p>1 Enabled</p> |

Table continues on the next page...

I2Cx_C2 field descriptions (continued)

| Field | Description |
|-----------------|--|
| 6 ADEXT | Address Extension Controls the number of bits used for the slave address. 0 7-bit address scheme 1 10-bit address scheme |
| 5 HDSR | High Drive Select Controls the drive capability of the I2C pads. 0 Normal drive mode 1 High drive mode |
| 4 SBRC | Slave Baud Rate Control Enables independent slave mode baud rate at maximum frequency, which forces clock stretching on SCL in very fast I2C modes. To a slave, an example of a "very fast" mode is when the master transfers at 40 kbit/s but the slave can capture the master's data at only 10 kbit/s. 0 The slave baud rate follows the master baud rate and clock stretching may occur 1 Slave baud rate is independent of the master baud rate |
| 3 RMEN | Range Address Matching Enable This bit controls the slave address matching for addresses between the values of the A1 and RA registers. When this bit is set, a slave address matching occurs for any address greater than the value of the A1 register and less than or equal to the value of the RA register. 0 Range mode disabled. No address matching occurs for an address within the range of values of the A1 and RA registers. 1 Range mode enabled. Address matching occurs when a slave receives an address within the range of values of the A1 and RA registers. |
| 2-0 AD[10:8] | Slave Address Contains the upper three bits of the slave address in the 10-bit address scheme. This field is valid only while the ADEXT bit is set. |

44.3.7 I2C Programmable Input Glitch Filter Register (I2Cx_FLT)

Address: Base address + 6h offset

| | | | | | | | | |
|-------|----------|---|---|---|---|-----|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | Reserved | 0 | | | | FLT | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Cx_FLT field descriptions

| Field | Description |
|---------------|--|
| 7 Reserved | This field is reserved. Writing this bit has no effect. |

Table continues on the next page...

I2Cx_FLT field descriptions (continued)

| Field | Description |
|-----------------|--|
| 6–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4–0 FLT | I2C Programmable Filter Factor Controls the width of the glitch, in terms of I2C module clock cycles, that the filter must absorb. For any glitch whose size is less than or equal to this width setting, the filter does not allow the glitch to pass. 00h No filter/bypass 01-1Fh Filter glitches up to width of n I2C module clock cycles, where $n=1-31d$ |

44.3.8 I2C Range Address register (I2Cx_RA)

Address: Base address + 7h offset

| | | | | | | | | |
|-------|-----|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | RAD | | | | | | | 0 |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Cx_RA field descriptions

| Field | Description |
|---------------|---|
| 7–1 RAD | Range Slave Address This field contains the slave address to be used by the I2C module. The field is used in the 7-bit address scheme. If I2C_C2[RMEN] is set to 1, any nonzero value write enables this register. This register value can be considered as a maximum boundary in the range matching mode. |
| 0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

44.3.9 I2C SMBus Control and Status register (I2Cx_SMB)

NOTE

When the SCL and SDA signals are held high for a length of time greater than the high timeout period, the SHTF1 flag sets. Before reaching this threshold, while the system is detecting how long these signals are being held high, a master assumes that the bus is free. However, the SHTF1 bit is set to 1 in the bus transmission process with the idle bus state.

NOTE

When the TCKSEL bit is set, there is no need to monitor the SHTF1 bit because the bus speed is too high to match the protocol of SMBus.

Address: Base address + 8h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|---------|---------|--------|------|-------|-------|---------|
| Read | FAACK | ALERTEN | SIICAEN | TCKSEL | SLTF | SHTF1 | SHTF2 | SHTF2IE |
| Write | | | | | w1c | | w1c | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Cx_SMB field descriptions

| Field | Description |
|--------------|--|
| 7 FAACK | <p>Fast NACK/ACK Enable</p> <p>For SMBus packet error checking, the CPU must be able to issue an ACK or NACK according to the result of receiving data byte.</p> <p>0 An ACK or NACK is sent on the following receiving data byte 1 Writing 0 to TXAK after receiving a data byte generates an ACK. Writing 1 to TXAK after receiving a data byte generates a NACK.</p> |
| 6 ALERTEN | <p>SMBus Alert Response Address Enable</p> <p>Enables or disables SMBus alert response address matching.</p> <p>NOTE: After the host responds to a device that used the alert response address, you must use software to put the device's address on the bus. The alert protocol is described in the SMBus specification.</p> <p>0 SMBus alert response address matching is disabled 1 SMBus alert response address matching is enabled</p> |
| 5 SIICAEN | <p>Second I2C Address Enable</p> <p>Enables or disables SMBus device default address.</p> <p>0 I2C address register 2 matching is disabled 1 I2C address register 2 matching is enabled</p> |
| 4 TCKSEL | <p>Timeout Counter Clock Select</p> <p>Selects the clock source of the timeout counter.</p> <p>0 Timeout counter counts at the frequency of the I2C module clock / 64 1 Timeout counter counts at the frequency of the I2C module clock</p> |
| 3 SLTF | <p>SCL Low Timeout Flag</p> <p>This bit is set when the SLT register (consisting of the SLTH and SLTL registers) is loaded with a non-zero value (LoValue) and an SCL low timeout occurs. Software clears this bit by writing a logic 1 to it.</p> <p>NOTE: The low timeout function is disabled when the SLT register's value is 0.</p> <p>0 No low timeout occurs 1 Low timeout occurs</p> |
| 2 SHTF1 | <p>SCL High Timeout Flag 1</p> <p>This read-only bit sets when SCL and SDA are held high more than clock × LoValue / 512, which indicates the bus is free. This bit is cleared automatically.</p> <p>0 No SCL high and SDA high timeout occurs 1 SCL high and SDA high timeout occurs</p> |

Table continues on the next page...

I2Cx_SMB field descriptions (continued)

| Field | Description |
|--------------|---|
| 1 SHTF2 | <p>SCL High Timeout Flag 2</p> <p>This bit sets when SCL is held high and SDA is held low more than $\text{clock} \times \text{LoValue} / 512$. Software clears this bit by writing 1 to it.</p> <p>0 No SCL high and SDA low timeout occurs 1 SCL high and SDA low timeout occurs</p> |
| 0 SHTF2IE | <p>SHTF2 Interrupt Enable</p> <p>Enables SCL high and SDA low timeout interrupt.</p> <p>0 SHTF2 interrupt is disabled 1 SHTF2 interrupt is enabled</p> |

44.3.10 I2C Address Register 2 (I2Cx_A2)

Address: Base address + 9h offset

| | | | | | | | | |
|-------|-----|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | SAD | | | | | | | 0 |
| Write | | | | | | | | |
| Reset | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |

I2Cx_A2 field descriptions

| Field | Description |
|---------------|--|
| 7–1 SAD | <p>SMBus Address</p> <p>Contains the slave address used by the SMBus. This field is used on the device default address or other related addresses.</p> |
| 0 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |

44.3.11 I2C SCL Low Timeout Register High (I2Cx_SLTH)

Address: Base address + Ah offset

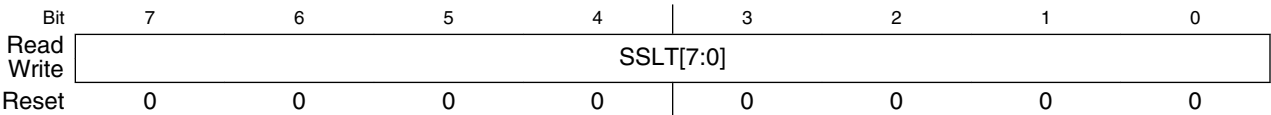
| | | | | | | | | |
|-------|------------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | SSLT[15:8] | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Cx_SLTH field descriptions

| Field | Description |
|-------------------|--|
| 7–0 SSLT[15:8] | <p>SSLT[15:8]</p> <p>Most significant byte of SCL low timeout value that determines the timeout period of SCL low.</p> |

44.3.12 I2C SCL Low Timeout Register Low (I2Cx_SLTL)

Address: Base address + Bh offset



I2Cx_SLTL field descriptions

| Field | Description |
|------------------|---|
| 7-0 SSLT[7:0] | SSLT[7:0] Least significant byte of SCL low timeout value that determines the timeout period of SCL low. |

44.4 Functional description

This section provides a comprehensive functional description of the I2C module.

44.4.1 I2C protocol

The I2C bus system uses a serial data line (SDA) and a serial clock line (SCL) for data transfers.

All devices connected to it must have open drain or open collector outputs. A logic AND function is exercised on both lines with external pull-up resistors. The value of these resistors depends on the system.

Normally, a standard instance of communication is composed of four parts:

1. START signal
2. Slave address transmission
3. Data transfer
4. STOP signal

The STOP signal should not be confused with the CPU STOP instruction. The following figure illustrates I2C bus system communication.

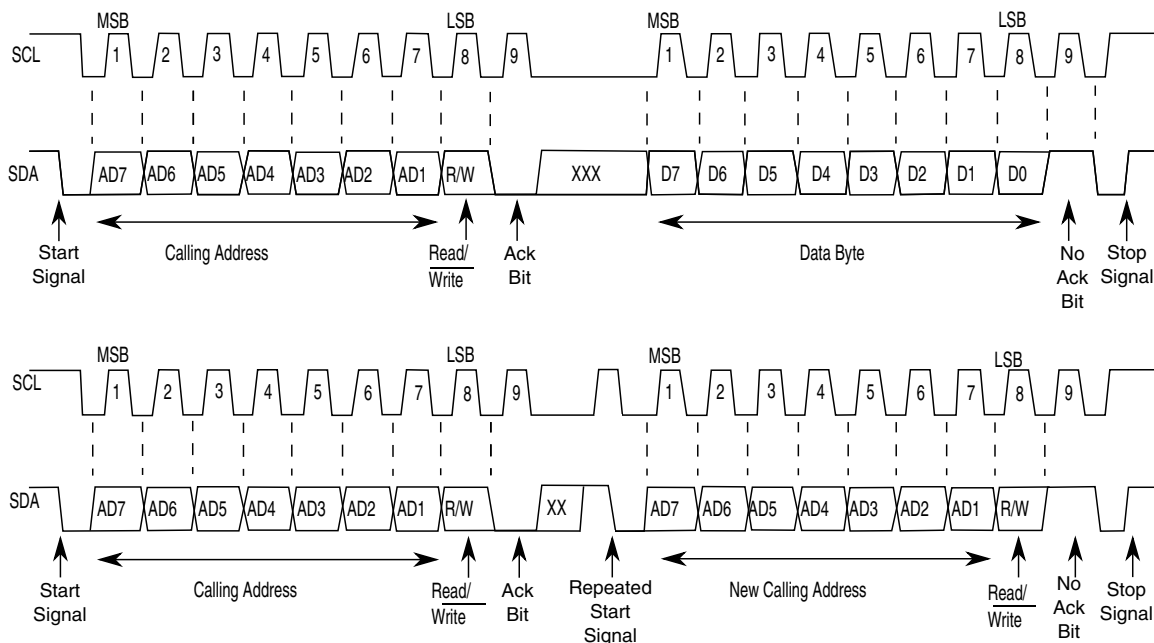


Figure 44-38. I2C bus transmission signals

44.4.1.1 START signal

The bus is free when no master device is engaging the bus (both SCL and SDA are high). When the bus is free, a master may initiate communication by sending a START signal. A START signal is defined as a high-to-low transition of SDA while SCL is high. This signal denotes the beginning of a new data transfer—each data transfer might contain several bytes of data—and brings all slaves out of their idle states.

44.4.1.2 Slave address transmission

Immediately after the START signal, the first byte of a data transfer is the slave address transmitted by the master. This address is a 7-bit calling address followed by an R/\overline{W} bit. The R/\overline{W} bit tells the slave the desired direction of data transfer.

- 1 = Read transfer: The slave transmits data to the master
- 0 = Write transfer: The master transmits data to the slave

Only the slave with a calling address that matches the one transmitted by the master responds by sending an acknowledge bit. The slave sends the acknowledge bit by pulling SDA low at the ninth clock.

No two slaves in the system can have the same address. If the I2C module is the master, it must not transmit an address that is equal to its own slave address. The I2C module cannot be master and slave at the same time. However, if arbitration is lost during an address cycle, the I2C module reverts to slave mode and operates correctly even if it is being addressed by another master.

44.4.1.3 Data transfers

When successful slave addressing is achieved, data transfer can proceed on a byte-by-byte basis in the direction specified by the $\overline{R/W}$ bit sent by the calling master.

All transfers that follow an address cycle are referred to as data transfers, even if they carry subaddress information for the slave device.

Each data byte is 8 bits long. Data may be changed only while SCL is low. Data must be held stable while SCL is high. There is one clock pulse on SCL for each data bit, and the MSB is transferred first. Each data byte is followed by a ninth (acknowledge) bit, which is signaled from the receiving device by pulling SDA low at the ninth clock. In summary, one complete data transfer needs nine clock pulses.

If the slave receiver does not acknowledge the master in the ninth bit, the slave must leave SDA high. The master interprets the failed acknowledgement as an unsuccessful data transfer.

If the master receiver does not acknowledge the slave transmitter after a data byte transmission, the slave interprets it as an end to data transfer and releases the SDA line.

In the case of a failed acknowledgement by either the slave or master, the data transfer is aborted and the master does one of two things:

- Relinquishes the bus by generating a STOP signal.
- Commences a new call by generating a repeated START signal.

44.4.1.4 STOP signal

The master can terminate the communication by generating a STOP signal to free the bus. A STOP signal is defined as a low-to-high transition of SDA while SCL is asserted.

The master can generate a STOP signal even if the slave has generated an acknowledgement, at which point the slave must release the bus.

44.4.1.5 Repeated START signal

The master may generate a START signal followed by a calling command without generating a STOP signal first. This action is called a repeated START. The master uses a repeated START to communicate with another slave or with the same slave in a different mode (transmit/receive mode) without releasing the bus.

44.4.1.6 Arbitration procedure

The I2C bus is a true multimaster bus that allows more than one master to be connected on it.

If two or more masters try to control the bus at the same time, a clock synchronization procedure determines the bus clock. The bus clock's low period is equal to the longest clock low period, and the high period is equal to the shortest one among the masters.

The relative priority of the contending masters is determined by a data arbitration procedure. A bus master loses arbitration if it transmits logic level 1 while another master transmits logic level 0. The losing masters immediately switch to slave receive mode and stop driving SDA output. In this case, the transition from master to slave mode does not generate a STOP condition. Meanwhile, hardware sets a status bit to indicate the loss of arbitration.

44.4.1.7 Clock synchronization

Because wire AND logic is performed on SCL, a high-to-low transition on SCL affects all devices connected on the bus. The devices start counting their low period and, after a device's clock has gone low, that device holds SCL low until the clock reaches its high state. However, the change of low to high in this device clock might not change the state of SCL if another device clock is still within its low period. Therefore, the synchronized clock SCL is held low by the device with the longest low period. Devices with shorter low periods enter a high wait state during this time; see the following diagram. When all applicable devices have counted off their low period, the synchronized clock SCL is released and pulled high. Afterward there is no difference between the device clocks and the state of SCL, and all devices start counting their high periods. The first device to complete its high period pulls SCL low again.

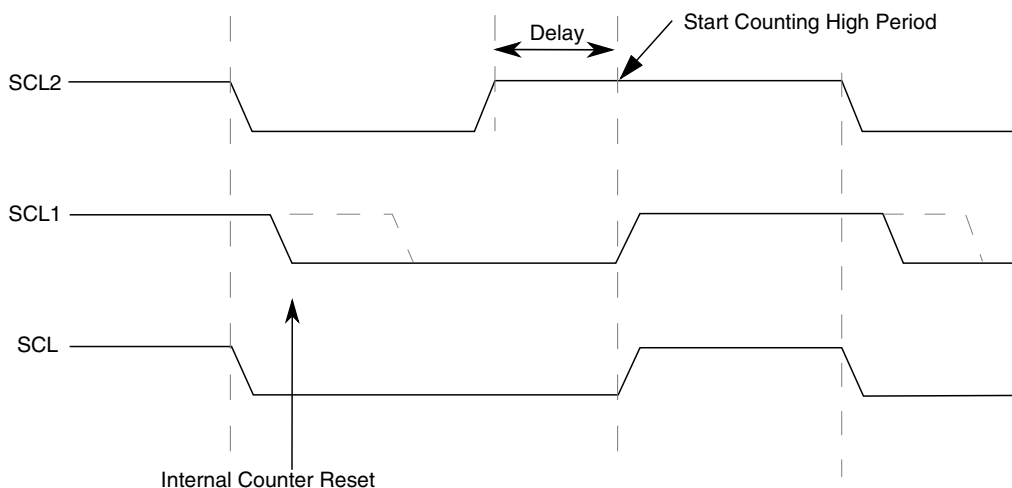


Figure 44-39. I2C clock synchronization

44.4.1.8 Handshaking

The clock synchronization mechanism can be used as a handshake in data transfers. A slave device may hold SCL low after completing a single byte transfer (9 bits). In this case, it halts the bus clock and forces the master clock into wait states until the slave releases SCL.

44.4.1.9 Clock stretching

The clock synchronization mechanism can be used by slaves to slow down the bit rate of a transfer. After the master drives SCL low, a slave can drive SCL low for the required period and then release it. If the slave's SCL low period is greater than the master's SCL low period, the resulting SCL bus signal's low period is stretched. In other words, the SCL bus signal's low period is increased to be the same length as the slave's SCL low period.

44.4.1.10 I2C divider and hold values

NOTE

For some cases on some devices, the SCL divider value may vary by ± 2 or ± 4 when ICR's value ranges from 00h to 0Fh. These potentially varying SCL divider values are highlighted in the following table. For the actual SCL divider values for your device, see the chip-specific details about the I2C module.

Table 44-41. I2C divider and hold values

| ICR (hex) | SCL divider | SDA hold value | SCL hold (start) value | SCL hold (stop) value | ICR (hex) | SCL divider (clocks) | SDA hold (clocks) | SCL hold (start) value | SCL hold (stop) value |
|-----------|-------------|----------------|------------------------|-----------------------|-----------|----------------------|-------------------|------------------------|-----------------------|
| 00 | 20 | 7 | 6 | 11 | 20 | 160 | 17 | 78 | 81 |
| 01 | 22 | 7 | 7 | 12 | 21 | 192 | 17 | 94 | 97 |
| 02 | 24 | 8 | 8 | 13 | 22 | 224 | 33 | 110 | 113 |
| 03 | 26 | 8 | 9 | 14 | 23 | 256 | 33 | 126 | 129 |
| 04 | 28 | 9 | 10 | 15 | 24 | 288 | 49 | 142 | 145 |
| 05 | 30 | 9 | 11 | 16 | 25 | 320 | 49 | 158 | 161 |
| 06 | 34 | 10 | 13 | 18 | 26 | 384 | 65 | 190 | 193 |
| 07 | 40 | 10 | 16 | 21 | 27 | 480 | 65 | 238 | 241 |
| 08 | 28 | 7 | 10 | 15 | 28 | 320 | 33 | 158 | 161 |
| 09 | 32 | 7 | 12 | 17 | 29 | 384 | 33 | 190 | 193 |
| 0A | 36 | 9 | 14 | 19 | 2A | 448 | 65 | 222 | 225 |
| 0B | 40 | 9 | 16 | 21 | 2B | 512 | 65 | 254 | 257 |
| 0C | 44 | 11 | 18 | 23 | 2C | 576 | 97 | 286 | 289 |
| 0D | 48 | 11 | 20 | 25 | 2D | 640 | 97 | 318 | 321 |
| 0E | 56 | 13 | 24 | 29 | 2E | 768 | 129 | 382 | 385 |
| 0F | 68 | 13 | 30 | 35 | 2F | 960 | 129 | 478 | 481 |
| 10 | 48 | 9 | 18 | 25 | 30 | 640 | 65 | 318 | 321 |
| 11 | 56 | 9 | 22 | 29 | 31 | 768 | 65 | 382 | 385 |
| 12 | 64 | 13 | 26 | 33 | 32 | 896 | 129 | 446 | 449 |
| 13 | 72 | 13 | 30 | 37 | 33 | 1024 | 129 | 510 | 513 |
| 14 | 80 | 17 | 34 | 41 | 34 | 1152 | 193 | 574 | 577 |
| 15 | 88 | 17 | 38 | 45 | 35 | 1280 | 193 | 638 | 641 |
| 16 | 104 | 21 | 46 | 53 | 36 | 1536 | 257 | 766 | 769 |
| 17 | 128 | 21 | 58 | 65 | 37 | 1920 | 257 | 958 | 961 |
| 18 | 80 | 9 | 38 | 41 | 38 | 1280 | 129 | 638 | 641 |
| 19 | 96 | 9 | 46 | 49 | 39 | 1536 | 129 | 766 | 769 |
| 1A | 112 | 17 | 54 | 57 | 3A | 1792 | 257 | 894 | 897 |
| 1B | 128 | 17 | 62 | 65 | 3B | 2048 | 257 | 1022 | 1025 |
| 1C | 144 | 25 | 70 | 73 | 3C | 2304 | 385 | 1150 | 1153 |
| 1D | 160 | 25 | 78 | 81 | 3D | 2560 | 385 | 1278 | 1281 |
| 1E | 192 | 33 | 94 | 97 | 3E | 3072 | 513 | 1534 | 1537 |
| 1F | 240 | 33 | 118 | 121 | 3F | 3840 | 513 | 1918 | 1921 |

44.4.2 10-bit address

For 10-bit addressing, 0x11110 is used for the first 5 bits of the first address byte. Various combinations of read/write formats are possible within a transfer that includes 10-bit addressing.

44.4.2.1 Master-transmitter addresses a slave-receiver

The transfer direction is not changed. When a 10-bit address follows a START condition, each slave compares the first 7 bits of the first byte of the slave address (11110XX) with its own address and tests whether the eighth bit (R/\overline{W} direction bit) is 0. It is possible that more than one device finds a match and generates an acknowledge (A1). Each slave that finds a match compares the 8 bits of the second byte of the slave address with its own address, but only one slave finds a match and generates an acknowledge (A2). The matching slave remains addressed by the master until it receives a STOP condition (P) or a repeated START condition (Sr) followed by a different slave address.

Table 44-42. Master-transmitter addresses slave-receiver with a 10-bit address

| | | | | | | | | | | | |
|---|---|---------------------|----|-----------------------------------|----|------|---|-----|------|-----|---|
| S | Slave address first 7 bits 11110 + AD10 + AD9 | R/ \overline{W} 0 | A1 | Slave address second byte AD[8:1] | A2 | Data | A | ... | Data | A/A | P |
|---|---|---------------------|----|-----------------------------------|----|------|---|-----|------|-----|---|

After the master-transmitter has sent the first byte of the 10-bit address, the slave-receiver sees an I2C interrupt. User software must ensure that for this interrupt, the contents of the Data register are ignored and not treated as valid data.

44.4.2.2 Master-receiver addresses a slave-transmitter

The transfer direction is changed after the second R/\overline{W} bit. Up to and including acknowledge bit A2, the procedure is the same as that described for a master-transmitter addressing a slave-receiver. After the repeated START condition (Sr), a matching slave remembers that it was addressed before. This slave then checks whether the first seven bits of the first byte of the slave address following Sr are the same as they were after the START condition (S), and it tests whether the eighth (R/\overline{W}) bit is 1. If there is a match, the slave considers that it has been addressed as a transmitter and generates acknowledge A3. The slave-transmitter remains addressed until it receives a STOP condition (P) or a repeated START condition (Sr) followed by a different slave address.

After a repeated START condition (Sr), all other slave devices also compare the first seven bits of the first byte of the slave address with their own addresses and test the eighth (R/\overline{W}) bit. However, none of them are addressed because $R/\overline{W} = 1$ (for 10-bit devices), or the 11110XX slave address (for 7-bit devices) does not match.

Table 44-43. Master-receiver addresses a slave-transmitter with a 10-bit address

| | | | | | | | | | | | | | | | |
|---|--|---------------------|----|-----------------------------------|----|----|--|---------------------|----|------|---|-----|------|---|---|
| S | Slave address first 7 bits 11110 + AD10 + AD9 | R/ \overline{W} 0 | A1 | Slave address second byte AD[8:1] | A2 | Sr | Slave address first 7 bits 11110 + AD10 + AD9 | R/ \overline{W} 1 | A3 | Data | A | ... | Data | A | P |
|---|--|---------------------|----|-----------------------------------|----|----|--|---------------------|----|------|---|-----|------|---|---|

After the master-receiver has sent the first byte of the 10-bit address, the slave-transmitter sees an I2C interrupt. User software must ensure that for this interrupt, the contents of the Data register are ignored and not treated as valid data.

44.4.3 Address matching

All received addresses can be requested in 7-bit or 10-bit address format.

- AD[7:1] in Address Register 1, which contains the I2C primary slave address, always participates in the address matching process. It provides a 7-bit address.
- If the ADEXT bit is set, AD[10:8] in Control Register 2 participates in the address matching process. It extends the I2C primary slave address to a 10-bit address.

Additional conditions that affect address matching include:

- If the GCAEN bit is set, general call participates the address matching process.
- If the ALERTEN bit is set, alert response participates the address matching process.
- If the SIICAEN bit is set, Address Register 2 participates in the address matching process.
- If the RMEN bit is set, when the Range Address register is programmed to a nonzero value, any address within the range of values of Address Register 1 (excluded) and the Range Address register (included) participates in the address matching process. The Range Address register must be programmed to a value greater than the value of Address Register 1.

When the I2C module responds to one of these addresses, it acts as a slave-receiver and the IAAS bit is set after the address cycle. Software must read the Data register after the first byte transfer to determine that the address is matched.

44.4.4 System management bus specification

SMBus provides a control bus for system and power management related tasks. A system can use SMBus to pass messages to and from devices instead of tripping individual control lines.

Removing the individual control lines reduces pin count. Accepting messages ensures future expandability. With the system management bus, a device can provide manufacturer information, tell the system what its model/part number is, save its state for a suspend event, report different types of errors, accept control parameters, and return its status.

44.4.4.1 Timeouts

The $T_{\text{TIMEOUT,MIN}}$ parameter allows a master or slave to conclude that a defective device is holding the clock low indefinitely or a master is intentionally trying to drive devices off the bus. The slave device must release the bus (stop driving the bus and let SCL and SDA float high) when it detects any single clock held low longer than $T_{\text{TIMEOUT,MIN}}$. Devices that have detected this condition must reset their communication and be able to receive a new START condition within the timeframe of $T_{\text{TIMEOUT,MAX}}$.

SMBus defines a clock low timeout, T_{TIMEOUT} , of 35 ms, specifies $T_{\text{LOW:SEXT}}$ as the cumulative clock low extend time for a slave device, and specifies $T_{\text{LOW:MEXT}}$ as the cumulative clock low extend time for a master device.

44.4.4.1.1 SCL low timeout

If the SCL line is held low by a slave device on the bus, no further communication is possible. Furthermore, the master cannot force the SCL line high to correct the error condition. To solve this problem, the SMBus protocol specifies that devices participating in a transfer must detect any clock cycle held low longer than a timeout value condition. Devices that have detected the timeout condition must reset the communication. When the I2C module is an active master, if it detects that SMBCLK low has exceeded the value of $T_{\text{TIMEOUT,MIN}}$, it must generate a stop condition within or after the current data byte in the transfer process. When the I2C module is a slave, if it detects the $T_{\text{TIMEOUT,MIN}}$ condition, it resets its communication and is then able to receive a new START condition.

44.4.4.1.2 SCL high timeout

When the I2C module has determined that the SMBCLK and SMBDAT signals have been high for at least $T_{\text{HIGH:MAX}}$, it assumes that the bus is idle.

A HIGH timeout occurs after a START condition appears on the bus but before a STOP condition appears on the bus. Any master detecting this scenario can assume the bus is free when either of the following occurs:

- SHTF1 rises.
- The BUSY bit is high and SHTF1 is high.

When the SMBDAT signal is low and the SMBCLK signal is high for a period of time, another kind of timeout occurs. The time period must be defined in software. SHTF2 is used as the flag when the time limit is reached. This flag is also an interrupt resource, so it triggers IICIF.

44.4.4.1.3 CSMBCLK TIMEOUT MEXT and CSMBCLK TIMEOUT SEXT

The following figure illustrates the definition of the timeout intervals $T_{\text{LOW:SEXT}}$ and $T_{\text{LOW:MEXT}}$. When in master mode, the I2C module must not cumulatively extend its clock cycles for a period greater than $T_{\text{LOW:MEXT}}$ within a byte, where each byte is defined as START-to-ACK, ACK-to-ACK, or ACK-to-STOP. When CSMBCLK TIMEOUT MEXT occurs, SMBus MEXT rises and also triggers the SLTF.

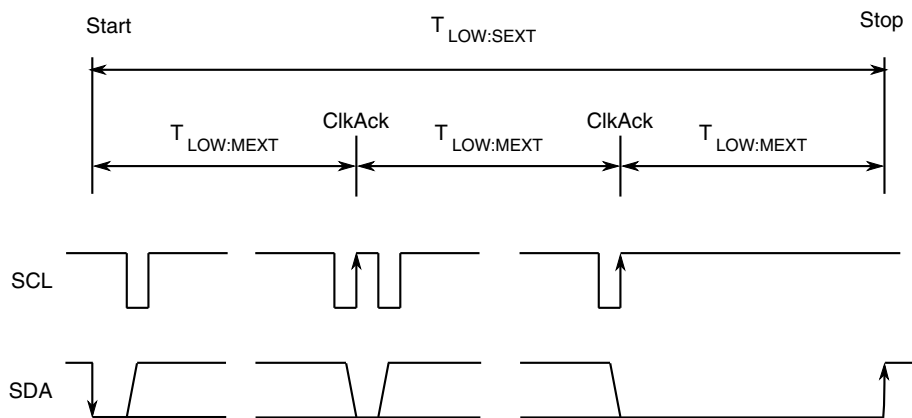


Figure 44-40. Timeout measurement intervals

A master is allowed to abort the transaction in progress to any slave that violates the $T_{\text{LOW:SEXT}}$ or $T_{\text{TIMEOUT,MIN}}$ specifications. To abort the transaction, the master issues a STOP condition at the conclusion of the byte transfer in progress. When a slave, the I2C module must not cumulatively extend its clock cycles for a period greater than $T_{\text{LOW:SEXT}}$ during any message from the initial START to the STOP. When CSMBCLK TIMEOUT SEXT occurs, SEXT rises and also triggers SLTF.

NOTE

CSMBCLK TIMEOUT SEXT and CSMBCLK TIMEOUT MEXT are optional functions that are implemented in the second step.

44.4.4.2 FAST ACK and NACK

To improve reliability and communication robustness, implementation of packet error checking (PEC) by SMBus devices is optional for SMBus devices but required for devices participating in and only during the address resolution protocol (ARP) process. The PEC is a CRC-8 error checking byte, calculated on all the message bytes. The PEC is appended to the message by the device that supplied the last data byte. If the PEC is present but not correct, a NACK is issued by the receiver. Otherwise an ACK is issued. To calculate the CRC-8 by software, this module can hold the SCL line low after receiving the eighth SCL (8th bit) if this byte is a data byte. So software can determine whether an ACK or NACK should be sent to the bus by setting or clearing the TXAK bit if the FACK (fast ACK/NACK enable) bit is enabled.

SMBus requires a device always to acknowledge its own address, as a mechanism to detect the presence of a removable device (such as a battery or docking station) on the bus. In addition to indicating a slave device busy condition, SMBus uses the NACK mechanism to indicate the reception of an invalid command or invalid data. Because such a condition may occur on the last byte of the transfer, SMBus devices are required to have the ability to generate the not acknowledge after the transfer of each byte and before the completion of the transaction. This requirement is important because SMBus does not provide any other resend signaling. This difference in the use of the NACK signaling has implications on the specific implementation of the SMBus port, especially in devices that handle critical system data such as the SMBus host and the SBS components.

NOTE

In the last byte of master receive slave transmit mode, the master must send a NACK to the bus, so FACK must be switched off before the last byte transmits.

44.4.5 Resets

The I2C module is disabled after a reset. The I2C module cannot cause a core reset.

44.4.6 Interrupts

The I2C module generates an interrupt when any of the events in the table found here occur, provided that the IICIE bit is set.

The interrupt is driven by the IICIF bit (of the I2C Status Register) and masked with the IICIE bit (of the I2C Control Register 1). The IICIF bit must be cleared (by software) by writing 1 to it in the interrupt routine. The SMBus timeouts interrupt is driven by SLTF and masked with the IICIE bit. The SLTF bit must be cleared by software by writing 1 to it in the interrupt routine. You can determine the interrupt type by reading the Status Register.

NOTE

In master receive mode, the FACK bit must be set to zero before the last byte transfer.

Table 44-44. Interrupt summary

| Interrupt source | Status | Flag | Local enable |
|-----------------------------------|--------|-------|-----------------|
| Complete 1-byte transfer | TCF | IICIF | IICIE |
| Match of received calling address | IAAS | IICIF | IICIE |
| Arbitration lost | ARBL | IICIF | IICIE |
| SMBus SCL low timeout | SLTF | IICIF | IICIE |
| SMBus SCL high SDA low timeout | SHTF2 | IICIF | IICIE & SHTF2IE |
| Wakeup from stop or wait mode | IAAS | IICIF | IICIE & WUEN |

44.4.6.1 Byte transfer interrupt

The Transfer Complete Flag (TCF) bit is set at the falling edge of the ninth clock to indicate the completion of a byte and acknowledgement transfer. When FACK is enabled, TCF is then set at the falling edge of eighth clock to indicate the completion of byte.

44.4.6.2 Address detect interrupt

When the calling address matches the programmed slave address (I2C Address Register) or when the GCAEN bit is set and a general call is received, the IAAS bit in the Status Register is set. The CPU is interrupted, provided the IICIE bit is set. The CPU must check the SRW bit and set its Tx mode accordingly.

44.4.6.3 Exit from low-power/stop modes

The slave receive input detect circuit and address matching feature are still active on low power modes (wait and stop). An asynchronous input matching slave address or general call address brings the CPU out of low power/stop mode if the interrupt is not masked. Therefore, TCF and IAAS both can trigger this interrupt.

44.4.6.4 Arbitration lost interrupt

The I2C is a true multimaster bus that allows more than one master to be connected on it. If two or more masters try to control the bus at the same time, the relative priority of the contending masters is determined by a data arbitration procedure. The I2C module asserts the arbitration-lost interrupt when it loses the data arbitration process and the ARBL bit in the Status Register is set.

Arbitration is lost in the following circumstances:

1. SDA is sampled as low when the master drives high during an address or data transmit cycle.
2. SDA is sampled as low when the master drives high during the acknowledge bit of a data receive cycle.
3. A START cycle is attempted when the bus is busy.
4. A repeated START cycle is requested in slave mode.
5. A STOP condition is detected when the master did not request it.

The ARBL bit must be cleared (by software) by writing 1 to it.

44.4.6.5 Timeout interrupt in SMBus

When the IICIE bit is set, the I2C module asserts a timeout interrupt (outputs SLTF and SHTF2) upon detection of any of the mentioned timeout conditions, with one exception. The SCL high and SDA high TIMEOUT mechanism must not be used to influence the timeout interrupt output, because this timeout indicates an idle condition on the bus. SHTF1 rises when it matches the SCL high and SDA high TIMEOUT and falls automatically just to indicate the bus status. The SHTF2's timeout period is the same as that of SHTF1, which is short compared to that of SLTF, so another control bit, SHTF2IE, is added to enable or disable it.

44.4.7 Programmable input glitch filter

An I2C glitch filter has been added outside legacy I2C modules but within the I2C package. This filter can absorb glitches on the I2C clock and data lines for the I2C module.

The width of the glitch to absorb can be specified in terms of the number of (half) I2C module clock cycles. A single Programmable Input Glitch Filter control register is provided. Effectively, any down-up-down or up-down-up transition on the data line that occurs within the number of clock cycles programmed in this register is ignored by the I2C module. The programmer must specify the size of the glitch (in terms of I2C module clock cycles) for the filter to absorb and not pass.

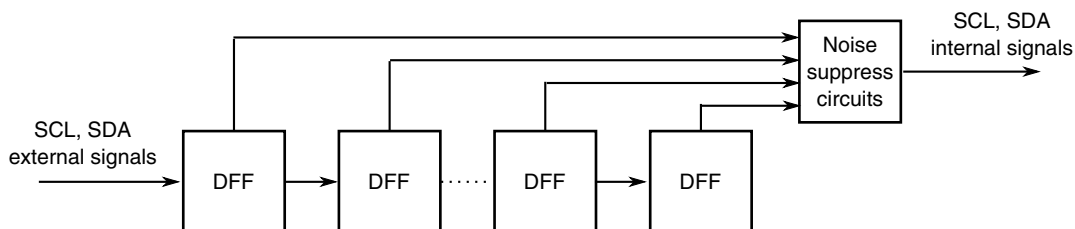


Figure 44-41. Programmable input glitch filter diagram

44.4.8 Address matching wake-up

When a primary, range, or general call address match occurs when the I2C module is in slave receive mode, the MCU wakes from a low power mode where no peripheral bus is running.

Data sent on the bus that is the same as a target device address might also wake the target MCU.

After the address matching IAAS bit is set, an interrupt is sent at the end of address matching to wake the core. The IAAS bit must be cleared after the clock recovery.

NOTE

After the system recovers and is in Run mode, restart the I2C module if it is needed to transfer packets. To avoid I2C transfer problems resulting from the situation, firmware should prevent the MCU execution of a STOP instruction when the I2C module is in the middle of a transfer.

44.4.9 DMA support

If the DMAEN bit is cleared and the IICIE bit is set, an interrupt condition generates an interrupt request.

If the DMAEN bit is set and the IICIE bit is set, an interrupt condition generates a DMA request instead. DMA requests are generated by the transfer complete flag (TCF).

If the DMAEN bit is set, only the TCF initiates a DMA request. All other events generate CPU interrupts.

NOTE

Before the last byte of master receive mode, TXAK must be set to send a NACK after the last byte's transfer. Therefore, the DMA must be disabled before the last byte's transfer.

NOTE

In 10-bit address mode transmission, the addresses to send occupy 2–3 bytes. During this transfer period, the DMA must be disabled because the C1 register is written to send a repeat start or to change the transfer direction.

