# THE DATASHEET OF

# XMS430FR5969IRGZR

MSP430FR5969, MSP430FR59691, MSP430FR5968, MSP430FR5967
MSP430FR5959, MSP430FR5958, MSP430FR5957
MSP430FR5949, MSP430FR5948, MSP430FR5947, MSP430FR59471

SLAS704G – OCTOBER 2012 – REVISED AUGUST 2018

# MSP430FR596x, MSP430FR594x Mixed-Signal Microcontrollers

## 1 Device Overview

### 1.1 Features

- Embedded Microcontroller
  - 16-Bit RISC Architecture up to 16-MHz Clock
  - Wide Supply Voltage Range From 3.6 V Down to 1.8 V (Minimum Supply Voltage is Restricted by SVS Levels, See the SVS Specifications)
- Optimized Ultra-Low-Power Modes
  - Active Mode: Approximately 100 µA/MHz
  - Standby (LPM3 With VLO): 0.4 µA (Typical)
  - Real-Time Clock (LPM3.5): 0.25 µA (Typical) (1)
  - Shutdown (LPM4.5): 0.02 µA (Typical)
- Ultra-Low-Power Ferroelectric RAM (FRAM)
  - Up to 64KB of Nonvolatile Memory
  - Ultra-Low-Power Writes
  - Fast Write at 125 ns Per Word (64KB in 4 ms)
  - Unified Memory = Program + Data + Storage in One Single Space
  - $10^{15}$ Write Cycle Endurance
  - Radiation Resistant and Nonmagnetic
- Intelligent Digital Peripherals
  - 32-Bit Hardware Multiplier (MPY)
  - 3-Channel Internal DMA
  - Real-Time Clock (RTC) With Calendar and Alarm Functions
  - Five 16-Bit Timers With up to Seven Capture/Compare Registers Each
  - 16-Bit Cyclic Redundancy Checker (CRC)
- High-Performance Analog
  - 16-Channel Analog Comparator
  - 12-Bit Analog-to-Digital Converter (ADC) With Internal Reference and Sample-and-Hold and up to 16 External Input Channels
- Multifunction Input/Output Ports
  - All Pins Support Capacitive Touch Capability With No Need for External Components
  - Accessible Bit-, Byte-, and Word-Wise (in Pairs)
  - Edge-Selectable Wake From LPM on All Ports
  - Programmable Pullup and Pulldown on All Ports
- Code Security and Encryption
  - 128-Bit or 256-Bit AES Security Encryption and Decryption Coprocessor
  - Random Number Seed for Random Number Generation Algorithms
- Enhanced Serial Communication
  - eUSCI_A0 and eUSCI_A1 Support
    - UART With Automatic Baud-Rate Detection
    - IrDA Encode and Decode
    - SPI
  - eUSCI_B0 Supports
    - $I^2C$ With Multiple Slave Addressing
    - SPI
  - Hardware UART and $I^2C$ Bootloader (BSL)
- Flexible Clock System
  - Fixed-Frequency DCO With 10 Selectable Factory-Trimmed Frequencies
  - Low-Power Low-Frequency Internal Clock Source (VLO)
  - 32-kHz Crystals (LFXT)
  - High-Frequency Crystals (HFXT)
- Development Tools and Software
  - Free Professional Development Environments With EnergyTrace++™ Technology
  - Development Kit (MSP-TS430RGZ48C)
- Family Members
  - Device Comparison Summarizes the Available Device Variants and Package Types
- For Complete Module Descriptions, See the *MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide*

(1) RTC is clocked by a 3.7-pF crystal.

### 1.2 Applications

- Metering
- Energy Harvested Sensor Nodes
- Wearable Electronics
- Sensor Management
- Data Logging

### 1.3 Description

The MSP430™ ultra-low-power (ULP) FRAM platform combines uniquely embedded FRAM and a holistic ultra-low-power system architecture, allowing innovators to increase performance at lowered energy budgets. FRAM technology combines the speed, flexibility, and endurance of SRAM with the stability and reliability of flash at much lower power.

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The MSP430 ULP FRAM portfolio consists of a diverse set of devices featuring FRAM, the ULP 16-bit MSP430 CPU, and intelligent peripherals targeted for various applications. The ULP architecture showcases seven low-power modes, optimized to achieve extended battery life in energy-challenged applications.