44.5 Initialization/application information

Module Initialization (Slave)

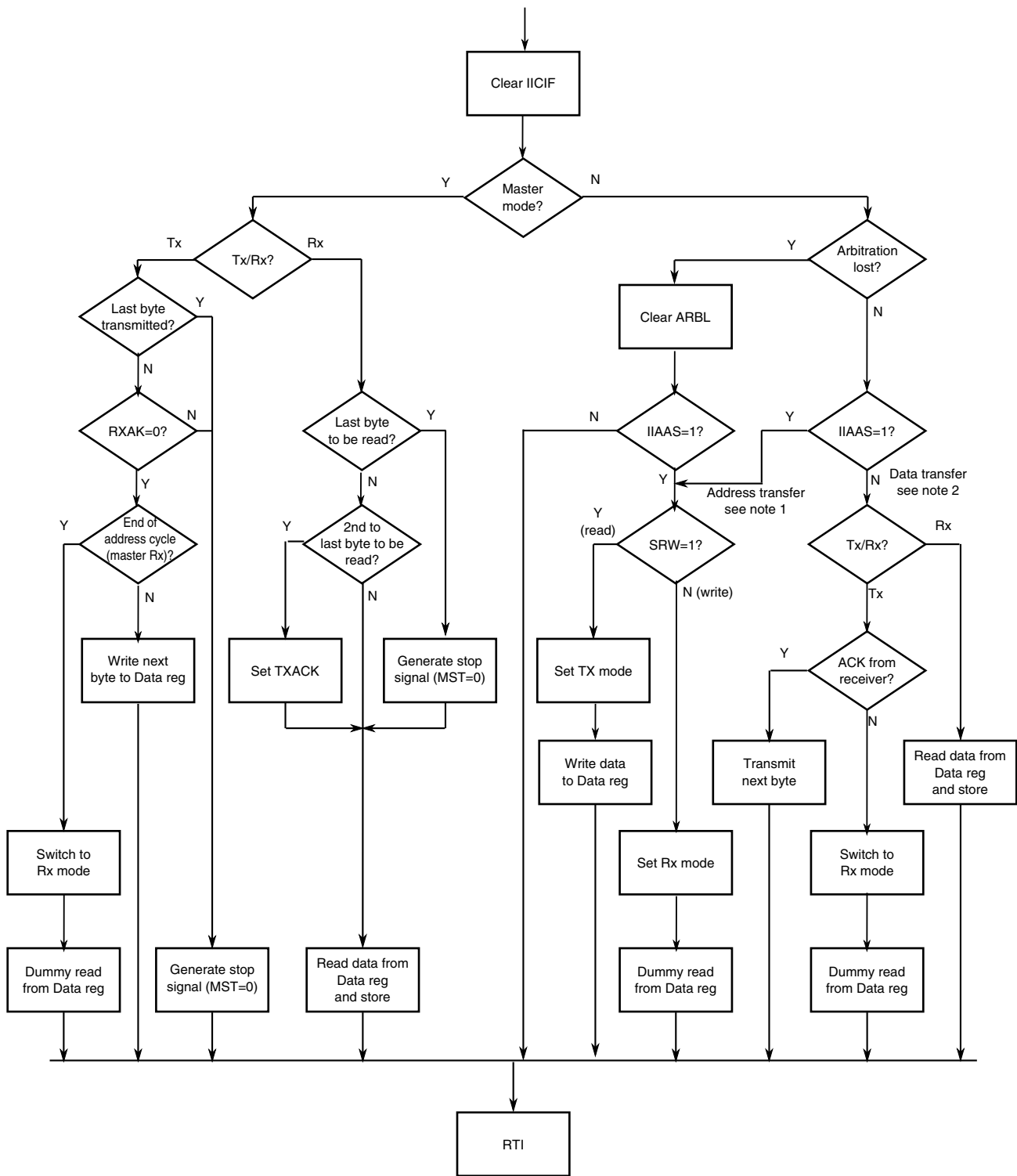
1. Write: Control Register 2
 - to enable or disable general call
 - to select 10-bit or 7-bit addressing mode
2. Write: Address Register 1 to set the slave address
3. Write: Control Register 1 to enable the I2C module and interrupts
4. Initialize RAM variables (IICEN = 1 and IICIE = 1) for transmit data
5. Initialize RAM variables used to achieve the routine shown in the following figure

Module Initialization (Master)

1. Write: Frequency Divider register to set the I2C baud rate (see example in description of [ICR](#))
2. Write: Control Register 1 to enable the I2C module and interrupts
3. Initialize RAM variables (IICEN = 1 and IICIE = 1) for transmit data
4. Initialize RAM variables used to achieve the routine shown in the following figure
5. Write: Control Register 1 to enable TX

6. Write: Control Register 1 to enable MST (master mode)
7. Write: Data register with the address of the target slave (the LSB of this byte determines whether the communication is master receive or transmit)

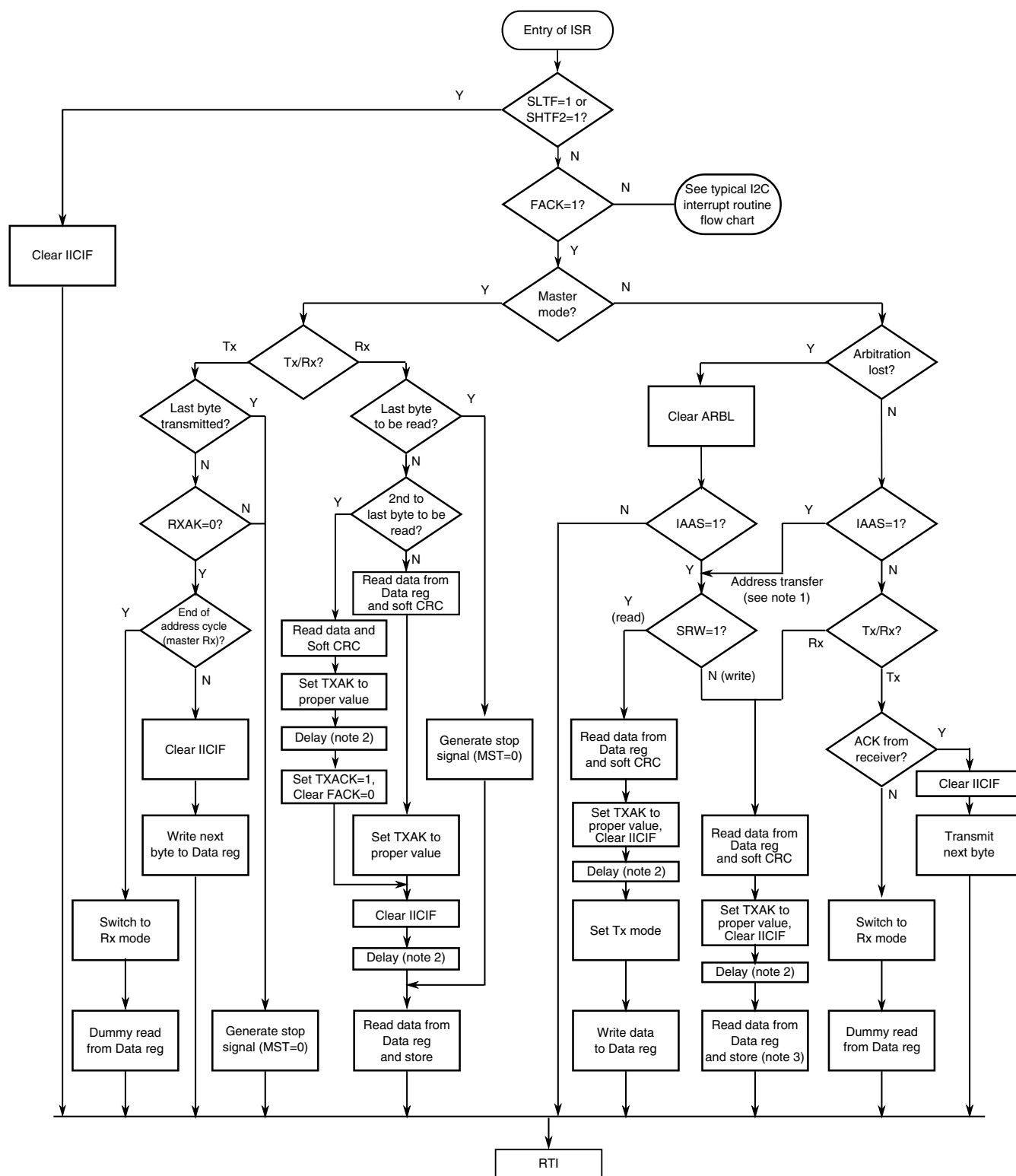
The routine shown in the following figure encompasses both master and slave I2C operations. For slave operation, an incoming I2C message that contains the proper address begins I2C communication. For master operation, communication must be initiated by writing the Data register. An example of an I2C driver which implements many of the steps described here is available in [AN4342: Using the Inter-Integrated Circuit on ColdFire+ and Kinetis](#) .



Notes:

1. If general call is enabled, check to determine if the received address is a general call address (0x00). If the received address is a general call address, the general call must be handled by user software.
2. When 10-bit addressing addresses a slave, the slave sees an interrupt following the first byte of the extended address. Ensure that for this interrupt, the contents of the Data register are ignored and not treated as a valid data transfer.

Figure 44-42. Typical I2C interrupt routine


Notes:

1. If general call or SIICAEN is enabled, check to determine if the received address is a general call address (0x00) or an SMBus device default address. In either case, they must be handled by user software.
2. In receive mode, one bit time delay may be needed before the first and second data reading, to wait for the possible longest time period (in worst case) of the 9th SCL cycle.
3. This read is a dummy read in order to reset the SMBus receiver state machine.

Figure 44-43. Typical I2C SMBus interrupt routine

Chapter 45

Universal Asynchronous Receiver/Transmitter (UART)

45.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The UART allows asynchronous serial communication with peripheral devices and CPUs.

45.1.1 Features

The UART includes the following features:

- Full-duplex operation
- Standard mark/space non-return-to-zero (NRZ) format
- Selectable IrDA 1.4 return-to-zero-inverted (RZI) format with programmable pulse width
- 13-bit baud rate selection with /32 fractional divide, based on the module clock frequency
- Programmable 8-bit or 9-bit data format
- Separately enabled transmitter and receiver
- Programmable transmitter output polarity
- Programmable receive input polarity
- Up to 14-bit break character transmission.

- 11-bit break character detection option
- Independent FIFO structure for transmit and receive
- Two receiver wakeup methods:
 - Idle line wakeup
 - Address mark wakeup
- Address match feature in the receiver to reduce address mark wakeup ISR overhead
- Ability to select MSB or LSB to be first bit on wire
- Hardware flow control support for request to send (RTS) and clear to send (CTS) signals
- Support for ISO 7816 protocol to interface with SIM cards and smart cards
 - Support for T=0 and T=1 protocols
 - Automatic retransmission of NACK'd packets with programmable retry threshold
 - Support for 11 and 12 ETU transfers
 - Detection of initial packet and automated transfer parameter programming
 - Interrupt-driven operation with seven ISO-7816 specific interrupts:
 - Wait time violated
 - Character wait time violated
 - Block wait time violated
 - Initial frame detected
 - Transmit error threshold exceeded
 - Receive error threshold exceeded
 - Guard time violated
- Interrupt-driven operation with 12 flags, not specific to ISO-7816 support
 - Transmitter data buffer at or below watermark
 - Transmission complete
 - Receiver data buffer at or above watermark
 - Idle receiver input

- Receiver data buffer overrun
- Receiver data buffer underflow
- Transmit data buffer overflow
- Noise error
- Framing error
- Parity error
- Active edge on receive pin
- LIN break detect
- Receiver framing error detection
- Hardware parity generation and checking
- 1/16 bit-time noise detection
- DMA interface

45.1.2 Modes of operation

The UART functions in the same way in all the normal modes.

It has the following low power modes:

- Wait mode
- Stop mode

45.1.2.1 Run mode

This is the normal mode of operation.

45.1.2.2 Wait mode

UART operation in the Wait mode depends on the state of the C1[UARTSWAI] field.

- If C1[UARTSWAI] is cleared, and the CPU is in Wait mode, the UART operates normally.
- If C1[UARTSWAI] is set, and the CPU is in Wait mode, the UART clock generation ceases and the UART module enters a power conservation state.

C1[UARTSWAI] does not initiate any power down or power up procedures for the ISO-7816 smartcard interface.

Setting C1[UARTSWAI] does not affect the state of the C2[RE] or C2[TE].

If C1[UARTSWAI] is set, any ongoing transmission or reception stops at the Wait mode entry. The transmission or reception resumes when either an internal or external interrupt brings the CPU out of Wait mode. Bringing the CPU out of Wait mode by reset aborts any ongoing transmission or reception and resets the UART.

45.1.2.3 Stop mode

The UART is inactive during Stop mode for reduced power consumption. The STOP instruction does not affect the UART register states, but the UART module clock is disabled. The UART operation resumes after an external interrupt brings the CPU out of Stop mode. Bringing the CPU out of Stop mode by reset aborts any ongoing transmission or reception and resets the UART. Entering or leaving Stop mode does not initiate any power down or power up procedures for the ISO-7816 smartcard interface.

45.2 UART signal descriptions

The UART signals are shown in the following table.

Table 45-1. UART signal descriptions

| Signal | Description | I/O |
|--------|-----------------|-----|
| CTS | Clear to send | I |
| RTS | Request to send | O |
| RXD | Receive data | I |
| TXD | Transmit data | O |

45.2.1 Detailed signal descriptions

The detailed signal descriptions of the UART are shown in the following table.

Table 45-2. UART—Detailed signal descriptions

| Signal | I/O | Description | |
|--------|-----|--|--|
| CTS | I | Clear to send. Indicates whether the UART can start transmitting data when flow control is enabled. | |
| | | State meaning | Asserted—Data transmission can start. Negated—Data transmission cannot start. |
| | | Timing | Assertion—When transmitting device's RTS asserts. Negation—When transmitting device's RTS deasserts. |
| RTS | O | Request to send. When driven by the receiver, indicates whether the UART is ready to receive data. When driven by the transmitter, can enable an external transceiver during transmission. | |
| | | State meaning | Asserted—When driven by the receiver, ready to receive data. When driven by the transmitter, enable the external transmitter. Negated—When driven by the receiver, not ready to receive data. When driven by the transmitter, disable the external transmitter. |
| | | Timing | Assertion—Can occur at any time; can assert asynchronously to the other input signals. Negation—Can occur at any time; can deassert asynchronously to the other input signals. |
| RXD | I | Receive data. Serial data input to receiver. | |
| | | State meaning | Whether RXD is interpreted as a 1 or 0 depends on the bit encoding method along with other configuration settings. |
| | | Timing | Sampled at a frequency determined by the module clock divided by the baud rate. |
| TXD | O | Transmit data. Serial data output from transmitter. | |
| | | State meaning | Whether TXD is interpreted as a 1 or 0 depends on the bit encoding method along with other configuration settings. |
| | | Timing | Driven at the beginning or within a bit time according to the bit encoding method along with other configuration settings. Otherwise, transmissions are independent of reception timing. |

45.3 Memory map and registers

This section provides a detailed description of all memory and registers.

Accessing reserved addresses within the memory map results in a transfer error. None of the contents of the implemented addresses are modified as a result of that access.

Only byte accesses are supported.

UART memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-----------------------------|------------------------------|
| 4006_A000 | UART Baud Rate Registers: High (UART0_BDH) | 8 | R/W | 00h | 45.3.1/1077 |
| 4006_A001 | UART Baud Rate Registers: Low (UART0_BDL) | 8 | R/W | 04h | 45.3.2/1078 |
| 4006_A002 | UART Control Register 1 (UART0_C1) | 8 | R/W | 00h | 45.3.3/1078 |
| 4006_A003 | UART Control Register 2 (UART0_C2) | 8 | R/W | 00h | 45.3.4/1080 |
| 4006_A004 | UART Status Register 1 (UART0_S1) | 8 | R | C0h | 45.3.5/1082 |
| 4006_A005 | UART Status Register 2 (UART0_S2) | 8 | R/W | 00h | 45.3.6/1085 |
| 4006_A006 | UART Control Register 3 (UART0_C3) | 8 | R/W | 00h | 45.3.7/1087 |
| 4006_A007 | UART Data Register (UART0_D) | 8 | R/W | 00h | 45.3.8/1088 |
| 4006_A008 | UART Match Address Registers 1 (UART0_MA1) | 8 | R/W | 00h | 45.3.9/1089 |
| 4006_A009 | UART Match Address Registers 2 (UART0_MA2) | 8 | R/W | 00h | 45.3.10/1090 |
| 4006_A00A | UART Control Register 4 (UART0_C4) | 8 | R/W | 00h | 45.3.11/1090 |
| 4006_A00B | UART Control Register 5 (UART0_C5) | 8 | R/W | 00h | 45.3.12/1091 |
| 4006_A00C | UART Extended Data Register (UART0_ED) | 8 | R | 00h | 45.3.13/1092 |
| 4006_A00D | UART Modem Register (UART0_MODEM) | 8 | R/W | 00h | 45.3.14/1093 |
| 4006_A00E | UART Infrared Register (UART0_IR) | 8 | R/W | 00h | 45.3.15/1094 |
| 4006_A010 | UART FIFO Parameters (UART0_PFIFO) | 8 | R/W | See section | 45.3.16/1095 |
| 4006_A011 | UART FIFO Control Register (UART0_CFIFO) | 8 | R/W | 00h | 45.3.17/1096 |
| 4006_A012 | UART FIFO Status Register (UART0_SFIFO) | 8 | R/W | C0h | 45.3.18/1097 |
| 4006_A013 | UART FIFO Transmit Watermark (UART0_TWFIFO) | 8 | R/W | 00h | 45.3.19/1098 |
| 4006_A014 | UART FIFO Transmit Count (UART0_TCFIFO) | 8 | R | 00h | 45.3.20/1099 |
| 4006_A015 | UART FIFO Receive Watermark (UART0_RWFIFO) | 8 | R/W | 01h | 45.3.21/1099 |
| 4006_A016 | UART FIFO Receive Count (UART0_RCFIFO) | 8 | R | 00h | 45.3.22/1100 |
| 4006_A018 | UART 7816 Control Register (UART0_C7816) | 8 | R/W | 00h | 45.3.23/1100 |
| 4006_A019 | UART 7816 Interrupt Enable Register (UART0_IE7816) | 8 | R/W | 00h | 45.3.24/1102 |
| 4006_A01A | UART 7816 Interrupt Status Register (UART0_IS7816) | 8 | R/W | 00h | 45.3.25/1103 |
| 4006_A01B | UART 7816 Wait Parameter Register (UART0_WP7816T0) | 8 | R/W | 0Ah | 45.3.26/1104 |

Table continues on the next page...

UART memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|--|-----------------|--------|-----------------------------|------------------------------|
| 4006_A01B | UART 7816 Wait Parameter Register (UART0_WP7816T1) | 8 | R/W | 0Ah | 45.3.27/1105 |
| 4006_A01C | UART 7816 Wait N Register (UART0_WN7816) | 8 | R/W | 00h | 45.3.28/1105 |
| 4006_A01D | UART 7816 Wait FD Register (UART0_WF7816) | 8 | R/W | 01h | 45.3.29/1106 |
| 4006_A01E | UART 7816 Error Threshold Register (UART0_ET7816) | 8 | R/W | 00h | 45.3.30/1106 |
| 4006_A01F | UART 7816 Transmit Length Register (UART0_TL7816) | 8 | R/W | 00h | 45.3.31/1107 |
| 4006_B000 | UART Baud Rate Registers: High (UART1_BDH) | 8 | R/W | 00h | 45.3.1/1077 |
| 4006_B001 | UART Baud Rate Registers: Low (UART1_BDL) | 8 | R/W | 04h | 45.3.2/1078 |
| 4006_B002 | UART Control Register 1 (UART1_C1) | 8 | R/W | 00h | 45.3.3/1078 |
| 4006_B003 | UART Control Register 2 (UART1_C2) | 8 | R/W | 00h | 45.3.4/1080 |
| 4006_B004 | UART Status Register 1 (UART1_S1) | 8 | R | C0h | 45.3.5/1082 |
| 4006_B005 | UART Status Register 2 (UART1_S2) | 8 | R/W | 00h | 45.3.6/1085 |
| 4006_B006 | UART Control Register 3 (UART1_C3) | 8 | R/W | 00h | 45.3.7/1087 |
| 4006_B007 | UART Data Register (UART1_D) | 8 | R/W | 00h | 45.3.8/1088 |
| 4006_B008 | UART Match Address Registers 1 (UART1_MA1) | 8 | R/W | 00h | 45.3.9/1089 |
| 4006_B009 | UART Match Address Registers 2 (UART1_MA2) | 8 | R/W | 00h | 45.3.10/1090 |
| 4006_B00A | UART Control Register 4 (UART1_C4) | 8 | R/W | 00h | 45.3.11/1090 |
| 4006_B00B | UART Control Register 5 (UART1_C5) | 8 | R/W | 00h | 45.3.12/1091 |
| 4006_B00C | UART Extended Data Register (UART1_ED) | 8 | R | 00h | 45.3.13/1092 |
| 4006_B00D | UART Modem Register (UART1_MODEM) | 8 | R/W | 00h | 45.3.14/1093 |
| 4006_B00E | UART Infrared Register (UART1_IR) | 8 | R/W | 00h | 45.3.15/1094 |
| 4006_B010 | UART FIFO Parameters (UART1_PFIFO) | 8 | R/W | See section | 45.3.16/1095 |
| 4006_B011 | UART FIFO Control Register (UART1_CFIFO) | 8 | R/W | 00h | 45.3.17/1096 |
| 4006_B012 | UART FIFO Status Register (UART1_SFIFO) | 8 | R/W | C0h | 45.3.18/1097 |
| 4006_B013 | UART FIFO Transmit Watermark (UART1_TWFIFO) | 8 | R/W | 00h | 45.3.19/1098 |
| 4006_B014 | UART FIFO Transmit Count (UART1_TCFIFO) | 8 | R | 00h | 45.3.20/1099 |
| 4006_B015 | UART FIFO Receive Watermark (UART1_RWFIFO) | 8 | R/W | 01h | 45.3.21/1099 |

Table continues on the next page...

UART memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|--|-----------------|--------|-------------|------------------------------|
| 4006_B016 | UART FIFO Receive Count (UART1_RCFIFO) | 8 | R | 00h | 45.3.22/1100 |
| 4006_B018 | UART 7816 Control Register (UART1_C7816) | 8 | R/W | 00h | 45.3.23/1100 |
| 4006_B019 | UART 7816 Interrupt Enable Register (UART1_IE7816) | 8 | R/W | 00h | 45.3.24/1102 |
| 4006_B01A | UART 7816 Interrupt Status Register (UART1_IS7816) | 8 | R/W | 00h | 45.3.25/1103 |
| 4006_B01B | UART 7816 Wait Parameter Register (UART1_WP7816T0) | 8 | R/W | 0Ah | 45.3.26/1104 |
| 4006_B01B | UART 7816 Wait Parameter Register (UART1_WP7816T1) | 8 | R/W | 0Ah | 45.3.27/1105 |
| 4006_B01C | UART 7816 Wait N Register (UART1_WN7816) | 8 | R/W | 00h | 45.3.28/1105 |
| 4006_B01D | UART 7816 Wait FD Register (UART1_WF7816) | 8 | R/W | 01h | 45.3.29/1106 |
| 4006_B01E | UART 7816 Error Threshold Register (UART1_ET7816) | 8 | R/W | 00h | 45.3.30/1106 |
| 4006_B01F | UART 7816 Transmit Length Register (UART1_TL7816) | 8 | R/W | 00h | 45.3.31/1107 |
| 4006_C000 | UART Baud Rate Registers: High (UART2_BDH) | 8 | R/W | 00h | 45.3.1/1077 |
| 4006_C001 | UART Baud Rate Registers: Low (UART2_BDL) | 8 | R/W | 04h | 45.3.2/1078 |
| 4006_C002 | UART Control Register 1 (UART2_C1) | 8 | R/W | 00h | 45.3.3/1078 |
| 4006_C003 | UART Control Register 2 (UART2_C2) | 8 | R/W | 00h | 45.3.4/1080 |
| 4006_C004 | UART Status Register 1 (UART2_S1) | 8 | R | C0h | 45.3.5/1082 |
| 4006_C005 | UART Status Register 2 (UART2_S2) | 8 | R/W | 00h | 45.3.6/1085 |
| 4006_C006 | UART Control Register 3 (UART2_C3) | 8 | R/W | 00h | 45.3.7/1087 |
| 4006_C007 | UART Data Register (UART2_D) | 8 | R/W | 00h | 45.3.8/1088 |
| 4006_C008 | UART Match Address Registers 1 (UART2_MA1) | 8 | R/W | 00h | 45.3.9/1089 |
| 4006_C009 | UART Match Address Registers 2 (UART2_MA2) | 8 | R/W | 00h | 45.3.10/1090 |
| 4006_C00A | UART Control Register 4 (UART2_C4) | 8 | R/W | 00h | 45.3.11/1090 |
| 4006_C00B | UART Control Register 5 (UART2_C5) | 8 | R/W | 00h | 45.3.12/1091 |
| 4006_C00C | UART Extended Data Register (UART2_ED) | 8 | R | 00h | 45.3.13/1092 |
| 4006_C00D | UART Modem Register (UART2_MODEM) | 8 | R/W | 00h | 45.3.14/1093 |
| 4006_C00E | UART Infrared Register (UART2_IR) | 8 | R/W | 00h | 45.3.15/1094 |
| 4006_C010 | UART FIFO Parameters (UART2_PFIFO) | 8 | R/W | See section | 45.3.16/1095 |

Table continues on the next page...

UART memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|--|-----------------|--------|-------------|------------------------------|
| 4006_C011 | UART FIFO Control Register (UART2_CFIFO) | 8 | R/W | 00h | 45.3.17/1096 |
| 4006_C012 | UART FIFO Status Register (UART2_SFIFO) | 8 | R/W | C0h | 45.3.18/1097 |
| 4006_C013 | UART FIFO Transmit Watermark (UART2_TWFIFO) | 8 | R/W | 00h | 45.3.19/1098 |
| 4006_C014 | UART FIFO Transmit Count (UART2_TCFIFO) | 8 | R | 00h | 45.3.20/1099 |
| 4006_C015 | UART FIFO Receive Watermark (UART2_RWFIFO) | 8 | R/W | 01h | 45.3.21/1099 |
| 4006_C016 | UART FIFO Receive Count (UART2_RCFIFO) | 8 | R | 00h | 45.3.22/1100 |
| 4006_C018 | UART 7816 Control Register (UART2_C7816) | 8 | R/W | 00h | 45.3.23/1100 |
| 4006_C019 | UART 7816 Interrupt Enable Register (UART2_IE7816) | 8 | R/W | 00h | 45.3.24/1102 |
| 4006_C01A | UART 7816 Interrupt Status Register (UART2_IS7816) | 8 | R/W | 00h | 45.3.25/1103 |
| 4006_C01B | UART 7816 Wait Parameter Register (UART2_WP7816T0) | 8 | R/W | 0Ah | 45.3.26/1104 |
| 4006_C01B | UART 7816 Wait Parameter Register (UART2_WP7816T1) | 8 | R/W | 0Ah | 45.3.27/1105 |
| 4006_C01C | UART 7816 Wait N Register (UART2_WN7816) | 8 | R/W | 00h | 45.3.28/1105 |
| 4006_C01D | UART 7816 Wait FD Register (UART2_WF7816) | 8 | R/W | 01h | 45.3.29/1106 |
| 4006_C01E | UART 7816 Error Threshold Register (UART2_ET7816) | 8 | R/W | 00h | 45.3.30/1106 |
| 4006_C01F | UART 7816 Transmit Length Register (UART2_TL7816) | 8 | R/W | 00h | 45.3.31/1107 |
| 4006_D000 | UART Baud Rate Registers: High (UART3_BDH) | 8 | R/W | 00h | 45.3.1/1077 |
| 4006_D001 | UART Baud Rate Registers: Low (UART3_BDL) | 8 | R/W | 04h | 45.3.2/1078 |
| 4006_D002 | UART Control Register 1 (UART3_C1) | 8 | R/W | 00h | 45.3.3/1078 |
| 4006_D003 | UART Control Register 2 (UART3_C2) | 8 | R/W | 00h | 45.3.4/1080 |
| 4006_D004 | UART Status Register 1 (UART3_S1) | 8 | R | C0h | 45.3.5/1082 |
| 4006_D005 | UART Status Register 2 (UART3_S2) | 8 | R/W | 00h | 45.3.6/1085 |
| 4006_D006 | UART Control Register 3 (UART3_C3) | 8 | R/W | 00h | 45.3.7/1087 |
| 4006_D007 | UART Data Register (UART3_D) | 8 | R/W | 00h | 45.3.8/1088 |
| 4006_D008 | UART Match Address Registers 1 (UART3_MA1) | 8 | R/W | 00h | 45.3.9/1089 |
| 4006_D009 | UART Match Address Registers 2 (UART3_MA2) | 8 | R/W | 00h | 45.3.10/1090 |
| 4006_D00A | UART Control Register 4 (UART3_C4) | 8 | R/W | 00h | 45.3.11/1090 |

Table continues on the next page...

UART memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|--|-----------------|--------|-----------------------------|------------------------------|
| 4006_D00B | UART Control Register 5 (UART3_C5) | 8 | R/W | 00h | 45.3.12/1091 |
| 4006_D00C | UART Extended Data Register (UART3_ED) | 8 | R | 00h | 45.3.13/1092 |
| 4006_D00D | UART Modem Register (UART3_MODEM) | 8 | R/W | 00h | 45.3.14/1093 |
| 4006_D00E | UART Infrared Register (UART3_IR) | 8 | R/W | 00h | 45.3.15/1094 |
| 4006_D010 | UART FIFO Parameters (UART3_PFIFO) | 8 | R/W | See section | 45.3.16/1095 |
| 4006_D011 | UART FIFO Control Register (UART3_CFIFO) | 8 | R/W | 00h | 45.3.17/1096 |
| 4006_D012 | UART FIFO Status Register (UART3_SFIFO) | 8 | R/W | C0h | 45.3.18/1097 |
| 4006_D013 | UART FIFO Transmit Watermark (UART3_TWFIFO) | 8 | R/W | 00h | 45.3.19/1098 |
| 4006_D014 | UART FIFO Transmit Count (UART3_TCFIFO) | 8 | R | 00h | 45.3.20/1099 |
| 4006_D015 | UART FIFO Receive Watermark (UART3_RWFIFO) | 8 | R/W | 01h | 45.3.21/1099 |
| 4006_D016 | UART FIFO Receive Count (UART3_RCFIFO) | 8 | R | 00h | 45.3.22/1100 |
| 4006_D018 | UART 7816 Control Register (UART3_C7816) | 8 | R/W | 00h | 45.3.23/1100 |
| 4006_D019 | UART 7816 Interrupt Enable Register (UART3_IE7816) | 8 | R/W | 00h | 45.3.24/1102 |
| 4006_D01A | UART 7816 Interrupt Status Register (UART3_IS7816) | 8 | R/W | 00h | 45.3.25/1103 |
| 4006_D01B | UART 7816 Wait Parameter Register (UART3_WP7816T0) | 8 | R/W | 0Ah | 45.3.26/1104 |
| 4006_D01B | UART 7816 Wait Parameter Register (UART3_WP7816T1) | 8 | R/W | 0Ah | 45.3.27/1105 |
| 4006_D01C | UART 7816 Wait N Register (UART3_WN7816) | 8 | R/W | 00h | 45.3.28/1105 |
| 4006_D01D | UART 7816 Wait FD Register (UART3_WF7816) | 8 | R/W | 01h | 45.3.29/1106 |
| 4006_D01E | UART 7816 Error Threshold Register (UART3_ET7816) | 8 | R/W | 00h | 45.3.30/1106 |
| 4006_D01F | UART 7816 Transmit Length Register (UART3_TL7816) | 8 | R/W | 00h | 45.3.31/1107 |

45.3.1 UART Baud Rate Registers: High (UARTx_BDH)

This register, along with the BDL register, controls the prescale divisor for UART baud rate generation. To update the 13-bit baud rate setting (SBR[12:0]), first write to BDH to buffer the high half of the new value and then write to BDL. The working value in BDH does not change until BDL is written.

BDL is reset to a nonzero value, but after reset, the baud rate generator remains disabled until the first time the receiver or transmitter is enabled, that is, when C2[RE] or C2[TE] is set.

Address: Base address + 0h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|--------|---------|---|-----|---|---|---|---|
| Read | LBKDIE | RXEDGIE | 0 | SBR | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_BDH field descriptions

| Field | Description |
|---------------|---|
| 7 LBKDIE | <p>LIN Break Detect Interrupt Enable</p> <p>Enables the LIN break detect flag, LBKDIF, to generate interrupt requests based on the state of LBKDDMAS.</p> <p>0 LBKDIF interrupt requests disabled. 1 LBKDIF interrupt requests enabled.</p> |
| 6 RXEDGIE | <p>RxD Input Active Edge Interrupt Enable</p> <p>Enables the receive input active edge, RXEDGIF, to generate interrupt requests.</p> <p>0 Hardware interrupts from RXEDGIF disabled using polling. 1 RXEDGIF interrupt request enabled.</p> |
| 5 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 4–0 SBR | <p>UART Baud Rate Bits</p> <p>The baud rate for the UART is determined by the 13 SBR fields. See Baud rate generation for details.</p> <p>NOTE:</p> <ul style="list-style-type: none"> The baud rate generator is disabled until C2[TE] or C2[RE] is set for the first time after reset. The baud rate generator is disabled when SBR = 0. Writing to BDH has no effect without writing to BDL, because writing to BDH puts the data in a temporary location until BDL is written. |

45.3.2 UART Baud Rate Registers: Low (UARTx_BDL)

This register, along with the BDH register, controls the prescale divisor for UART baud rate generation. To update the 13-bit baud rate setting, SBR[12:0], first write to BDH to buffer the high half of the new value and then write to BDL. The working value in BDH does not change until BDL is written. BDL is reset to a nonzero value, but after reset, the baud rate generator remains disabled until the first time the receiver or transmitter is enabled, that is, when C2[RE] or C2[TE] is set.

Address: Base address + 1h offset

| | | | | | | | | |
|-------|-----|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | SBR | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

UARTx_BDL field descriptions

| Field | Description |
|------------|--|
| 7–0 SBR | <p>UART Baud Rate Bits</p> <p>The baud rate for the UART is determined by the 13 SBR fields. See Baud rate generation for details.</p> <p>NOTE:</p> <ul style="list-style-type: none"> The baud rate generator is disabled until C2[TE] or C2[RE] is set for the first time after reset. The baud rate generator is disabled when SBR = 0. Writing to BDH has no effect without writing to BDL, because writing to BDH puts the data in a temporary location until BDL is written. When the 1/32 narrow pulse width is selected for infrared (IrDA), the baud rate fields must be even, the least significant bit is 0. See MODEM register for more details. |

45.3.3 UART Control Register 1 (UARTx_C1)

This read/write register controls various optional features of the UART system.

Address: Base address + 2h offset

| | | | | | | | | |
|-------|-------|----------|------|---|------|-----|----|----|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | LOOPS | UARTSWAI | RSRC | M | WAKE | ILT | PE | PT |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_C1 field descriptions

| Field | Description |
|------------|--|
| 7 LOOPS | <p>Loop Mode Select</p> <p>When LOOPS is set, the RxD pin is disconnected from the UART and the transmitter output is internally connected to the receiver input. The transmitter and the receiver must be enabled to use the loop function.</p> |

Table continues on the next page...

UARTx_C1 field descriptions (continued)

| Field | Description |
|---------------|--|
| | 0 Normal operation. 1 Loop mode where transmitter output is internally connected to receiver input. The receiver input is determined by RSRC. |
| 6 UARTSWAI | UART Stops in Wait Mode 0 UART clock continues to run in Wait mode. 1 UART clock freezes while CPU is in Wait mode. |
| 5 RSRC | Receiver Source Select This field has no meaning or effect unless the LOOPS field is set. When LOOPS is set, the RSRC field determines the source for the receiver shift register input. 0 Selects internal loop back mode. The receiver input is internally connected to transmitter output. 1 Single wire UART mode where the receiver input is connected to the transmit pin input signal. |
| 4 M | 9-bit or 8-bit Mode Select This field must be set when C7816[ISO_7816E] is set/enabled. 0 Normal—start + 8 data bits (MSB/LSB first as determined by MSBF) + stop. 1 Use—start + 9 data bits (MSB/LSB first as determined by MSBF) + stop. |
| 3 WAKE | Receiver Wakeup Method Select Determines which condition wakes the UART: <ul style="list-style-type: none"> Address mark in the most significant bit position of a received data character, or An idle condition on the receive pin input signal. 0 Idle line wakeup. 1 Address mark wakeup. |
| 2 ILT | Idle Line Type Select Determines when the receiver starts counting logic 1s as idle character bits. The count begins either after a valid start bit or after the stop bit. If the count begins after the start bit, then a string of logic 1s preceding the stop bit can cause false recognition of an idle character. Beginning the count after the stop bit avoids false idle character recognition, but requires properly synchronized transmissions. NOTE: <ul style="list-style-type: none"> In case the UART is programmed with ILT = 1, a logic of 1'b0 is automatically shifted after a received stop bit, therefore resetting the idle count. In case the UART is programmed for IDLE line wakeup (RWU = 1 and WAKE = 0), ILT has no effect on when the receiver starts counting logic 1s as idle character bits. In idle line wakeup, an idle character is recognized at anytime the receiver sees 10, 11, or 12 1s depending on the M, PE, and C4[M10] fields. 0 Idle character bit count starts after start bit. 1 Idle character bit count starts after stop bit. |
| 1 PE | Parity Enable Enables the parity function. When parity is enabled, parity function inserts a parity bit in the bit position immediately preceding the stop bit. This field must be set when C7816[ISO_7816E] is set/enabled. 0 Parity function disabled. 1 Parity function enabled. |

Table continues on the next page...

UARTx_C1 field descriptions (continued)

| Field | Description |
|---------|---|
| 0 PT | <p>Parity Type</p> <p>Determines whether the UART generates and checks for even parity or odd parity. With even parity, an even number of 1s clears the parity bit and an odd number of 1s sets the parity bit. With odd parity, an odd number of 1s clears the parity bit and an even number of 1s sets the parity bit. This field must be cleared when C7816[ISO_7816E] is set/enabled.</p> <p>0 Even parity. 1 Odd parity.</p> |

45.3.4 UART Control Register 2 (UARTx_C2)

This register can be read or written at any time.

Address: Base address + 3h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-----|------|-----|------|----|----|-----|-----|
| Read | TIE | TCIE | RIE | ILIE | TE | RE | RWU | SBK |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_C2 field descriptions

| Field | Description |
|-----------|--|
| 7 TIE | <p>Transmitter Interrupt or DMA Transfer Enable.</p> <p>Enables S1[TDRE] to generate interrupt requests or DMA transfer requests, based on the state of C5[TDMAS].</p> <p>NOTE: If C2[TIE] and C5[TDMAS] are both set, then TCIE must be cleared, and D[D] must not be written unless servicing a DMA request.</p> <p>0 TDRE interrupt and DMA transfer requests disabled. 1 TDRE interrupt or DMA transfer requests enabled.</p> |
| 6 TCIE | <p>Transmission Complete Interrupt Enable</p> <p>Enables the transmission complete flag, S1[TC], to generate interrupt requests .</p> <p>0 TC interrupt requests disabled. 1 TC interrupt requests enabled.</p> |
| 5 RIE | <p>Receiver Full Interrupt or DMA Transfer Enable</p> <p>Enables S1[RDRF] to generate interrupt requests or DMA transfer requests, based on the state of C5[RDMAS].</p> <p>0 RDRF interrupt and DMA transfer requests disabled. 1 RDRF interrupt or DMA transfer requests enabled.</p> |
| 4 ILIE | <p>Idle Line Interrupt Enable</p> <p>Enables the idle line flag, S1[IDLE], to generate interrupt requests</p> |

Table continues on the next page...

UARTx_C2 field descriptions (continued)

| Field | Description |
|----------|--|
| | 0 IDLE interrupt requests disabled. 1 IDLE interrupt requests enabled. |
| 3 TE | <p>Transmitter Enable</p> <p>Enables the UART transmitter. TE can be used to queue an idle preamble by clearing and then setting TE. When C7816[ISO_7816E] is set/enabled and C7816[TTYTYPE] = 1, this field is automatically cleared after the requested block has been transmitted. This condition is detected when TL7816[TLEN] = 0 and four additional characters are transmitted.</p> 0 Transmitter off. 1 Transmitter on. |
| 2 RE | <p>Receiver Enable</p> <p>Enables the UART receiver.</p> 0 Receiver off. 1 Receiver on. |
| 1 RWU | <p>Receiver Wakeup Control</p> <p>This field can be set to place the UART receiver in a standby state. RWU automatically clears when an RWU event occurs, that is, an IDLE event when C1[WAKE] is clear or an address match when C1[WAKE] is set. This field must be cleared when C7816[ISO_7816E] is set.</p> <p>NOTE: RWU must be set only with C1[WAKE] = 0 (wakeup on idle) if the channel is currently not idle. This can be determined by S2[RAF]. If the flag is set to wake up an IDLE event and the channel is already idle, it is possible that the UART will discard data. This is because the data must be received or a LIN break detected after an IDLE is detected before IDLE is allowed to reasserted.</p> 0 Normal operation. 1 RWU enables the wakeup function and inhibits further receiver interrupt requests. Normally, hardware wakes the receiver by automatically clearing RWU. |
| 0 SBK | <p>Send Break</p> <p>Toggling SBK sends one break character from the following: See Transmitting break characters for the number of logic 0s for the different configurations. Toggling implies clearing the SBK field before the break character has finished transmitting. As long as SBK is set, the transmitter continues to send complete break characters (10, 11, or 12 bits, or 13 or 14 bits). Ensure that C2[TE] is asserted atleast 1 clock before assertion of this bit.</p> <ul style="list-style-type: none"> 10, 11, or 12 logic 0s if S2[BRK13] is cleared 13 or 14 logic 0s if S2[BRK13] is set. <p>This field must be cleared when C7816[ISO_7816E] is set.</p> 0 Normal transmitter operation. 1 Queue break characters to be sent. |

45.3.5 UART Status Register 1 (UARTx_S1)

The S1 register provides inputs to the MCU for generation of UART interrupts or DMA requests. This register can also be polled by the MCU to check the status of its fields. To clear a flag, the status register should be read followed by a read or write to D register, depending on the interrupt flag type. Other instructions can be executed between the two steps as long the handling of I/O is not compromised, but the order of operations is important for flag clearing. When a flag is configured to trigger a DMA request, assertion of the associated DMA done signal from the DMA controller clears the flag.

NOTE

- If the condition that results in the assertion of the flag, interrupt, or DMA request is not resolved prior to clearing the flag, the flag, and interrupt/DMA request, reasserts. For example, if the DMA or interrupt service routine fails to write sufficient data to the transmit buffer to raise it above the watermark level, the flag reasserts and generates another interrupt or DMA request.
- Reading an empty data register to clear one of the flags of the S1 register causes the FIFO pointers to become misaligned. A receive FIFO flush reinitializes the pointers. A better way to prevent this situation is to always leave one byte in FIFO and this byte will be read eventually in clearing the flag bit.

Address: Base address + 4h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|----|------|------|----|----|----|----|
| Read | TDRE | TC | RDRF | IDLE | OR | NF | FE | PF |
| Write | | | | | | | | |
| Reset | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_S1 field descriptions

| Field | Description |
|-----------|---|
| 7 TDRE | <p>Transmit Data Register Empty Flag</p> <p>TDRE will set when the number of datawords in the transmit buffer (D and C3[T8]) is equal to or less than the number indicated by TWFIPO[TXWATER]. A character that is in the process of being transmitted is not included in the count. To clear TDRE, read S1 when TDRE is set and then write to the UART data register (D). For more efficient interrupt servicing, all data except the final value to be written to the buffer must be written to D/C3[T8]. Then S1 can be read before writing the final data value, resulting in the clearing of the TDRE flag. This is more efficient because the TDRE reasserts until the watermark has been exceeded. So, attempting to clear the TDRE with every write will be ineffective until sufficient data has been written.</p> |

Table continues on the next page...

UARTx_S1 field descriptions (continued)

| Field | Description |
|-----------|---|
| | <p>0 The amount of data in the transmit buffer is greater than the value indicated by TWFIPO[TXWATER].</p> <p>1 The amount of data in the transmit buffer is less than or equal to the value indicated by TWFIPO[TXWATER] at some point in time since the flag has been cleared.</p> |
| 6 TC | <p>Transmit Complete Flag</p> <p>TC is set when the transmit buffer is empty and no data, preamble, or break character is being transmitted. When TC is set, the transmit data output signal becomes idle (logic 1). TC is cleared by reading S1 with TC set and then doing one of the following: When C7816[ISO_7816E] is set/enabled, this field is set after any NACK signal has been received, but prior to any corresponding guard times expiring.</p> <ul style="list-style-type: none"> • Writing to D to transmit new data. • Queuing a preamble by clearing and then setting C2[TE]. • Queuing a break character by writing 1 to SBK in C2. <p>0 Transmitter active (sending data, a preamble, or a break).</p> <p>1 Transmitter idle (transmission activity complete).</p> |
| 5 RDRF | <p>Receive Data Register Full Flag</p> <p>RDRF is set when the number of datawords in the receive buffer is equal to or more than the number indicated by RWFIFO[RXWATER]. A dataword that is in the process of being received is not included in the count. To clear RDRF, read S1 when RDRF is set and then read D. For more efficient interrupt and DMA operation, read all data except the final value from the buffer, using D/C3[T8]/ED. Then read S1 and the final data value, resulting in the clearing of the RDRF flag. Even if RDRF is set, data will continue to be received until an overrun condition occurs. RDRF is prevented from setting while S2[LBKDE] is set. Additionally, when S2[LBKDE] is set, the received datawords are stored in the receive buffer but over-write each other.</p> <p>0 The number of datawords in the receive buffer is less than the number indicated by RXWATER.</p> <p>1 The number of datawords in the receive buffer is equal to or greater than the number indicated by RXWATER at some point in time since this flag was last cleared.</p> |
| 4 IDLE | <p>Idle Line Flag</p> <p>After the IDLE flag is cleared, a frame must be received (although not necessarily stored in the data buffer, for example if C2[RWU] is set), or a LIN break character must set the S2[LBKDIF] flag before an idle condition can set the IDLE flag. To clear IDLE, read UART status S1 with IDLE set and then read D. IDLE is set when either of the following appear on the receiver input:</p> <ul style="list-style-type: none"> • 10 consecutive logic 1s if C1[M] = 0 • 11 consecutive logic 1s if C1[M] = 1 and C4[M10] = 0 • 12 consecutive logic 1s if C1[M] = 1, C4[M10] = 1, and C1[PE] = 1 <p>Idle detection is not supported when 7816E is set/enabled and hence this flag is ignored.</p> <p>NOTE: When RWU is set and WAKE is cleared, an idle line condition sets the IDLE flag if RWUID is set, else the IDLE flag does not become set.</p> <p>0 Receiver input is either active now or has never become active since the IDLE flag was last cleared.</p> <p>1 Receiver input has become idle or the flag has not been cleared since it last asserted.</p> |
| 3 OR | <p>Receiver Overrun Flag</p> <p>OR is set when software fails to prevent the receive data register from overflowing with data. The OR bit is set immediately after the stop bit has been completely received for the dataword that overflows the buffer and all the other error flags (FE, NF, and PF) are prevented from setting. The data in the shift register is lost, but the data already in the UART data registers is not affected. If the OR flag is set, no data is stored in the data buffer even if sufficient room exists. Additionally, while the OR flag is set, the RDRF and IDLE flags are blocked from asserting, that is, transition from an inactive to an active state. To clear OR, read S1 when OR is set and then read D. See functional description for more details regarding the operation of</p> |

Table continues on the next page...

UARTx_S1 field descriptions (continued)

| Field | Description |
|---------|---|
| | <p>the OR bit.If LBKDE is enabled and a LIN Break is detected, the OR field asserts if S2[LBKDIF] is not cleared before the next data character is received. In 7816 mode, it is possible to configure a NACK to be returned by programing C7816[ONACK].</p> <p>0 No overrun has occurred since the last time the flag was cleared.</p> <p>1 Overrun has occurred or the overrun flag has not been cleared since the last overrun occurred.</p> |
| 2 NF | <p>Noise Flag</p> <p>NF is set when the UART detects noise on the receiver input. NF does not become set in the case of an overrun or while the LIN break detect feature is enabled (S2[LBKDE] = 1). When NF is set, it indicates only that a dataword has been received with noise since the last time it was cleared. There is no guarantee that the first dataword read from the receive buffer has noise or that there is only one dataword in the buffer that was received with noise unless the receive buffer has a depth of one. To clear NF, read S1 and then read D.</p> <p>0 No noise detected since the last time this flag was cleared. If the receive buffer has a depth greater than 1 then there may be data in the receiver buffer that was received with noise.</p> <p>1 At least one dataword was received with noise detected since the last time the flag was cleared.</p> |
| 1 FE | <p>Framing Error Flag</p> <p>FE is set when a logic 0 is accepted as the stop bit. FE does not set in the case of an overrun or while the LIN break detect feature is enabled (S2[LBKDE] = 1). FE inhibits further data reception until it is cleared. To clear FE, read S1 with FE set and then read D. The last data in the receive buffer represents the data that was received with the frame error enabled. Framing errors are not supported when 7816E is set/enabled. However, if this flag is set, data is still not received in 7816 mode.</p> <p>0 No framing error detected.</p> <p>1 Framing error.</p> |
| 0 PF | <p>Parity Error Flag</p> <p>PF is set when PE is set and the parity of the received data does not match its parity bit. The PF is not set in the case of an overrun condition. When PF is set, it indicates only that a dataword was received with parity error since the last time it was cleared. There is no guarantee that the first dataword read from the receive buffer has a parity error or that there is only one dataword in the buffer that was received with a parity error, unless the receive buffer has a depth of one. To clear PF, read S1 and then read D., S2[LBKDE] is disabled,Within the receive buffer structure the received dataword is tagged if it is received with a parity error. This information is available by reading the ED register prior to reading the D register.</p> <p>0 No parity error detected since the last time this flag was cleared. If the receive buffer has a depth greater than 1, then there may be data in the receive buffer what was received with a parity error.</p> <p>1 At least one dataword was received with a parity error since the last time this flag was cleared.</p> |

45.3.6 UART Status Register 2 (UARTx_S2)

The S2 register provides inputs to the MCU for generation of UART interrupts or DMA requests. Also, this register can be polled by the MCU to check the status of these bits. This register can be read or written at any time, with the exception of the MSBF and RXINV bits, which should be changed by the user only between transmit and receive packets.

Address: Base address + 5h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|--------|---------|------|-------|-------|-------|-------|-----|
| Read | LBKDIF | RXEDGIF | MSBF | RXINV | RWUID | BRK13 | LBKDE | RAF |
| Write | w1c | w1c | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_S2 field descriptions

| Field | Description |
|--------------|---|
| 7 LBKDIF | <p>LIN Break Detect Interrupt Flag</p> <p>LBKDIF is set when LBKDE is set and a LIN break character is detected on the receiver input. The LIN break characters are 11 consecutive logic 0s if C1[M] = 0 or 12 consecutive logic 0s if C1[M] = 1. LBKDIF is set after receiving the last LIN break character. LBKDIF is cleared by writing a 1 to it.</p> <p>0 No LIN break character detected. 1 LIN break character detected.</p> |
| 6 RXEDGIF | <p>RxD Pin Active Edge Interrupt Flag</p> <p>RXEDGIF is set when an active edge occurs on the RxD pin. The active edge is falling if RXINV = 0, and rising if RXINV=1. RXEDGIF is cleared by writing a 1 to it. See for additional details. RXEDGIF description</p> <p>NOTE: The active edge is detected only in two wire mode and on receiving data coming from the RxD pin.</p> <p>0 No active edge on the receive pin has occurred. 1 An active edge on the receive pin has occurred.</p> |
| 5 MSBF | <p>Most Significant Bit First</p> <p>Setting this field reverses the order of the bits that are transmitted and received on the wire. This field does not affect the polarity of the bits, the location of the parity bit, or the location of the start or stop bits. This field is automatically set when C7816[INIT] and C7816[ISO7816E] are enabled and an initial character is detected in T = 0 protocol mode.</p> <p>0 LSB (bit0) is the first bit that is transmitted following the start bit. Further, the first bit received after the start bit is identified as bit0. 1 MSB (bit8, bit7 or bit6) is the first bit that is transmitted following the start bit, depending on the setting of C1[M] and C1[PE]. Further, the first bit received after the start bit is identified as bit8, bit7, or bit6, depending on the setting of C1[M] and C1[PE].</p> |
| 4 RXINV | <p>Receive Data Inversion</p> |

Table continues on the next page...

UARTx_S2 field descriptions (continued)

| Field | Description |
|------------|--|
| | <p>Setting this field reverses the polarity of the received data input. In NRZ format, a one is represented by a mark and a zero is represented by a space for normal polarity, and the opposite for inverted polarity. In IrDA format, a zero is represented by short high pulse in the middle of a bit time remaining idle low for a one for normal polarity. A zero is represented by a short low pulse in the middle of a bit time remaining idle high for a one for inverted polarity. This field is automatically set when C7816[INIT] and C7816[ISO7816E] are enabled and an initial character is detected in T = 0 protocol mode.</p> <p>NOTE: Setting RXINV inverts the RxD input for data bits, start and stop bits, break, and idle. When C7816[ISO7816E] is set/enabled, only the data bits and the parity bit are inverted.</p> <p>0 Receive data is not inverted. 1 Receive data is inverted.</p> |
| 3 RWUID | <p>Receive Wakeup Idle Detect</p> <p>When RWU is set and WAKE is cleared, this field controls whether the idle character that wakes the receiver sets S1[IDLE]. This field must be cleared when C7816[ISO7816E] is set/enabled.</p> <p>0 S1[IDLE] is not set upon detection of an idle character. 1 S1[IDLE] is set upon detection of an idle character.</p> |
| 2 BRK13 | <p>Break Transmit Character Length</p> <p>Determines whether the transmit break character is 10, 11, or 12 bits long, or 13 or 14 bits long. See for the length of the break character for the different configurations. The detection of a framing error is not affected by this field. Transmitting break characters</p> <p>0 Break character is 10, 11, or 12 bits long. 1 Break character is 13 or 14 bits long.</p> |
| 1 LBKDE | <p>LIN Break Detection Enable</p> <p>Enables the LIN Break detection feature. While LBKDE is set, S1[RDRF], S1[NF], S1[FE], and S1[PF] are prevented from setting. When LBKDE is set, see . Overrun operation. LBKDE must be cleared when C7816[ISO7816E] is set.</p> <p>0 Break character detection is disabled. 1 Break character is detected at length of 11 bit times if C1[M] = 0 or 12 bits time if C1[M] = 1.</p> |
| 0 RAF | <p>Receiver Active Flag</p> <p>RAF is set when the UART receiver detects a logic 0 during the RT1 time period of the start bit search. RAF is cleared when the receiver detects an idle character when C7816[ISO7816E] is cleared/disabled. When C7816[ISO7816E] is enabled, the RAF is cleared if the C7816[TTYE] = 0 expires or the C7816[TTYE] = 1 expires.</p> <p>NOTE: In case C7816[ISO7816E] is set and C7816[TTYE] = 0, it is possible to configure the guard time to 12. However, if a NACK is required to be transmitted, the data transfer actually takes 13 ETU with the 13th ETU slot being an inactive buffer. Therefore, in this situation, the RAF may deassert one ETU prior to actually being inactive.</p> <p>0 UART receiver idle/inactive waiting for a start bit. 1 UART receiver active, RxD input not idle.</p> |

45.3.7 UART Control Register 3 (UARTx_C3)

Writing R8 does not have any effect. TXDIR and TXINV can be changed only between transmit and receive packets.

Address: Base address + 6h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|-------|-------|------|------|------|------|
| Read | R8 | T8 | TXDIR | TXINV | ORIE | NEIE | FEIE | PEIE |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_C3 field descriptions

| Field | Description |
|------------|--|
| 7 R8 | Received Bit 8 R8 is the ninth data bit received when the UART is configured for 9-bit data format, that is, if C1[M] = 1 or C4[M10] = 1. The R8 value corresponds to the current data value in the UARTx_D register. To read the 9th bit, read the value of UARTx_C3[R8], then read the UARTx_D register. |
| 6 T8 | Transmit Bit 8 T8 is the ninth data bit transmitted when the UART is configured for 9-bit data format, that is, if C1[M] = 1 or C4[M10] = 1. NOTE: If the value of T8 is the same as in the previous transmission, T8 does not have to be rewritten. The same value is transmitted until T8 is rewritten. To correctly transmit the 9th bit, write UARTx_C3[T8] to the desired value, then write the UARTx_D register with the remaining data. |
| 5 TXDIR | Transmitter Pin Data Direction in Single-Wire mode Determines whether the TXD pin is used as an input or output in the single-wire mode of operation. This field is relevant only to the single wire mode. When C7816[ISO7816E] is set/enabled and C7816[TTYTYPE] = 1, this field is automatically cleared after the requested block is transmitted. This condition is detected when TL7816[TLEN] = 0 and 4 additional characters are transmitted. Additionally, if C7816[ISO7816E] is set/enabled and C7816[TTYTYPE] = 0 and a NACK is being transmitted, the hardware automatically overrides this field as needed. In this situation, TXDIR does not reflect the temporary state associated with the NACK. 0 TXD pin is an input in single wire mode. 1 TXD pin is an output in single wire mode. |
| 4 TXINV | Transmit Data Inversion. Setting this field reverses the polarity of the transmitted data output. In NRZ format, a one is represented by a mark and a zero is represented by a space for normal polarity, and the opposite for inverted polarity. In IrDA format, a zero is represented by short high pulse in the middle of a bit time remaining idle low for a one for normal polarity, and a zero is represented by short low pulse in the middle of a bit time remaining idle high for a one for inverted polarity. This field is automatically set when C7816[INIT] and C7816[ISO7816E] are enabled and an initial character is detected in T = 0 protocol mode. NOTE: Setting TXINV inverts all transmitted values, including idle, break, start, and stop bits. In loop mode, if TXINV is set, the receiver gets the transmit inversion bit when RXINV is disabled. When C7816[ISO7816E] is set/enabled then only the transmitted data bits and parity bit are inverted. |

Table continues on the next page...

UARTx_C3 field descriptions (continued)

| Field | Description |
|-----------|--|
| | 0 Transmit data is not inverted. 1 Transmit data is inverted. |
| 3 ORIE | Overrun Error Interrupt Enable Enables the overrun error flag, S1[OR], to generate interrupt requests. 0 OR interrupts are disabled. 1 OR interrupt requests are enabled. |
| 2 NEIE | Noise Error Interrupt Enable Enables the noise flag, S1[NF], to generate interrupt requests. 0 NF interrupt requests are disabled. 1 NF interrupt requests are enabled. |
| 1 FEIE | Framing Error Interrupt Enable Enables the framing error flag, S1[FE], to generate interrupt requests. 0 FE interrupt requests are disabled. 1 FE interrupt requests are enabled. |
| 0 PEIE | Parity Error Interrupt Enable Enables the parity error flag, S1[PF], to generate interrupt requests. 0 PF interrupt requests are disabled. 1 PF interrupt requests are enabled. |

45.3.8 UART Data Register (UARTx_D)

This register is actually two separate registers. Reads return the contents of the read-only receive data register and writes go to the write-only transmit data register.

NOTE

- In 8-bit or 9-bit data format, only UART data register (D) needs to be accessed to clear the S1[RDRF] bit (assuming receiver buffer level is less than RWFIFO[RXWATER]). The C3 register needs to be read, prior to the D register, only if the ninth bit of data needs to be captured. Similarly, the ED register needs to be read, prior to the D register, only if the additional flag data for the dataword needs to be captured.
- In the normal 8-bit mode (M bit cleared) if the parity is enabled, you get seven data bits and one parity bit. That one parity bit is loaded into the D register. So, for the data

bits, mask off the parity bit from the value you read out of this register.

- When transmitting in 9-bit data format and using 8-bit write instructions, write first to transmit bit 8 in UART control register 3 (C3[T8]), then D. A write to C3[T8] stores the data in a temporary register. If D register is written first, and then the new data on data bus is stored in D, the temporary value written by the last write to C3[T8] gets stored in the C3[T8] register.

Address: Base address + 7h offset

| | | | | | | | | |
|-------|----|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | RT | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_D field descriptions

| Field | Description |
|-----------|--|
| 7–0 RT | Reads return the contents of the read-only receive data register and writes go to the write-only transmit data register. |

45.3.9 UART Match Address Registers 1 (UARTx_MA1)

The MA1 and MA2 registers are compared to input data addresses when the most significant bit is set and the associated C4[MAEN] field is set. If a match occurs, the following data is transferred to the data register. If a match fails, the following data is discarded. These registers can be read and written at anytime.

Address: Base address + 8h offset

| | | | | | | | | |
|-------|----|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | MA | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_MA1 field descriptions

| Field | Description |
|-----------|---------------|
| 7–0 MA | Match Address |

45.3.10 UART Match Address Registers 2 (UARTx_MA2)

These registers can be read and written at anytime. The MA1 and MA2 registers are compared to input data addresses when the most significant bit is set and the associated C4[MAEN] field is set. If a match occurs, the following data is transferred to the data register. If a match fails, the following data is discarded.

Address: Base address + 9h offset

| | | | | | | | | |
|-------|----|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | MA | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_MA2 field descriptions

| Field | Description |
|-----------|---------------|
| 7–0 MA | Match Address |

45.3.11 UART Control Register 4 (UARTx_C4)

Address: Base address + Ah offset

| | | | | | | | | |
|-------|-------|-------|-----|------|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | MAEN1 | MAEN2 | M10 | BRFA | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_C4 field descriptions

| Field | Description |
|------------|---|
| 7 MAEN1 | <p>Match Address Mode Enable 1</p> <p>See Match address operation for more information.</p> <p>0 All data received is transferred to the data buffer if MAEN2 is cleared.</p> <p>1 All data received with the most significant bit cleared, is discarded. All data received with the most significant bit set, is compared with contents of MA1 register. If no match occurs, the data is discarded. If match occurs, data is transferred to the data buffer. This field must be cleared when C7816[ISO7816E] is set/enabled.</p> |
| 6 MAEN2 | <p>Match Address Mode Enable 2</p> <p>See Match address operation for more information.</p> <p>0 All data received is transferred to the data buffer if MAEN1 is cleared.</p> <p>1 All data received with the most significant bit cleared, is discarded. All data received with the most significant bit set, is compared with contents of MA2 register. If no match occurs, the data is discarded. If a match occurs, data is transferred to the data buffer. This field must be cleared when C7816[ISO7816E] is set/enabled.</p> |

Table continues on the next page...

UARTx_C4 field descriptions (continued)

| Field | Description |
|-------------|---|
| 5 M10 | <p>10-bit Mode select</p> <p>Causes a tenth, non-memory mapped bit to be part of the serial transmission. This tenth bit is generated and interpreted as a parity bit. The M10 field does not affect the LIN send or detect break behavior. If M10 is set, then both C1[M] and C1[PE] must also be set. This field must be cleared when C7816[ISO7816E] is set/enabled.</p> <p>See Data format (non ISO-7816) for more information.</p> <p>0 The parity bit is the ninth bit in the serial transmission. 1 The parity bit is the tenth bit in the serial transmission.</p> |
| 4–0 BRFA | <p>Baud Rate Fine Adjust</p> <p>This bit field is used to add more timing resolution to the average baud frequency, in increments of 1/32. See Baud rate generation for more information.</p> |

45.3.12 UART Control Register 5 (UARTx_C5)

Address: Base address + Bh offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-------|---|-------|---|---|---|---|---|
| Read | TDMAS | 0 | RDMAS | 0 | 0 | 0 | 0 | 0 |
| Write | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_C5 field descriptions

| Field | Description |
|---------------|--|
| 7 TDMAS | <p>Transmitter DMA Select</p> <p>Configures the transmit data register empty flag, S1[TDRE], to generate interrupt or DMA requests if C2[TIE] is set.</p> <p>NOTE:</p> <ul style="list-style-type: none"> If C2[TIE] is cleared, TDRE DMA and TDRE interrupt request signals are not asserted when the TDRE flag is set, regardless of the state of TDMAS. If C2[TIE] and TDMAS are both set, then C2[TCIE] must be cleared, and D must not be written unless a DMA request is being serviced. <p>0 If C2[TIE] is set and the S1[TDRE] flag is set, the TDRE interrupt request signal is asserted to request interrupt service. 1 If C2[TIE] is set and the S1[TDRE] flag is set, the TDRE DMA request signal is asserted to request a DMA transfer.</p> |
| 6 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 5 RDMAS | <p>Receiver Full DMA Select</p> <p>Configures the receiver data register full flag, S1[RDRF], to generate interrupt or DMA requests if C2[RIE] is set.</p> <p>NOTE: If C2[RIE] is cleared, and S1[RDRF] is set, the RDRF DMA and RDRF interrupt request signals are not asserted, regardless of the state of RDMAS.</p> |

Table continues on the next page...

UARTx_C5 field descriptions (continued)

| Field | Description |
|-----------------|---|
| 0 | If C2[RIE] and S1[RDRF] are set, the RDRF interrupt request signal is asserted to request an interrupt service. |
| 1 | If C2[RIE] and S1[RDRF] are set, the RDRF DMA request signal is asserted to request a DMA transfer. |
| 4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

45.3.13 UART Extended Data Register (UARTx_ED)

This register contains additional information flags that are stored with a received dataword. This register may be read at any time but contains valid data only if there is a dataword in the receive FIFO.

NOTE

- The data contained in this register represents additional information regarding the conditions on which a dataword was received. The importance of this data varies with the application, and in some cases maybe completely optional. These fields automatically update to reflect the conditions of the next dataword whenever D is read.
- If S1[NF] and S1[PF] have not been set since the last time the receive buffer was empty, the NOISY and PARITYE fields will be zero.

Address: Base address + Ch offset

| | | | | | | | | |
|-------|-------|---------|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | NOISY | PARITYE | 0 | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_ED field descriptions

| Field | Description |
|--------------|--|
| 7 NOISY | The current received dataword contained in D and C3[R8] was received with noise. 0 The dataword was received without noise. 1 The data was received with noise. |
| 6 PARITYE | The current received dataword contained in D and C3[R8] was received with a parity error. 0 The dataword was received without a parity error. 1 The dataword was received with a parity error. |

Table continues on the next page...

UARTx_ED field descriptions (continued)

| Field | Description |
|-----------------|---|
| 5–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

45.3.14 UART Modem Register (UARTx_MODEM)

The MODEM register controls options for setting the modem configuration.

NOTE

RXRTSE, TXRTSPOL, TXRTSE, and TXCTSE must all be cleared when C7816[ISO7816EN] is enabled. This will cause the RTS to deassert during ISO-7816 wait times. The ISO-7816 protocol does not use the RTS and CTS signals.

Address: Base address + Dh offset

| | | | | | | | | |
|-------|---|---|---|---|--------|----------|--------|--------|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | RXRTSE | TXRTSPOL | TXRTSE | TXCTSE |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_MODEM field descriptions

| Field | Description |
|-----------------|--|
| 7–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3 RXRTSE | Receiver request-to-send enable Allows the RTS output to control the CTS input of the transmitting device to prevent receiver overrun. NOTE: Do not set both RXRTSE and TXRTSE. 0 The receiver has no effect on RTS. 1 RTS is deasserted if the number of characters in the receiver data register (FIFO) is equal to or greater than RWFIFO[RXWATER]. RTS is asserted when the number of characters in the receiver data register (FIFO) is less than RWFIFO[RXWATER]. |
| 2 TXRTSPOL | Transmitter request-to-send polarity Controls the polarity of the transmitter RTS. TXRTSPOL does not affect the polarity of the receiver RTS. RTS will remain negated in the active low state unless TXRTSE is set. 0 Transmitter RTS is active low. 1 Transmitter RTS is active high. |
| 1 TXRTSE | Transmitter request-to-send enable Controls RTS before and after a transmission. |

Table continues on the next page...

UARTx_MODEM field descriptions (continued)

| Field | Description |
|-------------|--|
| | <p>0 The transmitter has no effect on RTS.</p> <p>1 When a character is placed into an empty transmitter data buffer , RTS asserts one bit time before the start bit is transmitted. RTS deasserts one bit time after all characters in the transmitter data buffer and shift register are completely sent, including the last stop bit. (FIFO)(FIFO)</p> |
| 0 TXCTSE | <p>Transmitter clear-to-send enable</p> <p>TXCTSE controls the operation of the transmitter. TXCTSE can be set independently from the state of TXRTSE and RXRTSE.</p> <p>0 CTS has no effect on the transmitter.</p> <p>1 Enables clear-to-send operation. The transmitter checks the state of CTS each time it is ready to send a character. If CTS is asserted, the character is sent. If CTS is deasserted, the signal TXD remains in the mark state and transmission is delayed until CTS is asserted. Changes in CTS as a character is being sent do not affect its transmission.</p> |

45.3.15 UART Infrared Register (UARTx_IR)

The IR register controls options for setting the infrared configuration.

Address: Base address + Eh offset

| | | | | | | | | |
|-------|---|---|---|---|---|------|-----|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | | | IREN | TNP | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_IR field descriptions

| Field | Description |
|-----------------|---|
| 7–3 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 2 IREN | <p>Infrared enable</p> <p>Enables/disables the infrared modulation/demodulation.</p> <p>0 IR disabled.</p> <p>1 IR enabled.</p> |
| 1–0 TNP | <p>Transmitter narrow pulse</p> <p>Enables whether the UART transmits a 1/16, 3/16, 1/32, or 1/4 narrow pulse.</p> <p>00 3/16.</p> <p>01 1/16.</p> <p>10 1/32.</p> <p>11 1/4.</p> |

45.3.16 UART FIFO Parameters (UARTx_PFIFO)

This register provides the ability for the programmer to turn on and off FIFO functionality. It also provides the size of the FIFO that has been implemented. This register may be read at any time. This register must be written only when C2[RE] and C2[TE] are cleared/not set and when the data buffer/FIFO is empty.

Address: Base address + 10h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|---|------------|---|------|---|------------|---|
| Read | TXFE | | TXFIFOSIZE | | RXFE | | RXFIFOSIZE | |
| Write | | | | | | | | |
| Reset | 0 | * | * | * | 0 | * | * | * |

* Notes:

- TXFIFOSIZE field: The reset value depends on whether the specific UART instance supports the FIFO and on the size of that FIFO. See the Chip Configuration details for more information on the FIFO size supported for each UART instance.
- RXFIFOSIZE field: The reset value depends on whether the specific UART instance supports the FIFO and on the size of that FIFO. See the Chip Configuration details for more information on the FIFO size supported for each UART instance.

UARTx_PFIFO field descriptions

| Field | Description |
|-------------------|--|
| 7 TXFE | Transmit FIFO Enable When this field is set, the built in FIFO structure for the transmit buffer is enabled. The size of the FIFO structure is indicated by TXFIFOSIZE. If this field is not set, the transmit buffer operates as a FIFO of depth one dataword regardless of the value in TXFIFOSIZE. Both C2[TE] and C2[RE] must be cleared prior to changing this field. Additionally, TXFLUSH and RXFLUSH commands must be issued immediately after changing this field. 0 Transmit FIFO is not enabled. Buffer is depth 1. (Legacy support). 1 Transmit FIFO is enabled. Buffer is depth indicated by TXFIFOSIZE. |
| 6–4 TXFIFOSIZE | Transmit FIFO. Buffer Depth The maximum number of transmit datawords that can be stored in the transmit buffer. This field is read only. 000 Transmit FIFO/Buffer depth = 1 dataword. 001 Transmit FIFO/Buffer depth = 4 datawords. 010 Transmit FIFO/Buffer depth = 8 datawords. 011 Transmit FIFO/Buffer depth = 16 datawords. 100 Transmit FIFO/Buffer depth = 32 datawords. 101 Transmit FIFO/Buffer depth = 64 datawords. 110 Transmit FIFO/Buffer depth = 128 datawords. 111 Reserved. |
| 3 RXFE | Receive FIFO Enable |

Table continues on the next page...

UARTx_PFIFO field descriptions (continued)

| Field | Description |
|-------------------|---|
| | <p>When this field is set, the built in FIFO structure for the receive buffer is enabled. The size of the FIFO structure is indicated by the RXFIFOSIZE field. If this field is not set, the receive buffer operates as a FIFO of depth one dataword regardless of the value in RXFIFOSIZE. Both C2[TE] and C2[RE] must be cleared prior to changing this field. Additionally, TXFLUSH and RXFLUSH commands must be issued immediately after changing this field.</p> <p>0 Receive FIFO is not enabled. Buffer is depth 1. (Legacy support) 1 Receive FIFO is enabled. Buffer is depth indicted by RXFIFOSIZE.</p> |
| 2–0 RXFIFOSIZE | <p>Receive FIFO. Buffer Depth</p> <p>The maximum number of receive datawords that can be stored in the receive buffer before an overrun occurs. This field is read only.</p> <p>000 Receive FIFO/Buffer depth = 1 dataword. 001 Receive FIFO/Buffer depth = 4 datawords. 010 Receive FIFO/Buffer depth = 8 datawords. 011 Receive FIFO/Buffer depth = 16 datawords. 100 Receive FIFO/Buffer depth = 32 datawords. 101 Receive FIFO/Buffer depth = 64 datawords. 110 Receive FIFO/Buffer depth = 128 datawords. 111 Reserved.</p> |

45.3.17 UART FIFO Control Register (UARTx_CFIFO)

This register provides the ability to program various control fields for FIFO operation. This register may be read or written at any time. Note that writing to TXFLUSH and RXFLUSH may result in data loss and requires careful action to prevent unintended/unpredictable behavior. Therefore, it is recommended that TE and RE be cleared prior to flushing the corresponding FIFO.

Address: Base address + 11h offset

| | | | | | | | | |
|-------|---------|---------|---|---|---|-------|-------|-------|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | 0 | | 0 | | RXOFE | TXOFE | RXUFE |
| Write | TXFLUSH | RXFLUSH | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_CFIFO field descriptions

| Field | Description |
|--------------|--|
| 7 TXFLUSH | <p>Transmit FIFO/Buffer Flush</p> <p>Writing to this field causes all data that is stored in the transmit FIFO/buffer to be flushed. This does not affect data that is in the transmit shift register.</p> <p>0 No flush operation occurs. 1 All data in the transmit FIFO/Buffer is cleared out.</p> |

Table continues on the next page...

UARTx_CFIFO field descriptions (continued)

| Field | Description |
|-----------------|---|
| 6 RXFLUSH | Receive FIFO/Buffer Flush Writing to this field causes all data that is stored in the receive FIFO/buffer to be flushed. This does not affect data that is in the receive shift register. 0 No flush operation occurs. 1 All data in the receive FIFO/buffer is cleared out. |
| 5–3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 RXOFE | Receive FIFO Overflow Interrupt Enable When this field is set, the RXOF flag generates an interrupt to the host. 0 RXOF flag does not generate an interrupt to the host. 1 RXOF flag generates an interrupt to the host. |
| 1 TXOFE | Transmit FIFO Overflow Interrupt Enable When this field is set, the TXOF flag generates an interrupt to the host. 0 TXOF flag does not generate an interrupt to the host. 1 TXOF flag generates an interrupt to the host. |
| 0 RXUFE | Receive FIFO Underflow Interrupt Enable When this field is set, the RXUF flag generates an interrupt to the host. 0 RXUF flag does not generate an interrupt to the host. 1 RXUF flag generates an interrupt to the host. |

45.3.18 UART FIFO Status Register (UARTx_SFIFO)

This register provides status information regarding the transmit and receiver buffers/FIFOs, including interrupt information. This register may be written to or read at any time.

Address: Base address + 12h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|--------|--------|---|---|---|------|------|------|
| Read | TXEMPT | RXEMPT | 0 | | | RXOF | TXOF | RXUF |
| Write | | | | | | w1c | w1c | w1c |
| Reset | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_SFIFO field descriptions

| Field | Description |
|-------------|---|
| 7 TXEMPT | Transmit Buffer/FIFO Empty Asserts when there is no data in the Transmit FIFO/buffer. This field does not take into account data that is in the transmit shift register. |

Table continues on the next page...

UARTx_SFIFO field descriptions (continued)

| Field | Description |
|-----------------|---|
| | 0 Transmit buffer is not empty. 1 Transmit buffer is empty. |
| 6 RXEMPT | Receive Buffer/FIFO Empty Asserts when there is no data in the receive FIFO/Buffer. This field does not take into account data that is in the receive shift register. 0 Receive buffer is not empty. 1 Receive buffer is empty. |
| 5–3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 RXOF | Receiver Buffer Overflow Flag Indicates that more data has been written to the receive buffer than it can hold. This field will assert regardless of the value of CFIFO[RXOFE]. However, an interrupt will be issued to the host only if CFIFO[RXOFE] is set. This flag is cleared by writing a 1. 0 No receive buffer overflow has occurred since the last time the flag was cleared. 1 At least one receive buffer overflow has occurred since the last time the flag was cleared. |
| 1 TXOF | Transmitter Buffer Overflow Flag Indicates that more data has been written to the transmit buffer than it can hold. This field will assert regardless of the value of CFIFO[TXOFE]. However, an interrupt will be issued to the host only if CFIFO[TXOFE] is set. This flag is cleared by writing a 1. 0 No transmit buffer overflow has occurred since the last time the flag was cleared. 1 At least one transmit buffer overflow has occurred since the last time the flag was cleared. |
| 0 RXUF | Receiver Buffer Underflow Flag Indicates that more data has been read from the receive buffer than was present. This field will assert regardless of the value of CFIFO[RXUFE]. However, an interrupt will be issued to the host only if CFIFO[RXUFE] is set. This flag is cleared by writing a 1. 0 No receive buffer underflow has occurred since the last time the flag was cleared. 1 At least one receive buffer underflow has occurred since the last time the flag was cleared. |

45.3.19 UART FIFO Transmit Watermark (UARTx_TWFIFO)

This register provides the ability to set a programmable threshold for notification of needing additional transmit data. This register may be read at any time but must be written only when C2[TE] is not set. Changing the value of the watermark will not clear the S1[TDRE] flag.

Address: Base address + 13h offset

| | | | | | | | | |
|-------|---------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | TXWATER | | | | | | | |
| Write | | | | | | | | |
| Reset | | | | | | | | |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_TWFIFO field descriptions

| Field | Description |
|----------------|--|
| 7–0 TXWATER | <p>Transmit Watermark</p> <p>When the number of datawords in the transmit FIFO/buffer is equal to or less than the value in this register field, an interrupt via S1[TDRE] or a DMA request via C5[TDMAS] is generated as determined by C5[TDMAS] and C2[TIE]. For proper operation, the value in TXWATER must be set to be less than the size of the transmit buffer/FIFO size as indicated by PFIFO[TXFIFOSIZE] and PFIFO[TXFE].</p> |

45.3.20 UART FIFO Transmit Count (UARTx_TCFIFO)

This is a read only register that indicates how many datawords are currently in the transmit buffer/FIFO. It may be read at any time.

Address: Base address + 14h offset

| | | | | | | | | |
|-------|---------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | TXCOUNT | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_TCFIFO field descriptions

| Field | Description |
|----------------|--|
| 7–0 TXCOUNT | <p>Transmit Counter</p> <p>The value in this register indicates the number of datawords that are in the transmit FIFO/buffer. If a dataword is being transmitted, that is, in the transmit shift register, it is not included in the count. This value may be used in conjunction with PFIFO[TXFIFOSIZE] to calculate how much room is left in the transmit FIFO/buffer.</p> |

45.3.21 UART FIFO Receive Watermark (UARTx_RWFIFO)

This register provides the ability to set a programmable threshold for notification of the need to remove data from the receiver FIFO/buffer. This register may be read at any time but must be written only when C2[RE] is not asserted. Changing the value in this register will not clear S1[RDRF].

Address: Base address + 15h offset

| | | | | | | | | |
|-------|---------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | RXWATER | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

UARTx_RWFIFO field descriptions

| Field | Description |
|----------------|---|
| 7–0 RXWATER | <p>Receive Watermark</p> <p>When the number of datawords in the receive FIFO/buffer is equal to or greater than the value in this register field, an interrupt via S1[RDRF] or a DMA request via C5[RDMA5] is generated as determined by C5[RDMA5] and C2[RIE]. For proper operation, the value in RXWATER must be set to be less than the receive FIFO/buffer size as indicated by PFIFO[RXFIFOSIZE] and PFIFO[RXFE] and must be greater than 0.</p> |

45.3.22 UART FIFO Receive Count (UARTx_RCFIFO)

This is a read only register that indicates how many datawords are currently in the receive FIFO/buffer. It may be read at any time.

Address: Base address + 16h offset

| | | | | | | | | |
|-------|---------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | RXCOUNT | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_RCFIFO field descriptions

| Field | Description |
|----------------|---|
| 7–0 RXCOUNT | <p>Receive Counter</p> <p>The value in this register indicates the number of datawords that are in the receive FIFO/buffer. If a dataword is being received, that is, in the receive shift register, it is not included in the count. This value may be used in conjunction with PFIFO[RXFIFOSIZE] to calculate how much room is left in the receive FIFO/buffer.</p> |

45.3.23 UART 7816 Control Register (UARTx_C7816)

The C7816 register is the primary control register for ISO-7816 specific functionality. This register is specific to 7816 functionality and the values in this register have no effect on UART operation and should be ignored if ISO_7816E is not set/enabled. This register may be read at any time but values must be changed only when ISO_7816E is not set.

Address: Base address + 18h offset

| | | | | | | | | |
|-------|---|---|---|-------|-------|------|-------|-----------|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | 0 | | | ONACK | ANACK | INIT | TTYPE | ISO_7816E |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_C7816 field descriptions

| Field | Description |
|-----------------|--|
| 7–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 ONACK | Generate NACK on Overflow When this field is set, the receiver automatically generates a NACK response if a receive buffer overrun occurs, as indicated by S1[OR]. In many systems, this results in the transmitter resending the packet that overflowed until the retransmit threshold for that transmitter is reached. A NACK is generated only if TTYPE=0. This field operates independently of ANACK. See . Overflow NACK considerations 0 The received data does not generate a NACK when the receipt of the data results in an overflow event. 1 If the receiver buffer overflows, a NACK is automatically sent on a received character. |
| 3 ANACK | Generate NACK on Error When this field is set, the receiver automatically generates a NACK response if a parity error occurs or if INIT is set and an invalid initial character is detected. A NACK is generated only if TTYPE = 0. If ANACK is set, the UART attempts to retransmit the data indefinitely. To stop retransmission attempts, clear C2[TE] or ISO_7816E and do not set until S1[TC] sets C2[TE] again. 0 No NACK is automatically generated. 1 A NACK is automatically generated if a parity error is detected or if an invalid initial character is detected. |
| 2 INIT | Detect Initial Character When this field is set, all received characters are searched for a valid initial character. If an invalid initial character is identified, and ANACK is set, a NACK is sent. All received data is discarded and error flags blocked (S1[NF], S1[OR], S1[FE], S1[PF], IS7816[WT], IS7816[CWT], IS7816[BWT], IS7816[GTV]) until a valid initial character is detected. Upon detecting a valid initial character, the configuration values S2[MSBF], C3[TXINV], and S2[RXINV] are automatically updated to reflect the initial character that was received. The actual INIT data value is not stored in the receive buffer. Additionally, upon detection of a valid initial character, IS7816[INITD] is set and an interrupt issued as programmed by IE7816[INITDE]. When a valid initial character is detected, INIT is automatically cleared. This Initial Character Detect feature is supported only in T = 0 protocol mode. 0 Normal operating mode. Receiver does not seek to identify initial character. 1 Receiver searches for initial character. |
| 1 TTYPE | Transfer Type Indicates the transfer protocol being used. See ISO-7816 / smartcard support for more details. 0 T = 0 per the ISO-7816 specification. 1 T = 1 per the ISO-7816 specification. |
| 0 ISO_7816E | ISO-7816 Functionality Enabled Indicates that the UART is operating according to the ISO-7816 protocol. NOTE: This field must be modified only when no transmit or receive is occurring. If this field is changed during a data transfer, the data being transmitted or received may be transferred incorrectly. 0 ISO-7816 functionality is turned off/not enabled. 1 ISO-7816 functionality is turned on/enabled. |

45.3.24 UART 7816 Interrupt Enable Register (UARTx_IE7816)

The IE7816 register controls which flags result in an interrupt being issued. This register is specific to 7816 functionality, the corresponding flags that drive the interrupts are not asserted when 7816E is not set/enabled. However, these flags may remain set if they are asserted while 7816E was set and not subsequently cleared. This register may be read or written to at any time.

Address: Base address + 19h offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-----|------|------|--------|---|------|------|------|
| Read | WTE | CWTE | BWTE | INITDE | 0 | GTVE | TXTE | RXTE |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_IE7816 field descriptions

| Field | Description |
|---------------|---|
| 7 WTE | Wait Timer Interrupt Enable 0 The assertion of IS7816[WT] does not result in the generation of an interrupt. 1 The assertion of IS7816[WT] results in the generation of an interrupt. |
| 6 CWTE | Character Wait Timer Interrupt Enable 0 The assertion of IS7816[CWT] does not result in the generation of an interrupt. 1 The assertion of IS7816[CWT] results in the generation of an interrupt. |
| 5 BWTE | Block Wait Timer Interrupt Enable 0 The assertion of IS7816[BWT] does not result in the generation of an interrupt. 1 The assertion of IS7816[BWT] results in the generation of an interrupt. |
| 4 INITDE | Initial Character Detected Interrupt Enable 0 The assertion of IS7816[INITD] does not result in the generation of an interrupt. 1 The assertion of IS7816[INITD] results in the generation of an interrupt. |
| 3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 GTVE | Guard Timer Violated Interrupt Enable 0 The assertion of IS7816[GTV] does not result in the generation of an interrupt. 1 The assertion of IS7816[GTV] results in the generation of an interrupt. |
| 1 TXTE | Transmit Threshold Exceeded Interrupt Enable 0 The assertion of IS7816[TXT] does not result in the generation of an interrupt. 1 The assertion of IS7816[TXT] results in the generation of an interrupt. |
| 0 RXTE | Receive Threshold Exceeded Interrupt Enable 0 The assertion of IS7816[RXT] does not result in the generation of an interrupt. 1 The assertion of IS7816[RXT] results in the generation of an interrupt. |

45.3.25 UART 7816 Interrupt Status Register (UARTx_IS7816)

The IS7816 register provides a mechanism to read and clear the interrupt flags. All flags/interrupts are cleared by writing a 1 to the field location. Writing a 0 has no effect. All bits are "sticky", meaning they indicate that only the flag condition that occurred since the last time the bit was cleared, not that the condition currently exists. The status flags are set regardless of whether the corresponding field in the IE7816 is set or cleared. The IE7816 controls only if an interrupt is issued to the host processor. This register is specific to 7816 functionality and the values in this register have no affect on UART operation and should be ignored if 7816E is not set/enabled. This register may be read or written at anytime.