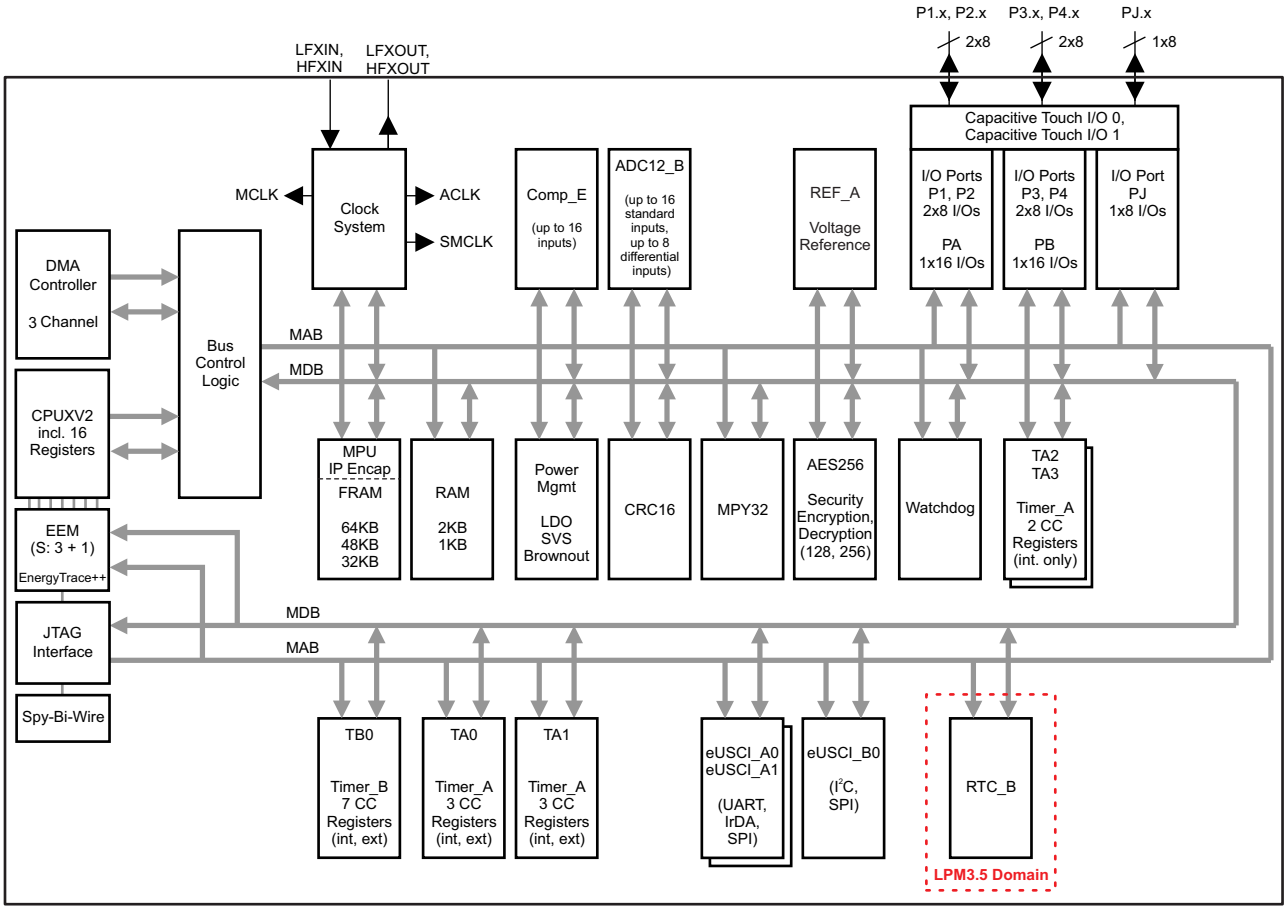
**Device Information**(1)

| PART NUMBER | PACKAGE | BODY SIZE(2) |
|---|---|---|
| MSP430FR5969IRGZ | VQFN (48) | 7 mm × 7 mm |
| MSP430FR5959IRHA | VQFN (40) | 6 mm × 6 mm |
| MSP430FR5959IDA | TSSOP (38) | 12.5 mm × 6.2 mm |

(1) For the most current part, package, and ordering information for all available devices, see the *Package Option Addendum* in Section 9, or see the TI website at www.ti.com.
(2) The sizes shown here are approximations. For the package dimensions with tolerances, see the *Mechanical Data* in Section 9.

## 1.4 Functional Block Diagram

Figure 1-1 shows the functional block diagram of the devices.




A. The low-frequency (LF) crystal oscillator and the corresponding LFXIN and LFXOUT pins are available in the MSP430FR5x6x and MSP430FR5x4x devices only.
RTC_B is available only in conjunction with the LF crystal oscillator in MSP430FR5x6x and MSP430FR5x4x devices.
B. The high-frequency (HF) crystal oscillator and the corresponding HFXIN and HFXOUT pins are available in the MSP430FR5x6x and MSP430FR5x5x devices only.
MSP430FR5x5x devices with the HF crystal oscillator only do not include the RTC_B module.

**Figure 1-1. Functional Block Diagram**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## 2 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| Changes from March 10, 2017 to August 29, 2018 | Page |
|---|---|

- Updated Section 3.1, *Related Products* ..... 6
- Added note (1) to Table 5-2, *SVS*..... 25
- Changed capacitor value from 4.7 µF to 470 nF in Figure 7-5, *ADC12_B Grounding and Noise Considerations* ... 119
- Changed capacitor value from 4.7 µF to 470 nF in the last paragraph of Section 7.2.1.2, *Design Requirements* ... 120
- Updated text and figure in Section 8.2, *Device Nomenclature* ..... 121


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# 3 Device Comparison

Table 3-1 summarizes the available family members.