Address: Base address + 1Ah offset

| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|-----|-----|-----|-------|---|-----|-----|-----|
| Read | WT | CWT | BWT | INITD | 0 | GTV | TXT | RXT |
| Write | w1c | w1c | w1c | w1c | | w1c | w1c | w1c |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_IS7816 field descriptions

| Field | Description |
|------------|--|
| 7 WT | <p>Wait Timer Interrupt</p> <p>Indicates that the wait time, the time between the leading edge of a character being transmitted and the leading edge of the next response character, has exceeded the programmed value. This flag asserts only when C7816[TTYPE] = 0. This interrupt is cleared by writing 1.</p> <p>0 Wait time (WT) has not been violated. 1 Wait time (WT) has been violated.</p> |
| 6 CWT | <p>Character Wait Timer Interrupt</p> <p>Indicates that the character wait time, the time between the leading edges of two consecutive characters in a block, has exceeded the programmed value. This flag asserts only when C7816[TTYPE] = 1. This interrupt is cleared by writing 1.</p> <p>0 Character wait time (CWT) has not been violated. 1 Character wait time (CWT) has been violated.</p> |
| 5 BWT | <p>Block Wait Timer Interrupt</p> <p>Indicates that the block wait time, the time between the leading edge of first received character of a block and the leading edge of the last character the previously transmitted block, has exceeded the programmed value. This flag asserts only when C7816[TTYPE] = 1. This interrupt is cleared by writing 1.</p> <p>0 Block wait time (BWT) has not been violated. 1 Block wait time (BWT) has been violated.</p> |
| 4 INITD | <p>Initial Character Detected Interrupt</p> <p>Indicates that a valid initial character is received. This interrupt is cleared by writing 1.</p> |

Table continues on the next page...

UARTx_IS7816 field descriptions (continued)

| Field | Description |
|---------------|---|
| | 0 A valid initial character has not been received. 1 A valid initial character has been received. |
| 3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2 GTV | Guard Timer Violated Interrupt Indicates that one or more of the character guard time, block guard time, or guard time are violated. This interrupt is cleared by writing 1. 0 A guard time (GT, CGT, or BGT) has not been violated. 1 A guard time (GT, CGT, or BGT) has been violated. |
| 1 TXT | Transmit Threshold Exceeded Interrupt Indicates that the transmit NACK threshold has been exceeded as indicated by ET7816[TXTHRESHOLD]. Regardless of whether this flag is set, the UART continues to retransmit indefinitely. This flag asserts only when C7816[TTYPE] = 0. If 7816E is cleared/disabled, ANACK is cleared/disabled, C2[TE] is cleared/disabled, C7816[TTYPE] = 1, or packet is transferred without receiving a NACK, the internal NACK detection counter is cleared and the count restarts from zero on the next received NACK. This interrupt is cleared by writing 1. 0 The number of retries and corresponding NACKS does not exceed the value in ET7816[TXTHRESHOLD]. 1 The number of retries and corresponding NACKS exceeds the value in ET7816[TXTHRESHOLD]. |
| 0 RXT | Receive Threshold Exceeded Interrupt Indicates that there are more than ET7816[RXTHRESHOLD] consecutive NACKS generated in response to parity errors on received data. This flag requires ANACK to be set. Additionally, this flag asserts only when C7816[TTYPE] = 0. Clearing this field also resets the counter keeping track of consecutive NACKS. The UART will continue to attempt to receive data regardless of whether this flag is set. If 7816E is cleared/disabled, RE is cleared/disabled, C7816[TTYPE] = 1, or packet is received without needing to issue a NACK, the internal NACK detection counter is cleared and the count restarts from zero on the next transmitted NACK. This interrupt is cleared by writing 1. 0 The number of consecutive NACKS generated as a result of parity errors and buffer overruns is less than or equal to the value in ET7816[RXTHRESHOLD]. 1 The number of consecutive NACKS generated as a result of parity errors and buffer overruns is greater than the value in ET7816[RXTHRESHOLD]. |

45.3.26 UART 7816 Wait Parameter Register (UARTx_WP7816T0)

The WP7816 register contains constants used in the generation of various wait timer counters. To save register space, this register is used differently when C7816[TTYPE] = 0 and C7816[TTYPE] = 1. This register may be read at any time. This register must be written to only when C7816[ISO_7816E] is not set.

Address: Base address + 1Bh offset

| | | | | | | | | |
|-------|---|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

UARTx_WP7816T0 field descriptions

| Field | Description |
|-----------|--|
| 7–0 WI | Wait Time Integer (C7816[TTYPE] = 0) Used to calculate the value used for the WT counter. It represents a value between 1 and 255. The value of zero is not valid. This value is used only when C7816[TTYPE] = 0. See Wait time and guard time parameters . |

45.3.27 UART 7816 Wait Parameter Register (UARTx_WP7816T1)

The WP7816 register contains constants used in the generation of various wait timer counters. To save register space, this register is used differently when C7816[TTYPE] = 0 and C7816[TTYPE] = 1. This register may be read at any time. This register must be written to only when C7816[ISO_7816E] is not set.

Address: Base address + 1Bh offset

| | | | | | | | | |
|-------|---|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

UARTx_WP7816T1 field descriptions

| Field | Description |
|------------|--|
| 7–4 CWI | Character Wait Time Integer (C7816[TTYPE] = 1) Used to calculate the value used for the CWT counter. It represents a value between 0 and 15. This value is used only when C7816[TTYPE] = 1. See Wait time and guard time parameters . |
| 3–0 BWI | Block Wait Time Integer (C7816[TTYPE] = 1) Used to calculate the value used for the BWT counter. It represent a value between 0 and 15. This value is used only when C7816[TTYPE] = 1. See Wait time and guard time parameters . |

45.3.28 UART 7816 Wait N Register (UARTx_WN7816)

The WN7816 register contains a parameter that is used in the calculation of the guard time counter. This register may be read at any time. This register must be written to only when C7816[ISO_7816E] is not set.

Address: Base address + 1Ch offset

| | | | | | | | | |
|-------|---|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_WN7816 field descriptions

| Field | Description |
|------------|---|
| 7–0 GTN | Guard Band N Defines a parameter used in the calculation of GT, CGT, and BGT counters. The value represents an integer number between 0 and 255. See Wait time and guard time parameters . |

45.3.29 UART 7816 Wait FD Register (UARTx_WF7816)

The WF7816 contains parameters that are used in the generation of various counters including GT, CGT, BGT, WT, and BWT. This register may be read at any time. This register must be written to only when C7816[ISO_7816E] is not set.

Address: Base address + 1Dh offset

| | | | | | | | | |
|-------|------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | GTFD | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

UARTx_WF7816 field descriptions

| Field | Description |
|-------------|---|
| 7–0 GTFD | FD Multiplier Used as another multiplier in the calculation of WT and BWT. This value represents a number between 1 and 255. The value of 0 is invalid. This value is not used in baud rate generation. See Wait time and guard time parameters and Baud rate generation . |

45.3.30 UART 7816 Error Threshold Register (UARTx_ET7816)

The ET7816 register contains fields that determine the number of NACKs that must be received or transmitted before the host processor is notified. This register may be read at anytime. This register must be written to only when C7816[ISO_7816E] is not set.

Address: Base address + 1Eh offset

| | | | | | | | | |
|-------|-------------|---|---|---|-------------|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | TXTHRESHOLD | | | | RXTHRESHOLD | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_ET7816 field descriptions

| Field | Description |
|--------------------|---|
| 7–4 TXTHRESHOLD | Transmit NACK Threshold The value written to this field indicates the maximum number of failed attempts (NACKs) a transmitted character can have before the host processor is notified. This field is meaningful only when |

Table continues on the next page...

UARTx_ET7816 field descriptions (continued)

| Field | Description |
|--------------------|--|
| | <p>C7816[TTYPE] = 0 and C7816[ANACK] = 1. The value read from this field represents the number of consecutive NACKs that have been received since the last successful transmission. This counter saturates at 4'hF and does not wrap around. Regardless of how many NACKs that are received, the UART continues to retransmit indefinitely. This flag only asserts when C7816[TTYPE] = 0. For additional information see the IS7816[TXT] field description.</p> <p>0 TXT asserts on the first NACK that is received. 1 TXT asserts on the second NACK that is received.</p> |
| 3–0 RXTHRESHOLD | <p>Receive NACK Threshold</p> <p>The value written to this field indicates the maximum number of consecutive NACKs generated as a result of a parity error or receiver buffer overruns before the host processor is notified. After the counter exceeds that value in the field, the IS7816[RXT] is asserted. This field is meaningful only when C7816[TTYPE] = 0. The value read from this field represents the number of consecutive NACKs that have been transmitted since the last successful reception. This counter saturates at 4'hF and does not wrap around. Regardless of the number of NACKs sent, the UART continues to receive valid packets indefinitely. For additional information, see IS7816[RXT] field description.</p> |

45.3.31 UART 7816 Transmit Length Register (UARTx_TL7816)

The TL7816 register is used to indicate the number of characters contained in the block being transmitted. This register is used only when C7816[TTYPE] = 1. This register may be read at anytime. This register must be written only when C2[TE] is not enabled.

Address: Base address + 1Fh offset

| | | | | | | | | |
|-------|------|---|---|---|---|---|---|---|
| Bit | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| Read | TLEN | | | | | | | |
| Write | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

UARTx_TL7816 field descriptions

| Field | Description |
|-------------|--|
| 7–0 TLEN | <p>Transmit Length</p> <p>This value plus four indicates the number of characters contained in the block being transmitted. This register is automatically decremented by 1 for each character in the information field portion of the block. Additionally, this register is automatically decremented by 1 for the first character of a CRC in the epilogue field. Therefore, this register must be programmed with the number of bytes in the data packet if an LRC is being transmitted, and the number of bytes + 1 if a CRC is being transmitted. This register is not decremented for characters that are assumed to be part of the Prologue field, that is, the first three characters transmitted in a block, or the LRC or last CRC character in the Epilogue field, that is, the last character transmitted. This field must be programed or adjusted only when C2[TE] is cleared.</p> |

45.4 Functional description

This section provides a complete functional description of the UART block.

The UART allows full duplex, asynchronous, NRZ serial communication between the CPU and remote devices, including other CPUs. The UART transmitter and receiver operate independently, although they use the same baud rate generator. The CPU monitors the status of the UART, writes the data to be transmitted, and processes received data.

45.4.1 Transmitter

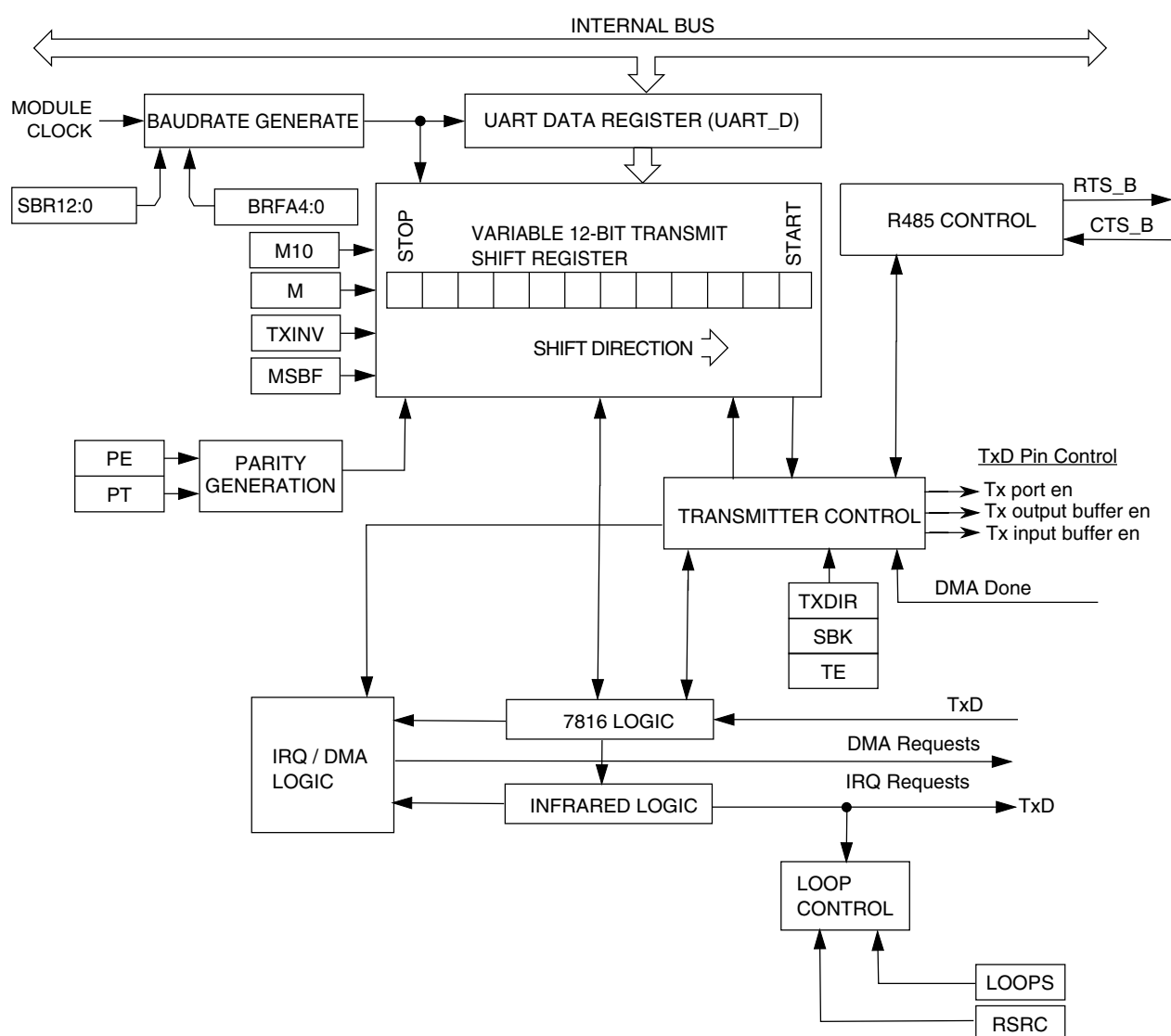


Figure 45-156. Transmitter Block Diagram

45.4.1.1 Transmitter character length

The UART transmitter can accommodate either 8, 9, or 10-bit data characters. The state of the C1[M] and C1[PE] bits and the C4[M10] bit determine the length of data characters. When transmitting 9-bit data, bit C3[T8] is the ninth bit (bit 8).

45.4.1.2 Transmission bit order

When S2[MSBF] is set, the UART automatically transmits the MSB of the data word as the first bit after the start bit. Similarly, the LSB of the data word is transmitted immediately preceding the parity bit, or the stop bit if parity is not enabled. All necessary bit ordering is handled automatically by the module. Therefore, the format of the data written to D for transmission is completely independent of the S2[MSBF] setting.

45.4.1.3 Character transmission

To transmit data, the MCU writes the data bits to the UART transmit buffer using UART data registers C3[T8] and D. Data in the transmit buffer is then transferred to the transmitter shift register as needed. The transmit shift register then shifts a frame out through the transmit data output signal after it has prefaced it with any required start and stop bits. The UART data registers, C3[T8] and D, provide access to the transmit buffer structure.

The UART also sets a flag, the transmit data register empty flag S1[TDRE], and generates an interrupt or DMA request (C5[TDMAS]) whenever the number of datawords in the transmit buffer is equal to or less than the value indicated by TWFIPO[TXWATER]. The transmit driver routine may respond to this flag by writing additional datawords to the transmit buffer using C3[T8]/D as space permits.

See [Application information](#) for specific programming sequences.

Setting C2[TE] automatically loads the transmit shift register with the following preamble:

- 10 logic 1s if C1[M] = 0
- 11 logic 1s if C1[M] = 1 and C4[M10] = 0
- 12 logic 1s if C1[M] = 1, C4[M10] = 1, C1[PE] = 1

After the preamble shifts out, control logic transfers the data from the D register into the transmit shift register. The transmitter automatically transmits the correct start bit and stop bit before and after the dataword.

When C7816[ISO_7816E] = 1, setting C2[TE] does not result in a preamble being generated. The transmitter starts transmitting as soon as the corresponding guard time expires. When C7816[TTYTYPE] = 0, the value in GT is used. When C7816[TTYTYPE] = 1, the value in BGT is used, because C2[TE] will remain asserted until the end of the block transfer. C2[TE] is automatically cleared when C7816[TTYTYPE] = 1 and the block being transmitted has completed. When C7816[TTYTYPE] = 0, the transmitter listens for a NACK indication. If no NACK is received, it is assumed that the character was correctly received. If a NACK is received, the transmitter resends the data, assuming that the number of retries for that character, that is, the number of NACKs received, is less than or equal to the value in ET7816[TXTHRESHOLD].

Hardware supports odd or even parity. When parity is enabled, the bit immediately preceding the stop bit is the parity bit.

When the transmit shift register is not transmitting a frame, the transmit data output signal goes to the idle condition, logic 1. If at any time software clears C2[TE], the transmitter enable signal goes low and the transmit signal goes idle.

If the software clears C2[TE] while a transmission is in progress, the character in the transmit shift register continues to shift out, provided S1[TC] was cleared during the data write sequence. To clear S1[TC], the S1 register must be read followed by a write to D register.

If S1[TC] is cleared during character transmission and C2[TE] is cleared, the transmission enable signal is deasserted at the completion of the current frame. Following this, the transmit data out signal enters the idle state even if there is data pending in the UART transmit data buffer. To ensure that all the data written in the FIFO is transmitted on the link before clearing C2[TE], wait for S1[TC] to set. Alternatively, the same can be achieved by setting TWFIFO[TXWATER] to 0x0 and waiting for S1[TDRE] to set.

45.4.1.4 Transmitting break characters

Setting C2[SBK] loads the transmit shift register with a break character. A break character contains all logic 0s and has no start, stop, or parity bit. Break character length depends on C1[M], C1[PE], S2[BRK13] and C4[M10]. See the following table.

Table 45-163. Transmit break character length

| S2[BRK13] | C1[M] | C4[M10] | C1[PE] | Bits transmitted |
|-----------|-------|---------|--------|------------------|
| 0 | 0 | — | — | 10 |
| 0 | 1 | 1 | 0 | 11 |
| 0 | 1 | 1 | 1 | 12 |
| 1 | 0 | — | — | 13 |
| 1 | 1 | — | — | 14 |

As long as C2[SBK] is set, the transmitter logic continuously loads break characters into the transmit shift register. After the software clears C2[SBK], the shift register finishes transmitting the last break character and then transmits at least one logic 1. The automatic logic 1 at the end of a break character guarantees the recognition of the start bit of the next character. Break bits are not supported when C7816[ISO_7816E] is set/enabled.

NOTE

When queuing a break character, it will be transmitted following the completion of the data value currently being shifted out from the shift register. This means that, if data is queued in the data buffer to be transmitted, the break character preempts that queued data. The queued data is then transmitted after the break character is complete.

45.4.1.5 Idle characters

An idle character contains all logic 1s and has no start, stop, or parity bit. Idle character length depends on C1[M], C1[PE] and C4[M10]. The preamble is a synchronizing idle character that begins the first transmission initiated after setting C2[TE]. When C7816[ISO_7816E] is set/enabled, idle characters are not sent or detected. When data is not being transmitted, the data I/O line is in an inactive state.

If C2[TE] is cleared during a transmission, the transmit data output signal becomes idle after completion of the transmission in progress. Clearing and then setting C2[TE] during a transmission queues an idle character to be sent after the dataword currently being transmitted.

Note

When queuing an idle character, the idle character will be transmitted following the completion of the data value currently being shifted out from the shift register. This means that if data is queued in the data buffer to be transmitted, the idle character preempts that queued data. The queued data is then transmitted after the idle character is complete.

If C2[TE] is cleared and the transmission is completed, the UART is not the master of the TXD pin.

45.4.1.6 Hardware flow control

The transmitter supports hardware flow control by gating the transmission with the value of CTS. If the clear-to-send operation is enabled, the character is transmitted when CTS is asserted. If CTS is deasserted in the middle of a transmission with characters remaining in the receiver data buffer, the character in the shift register is sent and TXD remains in the mark state until CTS is reasserted.

If the clear-to-send operation is disabled, the transmitter ignores the state of CTS. Also, if the transmitter is forced to send a continuous low condition because it is sending a break character, the transmitter ignores the state of CTS regardless of whether the clear-to-send operation is enabled.

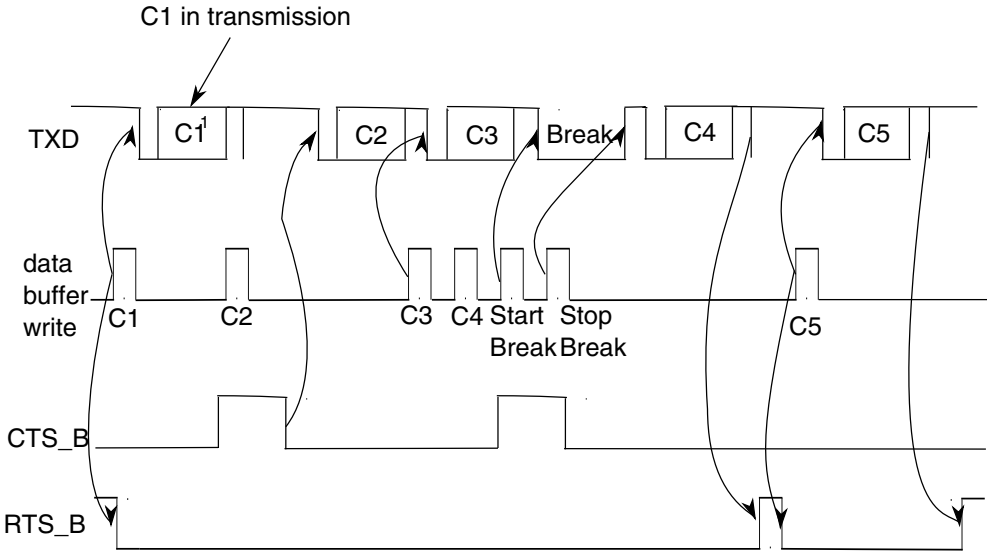
The transmitter's CTS signal can also be enabled even if the same UART receiver's RTS signal is disabled.

45.4.1.7 Transceiver driver enable

The transmitter can use RTS as an enable signal for the driver of an external transceiver. See [Transceiver driver enable using RTS](#) for details. If the request-to-send operation is enabled, when a character is placed into an empty transmitter data buffer, RTS asserts one bit time before the start bit is transmitted. RTS remains asserted for the whole time that the transmitter data buffer has any characters. RTS deasserts one bit time after all characters in the transmitter data buffer and shift register are completely sent, including the last stop bit. Transmitting a break character also asserts RTS, with the same assertion and deassertion timing as having a character in the transmitter data buffer.

The transmitter's RTS signal asserts only when the transmitter is enabled. However, the transmitter's RTS signal is unaffected by its CTS signal. RTS will remain asserted until the transfer is completed, even if the transmitter is disabled mid-way through a data transfer.

The following figure shows the functional timing information for the transmitter. Along with the actual character itself, TXD shows the start bit. The stop bit is also indicated, with a dashed line if necessary.



1. Cn = transmit characters

Figure 45-157. Transmitter RTS and CTS timing diagram

45.4.2 Receiver

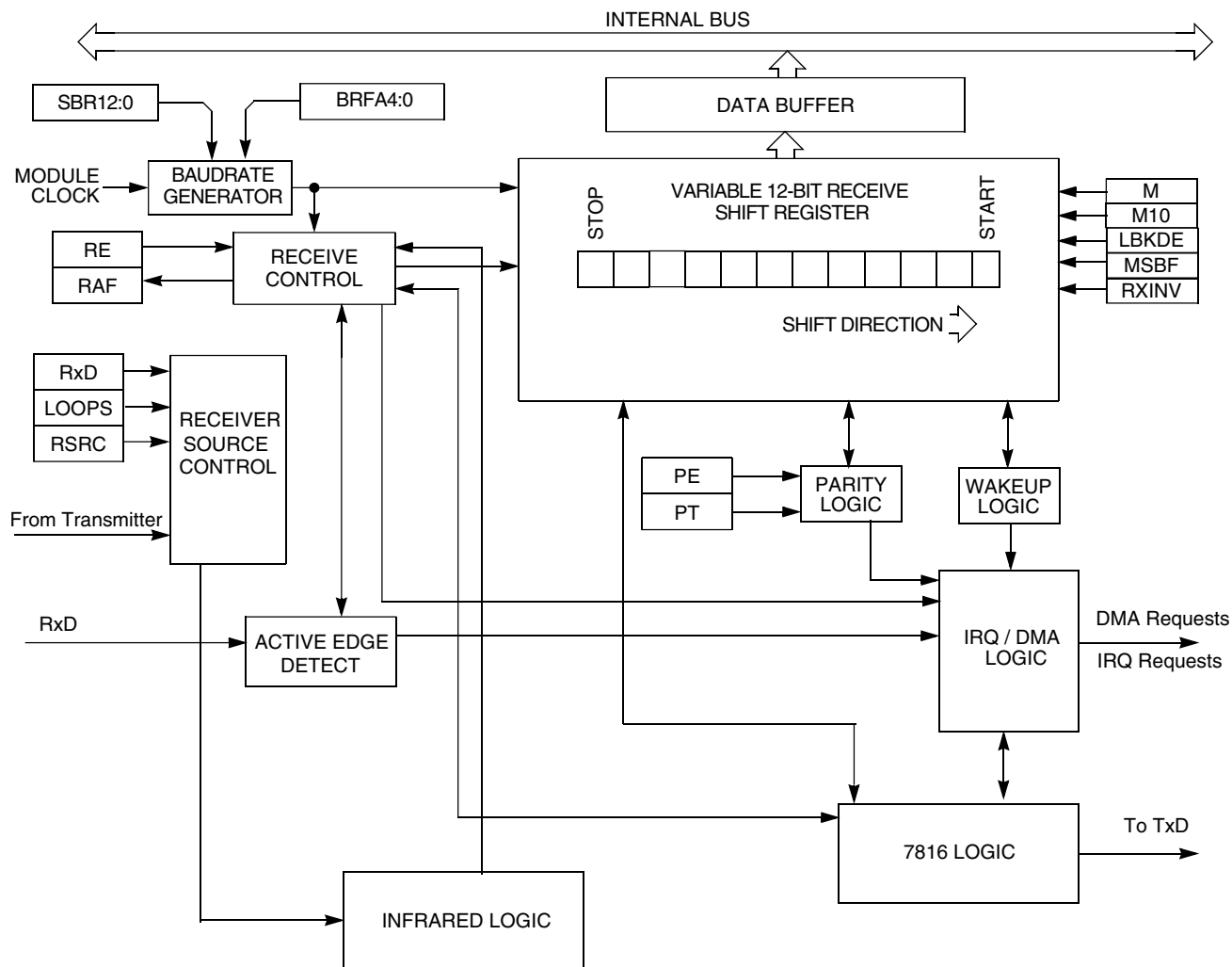


Figure 45-158. UART receiver block diagram

45.4.2.1 Receiver character length

The UART receiver can accommodate 8-, 9-, or 10-bit data characters. The states of C1[M], C1[PE] and C4[M10] determine the length of data characters. When receiving 9 or 10-bit data, C3[R8] is the ninth bit (bit 8).

45.4.2.2 Receiver bit ordering

When S2[MSBF] is set, the receiver operates such that the first bit received after the start bit is the MSB of the dataword. Similarly, the bit received immediately preceding the parity bit, or the stop bit if parity is not enabled, is treated as the LSB for the dataword. All necessary bit ordering is handled automatically by the module. Therefore, the format of the data read from receive data buffer is completely independent of S2[MSBF].

45.4.2.3 Character reception

During UART reception, the receive shift register shifts a frame in from the unsynchronized receiver input signal. After a complete frame shifts into the receive shift register, the data portion of the frame transfers to the UART receive buffer. Additionally, the noise and parity error flags that are calculated during the receive process are also captured in the UART receive buffer. The receive data buffer is accessible via the D and C3[T8] registers. Additional received information flags regarding the receive dataword can be read in ED register. S1[RDRF] is set if the number of resulting datawords in the receive buffer is equal to or greater than the number indicated by RWFIFO[RXWATER]. If the C2[RIE] is also set, RDRF generates an RDRF interrupt request. Alternatively, by programming C5[RDMAS], a DMA request can be generated.

When C7816[ISO_7816E] is set/enabled and C7816[TTYTYPE] = 0, character reception operates slightly differently. Upon receipt of the parity bit, the validity of the parity bit is checked. If C7816[ANACK] is set and the parity check fails, or if INIT and the received character is not a valid initial character, then a NACK is sent by the receiver. If the number of consecutive receive errors exceeds the threshold set by ET7816[RXTHRESHOLD], then IS7816[RXT] is set and an interrupt generated if IE7816[RXTE] is set. If an error is detected due to parity or an invalid initial character, the data is not transferred from the receive shift register to the receive buffer. Instead, the data is overwritten by the next incoming data.

When the C7816[ISO_7816E] is set/enabled, C7816[ONACK] is set/enabled, and the received character results in the receive buffer overflowing, a NACK is issued by the receiver. Additionally, S1[OR] is set and an interrupt is issued if required, and the data in the shift register is discarded.

45.4.2.4 Data sampling

The receiver samples the unsynchronized receiver input signal at the RT clock rate. The RT clock is an internal signal with a frequency 16 times the baud rate. To adjust for baud rate mismatch, the RT clock (see the following figure) is re-synchronized:

- After every start bit.
- After the receiver detects a data bit change from logic 1 to logic 0 (after the majority of data bit samples at RT8, RT9, and RT10 returns a valid logic 1 and the majority of the next RT8, RT9, and RT10 samples returns a valid logic 0).

To locate the start bit, data recovery logic does an asynchronous search for a logic 0 preceded by three logic 1s. When the falling edge of a possible start bit occurs, the RT clock begins to count to 16.

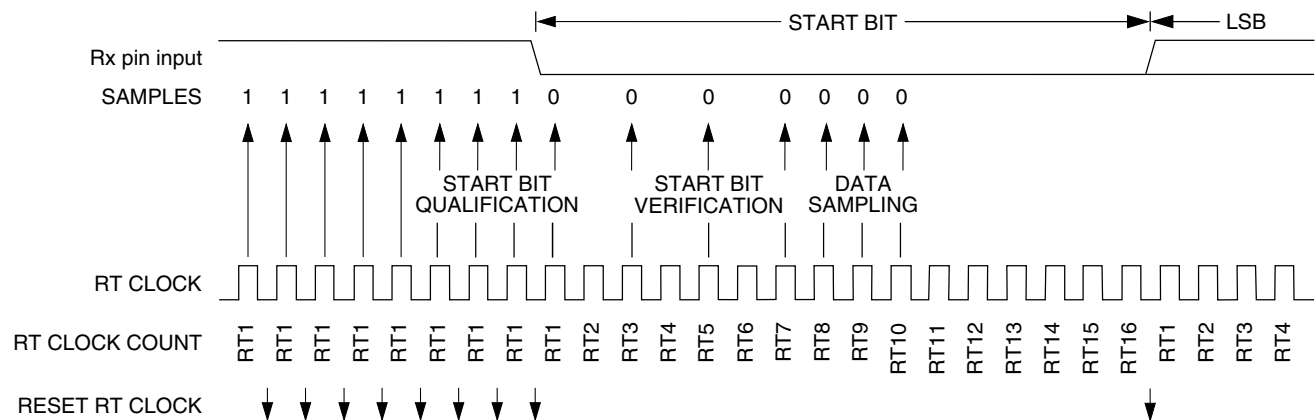


Figure 45-159. Receiver data sampling

To verify the start bit and to detect noise, data recovery logic takes samples at RT3, RT5, and RT7 when C7816[ISO_7816E] is cleared/disabled and RT8, RT9 and RT10 when C7816[ISO_7816E] is set/enabled. The following table summarizes the results of the start bit verification samples.

Table 45-164. Start bit verification

| RT3, RT5, and RT7 samples RT8, RT9, RT10 samples when 7816E | Start bit verification | Noise flag |
|--|------------------------|------------|
| 000 | Yes | 0 |
| 001 | Yes | 1 |
| 010 | Yes | 1 |
| 011 | No | 0 |
| 100 | Yes | 1 |
| 101 | No | 0 |
| 110 | No | 0 |
| 111 | No | 0 |

If start bit verification is not successful, the RT clock is reset and a new search for a start bit begins.

To determine the value of a data bit and to detect noise, recovery logic takes samples at RT8, RT9, and RT10. The following table summarizes the results of the data bit samples.

Table 45-165. Data bit recovery

| RT8, RT9, and RT10 samples | Data bit determination | Noise flag |
|----------------------------|------------------------|------------|
| 000 | 0 | 0 |
| 001 | 0 | 1 |
| 010 | 0 | 1 |
| 011 | 1 | 1 |
| 100 | 0 | 1 |
| 101 | 1 | 1 |
| 110 | 1 | 1 |
| 111 | 1 | 0 |

Note

The RT8, RT9, and RT10 samples do not affect start bit verification. If any or all of the RT8, RT9, and RT10 start bit samples are logic 1s following a successful start bit verification, the noise flag (S1[NF]) is set and the receiver assumes that the bit is a start bit (logic 0). With the exception of when C7816[ISO_7816E] is set/enabled, where the values of RT8, RT9 and RT10 exclusively determine if a start bit exists.

To verify a stop bit and to detect noise, recovery logic takes samples at RT8, RT9, and RT10. The following table summarizes the results of the stop bit samples. In the event that C7816[ISO_7816E] is set/enabled and C7816[TTYTYPE] = 0, verification of a stop bit does not take place. Rather, starting with RT8 the receiver transmits a NACK as programmed until time RT9 of the following time period. Framing Error detection is not supported when C7816[ISO_7816E] is set/enabled.

Table 45-166. Stop bit recovery

| RT8, RT9, and RT10 samples | Framing error flag | Noise flag |
|----------------------------|--------------------|------------|
| 000 | 1 | 0 |
| 001 | 1 | 1 |
| 010 | 1 | 1 |
| 011 | 0 | 1 |
| 100 | 1 | 1 |
| 101 | 0 | 1 |
| 110 | 0 | 1 |
| 111 | 0 | 0 |

In the following figure, the verification samples RT3 and RT5 determine that the first low detected was noise and not the beginning of a start bit. In this example $C7816[ISO_7816E] = 0$. The RT clock is reset and the start bit search begins again. The noise flag is not set because the noise occurred before the start bit was found.

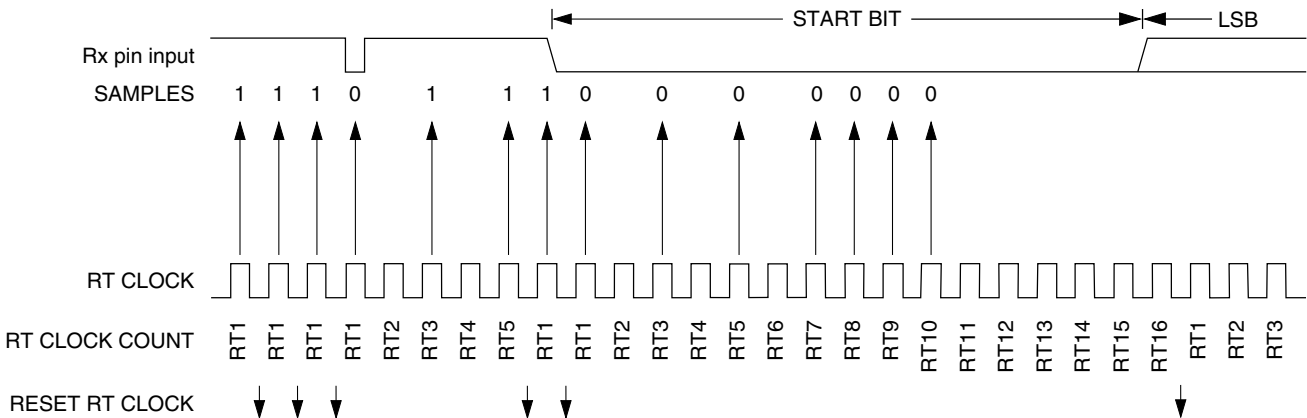


Figure 45-160. Start bit search example 1 ($C7816[ISO_7816E] = 0$)

In the following figure, verification sample at RT3 is high. In this example $C7816[ISO_7816E] = 0$. The RT3 sample sets the noise flag. Although the perceived bit time is misaligned, the data samples RT8, RT9, and RT10 are within the bit time and data recovery is successful.

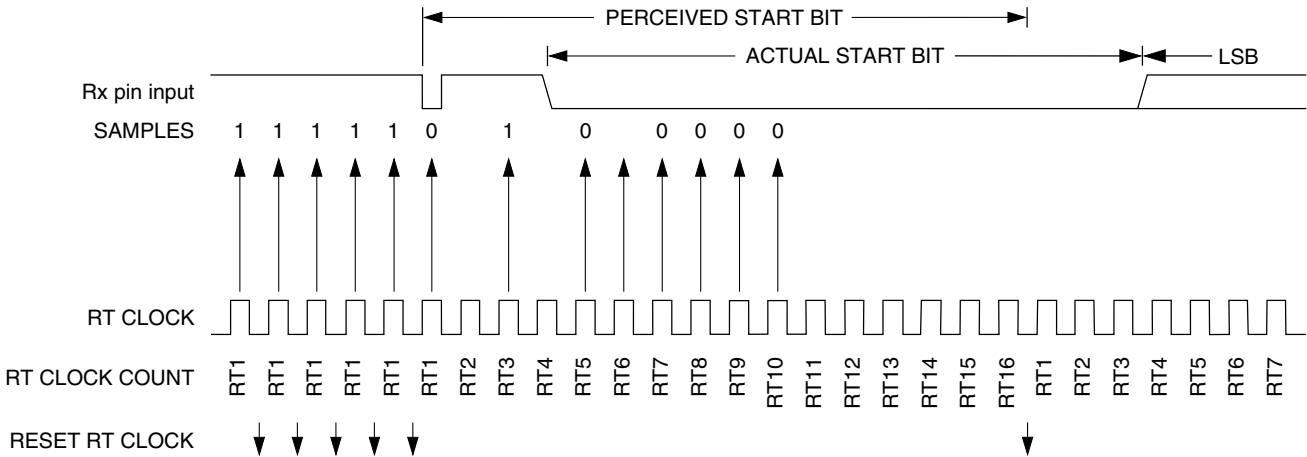


Figure 45-161. Start bit search example 2 ($C7816[ISO_7816E] = 0$)

In the following figure, a large burst of noise is perceived as the beginning of a start bit, although the test sample at RT5 is high. In this example $C7816[ISO_7816E] = 0$. The RT5 sample sets the noise flag. Although this is a worst-case misalignment of perceived bit time, the data samples RT8, RT9, and RT10 are within the bit time and data recovery is successful.

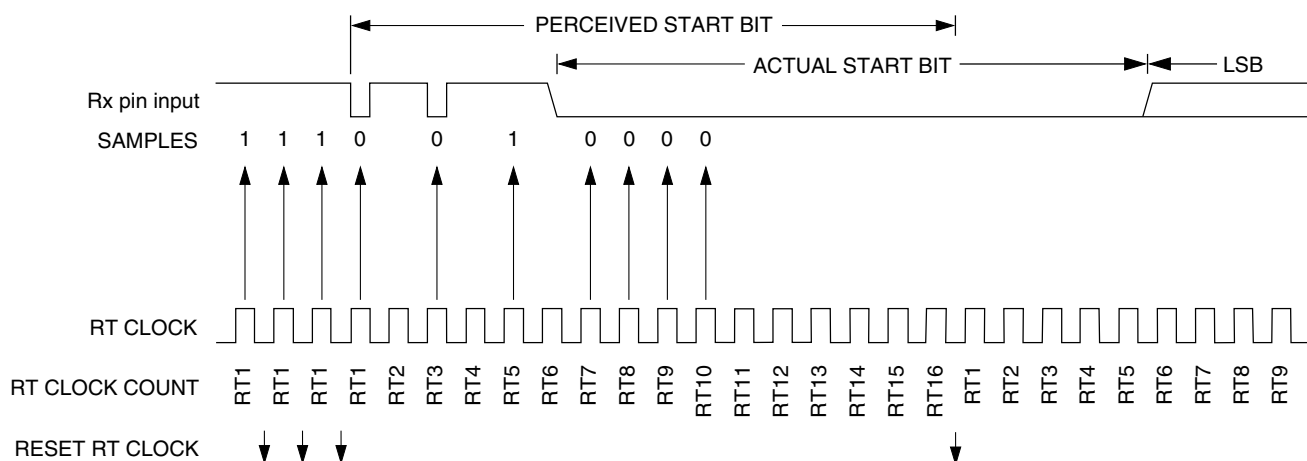


Figure 45-162. Start bit search example 3 (C7816[ISO_7816E] = 0)

The following figure shows the effect of noise early in the start bit time. In this example C7816[ISO_7816E] = 0. Although this noise does not affect proper synchronization with the start bit time, it does set the noise flag.

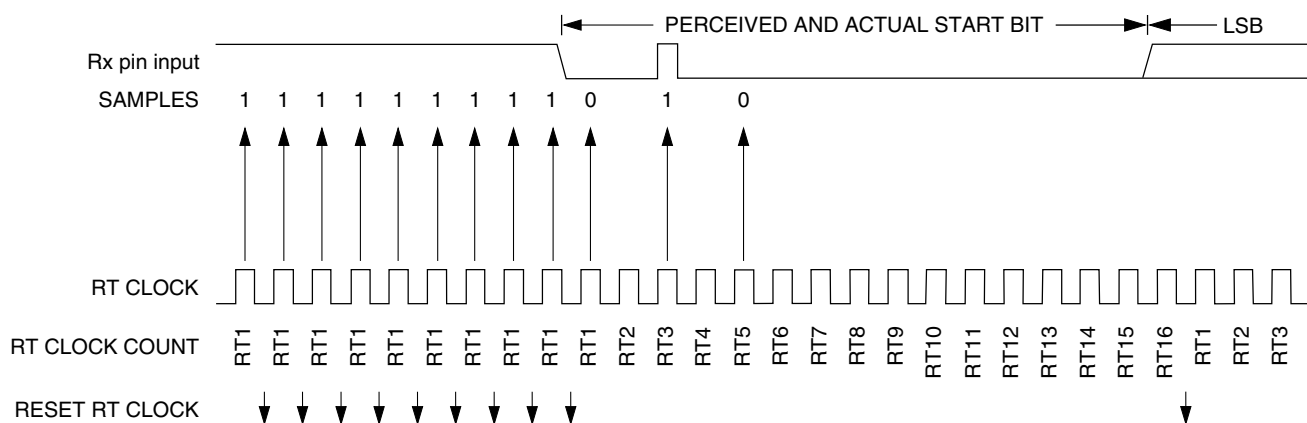


Figure 45-163. Start bit search example 4 (C7816[ISO_7816E] = 0)

The following figure shows a burst of noise near the beginning of the start bit that resets the RT clock. In this example C7816[ISO_7816E] = 0. The sample after the reset is low but is not preceded by three high samples that would qualify as a falling edge. Depending on the timing of the start bit search and on the data, the frame may be missed entirely or it may set the framing error flag.

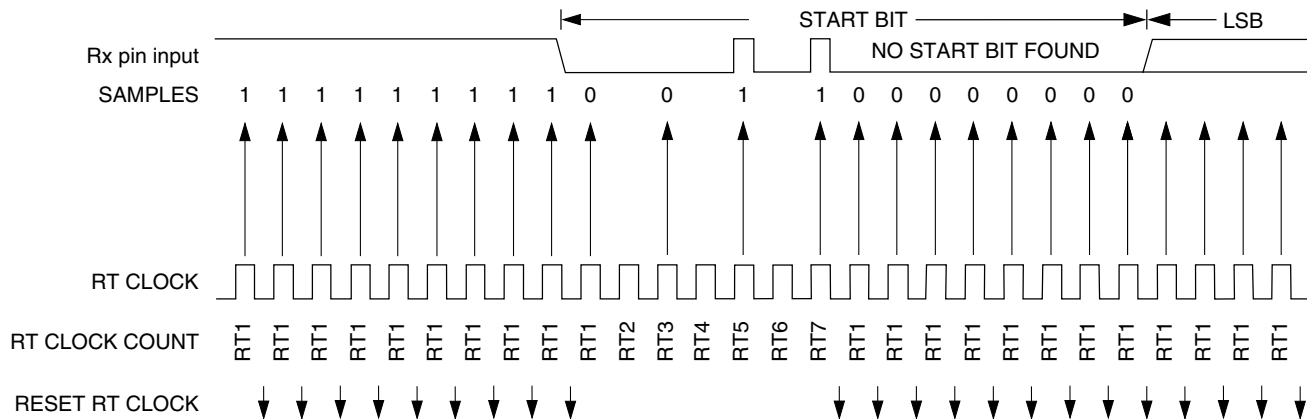


Figure 45-164. Start bit search example 5 (C7816[ISO_7816E] = 0)

In the following figure, a noise burst makes the majority of data samples RT8, RT9, and RT10 high. In this example C7816[ISO_7816E] = 0. This sets the noise flag but does not reset the RT clock. In start bits only, the RT8, RT9, and RT10 data samples are ignored. In this example, if C7816[ISO_7816E] = 1 then a start bit would not have been detected at all since at least two of the three samples (RT8, RT9, RT10) were high.

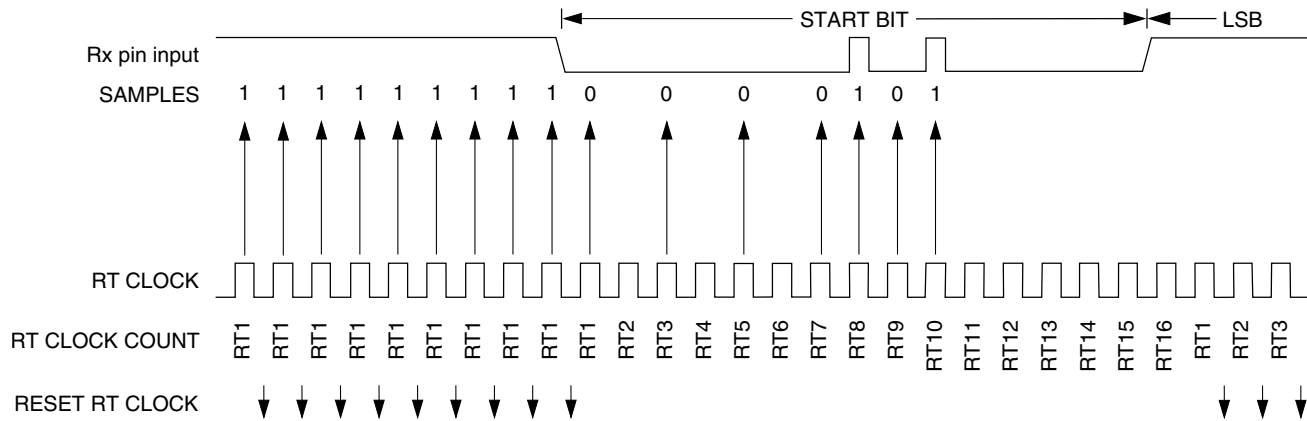


Figure 45-165. Start bit search example 6

45.4.2.5 Framing errors

If the data recovery logic does not detect a logic 1 where the stop bit should be in an incoming frame, it sets the framing error flag, S1[FE], if S2[LBKDE] is disabled. When S2[LBKDE] is disabled, a break character also sets the S1[FE] because a break character has no stop bit. S1[FE] is set at the same time that received data is placed in the receive data buffer. Framing errors are not supported when C7816[ISO7816E] is set/enabled. However, if S1[FE] is set, data will not be received when C7816[ISO7816E] is set.

45.4.2.6 Receiving break characters

The UART recognizes a break character when a start bit is followed by eight, nine, or ten logic 0 data bits and a logic 0 where the stop bit should be. Receiving a break character has these effects on UART registers:

- Sets the framing error flag, S1[FE].
- Writes an all 0 dataword to the data buffer, which may cause S1[RDRF] to set, depending on the watermark and number of values in the data buffer.
- May set the overrun flag, S1[OR], noise flag, S1[NF], parity error flag, S1[PE], or the receiver active flag, S2[RAF].

The detection threshold for a break character can be adjusted when using an internal oscillator in a LIN system by setting S2[LBKDE]. The UART break character detection threshold depends on C1[M], C1[PE], S2[LBKDE] and C4[M10]. See the following table.

Table 45-167. Receive break character detection threshold

| LBKDE | M | M10 | PE | Threshold (bits) |
|-------|---|-----|----|------------------|
| 0 | 0 | — | — | 10 |
| 0 | 1 | 0 | — | 11 |
| 0 | 1 | 1 | 1 | 12 |
| 1 | 0 | — | — | 11 |
| 1 | 1 | — | — | 12 |

While S2[LBKDE] is set, it will have these effects on the UART registers:

- Prevents S1[RDRF], S1[FE], S1[NF], and S1[PF] from being set. However, if they are already set, they will remain set.
- Sets the LIN break detect interrupt flag, S2[LBKDIF], if a LIN break character is received.

Break characters are not detected or supported when C7816[ISO_7816E] is set/enabled.

45.4.2.7 Hardware flow control

To support hardware flow control, the receiver can be programmed to automatically deassert and assert RTS.

- RTS remains asserted until the transfer is complete, even if the transmitter is disabled midway through a data transfer. See [Transceiver driver enable using RTS](#) for more details.
- If the receiver request-to-send functionality is enabled, the receiver automatically deasserts RTS if the number of characters in the receiver data register is equal to or greater than receiver data buffer's watermark, RWFIFO[RXWATER].
- The receiver asserts RTS when the number of characters in the receiver data register is less than the watermark. It is not affected if RDRF is asserted.
- Even if RTS is deasserted, the receiver continues to receive characters until the receiver data buffer is full or is overrun.
- If the receiver request-to-send functionality is disabled, the receiver RTS remains deasserted.

The following figure shows receiver hardware flow control functional timing. Along with the actual character itself, RXD shows the start bit. The stop bit can also be indicated, with a dashed line, if necessary. The watermark is set to 2.

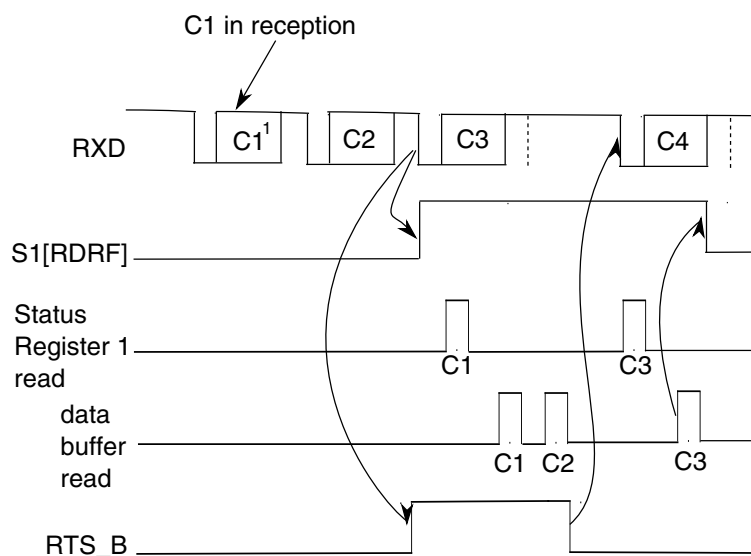


Figure 45-166. Receiver hardware flow control timing diagram

45.4.2.8 Infrared decoder

The infrared decoder converts the received character from the IrDA format to the NRZ format used by the receiver. It also has a 16-RT clock counter that filters noise and indicates when a 1 is received.

45.4.2.8.1 Start bit detection

When S2[RXINV] is cleared, the first rising edge of the received character corresponds to the start bit. The infrared decoder resets its counter. At this time, the receiver also begins its start bit detection process. After the start bit is detected, the receiver synchronizes its bit times to this start bit time. For the rest of the character reception, the infrared decoder's counter and the receiver's bit time counter count independently from each other.

45.4.2.8.2 Noise filtering

Any further rising edges detected during the first half of the infrared decoder counter are ignored by the decoder. Any pulses less than one RT clocks can be undetected by it regardless of whether it is seen in the first or second half of the count.

45.4.2.8.3 Low-bit detection

During the second half of the decoder count, a rising edge is decoded as a 0, which is sent to the receiver. The decoder counter is also reset.

45.4.2.8.4 High-bit detection

At 16-RT clocks after the previous rising edge, if a rising edge is not seen, then the decoder sends a 1 to the receiver.

If the next bit is a 0, which arrives late, then a low-bit is detected according to [Low-bit detection](#). The value sent to the receiver is changed from 1 to a 0. Then, if a noise pulse occurs outside the receiver's bit time sampling period, then the delay of a 0 is not recorded as noise.

45.4.2.9 Baud rate tolerance

A transmitting device may be operating at a baud rate below or above the receiver baud rate. Accumulated bit time misalignment can cause one of the three stop bit data samples (RT8, RT9, and RT10) to fall outside the actual stop bit. A noise error will occur if the RT8, RT9, and RT10 samples are not all the same logical values. A framing error will occur if the receiver clock is misaligned in such a way that the majority of the RT8, RT9, and RT10 stop bit samples are a logic 0.

As the receiver samples an incoming frame, it resynchronizes the RT clock on any valid falling edge within the frame. Resynchronization within frames corrects a misalignment between transmitter bit times and receiver bit times.

45.4.2.9.1 Slow data tolerance

The following figure shows how much a slow received frame can be misaligned without causing a noise error or a framing error. The slow stop bit begins at RT8 instead of RT1 but arrives in time for the stop bit data samples at RT8, RT9, and RT10.

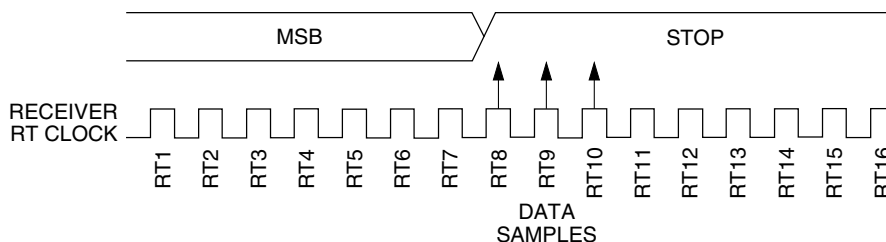


Figure 45-167. Slow data

For an 8-bit data character, data sampling of the stop bit takes the receiver 154 RT cycles (9 bit times \times 16 RT cycles + 10 RT cycles).

With the misaligned character shown in the [Figure 45-167](#), the receiver counts 154 RT cycles at the point when the count of the transmitting device is 147 RT cycles (9 bit times \times 16 RT cycles + 3 RT cycles).

The maximum percent difference between the receiver count and the transmitter count of a slow 8-bit data character with no errors is:

$$((154 - 147) \div 154) \times 100 = 4.54\%$$

For a 9-bit data character, data sampling of the stop bit takes the receiver 170 RT cycles (10 bit times \times 16 RT cycles + 10 RT cycles).

With the misaligned character shown in the [Figure 45-167](#), the receiver counts 170 RT cycles at the point when the count of the transmitting device is 163 RT cycles (10 bit times \times 16 RT cycles + 3 RT cycles).

The maximum percent difference between the receiver count and the transmitter count of a slow 9-bit character with no errors is:

$$((170 - 163) \div 170) \times 100 = 4.12\%$$

45.4.2.9.2 Fast data tolerance

The following figure shows how much a fast received frame can be misaligned. The fast stop bit ends at RT10 instead of RT16 but is still sampled at RT8, RT9, and RT10.

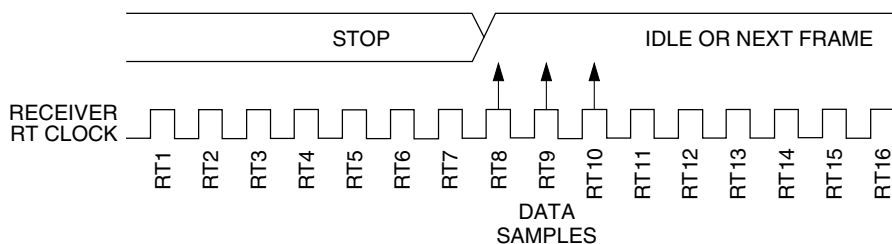


Figure 45-168. Fast data

For an 8-bit data character, data sampling of the stop bit takes the receiver 154 RT cycles (9 bit times \times 16 RT cycles + 10 RT cycles).

With the misaligned character shown in the [Figure 45-168](#), the receiver counts 154 RT cycles at the point when the count of the transmitting device is 160 RT cycles (10 bit times \times 16 RT cycles).

The maximum percent difference between the receiver count and the transmitter count of a fast 8-bit character with no errors is:

$$((154 - 160) \div 154) \times 100 = 3.90\%$$

For a 9-bit data character, data sampling of the stop bit takes the receiver 170 RT cycles (10 bit times \times 16 RT cycles + 10 RT cycles).

With the misaligned character shown in the [Figure 45-168](#), the receiver counts 170 RT cycles at the point when the count of the transmitting device is 176 RT cycles (11 bit times \times 16 RT cycles).

The maximum percent difference between the receiver count and the transmitter count of a fast 9-bit character with no errors is:

$$((170 - 176) \div 170) \times 100 = 3.53\%$$

45.4.2.10 Receiver wakeup

C1[WAKE] determines how the UART is brought out of the standby state to process an incoming message. C1[WAKE] enables either idle line wakeup or address mark wakeup.

Receiver wakeup is not supported when C7816[ISO_7816E] is set/enabled because multi-receiver systems are not allowed.

45.4.2.10.1 Idle input line wakeup (C1[WAKE] = 0)

In this wakeup method, an idle condition on the unsynchronized receiver input signal clears C2[RWU] and wakes the UART. The initial frame or frames of every message contain addressing information. All receivers evaluate the addressing information, and

receivers for which the message is addressed process the frames that follow. Any receiver for which a message is not addressed can set its C2[RWU] and return to the standby state. C2[RWU] remains set and the receiver remains in standby until another idle character appears on the unsynchronized receiver input signal.

Idle line wakeup requires that messages be separated by at least one idle character and that no message contains idle characters.

When C2[RWU] is 1 and S2[RWUID] is 0, the idle character that wakes the receiver does not set S1[IDLE] or the receive data register full flag, S1[RDRF]. The receiver wakes and waits for the first data character of the next message which is stored in the receive data buffer. When S2[RWUID] and C2[RWU] are set and C1[WAKE] is cleared, any idle condition sets S1[IDLE] and generates an interrupt if enabled.

Idle input line wakeup is not supported when C7816[ISO_7816E] is set/enabled.

45.4.2.10.2 Address mark wakeup (C1[WAKE] = 1)

In this wakeup method, a logic 1 in the bit position immediately preceding the stop bit of a frame clears C2[RWU] and wakes the UART. A logic 1 in the bit position immediately preceding the stop bit marks a frame as an address frame that contains addressing information. All receivers evaluate the addressing information, and the receivers for which the message is addressed process the frames that follow. Any receiver for which a message is not addressed can set its C2[RWU] and return to the standby state. C2[RWU] remains set and the receiver remains in standby until another address frame appears on the unsynchronized receiver input signal.

A logic 1 in the bit position immediately preceding the stop bit clears the receiver's C2[RWU] after the stop bit is received and places the received data into the receiver data buffer. Note that if Match Address operation is enabled i.e. C4[MAEN1] or C4[MAEN2] is set, then received frame is transferred to receive buffer only if the comparison matches.

Address mark wakeup allows messages to contain idle characters but requires that the bit position immediately preceding the stop bit be reserved for use in address frames.

If module is in standby mode and nothing triggers to wake the UART, no error flag is set even if an invalid error condition is detected on the receiving data line.

Address mark wakeup is not supported when C7816[ISO_7816E] is set/enabled.

45.4.2.10.3 Match address operation

Match address operation is enabled when C4[MAEN1] or C4[MAEN2] is set. In this function, a frame received by the RX pin with a logic 1 in the bit position of the address mark is considered an address and is compared with the associated MA1 or MA2 register.

The frame is transferred to the receive buffer, and S1[RDRF] is set, only if the comparison matches. All subsequent frames received with a logic 0 in the bit position of the address mark are considered to be data associated with the address and are transferred to the receive data buffer. If no marked address match occurs, then no transfer is made to the receive data buffer, and all following frames with logic 0 in the bit position of the address mark are also discarded. If both C4[MAEN1] and C4[MAEN2] are negated, the receiver operates normally and all data received is transferred to the receive data buffer.

Match address operation functions in the same way for both MA1 and MA2 registers. Note that the position of the address mark is the same as the Parity Bit when parity is enabled for 8 bit and 9 bit data formats.

- If only one of C4[MAEN1] and C4[MAEN2] is asserted, a marked address is compared only with the associated match register and data is transferred to the receive data buffer only on a match.
- If C4[MAEN1] and C4[MAEN2] are asserted, a marked address is compared with both match registers and data is transferred only on a match with either register.

Address match operation is not supported when C7816[ISO_7816E] is set/enabled.

45.4.3 Baud rate generation

A 13-bit modulus counter and a 5-bit fractional fine-adjust counter in the baud rate generator derive the baud rate for both the receiver and the transmitter. The value from 1 to 8191 written to SBR[12:0] determines the module clock divisor. The SBR bits are in the UART baud rate registers, BDH and BDL. The baud rate clock is synchronized with the module clock and drives the receiver. The fractional fine-adjust counter adds fractional delays to the baud rate clock to allow fine trimming of the baud rate to match the system baud rate. The transmitter is driven by the baud rate clock divided by 16. The receiver has an acquisition rate of 16 samples per bit time.

Baud rate generation is subject to two sources of error:

- Integer division of the module clock may not give the exact target frequency. This error can be reduced with the fine-adjust counter.
- Synchronization with the module clock can cause phase shift.

The [Table 45-168](#) lists the available baud divisor fine adjust values.

UART baud rate = UART module clock / (16 × (SBR[12:0] + BRFD))

The following table lists some examples of achieving target baud rates with a module clock frequency of 10.2 MHz, with and without fractional fine adjustment.

Table 45-168. Baud rates (example: module clock = 10.2 MHz)

| Bits SBR (decimal) | Bits BRFA | BRFD value | Receiver clock (Hz) | Transmitter clock (Hz) | Target Baud rate | Error (%) |
|--------------------------|--------------|-----------------|------------------------|---------------------------|---------------------|--------------|
| 17 | 00000 | 0 | 600,000.0 | 37,500.0 | 38,400 | 2.3 |
| 16 | 10011 | $19/32=0.59375$ | 614,689.3 | 38,418.08 | 38,400 | 0.047 |
| 33 | 00000 | 0 | 309,090.9 | 19,318.2 | 19,200 | 0.62 |
| 33 | 00110 | $6/32=0.1875$ | 307,344.6 | 19,209.04 | 19,200 | 0.047 |
| 66 | 00000 | 0 | 154,545.5 | 9659.1 | 9600 | 0.62 |
| 133 | 00000 | 0 | 76,691.7 | 4793.2 | 4800 | 0.14 |
| 266 | 00000 | 0 | 38,345.9 | 2396.6 | 2400 | 0.14 |
| 531 | 00000 | 0 | 19,209.0 | 1200.6 | 1200 | 0.11 |
| 1062 | 00000 | 0 | 9604.5 | 600.3 | 600 | 0.05 |
| 2125 | 00000 | 0 | 4800.0 | 300.0 | 300 | 0.00 |
| 4250 | 00000 | 0 | 2400.0 | 150.0 | 150 | 0.00 |
| 5795 | 00000 | 0 | 1760.1 | 110.0 | 110 | 0.00 |

Table 45-169. Baud rate fine adjust

| BRFA | Baud Rate Fractional Divisor (BRFD) |
|-----------|-------------------------------------|
| 0 0 0 0 0 | $0/32 = 0$ |
| 0 0 0 0 1 | $1/32 = 0.03125$ |
| 0 0 0 1 0 | $2/32 = 0.0625$ |
| 0 0 0 1 1 | $3/32 = 0.09375$ |
| 0 0 1 0 0 | $4/32 = 0.125$ |
| 0 0 1 0 1 | $5/32 = 0.15625$ |
| 0 0 1 1 0 | $6/32 = 0.1875$ |
| 0 0 1 1 1 | $7/32 = 0.21875$ |
| 0 1 0 0 0 | $8/32 = 0.25$ |
| 0 1 0 0 1 | $9/32 = 0.28125$ |
| 0 1 0 1 0 | $10/32 = 0.3125$ |
| 0 1 0 1 1 | $11/32 = 0.34375$ |
| 0 1 1 0 0 | $12/32 = 0.375$ |
| 0 1 1 0 1 | $13/32 = 0.40625$ |
| 0 1 1 1 0 | $14/32 = 0.4375$ |
| 0 1 1 1 1 | $15/32 = 0.46875$ |
| 1 0 0 0 0 | $16/32 = 0.5$ |
| 1 0 0 0 1 | $17/32 = 0.53125$ |
| 1 0 0 1 0 | $18/32 = 0.5625$ |

Table continues on the next page...

Table 45-169. Baud rate fine adjust (continued)

| BRFA | Baud Rate Fractional Divisor (BRFD) |
|-----------|-------------------------------------|
| 1 0 0 1 1 | 19/32 = 0.59375 |
| 1 0 1 0 0 | 20/32 = 0.625 |
| 1 0 1 0 1 | 21/32 = 0.65625 |
| 1 0 1 1 0 | 22/32 = 0.6875 |
| 1 0 1 1 1 | 23/32 = 0.71875 |
| 1 1 0 0 0 | 24/32 = 0.75 |
| 1 1 0 0 1 | 25/32 = 0.78125 |
| 1 1 0 1 0 | 26/32 = 0.8125 |
| 1 1 0 1 1 | 27/32 = 0.84375 |
| 1 1 1 0 0 | 28/32 = 0.875 |
| 1 1 1 0 1 | 29/32 = 0.90625 |
| 1 1 1 1 0 | 30/32 = 0.9375 |
| 1 1 1 1 1 | 31/32 = 0.96875 |

45.4.4 Data format (non ISO-7816)

Each data character is contained in a frame that includes a start bit and a stop bit. The rest of the data format depends upon C1[M], C1[PE], S2[MSBF] and C4[M10].

45.4.4.1 Eight-bit configuration

Clearing C1[M] configures the UART for 8-bit data characters, that is, eight bits are memory mapped in D. A frame with eight data bits has a total of 10 bits. The most significant bit of the eight data bits can be used as an address mark to wake the receiver. If the most significant bit is used in this way, then it serves as an address or data indication, leaving the remaining seven bits as actual data. When C1[PE] is set, the eighth data bit is automatically calculated as the parity bit. See the following table.

Table 45-170. Configuration of 8-bit data format

| UART_C1[PE] | Start bit | Data bits | Address bits | Parity bits | Stop bit |
|-------------|-----------|-----------|----------------|-------------|----------|
| 0 | 1 | 8 | 0 | 0 | 1 |
| 0 | 1 | 7 | 1 ¹ | 0 | 1 |
| 1 | 1 | 7 | 0 | 1 | 1 |

1. The address bit identifies the frame as an address character. See [Receiver wakeup](#).

45.4.4.2 Nine-bit configuration

When C1[M] is set and C4[M10] is cleared, the UART is configured for 9-bit data characters. If C1[PE] is enabled, the ninth bit is either C3[T8/R8] or the internally generated parity bit. This results in a frame consisting of a total of 11 bits. In the event that the ninth data bit is selected to be C3[T8], it will remain unchanged after transmission and can be used repeatedly without rewriting it, unless the value needs to be changed. This feature may be useful when the ninth data bit is being used as an address mark.

When C1[M] and C4[M10] are set, the UART is configured for 9-bit data characters, but the frame consists of a total of 12 bits. The 12 bits include the start and stop bits, the 9 data character bits, and a tenth internal data bit. Note that if C4[M10] is set, C1[PE] must also be set. In this case, the tenth bit is the internally generated parity bit. The ninth bit can either be used as an address mark or a ninth data bit.

See the following table.

Table 45-171. Configuration of 9-bit data formats

| C1[PE] | UC1[M] | C1[M10] | Start bit | Data bits | Address bits | Parity bits | Stop bit |
|--------|--------|---------|---|-----------|----------------|-------------|----------|
| 0 | 0 | 0 | See Eight-bit configuration | | | | |
| 0 | 0 | 1 | Invalid configuration | | | | |
| 0 | 1 | 0 | 1 | 9 | 0 | 0 | 1 |
| 0 | 1 | 0 | 1 | 8 | 1 ¹ | 0 | 1 |
| 0 | 1 | 1 | Invalid Configuration | | | | |
| 1 | 0 | 0 | See Eight-bit configuration | | | | |
| 1 | 0 | 1 | Invalid Configuration | | | | |
| 1 | 1 | 0 | 1 | 8 | 0 | 1 | 1 |
| 1 | 1 | 1 | 1 | 9 | 0 | 1 | 1 |
| 1 | 1 | 1 | 1 | 8 | 1 ² | 1 | 1 |

1. The address bit identifies the frame as an address character.
2. The address bit identifies the frame as an address character.

Note

Unless in 9-bit mode with M10 set, do not use address mark wakeup with parity enabled.

45.4.4.3 Timing examples

Timing examples of these configurations in the NRZ mark/space data format are illustrated in the following figures. The timing examples show all of the configurations in the following sub-sections along with the LSB and MSB first variations.

45.4.4.3.1 Eight-bit format with parity disabled

The most significant bit can be used for address mark wakeup.



Figure 45-169. Eight bits of data with LSB first



Figure 45-170. Eight bits of data with MSB first

45.4.4.3.2 Eight-bit format with parity enabled

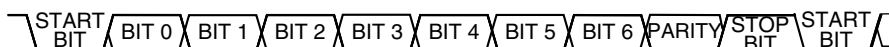


Figure 45-171. Seven bits of data with LSB first and parity



Figure 45-172. Seven bits of data with MSB first and parity

45.4.4.3.3 Nine-bit format with parity disabled

The most significant bit can be used for address mark wakeup.



Figure 45-173. Nine bits of data with LSB first



Figure 45-174. Nine bits of data with MSB first

45.4.4.3.4 Nine-bit format with parity enabled

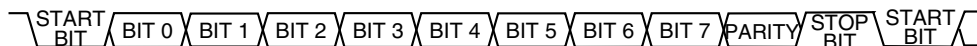


Figure 45-175. Eight bits of data with LSB first and parity

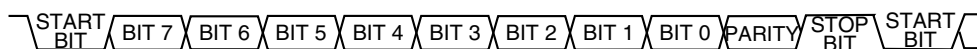


Figure 45-176. Eight bits of data with MSB first and parity

45.4.4.3.5 Non-memory mapped tenth bit for parity

The most significant memory-mapped bit can be used for address mark wakeup.



Figure 45-177. Nine bits of data with LSB first and parity



Figure 45-178. Nine bits of data with MSB first and parity

45.4.5 Single-wire operation

Normally, the UART uses two pins for transmitting and receiving. In single wire operation, the RXD pin is disconnected from the UART and the UART implements a half-duplex serial connection. The UART uses the TXD pin for both receiving and transmitting.

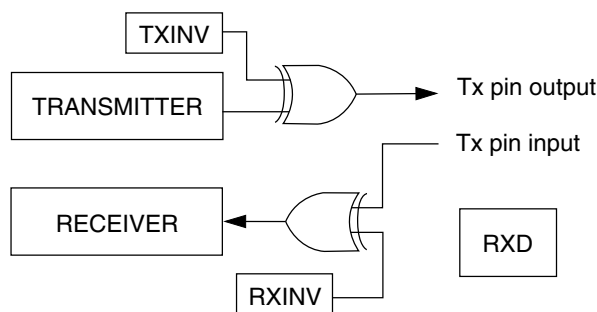


Figure 45-179. Single-wire operation (C1[LOOPS] = 1, C1[RSRC] = 1)

Enable single wire operation by setting C1[LOOPS] and the receiver source field, C1[RSRC]. Setting C1[LOOPS] disables the path from the unsynchronized receiver input signal to the receiver. Setting C1[RSRC] connects the receiver input to the output of the

TXD pin driver. Both the transmitter and receiver must be enabled ($C2[TE] = 1$ and $C2[RE] = 1$). When $C7816[ISO_7816EN]$ is set, it is not required that both $C2[TE]$ and $C2[RE]$ are set.

45.4.6 Loop operation

In loop operation, the transmitter output goes to the receiver input. The unsynchronized receiver input signal is disconnected from the UART.

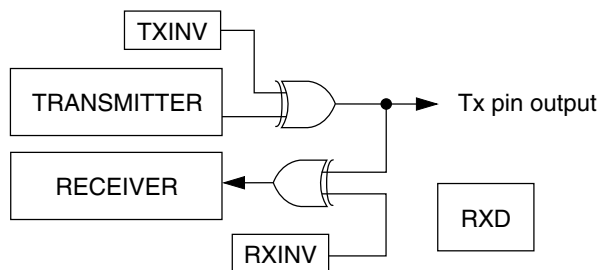


Figure 45-180. Loop operation ($C1[LOOPS] = 1$, $C1[RSRC] = 0$)

Enable loop operation by setting $C1[LOOPS]$ and clearing $C1[RSRC]$. Setting $C1[LOOPS]$ disables the path from the unsynchronized receiver input signal to the receiver. Clearing $C1[RSRC]$ connects the transmitter output to the receiver input. Both the transmitter and receiver must be enabled ($C2[TE] = 1$ and $C2[RE] = 1$). When $C7816[ISO_7816EN]$ is set, it is not required that both $C2[TE]$ and $C2[RE]$ are set.

45.4.7 ISO-7816/smartcard support

The UART provides mechanisms to support the ISO-7816 protocol that is commonly used to interface with smartcards. The ISO-7816 protocol is an NRZ, single wire, half-duplex interface. The TxD pin is used in open-drain mode because the data signal is used for both transmitting and receiving. There are multiple subprotocols within the ISO-7816 standard. The UART supports both $T = 0$ and $T = 1$ protocols. The module also provides for automated initial character detection and configuration, which allows for support of both direct convention and inverse convention data formats. A variety of interrupts specific to 7816 are provided in addition to the general interrupts to assist software. Additionally, the module is able to provide automated NACK responses and has programmed automated retransmission of failed packets. An assortment of programmable timeouts and guard band times are also supported.

The term elemental time unit (ETU) is frequently used in the context of ISO-7816. This concept is used to relate the frequency that the system (UART) is running at and the frequency that data is being transmitted and received. One ETU represents the time it

takes to transmit or receive a single bit. For example, a standard 7816 packet, excluding any guard time or NACK elements is 10 ETUs (start bit, 8 data bits, and a parity bit). Guard times and wait times are also measured in ETUs.,

NOTE

The ISO-7816 specification may have certain configuration options that are reserved. To maintain maximum flexibility to support future 7816 enhancements or devices that may not strictly conform to the specification, the UART does not prevent those options being used. Further, the UART may provide configuration options that exceed the flexibility of options explicitly allowed by the 7816 specification. Failure to correctly configure the UART may result in unexpected behavior or incompatibility with the ISO-7816 specification.

45.4.7.1 Initial characters

In ISO-7816 with T = 0 mode, the UART can be configured to use C7816[INIT] to detect the next valid initial character, referred to by the ISO-7816 specifically as a TS character. When the initial character is detected, the UART provides the host processor with an interrupt if IE7816[INITDE] is set. Additionally, the UART will alter S2[MSBF], C3[TXINV], and S2[RXINV] automatically, based on the initial character. The corresponding initial character and resulting register settings are listed in the following table.

Table 45-172. Initial character automated settings

| Initial character (bit 1-10) | Initial character (hex) | MSBF | TXINV | RXINV |
|------------------------------------|-------------------------|------|-------|-------|
| LHHL LLL LLH inverse convention | 3F | 1 | 1 | 1 |
| LHHL HHH LLH direct convention | 3B | 0 | 0 | 0 |

S2[MSBF], C3[TXINV], and S2[RXINV] must be reset to their default values before C7816[INIT] is set. Once C7816[INIT] is set, the receiver searches all received data for the first valid initial character. Detecting a Direct Convention Initial Character will cause no change to S2[MSBF], C3[TXINV], and S2[RXINV], while detecting an Inverse Convention Initial Character will cause these fields to set automatically. All data received, which is not a valid initial character, is ignored and all flags resulting from the invalid data are blocked from asserting. If C7816[ANACK] is set, a NACK is returned for invalid received initial characters and an RXT interrupt is generated as programmed.

45.4.7.2 Protocol T = 0

When T = 0 protocol is selected, a relatively complex error detection scheme is used. Data characters are formatted as illustrated in the following figure. This scheme is also used for answer to reset and Peripheral Pin Select (PPS) formats.

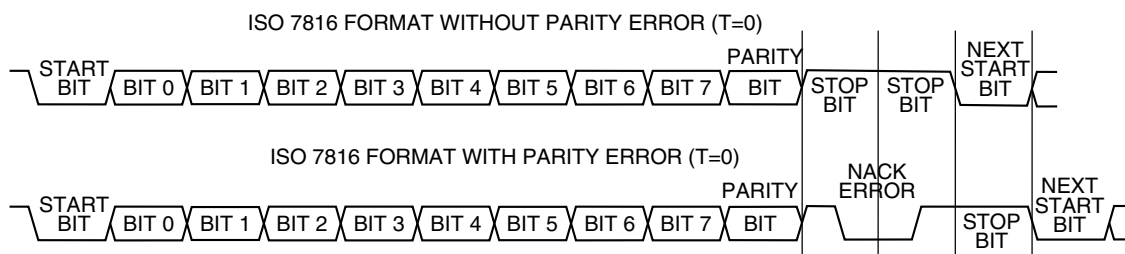


Figure 45-181. ISO-7816 T = 0 data format

As with other protocols supported by the UART, the data character includes a start bit. However, in this case, there are two stop bits rather than the typical single stop bit. In addition to a standard even parity check, the receiver has the ability to generate and return a NACK during the second half of the first stop bit period. The NACK must be at least one time period (ETU) in length and no more than two time periods (ETU) in length. The transmitter must wait for at least two time units (ETU) after detection of the error signal before attempting to retransmit the character.

It is assumed that the UART and the device (smartcard) know in advance which device is receiving and which is transmitting. No special mechanism is supplied by the UART to control receive and transmit in the mode other than C2[TE] and C2[RE]. Initial Character Detect feature is also supported in this mode.

45.4.7.3 Protocol T = 1

When T = 1 protocol is selected, the NACK error detection scheme is not used. Rather, the parity bit is used on a character basis and a CRC or LRC is used on the block basis, that is, for each group of characters. In this mode, the data format allows for a single stop bit although additional inactive bit periods may be present between the stop bit and the next start bit. Data characters are formatted as illustrated in the following figure.

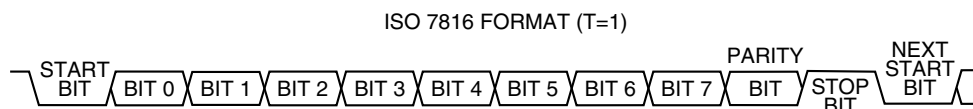


Figure 45-182. ISO 7816 T=1 data format

The smallest data unit that is transferred is a block. A block is made up of several data characters and may vary in size depending on the block type. The UART does not provide a mechanism to decode the block type. As part of the block, an LRC or CRC is included. The UART does not calculate the CRC or LRC for transmitted blocks, nor does it verify the validity of the CRC or LRC for received blocks. The 7816 protocol requires that the initiator and the smartcard (device) takes alternate turns in transmitting and receiving blocks. When the UART detects that the last character in a block has been transmitted it will automatically clear C2[TE], C3[TXDIR] and enter receive mode. Therefore, the software must program the transmit buffer with the next data to be transmitted and then enable C2[TE] and set C3[TXDIR], once the software has determined that the last character of the received block has been received. The UART detects that the last character of the transmit block has been sent when TL7816[TLEN] = 0 and four additional characters have been sent. The four additional characters are made up of three prior to TL7816[TLEN] decrementing (prologue) and one after TL7816[TLEN] = 0, the final character of the epilogue.

45.4.7.4 Wait time and guard time parameters

The ISO-7816 specification defines several wait time and guard time parameters. The UART allows for flexible configuration and violation detection of these settings. On reset, the wait time (IS7816[WT]) defaults to 9600 ETUs and guard time (GT) to 12 ETUs. These values are controlled by parameters in the WP7816, WN7816, and WF7816 registers. Additionally, the value of C7816[TTYPE] also factors into the calculation. The formulae used to calculate the number ETUs for each wait time and guard time value are shown in [Table 45-173](#).

Wait time (WT) is defined as the maximum allowable time between the leading edge of a character transmitted by the smartcard device and the leading edge of the previous character that was transmitted by the UART or the device. Similarly, character wait time (CWT) is defined as the maximum allowable time between the leading edge of two characters within the same block. Block wait time (BWT) is defined as the maximum time between the leading edge character of the last block received by the smartcard device and the leading edge of the first character transmitted by the smartcard device.

Guard time (GT) is defined as the minimum allowable time between the leading edge of two consecutive characters. Character guard time (CGT) is the minimum allowable time between the leading edges of two consecutive characters in the same direction, that is, transmission or reception. Block guard time (BGT) is the minimum allowable time between the leading edges of two consecutive characters in opposite directions, that is, transmission then reception or reception then transmission.

The GT and WT counters reset whenever $C7816[TTYPE] = 1$ or $C7816[ISO_7816E] = 0$ or a new dataword start bit has been received or transmitted as specified by the counter descriptions. The CWT, CGT, BWT, BGT counters reset whenever $C7816[TTYPE] = 0$ or $C7816[ISO_7816E] = 0$ or a new dataword start bit is received or transmitted as specified by the counter descriptions. When $C7816[TTYPE] = 1$, some of the counter values require an assumption regarding the first data transferred when the UART first starts. This assumption is required when the 7816E is disabled, when transition from $C7816[TTYPE] = 0$ to $C7816[TTYPE] = 1$ or when coming out of reset. In this case, it is assumed that the previous non-existent transfer was a received transfer.

The UART will automatically handle GT, CGT, and BGT such that the UART will not send a packet before the corresponding guard time expiring.

Table 45-173. Wait and guard time calculations

| Parameter | Reset value [ETU] | $C7816[TTYPE] = 0$ [ETU] | $C7816[TTYPE] = 1$ [ETU] |
|----------------------------|-------------------|--|--|
| Wait time (WT) | 9600 | $((WI + 1) \times 960 \times (GTFD + 1)) - 1$ | Not used |
| Character wait time (CWT) | Not used | Not used | $11 + 2^{(CWI - 1)}$ |
| Block wait time (BWT) | Not used | Not used | $10 + 2^{BWI} \times 960 \times (GTFD + 1)$ |
| Guard time (GT) | 12 | GTN not equal to 255 $12 + GTN$ GTN equal to 255 12 | Not used |
| Character guard time (CGT) | Not used | Not used | GTN not equal to 255 $12 + GTN$ GTN equal to 255 11 |
| Block guard time (BGT) | Not used | Not used | 22 |

45.4.7.5 Baud rate generation

The value in $WF7816[GTFD]$ does not impact the clock frequency. SBR and BRFD are used to generate the clock frequency. This clock frequency is used by the UART only and is not seen by the smartcard device. The transmitter clocks operates at 1/16 the frequency of the receive clock so that the receiver is able to sample the received value 16 times during the ETU.

45.4.7.6 UART restrictions in ISO-7816 operation

Due to the flexibility of the UART module, there are several features and interrupts that are not supported while running in ISO-7816 mode. These restrictions are documented within the register field definitions.

45.4.8 Infrared interface

The UART provides the capability of transmitting narrow pulses to an IR LED and receiving narrow pulses and transforming them to serial bits, which are sent to the UART. The IrDA physical layer specification defines a half-duplex infrared communication link for exchanging data. The full standard includes data rates up to 16 Mbits/s. This design covers data rates only between 2.4 kbits/s and 115.2 kbits/s.

The UART has an infrared transmit encoder and receive decoder. The UART transmits serial bits of data that are encoded by the infrared submodule to transmit a narrow pulse for every zero bit. No pulse is transmitted for every one bit. When receiving data, the IR pulses are detected using an IR photo diode and transformed to CMOS levels by the IR receive decoder, external from the MCU. The narrow pulses are then stretched by the infrared receive decoder to get back to a serial bit stream to be received by the UART. The polarity of transmitted pulses and expected receive pulses can be inverted so that a direct connection can be made to external IrDA transceiver modules that use active low pulses.

The infrared submodule receives its clock sources from the UART. One of these two clocks are selected in the infrared submodule to generate either 3/16, 1/16, 1/32, or 1/4 narrow pulses during transmission.

45.4.8.1 Infrared transmit encoder

The infrared transmit encoder converts serial bits of data from transmit shift register to the TXD signal. A narrow pulse is transmitted for a zero bit and no pulse for a one bit. The narrow pulse is sent in the middle of the bit with a duration of 1/32, 1/16, 3/16, or 1/4 of a bit time. A narrow high pulse is transmitted for a zero bit when C3[TXINV] is cleared, while a narrow low pulse is transmitted for a zero bit when C3[TXINV] is set.

45.4.8.2 Infrared receive decoder

The infrared receive block converts data from the RXD signal to the receive shift register. A narrow pulse is expected for each zero received and no pulse is expected for each one received. A narrow high pulse is expected for a zero bit when S2[RXINV] is cleared, while a narrow low pulse is expected for a zero bit when S2[RXINV] is set. This receive decoder meets the edge jitter requirement as defined by the IrDA serial infrared physical layer specification.

45.5 Reset

All registers reset to a particular value are indicated in [Memory map and registers](#).

45.6 System level interrupt sources

There are several interrupt signals that are sent from the UART. The following table lists the interrupt sources generated by the UART. The local enables for the UART interrupt sources are described in this table. Details regarding the individual operation of each interrupt are contained under various sub-sections of [Memory map and registers](#). However, [RXEDGIF description](#) also outlines additional details regarding the RXEDGIF interrupt because of its complexity of operation. Any of the UART interrupt requests listed in the table can be used to bring the CPU out of Wait mode.

Table 45-174. UART interrupt sources

| Interrupt Source | Flag | Local enable | DMA select |
|------------------|---------|--------------|------------|
| Transmitter | TDRE | TIE | TDMA5 = 0 |
| Transmitter | TC | TCIE | - |
| Receiver | IDLE | ILIE | - |
| Receiver | RDRF | RIE | RDMA5 = 0 |
| Receiver | LBKDIF | LBKDIE | - |
| Receiver | RXEDGIF | RXEDGIE | - |
| Receiver | OR | ORIE | - |
| Receiver | NF | NEIE | - |
| Receiver | FE | FEIE | - |
| Receiver | PF | PEIE | - |
| Receiver | RXUF | RXUFE | - |
| Transmitter | TXOF | TXOFE | - |
| Receiver | WT | WTWE | - |
| Receiver | CWT | CWTE | - |

Table continues on the next page...

Table 45-174. UART interrupt sources (continued)

| Interrupt Source | Flag | Local enable | DMA select |
|------------------|-------|--------------|------------|
| Receiver | BWT | BWTE | - |
| Receiver | INITD | INITDE | - |
| Receiver | TXT | TXTE | - |
| Receiver | RXT | RXTE | - |
| Receiver | GTV | GTVE | - |

45.6.1 RXEDGIF description

S2[RXEDGIF] is set when an active edge is detected on the RxD pin. Therefore, the active edge can be detected only when in two wire mode. A RXEDGIF interrupt is generated only when S2[RXEDGIF] is set. If RXEDGIE is not enabled before S2[RXEDGIF] is set, an interrupt is not generated.

45.6.1.1 RxD edge detect sensitivity

Edge sensitivity can be software programmed to be either falling or rising. The polarity of the edge sensitivity is selected using S2[RXINV]. To detect the falling edge, S2[RXINV] is programmed to 0. To detect the rising edge, S2[RXINV] is programmed to 1.

Synchronizing logic is used prior to detect edges. Prior to detecting an edge, the receive data on RxD input must be at the deasserted logic level. A falling edge is detected when the RxD input signal is seen as a logic 1 (the deasserted level) during one module clock cycle, and then a logic 0 (the asserted level) during the next cycle. A rising edge is detected when the input is seen as a logic 0 during one module clock cycle and then a logic 1 during the next cycle.

45.6.1.2 Clearing RXEDGIF interrupt request

Writing a logic 1 to S2[RXEDGIF] immediately clears the RXEDGIF interrupt request even if the RxD input remains asserted. S2[RXEDGIF] remains set if another active edge is detected on RxD while attempting to clear S2[RXEDGIF] by writing a 1 to it.

45.6.1.3 Exit from low-power modes

The receive input active edge detect circuit is still active on low power modes (Wait and Stop). An active edge on the receive input brings the CPU out of low power mode if the interrupt is not masked ($S2[RXEDGIF] = 1$).

45.7 DMA operation

In the transmitter, $S1[TDRE]$ can be configured to assert a DMA transfer request. In the receiver, $S1[RDRF]$, can be configured to assert a DMA transfer request. The following table shows the configuration field settings required to configure each flag for DMA operation.

Table 45-175. DMA configuration

| Flag | Request enable bit | DMA select bit |
|------|--------------------|----------------|
| TDRE | TIE = 1 | TDMAS = 1 |
| RDRF | RIE = 1 | RDMAS = 1 |

When a flag is configured for a DMA request, its associated DMA request is asserted when the flag is set. When $S1[RDRF]$ is configured as a DMA request, the clearing mechanism of reading $S1$, followed by reading D , does not clear the associated flag. The DMA request remains asserted until an indication is received that the DMA transactions are done. When this indication is received, the flag bit and the associated DMA request is cleared. If the DMA operation failed to remove the situation that caused the DMA request, another request is issued.

45.8 Application information

This section describes the UART application information.

45.8.1 Transmit/receive data buffer operation

The UART has independent receive and transmit buffers. The size of these buffers may vary depending on the implementation of the module. The implemented size of the buffers is a fixed constant via $PFIFO[TXFIFOSIZE]$ and $PFIFO[RXFIFOSIZE]$. Additionally, legacy support is provided that allows for the FIFO structure to operate as a

depth of one. This is the default/reset behavior of the module and can be adjusted using the PFIFO[RXFE] and PFIFO[TXFE] bits. Individual watermark levels are also provided for transmit and receive.

There are multiple ways to ensure that a data block, which is a set of characters, has completed transmission. These methods include:

1. Set TXFIFO[TXWATER] to 0. TDRE asserts when there is no further data in the transmit buffer. Alternatively the S1[TC] flag can be used to indicate when the transmit shift register is also empty.
2. Poll TCFIFO[TXCOUNT]. Assuming that only data for a data block has been put into the data buffer, when TCFIFO[TXCOUNT] = 0, all data has been transmitted or is in the process of transmission.
3. S1[TC] can be monitored. When S1[TC] asserts, it indicates that all data has been transmitted and there is no data currently being transmitted in the shift register.

45.8.2 ISO-7816 initialization sequence

This section outlines how to program the UART for ISO-7816 operation. Elements such as procedures to power up or power down the smartcard, and when to take those actions, are beyond the scope of this description. To set up the UART for ISO-7816 operation:

1. Select a baud rate. Write this value to the UART baud registers (BDH/L) to begin the baud rate generator. Remember that the baud rate generator is disabled when the baud rate is zero. Writing to the BDH has no effect without also writing to BDL. According to the 7816 specification the initial (default) baud rating setting should be $F_i = 372$ and $D_i = 1$ and a maximum frequency of 5 MHz. In other words, the BDH, BDL, and C4 registers should be programmed such that the transmission frequency provided to the smartcard device must be $1/372$ th of the clock and must not exceed 5 MHz.
2. Write to set BDH[LBKDIE] = 0.
3. Write to C1 to configure word length, parity, and other configuration fields (LOOPS, RSRC) and set C1[M] = 1, C1[PE] = 1, and C1[PT] = 0.
4. Write to set S2[RWUID] = 0 and S2[LBKDE] = 0.
5. Write to set MODEM[RXRTSE] = 0, MODEM[TXRTSPOL] = 0, MODEM[TXRTSE] = 0, and MODEM[TXCTSE] = 0.

6. Write to set up interrupt enable fields desired (C3[ORIE], C3[NEIE], C3[PEIE], and C3[FEIE])
7. Write to set C4[MAEN1] = 0 and C4[MAEN2] = 0.
8. Write to C5 register and configure DMA control register fields as desired for application.
9. Write to set C7816[INIT] = 1, C7816[TTYPE] = 0, and C7816[ISO_7816E] = 1. Program C7816[ONACK] and C7816[ANACK] as desired.
10. Write to IE7816 to set interrupt enable parameters as desired.
11. Write to ET7816 and set as desired.
12. Write to set C2[ILIE] = 0, C2[RE] = 1, C2[TE] = 1, C2[RWU] = 0, and C2[SBK] = 0. Set up interrupt enables C2[TIE], C2[TCIE], and C2[RIE] as desired.

At this time, the UART will start listening for an initial character. After being identified, it will automatically adjust S2[MSBF], C3[TXINV], and S2[RXINV]. The software must then receive and process an answer to reset. Upon processing the answer to reset, the software must write to set C2[RE] = 0 and C2[TE] = 0. The software should then adjust 7816 specific and UART generic parameters to match and configure data that was received during the answer on reset period. After the new settings have been programmed, including the new baud rate and C7816[TTYPE], C2[RE] and C2[TE] can be reenabled as required.

45.8.2.1 Transmission procedure for (C7816[TTYPE] = 0)

When the protocol selected is C7816[TTYPE] = 0, it is assumed that the software has a prior knowledge of who should be transmitting and receiving. Therefore, no mechanism is provided for automated transmission/receipt control. The software must monitor S1[TDRE], or configure for an interrupt, and provide additional data for transmission, as appropriate. Additionally, software should set C2[TE] = 1 and control TXDIR whenever it is the UART's turn to transmit information. For ease of monitoring, it is suggested that only data be transmitted until the next receiver/transmit switchover is loaded into the transmit FIFO/buffer.

45.8.2.2 Transmission procedure for (C7816[TTYPE] = 1)

When the protocol selected is C7816[TTYPE] = 1, data is transferred in blocks. Before starting a transmission, the software must write the size, in number of bytes, for the Information Field portion of the block into TLEN. If a CRC is being transmitted for the block, the value in TLEN must be one more than the size of the information field. The software must then set C2[TE] = 1 and C2[RE] = 1. The software must then monitor S1[TDRE]/interrupt and write the prologue, information, and epilogue field to the transmit buffer. TLEN automatically decrements, except for prologue bytes and the final epilogue byte. When the final epilogue byte has been transmitted, the UART automatically clears C2[TE] and C3[TXDIR] to 0, and the UART automatically starts capturing the response to the block that was transmitted. After the software has detected the receipt of the response, the transmission process must be repeated as needed with sufficient urgency to ensure that the block wait time and character wait times are not violated.

45.8.3 Initialization sequence (non ISO-7816)

To initiate a UART transmission:

1. Configure the UART.
 - a. Select a baud rate. Write this value to the UART baud registers (BDH/L) to begin the baud rate generator. Remember that the baud rate generator is disabled when the baud rate is zero. Writing to the BDH has no effect without also writing to BDL.
 - b. Write to C1 to configure word length, parity, and other configuration bits (LOOPS, RSRC, M, WAKE, ILT, PE, and PT). Write to C4, MA1, and MA2 to configure.
 - c. Enable the transmitter, interrupts, receiver, and wakeup as required, by writing to C2 (TIE, TCIE, RIE, ILIE, TE, RE, RWU, and SBK), S2 (MSBF and BRK13), and C3 (ORIE, NEIE, PEIE, and FEIE). A preamble or idle character is then shifted out of the transmitter shift register.
2. Transmit procedure for each byte.
 - a. Monitor S1[TDRE] by reading S1 or responding to the TDRE interrupt. The amount of free space in the transmit buffer directly using TCFIFO[TXCOUNT] can also be monitored.

- b. If the TDRE flag is set, or there is space in the transmit buffer, write the data to be transmitted to (C3[T8]/D). A new transmission will not result until data exists in the transmit buffer.
3. Repeat step 2 for each subsequent transmission.

Note

During normal operation, S1[TDRE] is set when the shift register is loaded with the next data to be transmitted from the transmit buffer and the number of datawords contained in the transmit buffer is less than or equal to the value in TWFIFO[TXWATER]. This occurs 9/16ths of a bit time after the start of the stop bit of the previous frame.

To separate messages with preambles with minimum idle line time, use this sequence between messages.

1. Write the last dataword of the first message to C3[T8]/D.
2. Wait for S1[TDRE] to go high with TWFIFO[TXWATER] = 0, indicating the transfer of the last frame to the transmit shift register.
3. Queue a preamble by clearing and then setting C2[TE].
4. Write the first and subsequent datawords of the second message to C3[T8]/D.

45.8.4 Overrun (OR) flag implications

To be flexible, the overrun flag (OR) operates slightly differently depending on the mode of operation. There may be implications that need to be carefully considered. This section clarifies the behavior and the resulting implications. Regardless of mode, if a dataword is received while S1[OR] is set, S1[RDRF] and S1[IDLE] are blocked from asserting. If S1[RDRF] or S1[IDLE] were previously asserted, they will remain asserted until cleared.

45.8.4.1 Overrun operation

The assertion of S1[OR] indicates that a significant event has occurred. The assertion indicates that received data has been lost because there was a lack of room to store it in the data buffer. Therefore, while S1[OR] is set, no further data is stored in the data buffer until S1[OR] is cleared. This ensures that the application will be able to handle the overrun condition.

In most applications, because the total amount of lost data is known, the application will attempt to return the system to a known state. Before S1[OR] is cleared, all received data will be dropped. For this, the software does the following.

1. Remove data from the receive data buffer. This could be done by reading data from the data buffer and processing it if the data in the FIFO was still valuable when the overrun event occurred, or using CFIFO[RXFLUSH] to clear the buffer.
2. Clear S1[OR]. Note that if data was cleared using CFIFO[RXFLUSH], then clearing S1[OR] will result in SFIFO[RXUF] asserting. This is because the only way to clear S1[OR] requires reading additional information from the FIFO. Care should be taken to disable the SFIFO[RXUF] interrupt prior to clearing the OR flag and then clearing SFIFO[RXUF] after the OR flag has been cleared.

Note that, in some applications, if an overrun event is responded to fast enough, the lost data can be recovered. For example, when C7816[ISO_7816E] is asserted, C7816[TTYTYPE]=1 and C7816[ONACK] = 1, the application may reasonably be able to determine whether the lost data will be resent by the device. In this scenario, flushing the receiver data buffer may not be required. Rather, if S1[OR] is cleared, the lost data may be resent and therefore may be recoverable.

When LIN break detect (LBKDE) is asserted, S1[OR] has significantly different behavior than in other modes. S1[OR] will be set, regardless of how much space is actually available in the data buffer, if a LIN break character has been detected and the corresponding flag, S2[LBKDIF], is not cleared before the first data character is received after S2[LBKDIF] asserted. This behavior is intended to allow the software sufficient time to read the LIN break character from the data buffer to ensure that a break character was actually detected. The checking of the break character was used on some older implementations and is therefore supported for legacy reasons. Applications that do not require this checking can simply clear S2[LBKDIF] without checking the stored value to ensure it is a break character.

45.8.5 Overrun NACK considerations

When C7816[ISO_7816E] is enabled and C7816[TTYTYPE] = 0, the retransmission feature of the 7816 protocol can be used to help avoid lost data when the data buffer overflows. Using C7816[ONACK], the module can be programmed to issue a NACK on an overflow event. Assuming that the smartcard device has implemented retransmission, the lost data will be retransmitted. While useful, there is a programming implication that may require special consideration. The need to transmit a NACK must be determined and committed to prior to the dataword being fully received. While the NACK is being received, it is possible that the application code will read the data buffer such that

sufficient room will be made to store the dataword that is being NACKed. Even if room has been made in the data buffer after the transmission of a NACK is completed, the received data will always be discarded as a result of an overflow and the ET7816[RXTHRESHOLD] value will be incremented by one. However, if sufficient space now exists to write the received data which was NACK'ed, S1[OR] will be blocked and kept from asserting.

45.8.6 Match address registers

The two match address registers allow a second match address function for a broadcast or general call address to the serial bus, as an example.

45.8.7 Modem feature

This section describes the modem features.

45.8.7.1 Ready-to-receive using RTS

To help to stop overrun of the receiver data buffer, the RTS signal can be used by the receiver to indicate to another UART that it is ready to receive data. The other UART can send the data when its CTS signal is asserted. This handshaking conforms to the TIA-232-E standard. A transceiver is necessary if the required voltage levels of the communication link do not match the voltage levels of the UART's RTS and CTS signals.

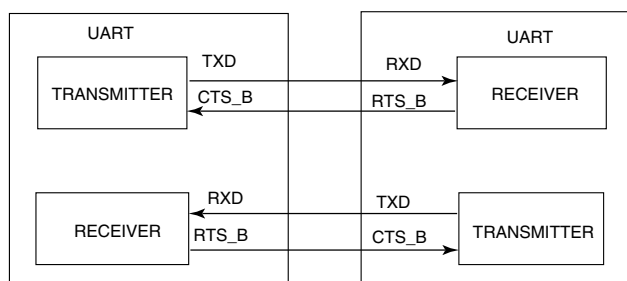


Figure 45-183. Ready-to-receive

The transmitter's CTS signal can be used for hardware flow control whether its RTS signal is used for hardware flow control, transceiver driver enable, or not at all.

45.8.7.2 Transceiver driver enable using RTS

RS-485 is a multiple drop communication protocol in which the UART transceiver's driver is 3-stated unless the UART is driving. The RTS signal can be used by the transmitter to enable the driver of a transceiver. The polarity of RTS can be matched to the polarity of the transceiver's driver enable signal. See the following figure.

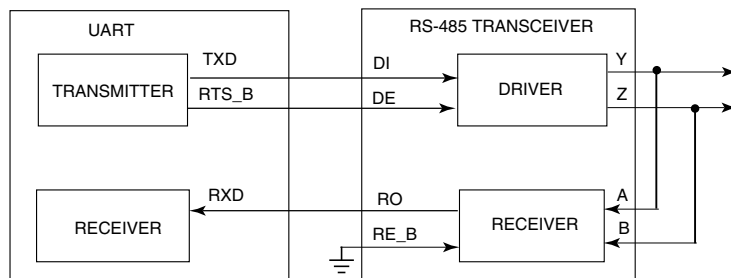


Figure 45-184. Transceiver driver enable using RTS

In the figure, the receiver enable signal is asserted. Another option for this connection is to connect RTS_B to both DE and RE_B. The transceiver's receiver is disabled while driving. A pullup can pull RXD to a non-floating value during this time. This option can be refined further by operating the UART in single wire mode, freeing the RXD pin for other uses.

45.8.8 IrDA minimum pulse width

The IrDA specifies a minimum pulse width of 1.6 μ s. The UART hardware does not include a mechanism to restrict/force the pulse width to be greater than or equal to 1.6 μ s. However, configuring the baud rate to 115.2 kbit/s and the narrow pulse width to 3/16 of a bit time results in a pulse width of 1.6 μ s.

45.8.9 Clearing 7816 wait timer (WT, BWT, CWT) interrupts

The 7816 wait timer interrupts associated with IS7816[WT], IS7816[BWT], and IS7816[CWT] will automatically reassert if they are cleared and the wait time is still violated. This behavior is similar to most of the other interrupts on the UART. In most cases, if the condition that caused the interrupt to trigger still exists when the interrupt is cleared, then the interrupt will reassert. For example, consider the following scenario:

1. IS7816[WT] is programmed to assert after 9600 cycles of unresponsiveness.
2. The 9600 cycles pass without a response resulting in the WT interrupt asserting.
3. The IS7816[WT] is cleared at cycle 9700 by the interrupt service routine.

4. After the WT interrupt has been cleared, the smartcard remains unresponsive. At cycle 9701 the WT interrupt will be reasserted.

If the intent of clearing the interrupt is such that it does not reassert, the interrupt service routine must remove or clear the condition that originally caused the interrupt to assert prior to clearing the interrupt. There are multiple ways that this can be accomplished, including ensuring that an event that results in the wait timer resetting occurs, such as, the transmission of another packet.

45.8.10 Legacy and reverse compatibility considerations

Recent versions of the UART have added several new features. Whenever reasonably possible, reverse compatibility was maintained. However, in some cases this was either not feasible or the behavior was deemed as not intended. This section describes several differences to legacy operation that resulted from these recent enhancements. If application code from previous versions is used, it must be reviewed and modified to take the following items into account. Depending on the application code, additional items that are not listed here may also need to be considered.

1. Various reserved registers and register bits are used, such as, MSFB and M10.
2. This module now generates an error when invalid address spaces are used.
3. While documentation indicated otherwise, in some cases it was possible for S1[IDLE] to assert even if S1[OR] was set.
4. S1[OR] will be set only if the data buffer (FIFO) does not have sufficient room. Previously, the data buffer was always a fixed size of one and the S1[OR] flag would set so long as S1[RDRF] was set even if there was room in the data buffer. While the clearing mechanism has remained the same for S1[RDRF], keeping the OR flag assertion tied to the RDRF event rather than the data buffer being full would have greatly reduced the usefulness of the buffer when its size is larger than one.
5. Previously, when C2[RWU] was set (and WAKE = 0), the IDLE flag could reassert up to every bit period causing an interrupt and requiring the host processor to reassert C2[RWU]. This behavior has been modified. Now, when C2[RWU] is set (and WAKE = 0), at least one non-idle bit must be detected before an idle can be detected.



Chapter 46

Integrated Interchip Sound (I2S) / Synchronous Audio Interface (SAI)

46.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The I²S (or I2S) module provides a synchronous audio interface (SAI) that supports full-duplex serial interfaces with frame synchronization such as I²S, AC97, TDM, and codec/DSP interfaces.

46.1.1 Features

Note that some of the features are not supported across all SAI instances; see the chip-specific information in the first section of this chapter.

- Transmitter with independent bit clock and frame sync supporting 1 data channel
- Receiver with independent bit clock and frame sync supporting 1 data channel
- Maximum Frame Size of 16 words
- Word size of between 8-bits and 32-bits
- Word size configured separately for first word and remaining words in frame
- Asynchronous 8 × 32-bit FIFO for each transmit and receive channel
- Supports graceful restart after FIFO error

46.1.2 Block diagram

The following block diagram also shows the module clocks.

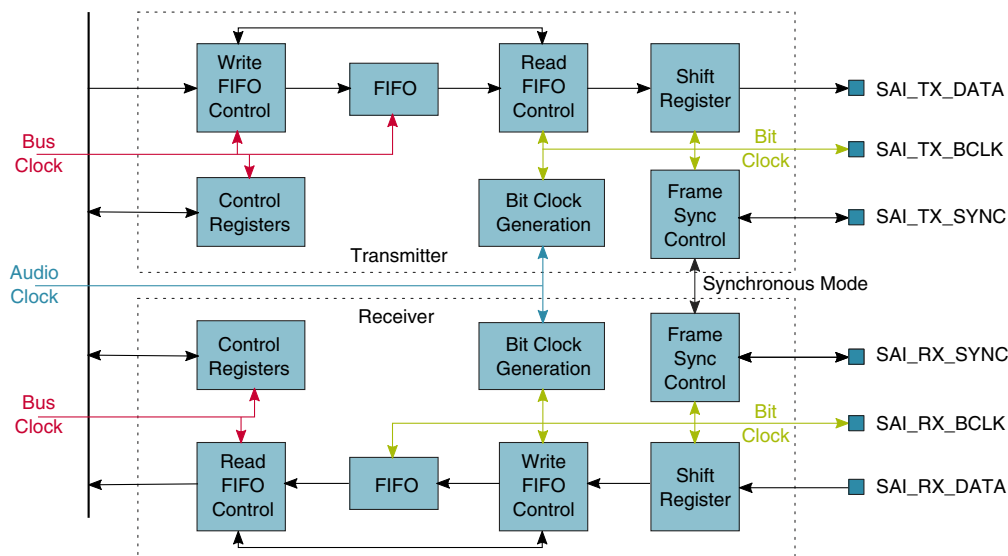


Figure 46-1. I²S/SAI block diagram

46.1.3 Modes of operation

The module operates in these MCU power modes: Run mode, stop modes, low-leakage modes, and Debug mode.

46.1.3.1 Run mode

In Run mode, the SAI transmitter and receiver operate normally.

46.1.3.2 Stop modes

In Stop mode, the SAI transmitter and/or receiver can continue operating provided the appropriate Stop Enable bit is set (TCSR[STOPE] and/or RCSR[STOPE], respectively), and provided the transmitter and/or receiver is/are using an externally generated bit clock or an Audio Master Clock that remains operating in Stop mode. The SAI transmitter and/or receiver can generate an asynchronous interrupt to wake the CPU from Stop mode.

In Stop mode, if the Transmitter Stop Enable (TCSR[STOPE]) bit is clear, the transmitter is disabled after completing the current transmit frame, and, if the Receiver Stop Enable (RCSR[STOPE]) bit is clear, the receiver is disabled after completing the current receive frame. Entry into Stop mode is prevented—not acknowledged—while waiting for the transmitter and receiver to be disabled at the end of the current frame.

46.1.3.3 Low-leakage modes

When entering low-leakage modes, the Stop Enable (TCSR[STOPE] and RCSR[STOPE]) bits are ignored and the SAI is disabled after completing the current transmit and receive Frames. Entry into stop mode is prevented (not acknowledged) while waiting for the transmitter and receiver to be disabled at the end of the current frame.

46.1.3.4 Debug mode

In Debug mode, the SAI transmitter and/or receiver can continue operating provided the Debug Enable bit is set. When TCSR[DBGE] or RCSR[DBGE] bit is clear and Debug mode is entered, the SAI is disabled after completing the current transmit or receive frame. The transmitter and receiver bit clocks are not affected by Debug mode.

46.2 External signals

| Name | Function | I/O |
|-------------|--|-----|
| SAI_TX_BCLK | Transmit Bit Clock. The bit clock is an input when externally generated and an output when internally generated. | I/O |
| SAI_TX_SYNC | Transmit Frame Sync. The frame sync is an input sampled synchronously by the bit clock when externally generated and an output generated synchronously by the bit clock when internally generated. | I/O |
| SAI_TX_DATA | Transmit Data. The transmit data is generated synchronously by the bit clock and is tristated whenever not transmitting a word. | O |
| SAI_RX_BCLK | Receive Bit Clock. The bit clock is an input when externally generated and an output when internally generated. | I/O |
| SAI_RX_SYNC | Receive Frame Sync. The frame sync is an input sampled synchronously by the bit clock when externally generated and an output generated synchronously by the bit clock when internally generated. | I/O |
| SAI_RX_DATA | Receive Data. The receive data is sampled synchronously by the bit clock. | I |
| SAI_MCLK | Audio Master Clock. The master clock is an input when externally generated and an output when internally generated. | I/O |

46.3 Memory map and register definition

A read or write access to an address from offset 0x108 and above will result in a bus error.

I2S memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|-----------------------|-------------|------------------------------|
| 4002_F000 | SAI Transmit Control Register (I2S0_TCSR) | 32 | R/W | 0000_0000h | 46.3.1/1155 |
| 4002_F004 | SAI Transmit Configuration 1 Register (I2S0_TCR1) | 32 | R/W | 0000_0000h | 46.3.2/1158 |
| 4002_F008 | SAI Transmit Configuration 2 Register (I2S0_TCR2) | 32 | R/W | 0000_0000h | 46.3.3/1158 |
| 4002_F00C | SAI Transmit Configuration 3 Register (I2S0_TCR3) | 32 | R/W | 0000_0000h | 46.3.4/1160 |
| 4002_F010 | SAI Transmit Configuration 4 Register (I2S0_TCR4) | 32 | R/W | 0000_0000h | 46.3.5/1161 |
| 4002_F014 | SAI Transmit Configuration 5 Register (I2S0_TCR5) | 32 | R/W | 0000_0000h | 46.3.6/1162 |
| 4002_F020 | SAI Transmit Data Register (I2S0_TDR0) | 32 | W (always reads 0) | 0000_0000h | 46.3.7/1163 |
| 4002_F040 | SAI Transmit FIFO Register (I2S0_TFR0) | 32 | R | 0000_0000h | 46.3.8/1164 |
| 4002_F060 | SAI Transmit Mask Register (I2S0_TMR) | 32 | R/W | 0000_0000h | 46.3.9/1164 |
| 4002_F080 | SAI Receive Control Register (I2S0_RCSR) | 32 | R/W | 0000_0000h | 46.3.10/1165 |
| 4002_F084 | SAI Receive Configuration 1 Register (I2S0_RCR1) | 32 | R/W | 0000_0000h | 46.3.11/1168 |
| 4002_F088 | SAI Receive Configuration 2 Register (I2S0_RCR2) | 32 | R/W | 0000_0000h | 46.3.12/1169 |
| 4002_F08C | SAI Receive Configuration 3 Register (I2S0_RCR3) | 32 | R/W | 0000_0000h | 46.3.13/1170 |
| 4002_F090 | SAI Receive Configuration 4 Register (I2S0_RCR4) | 32 | R/W | 0000_0000h | 46.3.14/1171 |
| 4002_F094 | SAI Receive Configuration 5 Register (I2S0_RCR5) | 32 | R/W | 0000_0000h | 46.3.15/1173 |
| 4002_F0A0 | SAI Receive Data Register (I2S0_RDR0) | 32 | R | 0000_0000h | 46.3.16/1173 |
| 4002_F0C0 | SAI Receive FIFO Register (I2S0_RFR0) | 32 | R | 0000_0000h | 46.3.17/1174 |
| 4002_F0E0 | SAI Receive Mask Register (I2S0_RMR) | 32 | R/W | 0000_0000h | 46.3.18/1174 |
| 4002_F100 | SAI MCLK Control Register (I2S0_MCR) | 32 | R/W | 0000_0000h | 46.3.19/1175 |
| 4002_F104 | SAI MCLK Divide Register (I2S0_MDR) | 32 | R/W | 0000_0000h | 46.3.20/1176 |

46.3.1 SAI Transmit Control Register (I2Sx_TCSR)

Address: 4002_F000h base + 0h offset = 4002_F000h

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|----|-------|------|-----|----|----|----|----|----|-----|-----|-----|-----|-----|----|----|
| R | TE | STOPE | DBGE | BCE | 0 | 0 | 0 | SR | 0 | WSF | SEF | FEF | FWF | FRF | | |
| W | | | | | | | FR | | | | | w1c | w1c | w1c | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|------|------|------|------|------|---|---|---|---|---|---|------|------|
| R | 0 | | | | | | | | 0 | | | 0 | | | | |
| W | | | | WSIE | SEIE | FEIE | FWIE | FRIE | | | | | | | FWDE | FRDE |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_TCSR field descriptions

| Field | Description |
|-------------|---|
| 31 TE | Transmitter Enable Enables/disables the transmitter. When software clears this field, the transmitter remains enabled, and this bit remains set, until the end of the current frame. 0 Transmitter is disabled. 1 Transmitter is enabled, or transmitter has been disabled and has not yet reached end of frame. |
| 30 STOPE | Stop Enable Configures transmitter operation in Stop mode. This field is ignored and the transmitter is disabled in all low-leakage stop modes. 0 Transmitter disabled in Stop mode. 1 Transmitter enabled in Stop mode. |
| 29 DBGE | Debug Enable |

Table continues on the next page...

I2Sx_TCSR field descriptions (continued)

| Field | Description |
|-------------------|---|
| | <p>Enables/disables transmitter operation in Debug mode. The transmit bit clock is not affected by debug mode.</p> <p>0 Transmitter is disabled in Debug mode, after completing the current frame. 1 Transmitter is enabled in Debug mode.</p> |
| 28 BCE | <p>Bit Clock Enable</p> <p>Enables the transmit bit clock, separately from the TE. This field is automatically set whenever TE is set. When software clears this field, the transmit bit clock remains enabled, and this bit remains set, until the end of the current frame.</p> <p>0 Transmit bit clock is disabled. 1 Transmit bit clock is enabled.</p> |
| 27–26 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 25 FR | <p>FIFO Reset</p> <p>Resets the FIFO pointers. Reading this field will always return zero. FIFO pointers should only be reset when the transmitter is disabled or the FIFO error flag is set.</p> <p>0 No effect. 1 FIFO reset.</p> |
| 24 SR | <p>Software Reset</p> <p>When set, resets the internal transmitter logic including the FIFO pointers. Software-visible registers are not affected, except for the status registers.</p> <p>0 No effect. 1 Software reset.</p> |
| 23–21 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 20 WSF | <p>Word Start Flag</p> <p>Indicates that the start of the configured word has been detected. Write a logic 1 to this field to clear this flag.</p> <p>0 Start of word not detected. 1 Start of word detected.</p> |
| 19 SEF | <p>Sync Error Flag</p> <p>Indicates that an error in the externally-generated frame sync has been detected. Write a logic 1 to this field to clear this flag.</p> <p>0 Sync error not detected. 1 Frame sync error detected.</p> |
| 18 FEF | <p>FIFO Error Flag</p> <p>Indicates that an enabled transmit FIFO has underrun. Write a logic 1 to this field to clear this flag.</p> <p>0 Transmit underrun not detected. 1 Transmit underrun detected.</p> |

Table continues on the next page...

I2Sx_TCSR field descriptions (continued)

| Field | Description |
|-------------------|---|
| 17 FWF | FIFO Warning Flag Indicates that an enabled transmit FIFO is empty. 0 No enabled transmit FIFO is empty. 1 Enabled transmit FIFO is empty. |
| 16 FRF | FIFO Request Flag Indicates that the number of words in an enabled transmit channel FIFO is less than or equal to the transmit FIFO watermark. 0 Transmit FIFO watermark has not been reached. 1 Transmit FIFO watermark has been reached. |
| 15–13 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 12 WSIE | Word Start Interrupt Enable Enables/disables word start interrupts. 0 Disables interrupt. 1 Enables interrupt. |
| 11 SEIE | Sync Error Interrupt Enable Enables/disables sync error interrupts. 0 Disables interrupt. 1 Enables interrupt. |
| 10 FEIE | FIFO Error Interrupt Enable Enables/disables FIFO error interrupts. 0 Disables the interrupt. 1 Enables the interrupt. |
| 9 FWIE | FIFO Warning Interrupt Enable Enables/disables FIFO warning interrupts. 0 Disables the interrupt. 1 Enables the interrupt. |
| 8 FRIE | FIFO Request Interrupt Enable Enables/disables FIFO request interrupts. 0 Disables the interrupt. 1 Enables the interrupt. |
| 7–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4–2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 FWDE | FIFO Warning DMA Enable |

Table continues on the next page...

I2Sx_TCSR field descriptions (continued)

| Field | Description |
|-----------|--|
| | Enables/disables DMA requests. 0 Disables the DMA request. 1 Enables the DMA request. |
| 0 FRDE | FIFO Request DMA Enable Enables/disables DMA requests. 0 Disables the DMA request. 1 Enables the DMA request. |

46.3.2 SAI Transmit Configuration 1 Register (I2Sx_TCR1)

Address: 4002_F000h base + 4h offset = 4002_F004h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|-----|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | TFW | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

I2Sx_TCR1 field descriptions

| Field | Description |
|------------------|--|
| 31–3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2–0 TFW | Transmit FIFO Watermark Configures the watermark level for all enabled transmit channels. |

46.3.3 SAI Transmit Configuration 2 Register (I2Sx_TCR2)

This register must not be altered when TCSR[TE] is set.

Address: 4002_F000h base + 8h offset = 4002_F008h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | | | | | | | | | 0 | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|-----|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | DIV | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_TCR2 field descriptions

| Field | Description |
|---------------|---|
| 31–30 SYNC | <p>Synchronous Mode</p> <p>Configures between asynchronous and synchronous modes of operation. When configured for a synchronous mode of operation, the receiver must be configured for asynchronous operation.</p> <p>00 Asynchronous mode. 01 Synchronous with receiver. 10 Synchronous with another SAI transmitter. 11 Synchronous with another SAI receiver.</p> |
| 29 BCS | <p>Bit Clock Swap</p> <p>This field swaps the bit clock used by the transmitter. When the transmitter is configured in asynchronous mode and this bit is set, the transmitter is clocked by the receiver bit clock (SAI_RX_BCLK). This allows the transmitter and receiver to share the same bit clock, but the transmitter continues to use the transmit frame sync (SAI_TX_SYNC).</p> <p>When the transmitter is configured in synchronous mode, the transmitter BCS field and receiver BCS field must be set to the same value. When both are set, the transmitter and receiver are both clocked by the transmitter bit clock (SAI_TX_BCLK) but use the receiver frame sync (SAI_RX_SYNC).</p> <p>0 Use the normal bit clock source. 1 Swap the bit clock source.</p> |
| 28 BCI | <p>Bit Clock Input</p> <p>When this field is set and using an internally generated bit clock in either synchronous or asynchronous mode, the bit clock actually used by the transmitter is delayed by the pad output delay (the transmitter is clocked by the pad input as if the clock was externally generated). This has the effect of decreasing the data input setup time, but increasing the data output valid time.</p> <p>The slave mode timing from the datasheet should be used for the transmitter when this bit is set. In synchronous mode, this bit allows the transmitter to use the slave mode timing from the datasheet, while the receiver uses the master mode timing. This field has no effect when configured for an externally generated bit clock .</p> <p>0 No effect. 1 Internal logic is clocked as if bit clock was externally generated.</p> |
| 27–26 MSEL | <p>MCLK Select</p> <p>Selects the audio Master Clock option used to generate an internally generated bit clock. This field has no effect when configured for an externally generated bit clock.</p> <p>NOTE: Depending on the device, some Master Clock options might not be available. See the chip configuration details for the availability and chip-specific meaning of each option.</p> <p>00 Bus Clock selected. 01 Master Clock (MCLK) 1 option selected. 10 Master Clock (MCLK) 2 option selected. 11 Master Clock (MCLK) 3 option selected.</p> |
| 25 BCP | <p>Bit Clock Polarity</p> <p>Configures the polarity of the bit clock.</p> <p>0 Bit clock is active high with drive outputs on rising edge and sample inputs on falling edge. 1 Bit clock is active low with drive outputs on falling edge and sample inputs on rising edge.</p> |

Table continues on the next page...

I2Sx_TCR2 field descriptions (continued)

| Field | Description |
|------------------|--|
| 24 BCD | Bit Clock Direction Configures the direction of the bit clock. 0 Bit clock is generated externally in Slave mode. 1 Bit clock is generated internally in Master mode. |
| 23–8 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 7–0 DIV | Bit Clock Divide Divides down the audio master clock to generate the bit clock when configured for an internal bit clock. The division value is (DIV + 1) * 2. |

46.3.4 SAI Transmit Configuration 3 Register (I2Sx_TCR3)

This register must not be altered when TCSR[TE] is set.

Address: 4002_F000h base + Ch offset = 4002_F00Ch

| | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|-----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | |
| R | 0 | | | | | | | | 0 | | | | | | | | TCE |
| W | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |
| R | 0 | | | | | | | | | | | | WDFL | | | | |
| W | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

I2Sx_TCR3 field descriptions

| Field | Description |
|-------------------|---|
| 31–24 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 23–17 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 16 TCE | Transmit Channel Enable Enables the corresponding data channel for transmit operation. A channel must be enabled before its FIFO is accessed. 0 Transmit data channel N is disabled. 1 Transmit data channel N is enabled. |
| 15–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

Table continues on the next page...

I2Sx_TCR3 field descriptions (continued)

| Field | Description |
|-------------|---|
| 3–0 WDFL | Word Flag Configuration Configures which word sets the start of word flag. The value written must be one less than the word number. For example, writing 0 configures the first word in the frame. When configured to a value greater than TCR4[FRSZ], then the start of word flag is never set. |

46.3.5 SAI Transmit Configuration 4 Register (I2Sx_TCR4)

This register must not be altered when TCSR[TE] is set.

Address: 4002_F000h base + 10h offset = 4002_F010h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | | 0 | | 0 | 0 | | 0 | | | 0 | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | 0 | | | | | | | | 0 | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_TCR4 field descriptions

| Field | Description |
|-------------------|---|
| 31–29 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 28 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 27–26 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 25–24 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 23–20 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 19–16 FRSZ | Frame size Configures the number of words in each frame. The value written must be one less than the number of words in the frame. For example, write 0 for one word per frame. The maximum supported frame size is 16 words. |
| 15–13 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 12–8 SYWD | Sync Width Configures the length of the frame sync in number of bit clocks. The value written must be one less than the number of bit clocks. For example, write 0 for the frame sync to assert for one bit clock only. The sync width cannot be configured longer than the first word of the frame. |

Table continues on the next page...

I2Sx_TCR4 field descriptions (continued)

| Field | Description |
|-----------------|--|
| 7–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 MF | MSB First Configures whether the LSB or the MSB is transmitted first. 0 LSB is transmitted first. 1 MSB is transmitted first. |
| 3 FSE | Frame Sync Early 0 Frame sync asserts with the first bit of the frame. 1 Frame sync asserts one bit before the first bit of the frame. |
| 2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 FSP | Frame Sync Polarity Configures the polarity of the frame sync. 0 Frame sync is active high. 1 Frame sync is active low. |
| 0 FSD | Frame Sync Direction Configures the direction of the frame sync. 0 Frame sync is generated externally in Slave mode. 1 Frame sync is generated internally in Master mode. |

46.3.6 SAI Transmit Configuration 5 Register (I2Sx_TCR5)

This register must not be altered when TCSR[TE] is set.

Address: 4002_F000h base + 14h offset = 4002_F014h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_TCR5 field descriptions

| Field | Description |
|-------------------|--|
| 31–29 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 28–24 WNW | Word N Width Configures the number of bits in each word, for each word except the first in the frame. The value written must be one less than the number of bits per word. Word width of less than 8 bits is not supported. |

Table continues on the next page...

I2Sx_TCR5 field descriptions (continued)

| Field | Description |
|-------------------|---|
| 23–21 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 20–16 W0W | Word 0 Width Configures the number of bits in the first word in each frame. The value written must be one less than the number of bits in the first word. Word width of less than 8 bits is not supported if there is only one word per frame. |
| 15–13 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 12–8 FBT | First Bit Shifted Configures the bit index for the first bit transmitted for each word in the frame. If configured for MSB First, the index of the next bit transmitted is one less than the current bit transmitted. If configured for LSB First, the index of the next bit transmitted is one more than the current bit transmitted. The value written must be greater than or equal to the word width when configured for MSB First. The value written must be less than or equal to 31-word width when configured for LSB First. |
| 7–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

46.3.7 SAI Transmit Data Register (I2Sx_TDRn)

Address: 4002_F000h base + 20h offset + (4d × i), where i=0d to 0d

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-----------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | TDR[31:0] | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_TDRn field descriptions

| Field | Description |
|-------------------|---|
| 31–0 TDR[31:0] | Transmit Data Register The corresponding TCR3[TCE] bit must be set before accessing the channel's transmit data register. Writes to this register when the transmit FIFO is not full will push the data written into the transmit data FIFO. Writes to this register when the transmit FIFO is full are ignored. |

46.3.8 SAI Transmit FIFO Register (I2Sx_TFRn)

The MSB of the read and write pointers is used to distinguish between FIFO full and empty conditions. If the read and write pointers are identical, then the FIFO is empty. If the read and write pointers are identical except for the MSB, then the FIFO is full.

Address: 4002_F000h base + 40h offset + (4d × i), where i=0d to 0d

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|-----|-----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | 0 | | | | | | | | | | | | WFP | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | RFP | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_TFRn field descriptions

| Field | Description |
|-------------------|---|
| 31 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 30–20 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 19–16 WFP | Write FIFO Pointer FIFO write pointer for transmit data channel. |
| 15–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3–0 RFP | Read FIFO Pointer FIFO read pointer for transmit data channel. |

46.3.9 SAI Transmit Mask Register (I2Sx_TMR)

This register is double-buffered and updates:

1. When TCSR[TE] is first set
2. At the end of each frame.

This allows the masked words in each frame to change from frame to frame.

Address: 4002_F000h base + 60h offset = 4002_F060h

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | 0 | | | | | | | | | | | | | | | | TWM | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_TMR field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 TWM | Transmit Word Mask Configures whether the transmit word is masked (transmit data pin tristated and transmit data not read from FIFO) for the corresponding word in the frame. 0 Word N is enabled. 1 Word N is masked. The transmit data pins are tri-stated when masked. |

46.3.10 SAI Receive Control Register (I2Sx_RCSR)

Address: 4002_F000h base + 80h offset = 4002_F080h

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|----|-------|------|-----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|
| R | RE | STOPE | DBGE | BCE | 0 | | 0 | SR | 0 | | | WSF | SEF | FEF | FWF | FRF |
| W | | | | | | | FR | | | | | w1c | w1c | w1c | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |
|-------|----|----|----|------|------|------|------|------|---|---|---|---|---|---|---|------|------|
| R | 0 | | | WSIE | SEIE | FEIE | FWIE | FRIE | 0 | | | | 0 | | | FWDE | FRDE |
| W | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

I2Sx_RCSR field descriptions

| Field | Description |
|-------------------|---|
| 31 RE | <p>Receiver Enable</p> <p>Enables/disables the receiver. When software clears this field, the receiver remains enabled, and this bit remains set, until the end of the current frame.</p> <p>0 Receiver is disabled. 1 Receiver is enabled, or receiver has been disabled and has not yet reached end of frame.</p> |
| 30 STOPE | <p>Stop Enable</p> <p>Configures receiver operation in Stop mode. This bit is ignored and the receiver is disabled in all low-leakage stop modes.</p> <p>0 Receiver disabled in Stop mode. 1 Receiver enabled in Stop mode.</p> |
| 29 DBGE | <p>Debug Enable</p> <p>Enables/disables receiver operation in Debug mode. The receive bit clock is not affected by Debug mode.</p> <p>0 Receiver is disabled in Debug mode, after completing the current frame. 1 Receiver is enabled in Debug mode.</p> |
| 28 BCE | <p>Bit Clock Enable</p> <p>Enables the receive bit clock, separately from RE. This field is automatically set whenever RE is set. When software clears this field, the receive bit clock remains enabled, and this field remains set, until the end of the current frame.</p> <p>0 Receive bit clock is disabled. 1 Receive bit clock is enabled.</p> |
| 27–26 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 25 FR | <p>FIFO Reset</p> <p>Resets the FIFO pointers. Reading this field will always return zero. FIFO pointers should only be reset when the receiver is disabled or the FIFO error flag is set.</p> <p>0 No effect. 1 FIFO reset.</p> |
| 24 SR | <p>Software Reset</p> <p>Resets the internal receiver logic including the FIFO pointers. Software-visible registers are not affected, except for the status registers.</p> <p>0 No effect. 1 Software reset.</p> |
| 23–21 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 20 WSF | <p>Word Start Flag</p> <p>Indicates that the start of the configured word has been detected. Write a logic 1 to this field to clear this flag.</p> |

Table continues on the next page...

I2Sx_RCSR field descriptions (continued)

| Field | Description |
|-------------------|--|
| | <p>0 Start of word not detected.</p> <p>1 Start of word detected.</p> |
| 19 SEF | <p>Sync Error Flag</p> <p>Indicates that an error in the externally-generated frame sync has been detected. Write a logic 1 to this field to clear this flag.</p> <p>0 Sync error not detected.</p> <p>1 Frame sync error detected.</p> |
| 18 FEF | <p>FIFO Error Flag</p> <p>Indicates that an enabled receive FIFO has overflowed. Write a logic 1 to this field to clear this flag.</p> <p>0 Receive overflow not detected.</p> <p>1 Receive overflow detected.</p> |
| 17 FWF | <p>FIFO Warning Flag</p> <p>Indicates that an enabled receive FIFO is full.</p> <p>0 No enabled receive FIFO is full.</p> <p>1 Enabled receive FIFO is full.</p> |
| 16 FRF | <p>FIFO Request Flag</p> <p>Indicates that the number of words in an enabled receive channel FIFO is greater than the receive FIFO watermark.</p> <p>0 Receive FIFO watermark not reached.</p> <p>1 Receive FIFO watermark has been reached.</p> |
| 15–13 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 12 WSIE | <p>Word Start Interrupt Enable</p> <p>Enables/disables word start interrupts.</p> <p>0 Disables interrupt.</p> <p>1 Enables interrupt.</p> |
| 11 SEIE | <p>Sync Error Interrupt Enable</p> <p>Enables/disables sync error interrupts.</p> <p>0 Disables interrupt.</p> <p>1 Enables interrupt.</p> |
| 10 FEIE | <p>FIFO Error Interrupt Enable</p> <p>Enables/disables FIFO error interrupts.</p> <p>0 Disables the interrupt.</p> <p>1 Enables the interrupt.</p> |
| 9 FWIE | <p>FIFO Warning Interrupt Enable</p> <p>Enables/disables FIFO warning interrupts.</p> |

Table continues on the next page...

I2Sx_RCSR field descriptions (continued)

| Field | Description |
|-----------------|---|
| | 0 Disables the interrupt. 1 Enables the interrupt. |
| 8 FRIE | FIFO Request Interrupt Enable Enables/disables FIFO request interrupts. 0 Disables the interrupt. 1 Enables the interrupt. |
| 7–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4–2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 FWDE | FIFO Warning DMA Enable Enables/disables DMA requests. 0 Disables the DMA request. 1 Enables the DMA request. |
| 0 FRDE | FIFO Request DMA Enable Enables/disables DMA requests. 0 Disables the DMA request. 1 Enables the DMA request. |

46.3.11 SAI Receive Configuration 1 Register (I2Sx_RCR1)

Address: 4002_F000h base + 84h offset = 4002_F084h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|-----|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | RFW | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

I2Sx_RCR1 field descriptions

| Field | Description |
|------------------|---|
| 31–3 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 2–0 RFW | Receive FIFO Watermark Configures the watermark level for all enabled receiver channels. |

46.3.12 SAI Receive Configuration 2 Register (I2Sx_RCR2)

This register must not be altered when RCSR[RE] is set.

Address: 4002_F000h base + 88h offset = 4002_F088h

| | | | | | | | | | | | | | | | | |
|-------|------|----|-----|-----|------|----|-----|-----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | SYNC | | BCS | BCI | MSEL | | BCP | BCD | 0 | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|-----|---|---|---|---|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | DIV | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_RCR2 field descriptions

| Field | Description |
|---------------|---|
| 31–30 SYNC | <p>Synchronous Mode</p> <p>Configures between asynchronous and synchronous modes of operation. When configured for a synchronous mode of operation, the transmitter must be configured for asynchronous operation.</p> <p>00 Asynchronous mode. 01 Synchronous with transmitter. 10 Synchronous with another SAI receiver. 11 Synchronous with another SAI transmitter.</p> |
| 29 BCS | <p>Bit Clock Swap</p> <p>This field swaps the bit clock used by the receiver. When the receiver is configured in asynchronous mode and this bit is set, the receiver is clocked by the transmitter bit clock (SAI_TX_BCLK). This allows the transmitter and receiver to share the same bit clock, but the receiver continues to use the receiver frame sync (SAI_RX_SYNC).</p> <p>When the receiver is configured in synchronous mode, the transmitter BCS field and receiver BCS field must be set to the same value. When both are set, the transmitter and receiver are both clocked by the receiver bit clock (SAI_RX_BCLK) but use the transmitter frame sync (SAI_TX_SYNC).</p> <p>0 Use the normal bit clock source. 1 Swap the bit clock source.</p> |
| 28 BCI | <p>Bit Clock Input</p> <p>When this field is set and using an internally generated bit clock in either synchronous or asynchronous mode, the bit clock actually used by the receiver is delayed by the pad output delay (the receiver is clocked by the pad input as if the clock was externally generated). This has the effect of decreasing the data input setup time, but increasing the data output valid time.</p> <p>The slave mode timing from the datasheet should be used for the receiver when this bit is set. In synchronous mode, this bit allows the receiver to use the slave mode timing from the datasheet, while the transmitter uses the master mode timing. This field has no effect when configured for an externally generated bit clock .</p> <p>0 No effect. 1 Internal logic is clocked as if bit clock was externally generated.</p> |

Table continues on the next page...

I2Sx_RCR2 field descriptions (continued)

| Field | Description |
|------------------|---|
| 27–26 MSEL | <p>MCLK Select</p> <p>Selects the audio Master Clock option used to generate an internally generated bit clock. This field has no effect when configured for an externally generated bit clock.</p> <p>NOTE: Depending on the device, some Master Clock options might not be available. See the chip configuration details for the availability and chip-specific meaning of each option.</p> <p>00 Bus Clock selected. 01 Master Clock (MCLK) 1 option selected. 10 Master Clock (MCLK) 2 option selected. 11 Master Clock (MCLK) 3 option selected.</p> |
| 25 BCP | <p>Bit Clock Polarity</p> <p>Configures the polarity of the bit clock.</p> <p>0 Bit Clock is active high with drive outputs on rising edge and sample inputs on falling edge. 1 Bit Clock is active low with drive outputs on falling edge and sample inputs on rising edge.</p> |
| 24 BCD | <p>Bit Clock Direction</p> <p>Configures the direction of the bit clock.</p> <p>0 Bit clock is generated externally in Slave mode. 1 Bit clock is generated internally in Master mode.</p> |
| 23–8 Reserved | <p>This field is reserved. This read-only field is reserved and always has the value 0.</p> |
| 7–0 DIV | <p>Bit Clock Divide</p> <p>Divides down the audio master clock to generate the bit clock when configured for an internal bit clock. The division value is (DIV + 1) * 2.</p> |

46.3.13 SAI Receive Configuration 3 Register (I2Sx_RCR3)

This register must not be altered when RCSR[RE] is set.

Address: 4002_F000h base + 8Ch offset = 4002_F08Ch

| | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|------|----|----|----|-----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | |
| R | 0 | | | | | | | | 0 | | | | | | | | RCE |
| W | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |
| R | 0 | | | | | | | | | | | | WDFL | | | | |
| W | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

I2Sx_RCR3 field descriptions

| Field | Description |
|-------------------|---|
| 31–24 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 23–17 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 16 RCE | Receive Channel Enable Enables the corresponding data channel for receive operation. A channel must be enabled before its FIFO is accessed. 0 Receive data channel N is disabled. 1 Receive data channel N is enabled. |
| 15–4 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 3–0 WDFL | Word Flag Configuration Configures which word the start of word flag is set. The value written should be one less than the word number (for example, write zero to configure for the first word in the frame). When configured to a value greater than the Frame Size field, then the start of word flag is never set. |

46.3.14 SAI Receive Configuration 4 Register (I2Sx_RCR4)

This register must not be altered when RCSR[RE] is set.

Address: 4002_F000h base + 90h offset = 4002_F090h

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | | 0 | | 0 | | 0 | | 0 | | 0 | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | 0 | | | | | | | | 0 | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_RCR4 field descriptions

| Field | Description |
|-------------------|---|
| 31–29 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 28 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 27–26 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 25–24 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

Table continues on the next page...

I2Sx_RCR4 field descriptions (continued)

| Field | Description |
|-------------------|---|
| 23–20 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 19–16 FRSZ | Frame Size Configures the number of words in each frame. The value written must be one less than the number of words in the frame. For example, write 0 for one word per frame. The maximum supported frame size is 16 words. |
| 15–13 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 12–8 SYWD | Sync Width Configures the length of the frame sync in number of bit clocks. The value written must be one less than the number of bit clocks. For example, write 0 for the frame sync to assert for one bit clock only. The sync width cannot be configured longer than the first word of the frame. |
| 7–5 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 4 MF | MSB First Configures whether the LSB or the MSB is received first. 0 LSB is received first. 1 MSB is received first. |
| 3 FSE | Frame Sync Early 0 Frame sync asserts with the first bit of the frame. 1 Frame sync asserts one bit before the first bit of the frame. |
| 2 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 1 FSP | Frame Sync Polarity Configures the polarity of the frame sync. 0 Frame sync is active high. 1 Frame sync is active low. |
| 0 FSD | Frame Sync Direction Configures the direction of the frame sync. 0 Frame Sync is generated externally in Slave mode. 1 Frame Sync is generated internally in Master mode. |

46.3.15 SAI Receive Configuration 5 Register (I2Sx_RCR5)

This register must not be altered when RCSR[RE] is set.

Address: 4002_F000h base + 94h offset = 4002_F094h

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | 0 | | | | | | | | | | 0 | | | | | | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_RCR5 field descriptions

| Field | Description |
|-------------------|--|
| 31–29 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 28–24 WNW | Word N Width Configures the number of bits in each word, for each word except the first in the frame. The value written must be one less than the number of bits per word. Word width of less than 8 bits is not supported. |
| 23–21 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 20–16 W0W | Word 0 Width Configures the number of bits in the first word in each frame. The value written must be one less than the number of bits in the first word. Word width of less than 8 bits is not supported if there is only one word per frame. |
| 15–13 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 12–8 FBT | First Bit Shifted Configures the bit index for the first bit received for each word in the frame. If configured for MSB First, the index of the next bit received is one less than the current bit received. If configured for LSB First, the index of the next bit received is one more than the current bit received. The value written must be greater than or equal to the word width when configured for MSB First. The value written must be less than or equal to 31-word width when configured for LSB First. |
| 7–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

46.3.16 SAI Receive Data Register (I2Sx_RDRn)

Reading this register introduces one additional peripheral clock wait state on each read.

Address: 4002_F000h base + A0h offset + (4d × i), where i=0d to 0d

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_RDR_n field descriptions

| Field | Description |
|-------------------|---|
| 31–0 RDR[31:0] | <p>Receive Data Register</p> <p>The corresponding RCR3[RCE] bit must be set before accessing the channel's receive data register. Reads from this register when the receive FIFO is not empty will return the data from the top of the receive FIFO. Reads from this register when the receive FIFO is empty are ignored.</p> |

46.3.17 SAI Receive FIFO Register (I2Sx_RFR_n)

The MSB of the read and write pointers is used to distinguish between FIFO full and empty conditions. If the read and write pointers are identical, then the FIFO is empty. If the read and write pointers are identical except for the MSB, then the FIFO is full.

Address: 4002_F000h base + C0h offset + (4d × i), where i=0d to 0d

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
| R | 0 | | | | | | | | | | | | WFP | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|---|---|---|---|---|---|-----|---|---|---|
| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | 0 | | | | | | | | | | | RFP | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_RFR_n field descriptions

| Field | Description |
|-------------------|--|
| 31–20 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 19–16 WFP | <p>Write FIFO Pointer</p> <p>FIFO write pointer for receive data channel.</p> |
| 15 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 14–4 Reserved | <p>This field is reserved.</p> <p>This read-only field is reserved and always has the value 0.</p> |
| 3–0 RFP | <p>Read FIFO Pointer</p> <p>FIFO read pointer for receive data channel.</p> |

46.3.18 SAI Receive Mask Register (I2Sx_RMR)

This register is double-buffered and updates:

1. When RCSR[RE] is first set
2. At the end of each frame

This allows the masked words in each frame to change from frame to frame.

Address: 4002_F000h base + E0h offset = 4002_F0E0h

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | 0 | | | | | | | | | | | | | | | | RWM | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_RMR field descriptions

| Field | Description |
|-------------------|--|
| 31–16 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 15–0 RWM | Receive Word Mask Configures whether the receive word is masked (received data ignored and not written to receive FIFO) for the corresponding word in the frame. 0 Word N is enabled. 1 Word N is masked. |

46.3.19 SAI MCLK Control Register (I2Sx_MCR)

The MCLK Control Register (MCR) controls the clock source and direction of the audio master clock.

Address: 4002_F000h base + 100h offset = 4002_F100h

| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 |
|-------|-----|-----|----|----|----|----|------|----|----|----|----|----|----|----|----|----|
| R | DUF | | 0 | | | | | | 0 | | | | | | | |
| W | | MOE | | | | | MICS | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| R | 0 | | | | | | | | | | | | | | | |
| W | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

I2Sx_MCR field descriptions

| Field | Description |
|-----------|---|
| 31 DUF | Divider Update Flag Provides the status of on-the-fly updates to the MCLK divider ratio. |

Table continues on the next page...

I2Sx_MCR field descriptions (continued)

| Field | Description |
|-------------------|---|
| | 0 MCLK divider ratio is not being updated currently. 1 MCLK divider ratio is updating on-the-fly. Further updates to the MCLK divider ratio are blocked while this flag remains set. |
| 30 MOE | MCLK Output Enable Enables the MCLK divider and configures the MCLK signal pin as an output. When software clears this field, it remains set until the MCLK divider is fully disabled. 0 MCLK signal pin is configured as an input that bypasses the MCLK divider. 1 MCLK signal pin is configured as an output from the MCLK divider and the MCLK divider is enabled. |
| 29–26 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 25–24 MICS | MCLK Input Clock Select Selects the clock input to the MCLK divider. This field cannot be changed while the MCLK divider is enabled. See the chip configuration details for information about the connections to these inputs. 00 MCLK divider input clock 0 selected. 01 MCLK divider input clock 1 selected. 10 MCLK divider input clock 2 selected. 11 MCLK divider input clock 3 selected. |
| 23–0 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |

46.3.20 SAI MCLK Divide Register (I2Sx_MDR)

The MCLK Divide Register (MDR) configures the MCLK divide ratio. Although the MDR can be changed when the MCLK divider clock is enabled, additional writes to the MDR are blocked while MCR[DUF] is set. Writes to the MDR when the MCLK divided clock is disabled do not set MCR[DUF].

Address: 4002_F000h base + 104h offset = 4002_F104h

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|-------|----|----|----|----|--------|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | 0 | | | | | | | | | | | | FRACT | | | | | DIVIDE | | | | | | | | | | | | | | |
| W | 0 | | | | | | | | | | | | 0 | | | | | 0 | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

I2Sx_MDR field descriptions

| Field | Description |
|-------------------|---|
| 31–20 Reserved | This field is reserved. This read-only field is reserved and always has the value 0. |
| 19–12 FRACT | MCLK Fraction Sets the MCLK divide ratio such that: $MCLK\ output = MCLK\ input * ((FRACT + 1) / (DIVIDE + 1))$. FRACT must be set equal or less than the value in the DIVIDE field. |

Table continues on the next page...

I2Sx_MDR field descriptions (continued)

| Field | Description |
|----------------|--|
| | NOTE: When using fractional divide values, the MCLK duty cycle will not always be 50/50. See Audio master clock . |
| 11–0 DIVIDE | <p>MCLK Divide</p> <p>Sets the MCLK divide ratio such that: $MCLK\ output = MCLK\ input * (FRACT + 1) / (DIVIDE + 1)$. FRACT must be set equal or less than the value in the DIVIDE field.</p> <p>NOTE: When using fractional divide values, the MCLK duty cycle will not always be 50/50. See Audio master clock.</p> |

46.4 Functional description

This section provides a complete functional description of the block.

46.4.1 SAI clocking

The SAI clocks include:

- The audio master clock
- The bit clock
- The bus clock

46.4.1.1 Audio master clock

The audio master clock is used to generate the bit clock when the receiver or transmitter is configured for an internally generated bit clock. The transmitter and receiver can independently select between the bus clock and up to three audio master clocks to generate the bit clock.

Each SAI peripheral can control the input clock selection, pin direction and divide ratio of one audio master clock. The input clock selection and pin direction cannot be altered if an SAI module using that audio master clock has been enabled. The MCLK divide ratio can be altered while an SAI is using that master clock, although the change in the divide ratio takes several cycles. MCR[DUF] can be polled to determine when the divide ratio change has completed.

The audio master clock generation and selection is chip-specific. Refer to chip-specific clocking information about how the audio master clocks are generated. A typical implementation appears in the following figure.

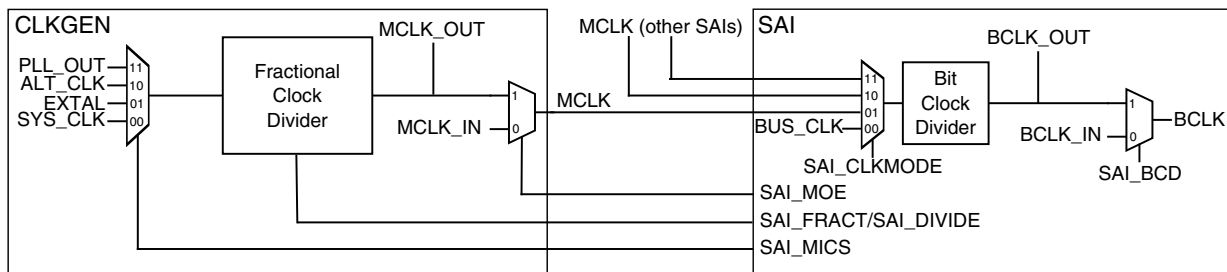


Figure 46-50. SAI master clock generation

The MCLK fractional clock divider uses both clock edges from the input clock to generate a divided down clock that will approximate the output frequency, but without creating any new clock edges. Configuring FRACT and DIVIDE to the same value will result in a divide by 1 clock, while configuring FRACT higher than DIVIDE is not supported. The duty cycle can range from 66/33 when FRACT is set to one less than DIVIDE down to 50/50 for integer divide ratios, and will approach 50/50 for large non-integer divide ratios. There is no cycle to cycle jitter or duty cycle variance when the divide ratio is an integer or half integer, otherwise the divider output will oscillate between the two divided frequencies that are the closest integer or half integer divisors of the divider input clock frequency. The maximum jitter is therefore equal to half the divider input clock period, since both edges of the input clock are used in generating the divided clock.

46.4.1.2 Bit clock

The SAI transmitter and receiver support asynchronous free-running bit clocks that can be generated internally from an audio master clock or supplied externally. There is also the option for synchronous bit clock and frame sync operation between the receiver and transmitter or between multiple SAI peripherals.

Externally generated bit clocks must be:

- Enabled before the SAI transmitter or receiver is enabled
- Disabled after the SAI transmitter or receiver is disabled and completes its current frames

If the SAI transmitter or receiver is using an externally generated bit clock in asynchronous mode and that bit clock is generated by an SAI that is disabled in stop mode, then the transmitter or receiver should be disabled by software before entering stop mode. This issue does not apply when the transmitter or receiver is in a synchronous mode because all synchronous SAIs are enabled and disabled simultaneously.

46.4.1.3 Bus clock

The bus clock is used by the control and configuration registers and to generate synchronous interrupts and DMA requests.

NOTE

Although there is no specific minimum bus clock frequency specified, the bus clock frequency must be fast enough (relative to the bit clock frequency) to ensure that the FIFOs can be serviced, without generating either a transmitter FIFO underrun or receiver FIFO overflow condition.

46.4.2 SAI resets

The SAI is asynchronously reset on system reset. The SAI has a software reset and a FIFO reset.

46.4.2.1 Software reset

The SAI transmitter includes a software reset that resets all transmitter internal logic, including the bit clock generation, status flags, and FIFO pointers. It does not reset the configuration registers. The software reset remains asserted until cleared by software.

The SAI receiver includes a software reset that resets all receiver internal logic, including the bit clock generation, status flags and FIFO pointers. It does not reset the configuration registers. The software reset remains asserted until cleared by software.

46.4.2.2 FIFO reset

The SAI transmitter includes a FIFO reset that synchronizes the FIFO write pointer to the same value as the FIFO read pointer. This empties the FIFO contents and is to be used after TCSR[FEF] is set, and before the FIFO is re-initialized and TCSR[FEF] is cleared. The FIFO reset is asserted for one cycle only.

The SAI receiver includes a FIFO reset that synchronizes the FIFO read pointer to the same value as the FIFO write pointer. This empties the FIFO contents and is to be used after the RCSR[FEF] is set and any remaining data has been read from the FIFO, and before the RCSR[FEF] is cleared. The FIFO reset is asserted for one cycle only.

46.4.3 Synchronous modes

The SAI transmitter and receiver can operate synchronously to each other.

46.4.3.1 Synchronous mode

The SAI transmitter and receiver can be configured to operate with synchronous bit clock and frame sync.

If the transmitter bit clock and frame sync are to be used by both the transmitter and receiver:

- The transmitter must be configured for asynchronous operation and the receiver for synchronous operation.
- In synchronous mode, the receiver is enabled only when both the transmitter and receiver are enabled.
- It is recommended that the transmitter is the last enabled and the first disabled.

If the receiver bit clock and frame sync are to be used by both the transmitter and receiver:

- The receiver must be configured for asynchronous operation and the transmitter for synchronous operation.
- In synchronous mode, the transmitter is enabled only when both the receiver and transmitter are both enabled.
- It is recommended that the receiver is the last enabled and the first disabled.

When operating in synchronous mode, only the bit clock, frame sync, and transmitter/receiver enable are shared. The transmitter and receiver otherwise operate independently, although configuration registers must be configured consistently across both the transmitter and receiver.

46.4.4 Frame sync configuration

When enabled, the SAI continuously transmits and/or receives frames of data. Each frame consists of a fixed number of words and each word consists of a fixed number of bits. Within each frame, any given word can be masked causing the receiver to ignore that word and the transmitter to tri-state for the duration of that word.

The frame sync signal is used to indicate the start of each frame. A valid frame sync requires a rising edge (if active high) or falling edge (if active low) to be detected and the transmitter or receiver cannot be busy with a previous frame. A valid frame sync is also ignored (slave mode) or not generated (master mode) for the first four bit clock cycles after enabling the transmitter or receiver.

The transmitter and receiver frame sync can be configured independently with any of the following options:

- Externally generated or internally generated
- Active high or active low
- Assert with the first bit in frame or asserts one bit early
- Assert for a duration between 1 bit clock and the first word length
- Frame length from 1 to 16 words per frame
- Word length to support 8 to 32 bits per word
 - First word length and remaining word lengths can be configured separately
- Words can be configured to transmit/receive MSB first or LSB first

These configuration options cannot be changed after the SAI transmitter or receiver is enabled.

46.4.5 Data FIFO

Each transmit and receive channel includes a FIFO of size 8×32 -bit. The FIFO data is accessed using the SAI Transmit/Receive Data Registers.

46.4.5.1 Data alignment

Data in the FIFO can be aligned anywhere within the 32-bit wide register through the use of the First Bit Shifted configuration field, which selects the bit index (between 31 and 0) of the first bit shifted.

Examples of supported data alignment and the required First Bit Shifted configuration are illustrated in [Figure 46-51](#) for LSB First configurations and [Figure 46-52](#) for MSB First configurations.

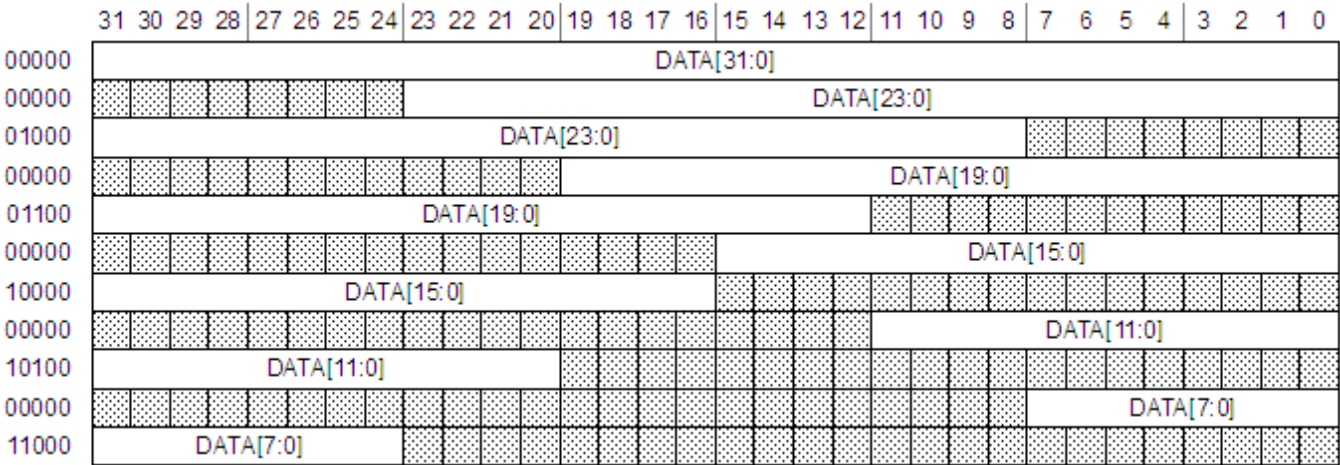


Figure 46-51. SAI first bit shifted, LSB first

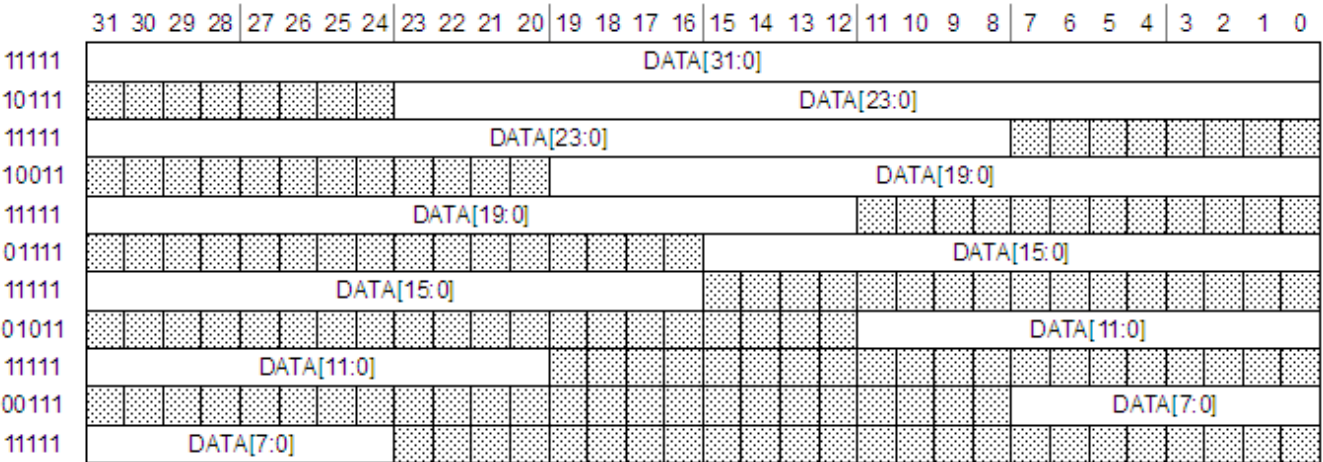


Figure 46-52. SAI first bit shifted, MSB first

46.4.5.2 FIFO pointers

When writing to a TDR, the WFP of the corresponding TFR increments after each valid write. The SAI supports 8-bit, 16-bit and 32-bit writes to the TDR and the FIFO pointer will increment after each individual write. Note that 8-bit writes should only be used when transmitting up to 8-bit data and 16-bit writes should only be used when transmitting up to 16-bit data.

Writes to a TDR are ignored if the corresponding bit of TCR3[TCE] is clear or if the FIFO is full. If the Transmit FIFO is empty, the TDR must be written at least three bit clocks before the start of the next unmasked word to avoid a FIFO underrun.

When reading an RDR, the RFP of the corresponding RFR increments after each valid read. The SAI supports 8-bit, 16-bit and 32-bit reads from the RDR and the FIFO pointer will increment after each individual read. Note that 8-bit reads should only be used when receiving up to 8-bit data and 16-bit reads should only be used when receiving up to 16-bit data.

Reads from an RDR are ignored if the corresponding bit of RCR3[RCE] is clear or if the FIFO is empty. If the Receive FIFO is full, the RDR must be read at least three bit clocks before the end of an unmasked word to avoid a FIFO overrun.

46.4.6 Word mask register

The SAI transmitter and receiver each contain a word mask register, namely TMR and RMR, that can be used to mask any word in the frame. Because the word mask register is double buffered, software can update it before the end of each frame to mask a particular word in the next frame.

The TMR causes the Transmit Data pin to be tri-stated for the length of each selected word and the transmit FIFO is not read for masked words.

The RMR causes the received data for each selected word to be discarded and not written to the receive FIFO.

46.4.7 Interrupts and DMA requests

The SAI transmitter and receiver generate separate interrupts and separate DMA requests, but support the same status flags. Asynchronous versions of the transmitter and receiver interrupts are generated to wake up the CPU from stop mode.

46.4.7.1 FIFO request flag

The FIFO request flag is set based on the number of entries in the FIFO and the FIFO watermark configuration.

The transmit FIFO request flag is set when the number of entries in any of the enabled transmit FIFOs is less than or equal to the transmit FIFO watermark configuration and is cleared when the number of entries in each enabled transmit FIFO is greater than the transmit FIFO watermark configuration.

The receive FIFO request flag is set when the number of entries in any of the enabled receive FIFOs is greater than the receive FIFO watermark configuration and is cleared when the number of entries in each enabled receive FIFO is less than or equal to the receive FIFO watermark configuration.

The FIFO request flag can generate an interrupt or a DMA request.

46.4.7.2 FIFO warning flag

The FIFO warning flag is set based on the number of entries in the FIFO.

The transmit warning flag is set when the number of entries in any of the enabled transmit FIFOs is empty and is cleared when the number of entries in each enabled transmit FIFO is not empty.

The receive warning flag is set when the number of entries in any of the enabled receive FIFOs is full and is cleared when the number of entries in each enabled receive FIFO is not full.

The FIFO warning flag can generate an Interrupt or a DMA request.

46.4.7.3 FIFO error flag

The transmit FIFO error flag is set when the any of the enabled transmit FIFOs underflow. After it is set, all enabled transmit channels repeat the last valid word read from the transmit FIFO until TCSR[FEF] is cleared and the next transmit frame starts. All enabled transmit FIFOs must be reset and initialized with new data before TCSR[FEF] is cleared.

RCSR[FEF] is set when the any of the enabled receive FIFOs overflow. After it is set, all enabled receive channels discard received data until RCSR[FEF] is cleared and the next next receive frame starts. All enabled receive FIFOs should be emptied before RCSR[FEF] is cleared.

The FIFO error flag can generate only an interrupt.

46.4.7.4 Sync error flag

The sync error flag, TCSR[SEF] or RCSR[SEF], is set when configured for an externally generated frame sync and the external frame sync asserts when the transmitter or receiver is busy with the previous frame. The external frame sync assertion is ignored and the sync error flag is set. When the sync error flag is set, the transmitter or receiver continues checking for frame sync assertion when idle or at the end of each frame.

The sync error flag can generate an interrupt only.

46.4.7.5 Word start flag

The word start flag is set at the start of the second bit clock for the selected word, as configured by the Word Flag register field.

The word start flag can generate an interrupt only.



Chapter 47

General-Purpose Input/Output (GPIO)

47.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The GPIO registers support 8-bit, 16-bit or 32-bit accesses.

The GPIO data direction and output data registers control the direction and output data of each pin when the pin is configured for the GPIO function. The GPIO input data register displays the logic value on each pin when the pin is configured for any digital function, provided the corresponding Port Control and Interrupt module for that pin is enabled.

Efficient bit manipulation of the general-purpose outputs is supported through the addition of set, clear, and toggle write-only registers for each port output data register.

47.1.1 Features

- Features of the GPIO module include:
 - Port Data Input register visible in all digital pin-multiplexing modes
 - Port Data Input register with corresponding set/clear/toggle registers
 - Port Data Direction register

NOTE

The GPIO module is clocked by system clock.

47.1.2 Modes of operation

The following table depicts different modes of operation and the behavior of the GPIO module in these modes.

Table 47-1. Modes of operation

| Modes of operation | Description |
|--------------------|------------------------------------|
| Run | The GPIO module operates normally. |
| Wait | The GPIO module operates normally. |
| Stop | The GPIO module is disabled. |
| Debug | The GPIO module operates normally. |

47.1.3 GPIO signal descriptions

Table 47-2. GPIO signal descriptions

| GPIO signal descriptions | Description | I/O |
|--------------------------|------------------------------|-----|
| PORTA31–PORTA0 | General-purpose input/output | I/O |
| PORTB31–PORTB0 | General-purpose input/output | I/O |
| PORTC31–PORTC0 | General-purpose input/output | I/O |
| PORTD31–PORTD0 | General-purpose input/output | I/O |
| PORTE31–PORTE0 | General-purpose input/output | I/O |

NOTE

Not all pins within each port are implemented on each device. See the chapter on signal multiplexing for the number of GPIO ports available in the device.

47.1.3.1 Detailed signal description

Table 47-3. GPIO interface-detailed signal descriptions

| Signal | I/O | Description | |
|--|-----|------------------------------|--|
| PORTA31–PORTA0 PORTB31–PORTB0 PORTC31–PORTC0 PORTD31–PORTD0 PORTE31–PORTE0 | I/O | General-purpose input/output | |
| | | State meaning | Asserted: The pin is logic 1. Deasserted: The pin is logic 0. |
| | | Timing | Assertion: When output, this signal occurs on the rising-edge of the system clock. For input, it may occur at any time and input may be asserted asynchronously to the system clock. Deassertion: When output, this signal occurs on the rising-edge of the system clock. For input, it may occur at any time and input may be asserted asynchronously to the system clock. |

NOTE

Not all pins within each port are implemented on each device.
See the chapter on signal multiplexing for the number of GPIO ports available in the device.

47.2 Memory map and register definition

Any read or write access to the GPIO memory space that is outside the valid memory map results in a bus error.

GPIO memory map

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|--|-----------------|-----------------------|-------------|-----------------------------|
| 400F_F000 | Port Data Output Register (GPIOA_PDOR) | 32 | R/W | 0000_0000h | 47.2.1/1191 |
| 400F_F004 | Port Set Output Register (GPIOA_PSOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.2/1192 |
| 400F_F008 | Port Clear Output Register (GPIOA_PCOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.3/1192 |
| 400F_F00C | Port Toggle Output Register (GPIOA_PTOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.4/1193 |

Table continues on the next page...

GPIO memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/ page |
|------------------------|---|-----------------|-----------------------|-------------|-----------------------------|
| 400F_F010 | Port Data Input Register (GPIOA_PDIR) | 32 | R | 0000_0000h | 47.2.5/1193 |
| 400F_F014 | Port Data Direction Register (GPIOA_PDDR) | 32 | R/W | 0000_0000h | 47.2.6/1194 |
| 400F_F040 | Port Data Output Register (GPIOB_PDOR) | 32 | R/W | 0000_0000h | 47.2.1/1191 |
| 400F_F044 | Port Set Output Register (GPIOB_PSOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.2/1192 |
| 400F_F048 | Port Clear Output Register (GPIOB_PCOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.3/1192 |
| 400F_F04C | Port Toggle Output Register (GPIOB_PTOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.4/1193 |
| 400F_F050 | Port Data Input Register (GPIOB_PDIR) | 32 | R | 0000_0000h | 47.2.5/1193 |
| 400F_F054 | Port Data Direction Register (GPIOB_PDDR) | 32 | R/W | 0000_0000h | 47.2.6/1194 |
| 400F_F080 | Port Data Output Register (GPIOC_PDOR) | 32 | R/W | 0000_0000h | 47.2.1/1191 |
| 400F_F084 | Port Set Output Register (GPIOC_PSOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.2/1192 |
| 400F_F088 | Port Clear Output Register (GPIOC_PCOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.3/1192 |
| 400F_F08C | Port Toggle Output Register (GPIOC_PTOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.4/1193 |
| 400F_F090 | Port Data Input Register (GPIOC_PDIR) | 32 | R | 0000_0000h | 47.2.5/1193 |
| 400F_F094 | Port Data Direction Register (GPIOC_PDDR) | 32 | R/W | 0000_0000h | 47.2.6/1194 |
| 400F_F0C0 | Port Data Output Register (GPIOD_PDOR) | 32 | R/W | 0000_0000h | 47.2.1/1191 |
| 400F_F0C4 | Port Set Output Register (GPIOD_PSOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.2/1192 |
| 400F_F0C8 | Port Clear Output Register (GPIOD_PCOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.3/1192 |
| 400F_F0CC | Port Toggle Output Register (GPIOD_PTOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.4/1193 |
| 400F_F0D0 | Port Data Input Register (GPIOD_PDIR) | 32 | R | 0000_0000h | 47.2.5/1193 |
| 400F_F0D4 | Port Data Direction Register (GPIOD_PDDR) | 32 | R/W | 0000_0000h | 47.2.6/1194 |
| 400F_F100 | Port Data Output Register (GPIOE_PDOR) | 32 | R/W | 0000_0000h | 47.2.1/1191 |
| 400F_F104 | Port Set Output Register (GPIOE_PSOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.2/1192 |

Table continues on the next page...

GPIO memory map (continued)

| Absolute address (hex) | Register name | Width (in bits) | Access | Reset value | Section/page |
|------------------------|---|-----------------|-----------------------|-------------|-----------------------------|
| 400F_F108 | Port Clear Output Register (GPIOE_PCOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.3/1192 |
| 400F_F10C | Port Toggle Output Register (GPIOE_PTOR) | 32 | W (always reads 0) | 0000_0000h | 47.2.4/1193 |
| 400F_F110 | Port Data Input Register (GPIOE_PDIR) | 32 | R | 0000_0000h | 47.2.5/1193 |
| 400F_F114 | Port Data Direction Register (GPIOE_PDDR) | 32 | R/W | 0000_0000h | 47.2.6/1194 |

47.2.1 Port Data Output Register (GPIOx_PDOR)

This register configures the logic levels that are driven on each general-purpose output pins.

NOTE

Do not modify pin configuration registers associated with pins not available in your selected package. All unbonded pins not available in your package will default to DISABLE state for lowest power consumption.

Address: Base address + 0h offset

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|
| Bit | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| R | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| W | PDO | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reset | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

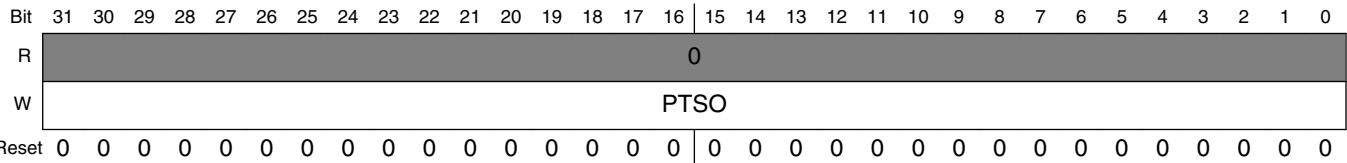
GPIOx_PDOR field descriptions

| Field | Description |
|-------------|--|
| 31–0 PDO | <p>Port Data Output</p> <p>Register bits for unbonded pins return a undefined value when read.</p> <p>0 Logic level 0 is driven on pin, provided pin is configured for general-purpose output.</p> <p>1 Logic level 1 is driven on pin, provided pin is configured for general-purpose output.</p> |

47.2.2 Port Set Output Register (GPIOx_PSOR)

This register configures whether to set the fields of the PDOR.

Address: Base address + 4h offset



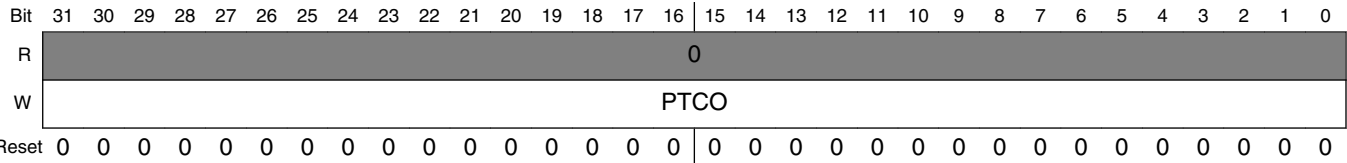
GPIOx_PSOR field descriptions

| Field | Description |
|--------------|---|
| 31–0 PTSO | Port Set Output Writing to this register will update the contents of the corresponding bit in the PDOR as follows: 0 Corresponding bit in PDORn does not change. 1 Corresponding bit in PDORn is set to logic 1. |

47.2.3 Port Clear Output Register (GPIOx_PCOR)

This register configures whether to clear the fields of PDOR.

Address: Base address + 8h offset

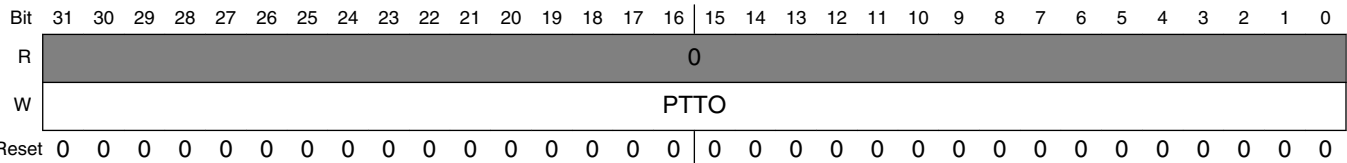


GPIOx_PCOR field descriptions

| Field | Description |
|--------------|---|
| 31–0 PTCO | Port Clear Output Writing to this register will update the contents of the corresponding bit in the Port Data Output Register (PDOR) as follows: 0 Corresponding bit in PDORn does not change. 1 Corresponding bit in PDORn is cleared to logic 0. |

47.2.4 Port Toggle Output Register (GPIOx_PTOR)

Address: Base address + Ch offset



GPIOx_PTOR field descriptions

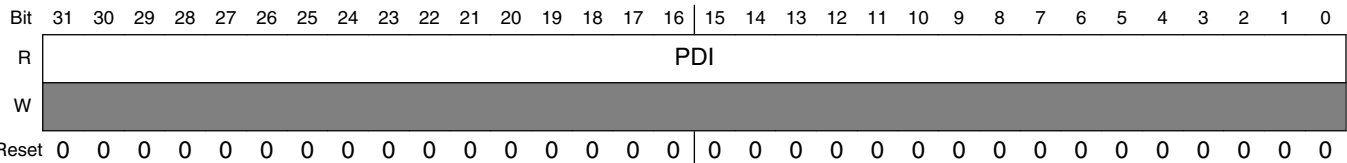
| Field | Description |
|--------------|--|
| 31–0 PTTO | Port Toggle Output Writing to this register will update the contents of the corresponding bit in the PDOR as follows: 0 Corresponding bit in PDORn does not change. 1 Corresponding bit in PDORn is set to the inverse of its existing logic state. |

47.2.5 Port Data Input Register (GPIOx_PDIR)

NOTE

Do not modify pin configuration registers associated with pins not available in your selected package. All unbonded pins not available in your package will default to DISABLE state for lowest power consumption.

Address: Base address + 10h offset



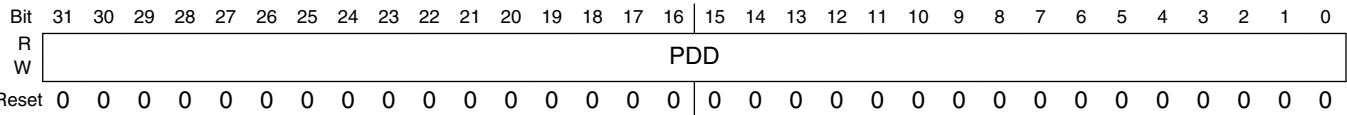
GPIOx_PDIR field descriptions

| Field | Description |
|-------------|---|
| 31–0 PDI | Port Data Input Reads 0 at the unimplemented pins for a particular device. Pins that are not configured for a digital function read 0. If the Port Control and Interrupt module is disabled, then the corresponding bit in PDIR does not update. 0 Pin logic level is logic 0, or is not configured for use by digital function. 1 Pin logic level is logic 1. |

47.2.6 Port Data Direction Register (GPIOx_PDDR)

The PDDR configures the individual port pins for input or output.

Address: Base address + 14h offset



GPIOx_PDDR field descriptions

| Field | Description |
|-------------|--|
| 31–0 PDD | Port Data Direction Configures individual port pins for input or output. 0 Pin is configured as general-purpose input, for the GPIO function. 1 Pin is configured as general-purpose output, for the GPIO function. |

47.3 Functional description

47.3.1 General-purpose input

The logic state of each pin is available via the Port Data Input registers, provided the pin is configured for a digital function and the corresponding Port Control and Interrupt module is enabled.

The Port Data Input registers return the synchronized pin state after any enabled digital filter in the Port Control and Interrupt module. The input pin synchronizers are shared with the Port Control and Interrupt module, so that if the corresponding Port Control and Interrupt module is disabled, then synchronizers are also disabled. This reduces power consumption when a port is not required for general-purpose input functionality.

47.3.2 General-purpose output

The logic state of each pin can be controlled via the port data output registers and port data direction registers, provided the pin is configured for the GPIO function. The following table depicts the conditions for a pin to be configured as input/output.

| | |
|----|------|
| If | Then |
|----|------|

Table continues on the next page...

| | |
|--|--|
| A pin is configured for the GPIO function and the corresponding port data direction register bit is clear. | The pin is configured as an input. |
| A pin is configured for the GPIO function and the corresponding port data direction register bit is set. | The pin is configured as an output and the logic state of the pin is equal to the corresponding port data output register. |

To facilitate efficient bit manipulation on the general-purpose outputs, pin data set, pin data clear, and pin data toggle registers exist to allow one or more outputs within one port to be set, cleared, or toggled from a single register write.

The corresponding Port Control and Interrupt module does not need to be enabled to update the state of the port data direction registers and port data output registers including the set/clear/toggle registers.



Chapter 48

JTAG Controller (JTAGC)

48.1 Introduction

NOTE

For the chip-specific implementation details of this module's instances, see the chip configuration information.

The JTAGC block provides the means to test chip functionality and connectivity while remaining transparent to system logic when not in test mode. Testing is performed via a boundary scan technique, as defined in the IEEE 1149.1-2001 standard. All data input to and output from the JTAGC block is communicated in serial format.

48.1.1 Block diagram

The following is a simplified block diagram of the JTAG Controller (JTAGC) block. Refer to the chip-specific configuration information as well as [Register description](#) for more information about the JTAGC registers.

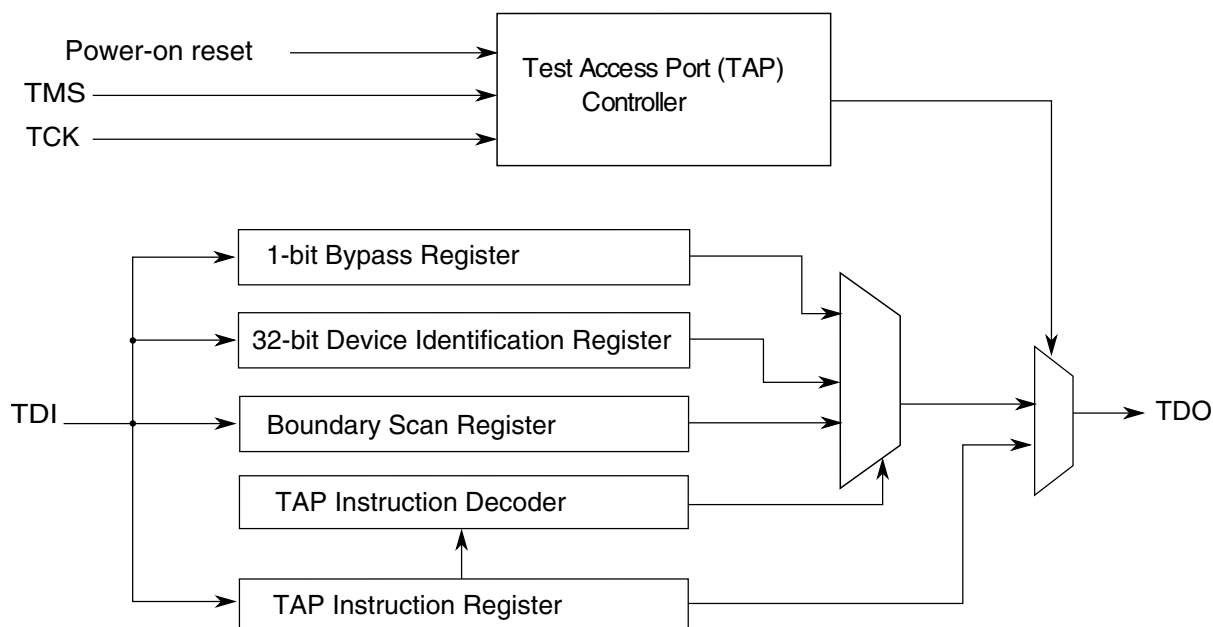


Figure 48-1. JTAG (IEEE 1149.1) block diagram

48.1.2 Features

The JTAGC block is compliant with the IEEE 1149.1-2001 standard, and supports the following features:

- IEEE 1149.1-2001 Test Access Port (TAP) interface
 - 4 pins (TDI, TMS, TCK, and TDO)
- Instruction register that supports several IEEE 1149.1-2001 defined instructions as well as several public and private device-specific instructions. Refer to [Table 48-3](#) for a list of supported instructions.
- Bypass register, boundary scan register, and device identification register.
- TAP controller state machine that controls the operation of the data registers, instruction register and associated circuitry.

48.1.3 Modes of operation

The JTAGC block uses a power-on reset indication as its primary reset signals. Several IEEE 1149.1-2001 defined test modes are supported, as well as a bypass mode.

48.1.3.1 Reset

The JTAGC block is placed in reset when either power-on reset is asserted, or the TMS input is held high for enough consecutive rising edges of TCK to sequence the TAP controller state machine into the Test-Logic-Reset state. Holding TMS high for five consecutive rising edges of TCK guarantees entry into the Test-Logic-Reset state regardless of the current TAP controller state. Asserting power-on reset results in asynchronous entry into the reset state. While in reset, the following actions occur:

- The TAP controller is forced into the Test-Logic-Reset state, thereby disabling the test logic and allowing normal operation of the on-chip system logic to continue unhindered
- The instruction register is loaded with the IDCODE instruction

48.1.3.2 IEEE 1149.1-2001 defined test modes

The JTAGC block supports several IEEE 1149.1-2001 defined test modes. A test mode is selected by loading the appropriate instruction into the instruction register while the JTAGC is enabled. Supported test instructions include EXTEST, HIGHZ, CLAMP, SAMPLE and SAMPLE/PRELOAD. Each instruction defines the set of data register(s) that may operate and interact with the on-chip system logic while the instruction is current. Only one test data register path is enabled to shift data between TDI and TDO for each instruction.

The boundary scan register is enabled for serial access between TDI and TDO when the EXTEST, SAMPLE or SAMPLE/PRELOAD instructions are active. The single-bit bypass register shift stage is enabled for serial access between TDI and TDO when the BYPASS, HIGHZ, CLAMP or reserved instructions are active. The functionality of each test mode is explained in more detail in [JTAGC block instructions](#).

48.1.3.3 Bypass mode

When no test operation is required, the BYPASS instruction can be loaded to place the JTAGC block into bypass mode. While in bypass mode, the single-bit bypass shift register is used to provide a minimum-length serial path to shift data between TDI and TDO.

48.2 External signal description

The JTAGC consists of a set of signals that connect to off chip development tools and allow access to test support functions. The JTAGC signals are outlined in the following table and described in the following sections.

Table 48-1. JTAG signal properties

| Name | I/O | Function | Reset State | Pull |
|------|--------|------------------|---------------------|------|
| TCK | Input | Test Clock | — | Down |
| TDI | Input | Test Data In | — | Up |
| TDO | Output | Test Data Out | High Z ¹ | — |
| TMS | Input | Test Mode Select | — | Up |

1. TDO output buffer enable is negated when the JTAGC is not in the Shift-IR or Shift-DR states. A weak pull may be implemented at the TDO pad for use when JTAGC is inactive.

48.2.1 TCK—Test clock input

Test Clock Input (TCK) is an input pin used to synchronize the test logic and control register access through the TAP.

48.2.2 TDI—Test data input

Test Data Input (TDI) is an input pin that receives serial test instructions and data. TDI is sampled on the rising edge of TCK.

48.2.3 TDO—Test data output

Test Data Output (TDO) is an output pin that transmits serial output for test instructions and data. TDO is three-stateable and is actively driven only in the Shift-IR and Shift-DR states of the TAP controller state machine, which is described in [TAP controller state machine](#).

48.2.4 TMS—Test mode select

Test Mode Select (TMS) is an input pin used to sequence the IEEE 1149.1-2001 test control state machine. TMS is sampled on the rising edge of TCK.

48.3 Register description

This section provides a detailed description of the JTAGC block registers accessible through the TAP interface, including data registers and the instruction register. Individual bit-level descriptions and reset states of each register are included. These registers are not memory-mapped and can only be accessed through the TAP.

48.3.1 Instruction register

The JTAGC block uses a 4-bit instruction register as shown in the following figure. The instruction register allows instructions to be loaded into the block to select the test to be performed or the test data register to be accessed or both. Instructions are shifted in through TDI while the TAP controller is in the Shift-IR state, and latched on the falling edge of TCK in the Update-IR state. The latched instruction value can only be changed in the Update-IR and Test-Logic-Reset TAP controller states. Synchronous entry into the Test-Logic-Reset state results in the IDCODE instruction being loaded on the falling edge of TCK. Asynchronous entry into the Test-Logic-Reset state results in asynchronous loading of the IDCODE instruction. During the Capture-IR TAP controller state, the instruction shift register is loaded with the value 0001b , making this value the register's read value when the TAP controller is sequenced into the Shift-IR state.

| | | | | |
|--------|------------------|---|---|---|
| | 3 | 2 | 1 | 0 |
| R | 0 | 0 | 0 | 1 |
| W | Instruction Code | | | |
| Reset: | 0 | 0 | 0 | 1 |

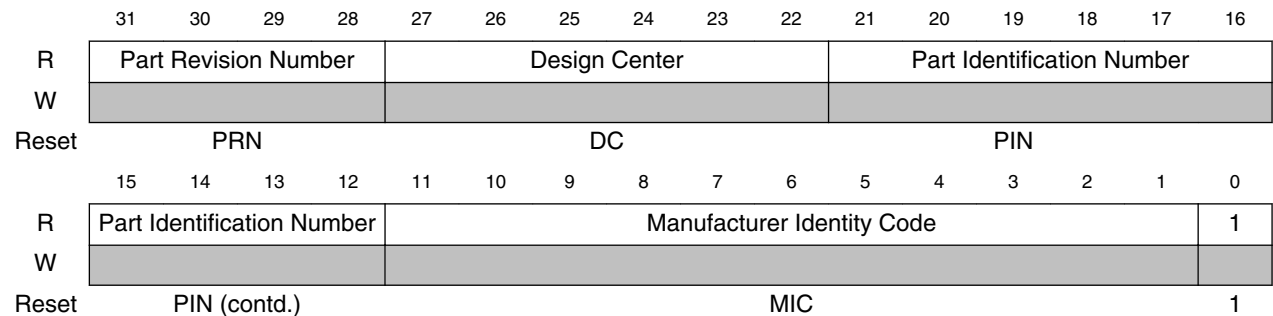
Figure 48-2. Instruction register

48.3.2 Bypass register

The bypass register is a single-bit shift register path selected for serial data transfer between TDI and TDO when the BYPASS, CLAMP, HIGHZ or reserve instructions are active. After entry into the Capture-DR state, the single-bit shift register is set to a logic 0. Therefore, the first bit shifted out after selecting the bypass register is always a logic 0.

48.3.3 Device identification register

The device identification (JTAG ID) register, shown in the following figure, allows the revision number, part number, manufacturer, and design center responsible for the design of the part to be determined through the TAP. The device identification register is selected for serial data transfer between TDI and TDO when the IDCODE instruction is active. Entry into the Capture-DR state while the device identification register is selected loads the IDCODE into the shift register to be shifted out on TDO in the Shift-DR state. No action occurs in the Update-DR state.



The following table describes the device identification register functions.

Table 48-2. Device identification register field descriptions

| Field | Description |
|-----------|--|
| PRN | Part Revision Number. Contains the revision number of the part. Value is 0x0. |
| DC | Design Center. Indicates the design center. Value is 0x2C. |
| PIN | Part Identification Number. Contains the part number of the device. Value is TBD. |
| MIC | Manufacturer Identity Code. Contains the reduced Joint Electron Device Engineering Council (JEDEC) ID. Value is 0x00E. |
| IDCODE ID | IDCODE Register ID. Identifies this register as the device identification register and not the bypass register. Always set to 1. |

48.3.4 Boundary scan register

The boundary scan register is connected between TDI and TDO when the EXTEST, SAMPLE or SAMPLE/PRELOAD instructions are active. It is used to capture input pin data, force fixed values on output pins, and select a logic value and direction for bidirectional pins. Each bit of the boundary scan register represents a separate boundary scan register cell, as described in the IEEE 1149.1-2001 standard and discussed in [Boundary scan](#). The size of the boundary scan register and bit ordering is device-dependent and can be found in the device BSDL file.

48.4 Functional description

This section explains the JTAGC functional description.

48.4.1 JTAGC reset configuration

While in reset, the TAP controller is forced into the Test-Logic-Reset state, thus disabling the test logic and allowing normal operation of the on-chip system logic. In addition, the instruction register is loaded with the IDCODE instruction.

48.4.2 IEEE 1149.1-2001 (JTAG) Test Access Port

The JTAGC block uses the IEEE 1149.1-2001 TAP for accessing registers. This port can be shared with other TAP controllers on the MCU. Ownership of the port is determined by the value of the currently loaded instruction.

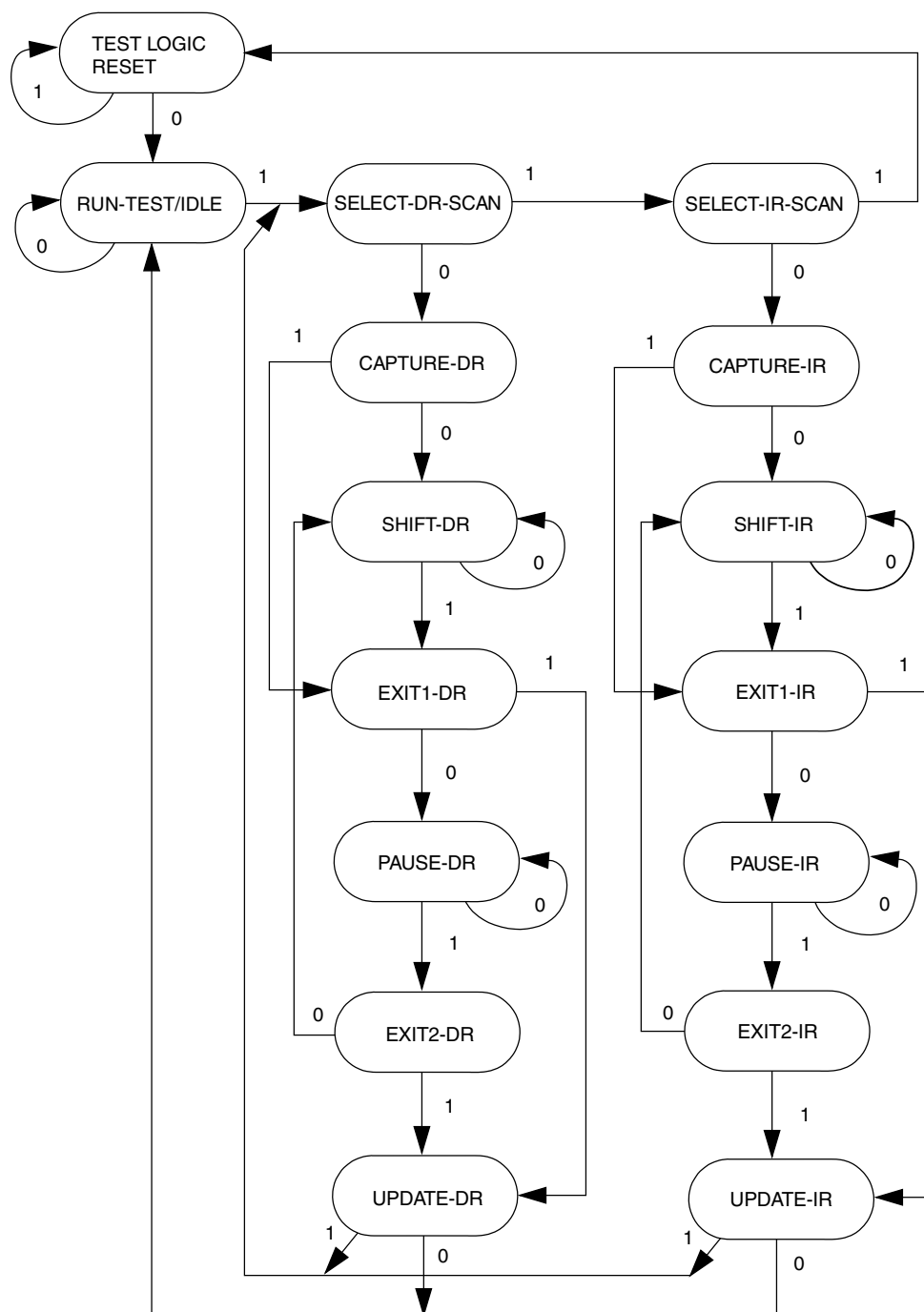
Data is shifted between TDI and TDO through the selected register starting with the least significant bit, as illustrated in the following figure. This applies for the instruction register, test data registers, and the bypass register.



Figure 48-3. Shifting data through a register

48.4.3 TAP controller state machine

The TAP controller is a synchronous state machine that interprets the sequence of logical values on the TMS pin. The following figure shows the machine's states. The value shown next to each state is the value of the TMS signal sampled on the rising edge of the TCK signal. As the following figure shows, holding TMS at logic 1 while clocking TCK through a sufficient number of rising edges also causes the state machine to enter the Test-Logic-Reset state.



The value shown adjacent to each state transition in this figure represents the value of TMS at the time of a rising edge of TCK.

Figure 48-4. IEEE 1149.1-2001 TAP controller finite state machine

48.4.3.1 Enabling the TAP controller

The JTAGC TAP controller is enabled by setting the JTAGC enable to a logic 1 value.

48.4.3.2 Selecting an IEEE 1149.1-2001 register

Access to the JTAGC data registers is achieved by loading the instruction register with any of the JTAGC block instructions while the JTAGC is enabled. Instructions are shifted in via the Select-IR-Scan path and loaded in the Update-IR state. At this point, all data register access is performed via the Select-DR-Scan path.

The Select-DR-Scan path is used to read or write the register data by shifting in the data (LSB first) during the Shift-DR state. When reading a register, the register value is loaded into the IEEE 1149.1-2001 shifter during the Capture-DR state. When writing a register, the value is loaded from the IEEE 1149.1-2001 shifter to the register during the Update-DR state. When reading a register, there is no requirement to shift out the entire register contents. Shifting may be terminated once the required number of bits have been acquired.

48.4.4 JTAGC block instructions

The JTAGC block implements the IEEE 1149.1-2001 defined instructions listed in the following table. This section gives an overview of each instruction; refer to the IEEE 1149.1-2001 standard for more details. All undefined opcodes are reserved.

Table 48-3. 4-bit JTAG instructions

| Instruction | Code[3:0] | Instruction summary |
|------------------------|-----------|---|
| IDCODE | 0000 | Selects device identification register for shift |
| EZPORT | 0001 | Enables the EZPORT function for the SoC |
| SAMPLE/PRELOAD | 0010 | Selects boundary scan register for shifting, sampling, and preloading without disturbing functional operation |
| SAMPLE | 0011 | Selects boundary scan register for shifting and sampling without disturbing functional operation |
| EXTEST | 0100 | Selects boundary scan register and applies preloaded values to output pins. NOTE: Execution of this instruction asserts functional reset. |
| Factory debug reserved | 0101 | Intended for factory debug only |
| Factory debug reserved | 0110 | Intended for factory debug only |
| Factory debug reserved | 0111 | Intended for factory debug only |
| ARM JTAG-DP Reserved | 1000 | This instruction goes the ARM JTAG-DP controller. See the ARM JTAG-DP documentation for more information. |
| HIGHZ | 1001 | Selects bypass register and three-states all output pins. NOTE: Execution of this instruction asserts functional reset. |

Table continues on the next page...

Table 48-3. 4-bit JTAG instructions (continued)

| Instruction | Code[3:0] | Instruction summary |
|----------------------|-----------|--|
| ARM JTAG-DP Reserved | 1010 | This instruction goes the ARM JTAG-DP controller. See the ARM JTAG-DP documentation for more information. |
| ARM JTAG-DP Reserved | 1011 | This instruction goes the ARM JTAG-DP controller. See the ARM JTAG-DP documentation for more information. |
| CLAMP | 1100 | Selects bypass register and applies preloaded values to output pins. NOTE: Execution of this instruction asserts functional reset. |
| EZPORT | 1101 | Enables the EZPORT function for the SoC |
| ARM JTAG-DP Reserved | 1110 | This instruction goes the ARM JTAG-DP controller. See the ARM JTAG-DP documentation for more information. |
| BYPASS | 1111 | Selects bypass register for data operations |

48.4.4.1 IDCODE instruction

IDCODE selects the 32-bit device identification register as the shift path between TDI and TDO. This instruction allows interrogation of the MCU to determine its version number and other part identification data. IDCODE is the instruction placed into the instruction register when the JTAGC block is reset.

48.4.4.2 EZPORT instruction

The EZPORT instruction allows for the EZPORT module to program the on-chip flash from a simple 4-pin interface. The JTAGC forces the core into a reset state and forces the EZPORT mode select/chip select low. In this mode, the flash can be programmed through the JTAG test port pins, which are connected to the EZPORT module.

48.4.4.3 SAMPLE/PRELOAD instruction

The SAMPLE/PRELOAD instruction has two functions:

- The SAMPLE portion of the instruction obtains a sample of the system data and control signals present at the MCU input pins and just before the boundary scan register cells at the output pins. This sampling occurs on the rising edge of TCK in the Capture-DR state when the SAMPLE/PRELOAD instruction is active. The

sampled data is viewed by shifting it through the boundary scan register to the TDO output during the Shift-DR state. Both the data capture and the shift operation are transparent to system operation.

- The PRELOAD portion of the instruction initializes the boundary scan register cells before selecting the EXTEST or CLAMP instructions to perform boundary scan tests. This is achieved by shifting in initialization data to the boundary scan register during the Shift-DR state. The initialization data is transferred to the parallel outputs of the boundary scan register cells on the falling edge of TCK in the Update-DR state. The data is applied to the external output pins by the EXTEST or CLAMP instruction. System operation is not affected.

48.4.4.4 SAMPLE instruction

The SAMPLE instruction obtains a sample of the system data and control signals present at the MCU input pins and just before the boundary scan register cells at the output pins. This sampling occurs on the rising edge of TCK in the Capture-DR state when the SAMPLE instruction is active. The sampled data is viewed by shifting it through the boundary scan register to the TDO output during the Shift-DR state. There is no defined action in the Update-DR state. Both the data capture and the shift operation are transparent to system operation.

48.4.4.5 EXTEST External test instruction

EXTEST selects the boundary scan register as the shift path between TDI and TDO. It allows testing of off-chip circuitry and board-level interconnections by driving preloaded data contained in the boundary scan register onto the system output pins. Typically, the preloaded data is loaded into the boundary scan register using the SAMPLE/PRELOAD instruction before the selection of EXTEST. EXTEST asserts the internal system reset for the MCU to force a predictable internal state while performing external boundary scan operations.

48.4.4.6 HIGHZ instruction

HIGHZ selects the bypass register as the shift path between TDI and TDO. While HIGHZ is active all output drivers are placed in an inactive drive state (e.g., high impedance). HIGHZ also asserts the internal system reset for the MCU to force a predictable internal state.

48.4.4.7 CLAMP instruction

CLAMP allows the state of signals driven from MCU pins to be determined from the boundary scan register while the bypass register is selected as the serial path between TDI and TDO. CLAMP enhances test efficiency by reducing the overall shift path to a single bit (the bypass register) while conducting an EXTEST type of instruction through the boundary scan register. CLAMP also asserts the internal system reset for the MCU to force a predictable internal state.

48.4.4.8 BYPASS instruction

BYPASS selects the bypass register, creating a single-bit shift register path between TDI and TDO. BYPASS enhances test efficiency by reducing the overall shift path when no test operation of the MCU is required. This allows more rapid movement of test data to and from other components on a board that are required to perform test functions. While the BYPASS instruction is active the system logic operates normally.

48.4.5 Boundary scan

The boundary scan technique allows signals at component boundaries to be controlled and observed through the shift-register stage associated with each pad. Each stage is part of a larger boundary scan register cell, and cells for each pad are interconnected serially to form a shift-register chain around the border of the design. The boundary scan register consists of this shift-register chain, and is connected between TDI and TDO when the EXTEST, SAMPLE, or SAMPLE/PRELOAD instructions are loaded. The shift-register chain contains a serial input and serial output, as well as clock and control signals.

48.5 Initialization/Application information

The test logic is a static logic design, and TCK can be stopped in either a high or low state without loss of data. However, the system clock is not synchronized to TCK internally. Any mixed operation using both the test logic and the system functional logic requires external synchronization.

To initialize the JTAGC block and enable access to registers, the following sequence is required:

1. Place the JTAGC in reset through TAP controller state machine transitions controlled by TMS
2. Load the appropriate instruction for the test or action to be performed



Chapter 49

Release Notes for Revision 6

49.1 General changes throughout document

- Updated supported part numbers
- Updated document number
- Editorial changes throughout the document
- Removed RTC_CR[WPS] bitfield in the RTC chapter
- Removed DMA_EARS register in the DMA chapter

49.2 About This Document chapter changes

- No substantial content changes

49.3 Introduction chapter changes

- No substantial content changes

49.4 Chip Configuration chapter changes

- No substantial content changes

49.5 Memory Map chapter changes

- No substantial content changes

49.6 Clock Distribution chapter changes

- No substantial content changes

49.7 Reset and Boot chapter changes

- No substantial content changes

49.8 Power Management chapter changes

- No substantial content changes

49.9 Security chapter changes

- No substantial content changes

49.10 Debug chapter changes

- No substantial content changes

49.11 Signal Multiplexing and Signal Descriptions chapter changes

- No substantial content changes

49.12 PORT changes

- No substantial content changes

49.13 SIM changes

- In Flash Config Register 1, for field NVMSIZE, updated description for field value 111.

49.14 RCM changes

- No substantial content changes

49.15 SMC changes

- No substantial content changes

49.16 PMC changes

- No substantial content changes

49.17 LLWU changes

- No substantial content changes

49.18 MCM changes

- No substantial content changes

49.19 Crossbar switch module changes

- Changed reset values of PRS and CRS registers to 0. Added footnote to refer to chip-specific info.

49.20 AIPS module changes

- No substantial content changes

49.21 DMAMUX module changes

- In section Enabling and configuring sources, the DMA channel number used in the example from channel 2 to channel 1.
- In DMA channels with periodic triggering capability section, modified Figure DMAMUX triggered channels.
- Editorial (non-technical) fixes in some sections.
- Added section Always-enabled DMA sources.
- Changed the register name from CHCONFIG to CHCFG.
- In the section "Enabling and configuring sources," updated DMAMUX_BASE_ADDR in example code.

49.22 eDMA module changes

- HRS register:
 - Changed access to Read-Only.
- CR register:
 - Reserved bit LSB+3: Changed access to Read/Write Reserved.
 - Reserved bit LSB: Changed access Read/Write Reserved.
- Changed topic title from "Error reporting and handling" to "Fault reporting and handling".
- Editorial changes.
- Changed the chapter title to "Enhanced Direct Memory Access".
- Changed the title of [eDMA system block diagram](#) (was "Block diagram") and revised its content to reflect the entire eDMA system.
- In [Features](#), changed "Support to cancel transfers via software" to "Support to cancel transfers via software error detection and error correction."

49.23 EWM changes

- No substantial content changes

49.24 WDOG changes

- No substantial content changes

49.25 MCG changes

- No substantial content changes

49.26 OSC changes

- No substantial content changes

49.27 RTC Oscillator changes

- No substantial content changes

49.28 FMC changes

- No substantial content changes

49.29 FTFM changes

- No substantial content changes

49.30 EzPort changes

In "Command descriptions" section, added timing diagrams for each command sequence.

49.31 CRC changes

Editorial change in the section "CRC initialization/reinitialization."

49.32 MMCAU changes

- No substantial content changes

49.33 RNGA chapter changes

- Updated description of RNGA Control Register, RNG_CR[HA] field, RNG_SR[OREG_LVL] field, RNG_SR[ERRI] field, RNG Output Register, RNG_ER[EXT_ENT] field
- Updated RNGA block diagram
- Updated description of RNGA Control Block
- Updated description of Initialization/application information.

In "Overview," updated bulleted item from "Mouse and keyboard motions, or equivalent if being used on a cell phone or PDA" to "Real-time system inputs that can be characterized as 'random'."

49.34 ADC changes

- Updated the bit field description of CFG1[ADICLK] to Bus Clock/2

49.35 CMP changes

- No substantial content changes

49.36 DAC changes

- No substantial content changes

49.37 VREF changes

- No substantial content changes

49.38 PDB changes

- Added the following sentence to section "PDB pre-trigger and trigger outputs":
"When the ADC receives the rising edge of the trigger, the ADC will start conversion as the precondition determined by pre-triggers."

49.39 FTM changes

- No substantial content changes

49.40 PIT module changes

- MCR[MDIS or Reserved] bit.
 - Changed Reserved access to R/W.
- TFLG, TCTRL, CVAL, and LDVAL registers:
 - For implementations that use 6 channels, 6 channels can now be shown.
- Removed "-RTI" from chapter title

49.41 LPTMR changes

- No substantial content changes

49.42 CMT changes

- No substantial content changes

49.43 RTC changes

- No substantial content changes

49.44 SPI module changes

- Revised the field description of DSPI_CTARn_SLAVE[FMSZ]
 - In the Combined Serial Interface (CSI) Configuration, revised the note
 - In the Timed Serial Bus (TSB) section, revised the figure
 - Editorial updates
 - Notes added in DSPI_CTARn_SLAVE[CPOL] bit description
 - Notes added in DSPI_CTARn[CPOL] bit description
 - In DSPI_MCR changed [Reserved](#) bit from read-only to read/write
- In [Status Register \(SPI_SR\)](#) changed reset value of read-only [Reserved](#) field from 0 to 1

49.45 I2C changes

- In Inter-Integrated Circuit (I2C) chapter, added new section "I2C module address matching to wake the device from stop mode"
- Updated and clarified the flowchart figure "Typical I2C SMBus interrupt routine".
 - Used the wording "I2C module clock" instead of "bus clock" in the register definitions and the "Programmable input glitch filter" section.
 - Updated in the statements of register fields S[IAAS], S[RAM], C2[RMEN], RA[RAD] and the section "Address matching", to clarify that the Range Address register is only meaningful when the C2[RMEN] bit is set.
 - Added notes in the sections "Address matching wake-up" and "Double buffering mode".

49.46 UART changes

- Updated the section "RXEDGIF description"

49.47 I2S/SAI changes

49.48 GPIO changes

- No substantial content changes

49.49 JTAGC module changes

- No substantial content changes



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