**Table 3-1. Device Comparison(1)(2)**

| DEVICE | FRAM (KB) | SRAM (KB) | CLOCK SYSTEM | ADC12_B | Comp_E | Timer_A(3) | Timer_B(4) | eUSCI | | AES | BSL | I/O | PACKAGE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | A(5) | B(6) | | | | |
| MSP430FR5969 | 64 | 2 | DCO **HFXT LFXT** | 16 ext, 2 int ch. | 16 ch. | 3, 3(7) 2, 2(8) | 7 | 2 | 1 | yes | UART | 40 | 48 RGZ |
| MSP430FR59691 | 64 | 2 | DCO **HFXT LFXT** | 16 ext, 2 int ch. | 16 ch. | 3, 3(7) 2, 2(8) | 7 | 2 | 1 | yes | $I^2C$ | 40 | 48 RGZ |
| MSP430FR5968 | 48 | 2 | DCO **HFXT LFXT** | 16 ext, 2 int ch. | 16 ch. | 3, 3(7) 2, 2(8) | 7 | 2 | 1 | yes | UART | 40 | 48 RGZ |
| MSP430FR5967 | 32 | 1 | DCO **HFXT LFXT** | 16 ext, 2 int ch. | 16 ch. | 3, 3(7) 2, 2(8) | 7 | 2 | 1 | yes | UART | 40 | 48 RGZ |
| MSP430FR5949 | 64 | 2 | DCO **LFXT** | 14 ext, 2 int ch. | 16 ch. | 3, 3(7) 2, 2(8) | 7 | 2 | 1 | yes | UART | 33 | 40 RHA |
| | | | | 12 ext, 2 int ch. | | | | | | | | 31 | 38 DA |
| MSP430FR5948 | 48 | 2 | DCO **LFXT** | 14 ext, 2 int ch. | 16 ch. | 3, 3(7) 2, 2(8) | 7 | 2 | 1 | yes | UART | 33 | 40 RHA |
| | | | | 12 ext, 2 int ch. | | | | | | | | 31 | 38 DA |
| MSP430FR5947 | 32 | 1 | DCO **LFXT** | 14 ext, 2 int ch. | 16 ch. | 3, 3(7) 2, 2(8) | 7 | 2 | 1 | yes | UART | 33 | 40 RHA |
| | | | | 12 ext, 2 int ch. | | | | | | | | 31 | 38 DA |
| MSP430FR59471 | 32 | 1 | DCO **LFXT** | 14 ext, 2 int ch. | 16 ch. | 3, 3(7) 2, 2(8) | 7 | 2 | 1 | yes | $I^2C$ | 33 | 40 RHA |
| MSP430FR5959 | 64 | 2 | DCO **HFXT** | 14 ext, 2 int ch. | 16 ch. | 3, 3(7) 2, 2(8) | 7 | 2 | 1 | yes | UART | 33 | 40 RHA |
| | | | | 12 ext, 2 int ch. | | | | | | | | 31 | 38 DA |
| MSP430FR5958 | 48 | 2 | DCO **HFXT** | 14 ext, 2 int ch. | 16 ch. | 3, 3(7) 2, 2(8) | 7 | 2 | 1 | yes | UART | 33 | 40 RHA |
| | | | | 12 ext, 2 int ch. | | | | | | | | 31 | 38 DA |
| MSP430FR5957 | 32 | 1 | DCO **HFXT** | 14 ext, 2 int ch. | 16 ch. | 3, 3(7) 2, 2(8) | 7 | 2 | 1 | yes | UART | 33 | 40 RHA |
| | | | | 12 ext, 2 int ch. | | | | | | | | 31 | 38 DA |

(1) For the most current device, package, and ordering information for all available devices, see the *Package Option Addendum* in Section 9, or see the TI website at www.ti.com.
(2) Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/packaging.
(3) Each number in the sequence represents an instantiation of Timer_A with its associated number of capture/compare registers and PWM output generators available. For example, a number sequence of 3, 5 would represent two instantiations of Timer_A, the first instantiation having 3 capture/compare registers and PWM output generators and the second instantiation having 5 capture/compare registers and PWM output generators, respectively.
(4) Each number in the sequence represents an instantiation of Timer_B with its associated number of capture/compare registers and PWM output generators available. For example, a number sequence of 3, 5 would represent two instantiations of Timer_B, the first instantiation having 3 capture/compare registers and PWM output generators and the second instantiation having 5 capture/compare registers and PWM output generators, respectively.
(5) eUSCI_A supports UART with automatic baud-rate detection, IrDA encode and decode, and SPI.
(6) eUSCI_B supports $I^2C$ with multiple slave addresses, and SPI.
(7) Timers TA0 and TA1 provide internal and external capture/compare inputs and internal and external PWM outputs.
(8) Timers TA2 and TA3 provide only internal capture/compare inputs and only internal PWM outputs (if any).

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## 3.1 Related Products

For information about other devices in this family of products or related products, see the following links.

**TI 16-bit and 32-bit microcontrollers** High-performance, low-power solutions to enable the autonomous future

**Products for MSP430 ultra-low-power sensing and measurement microcontrollers** One platform. One ecosystem. Endless possibilities.

**Products for MSP430 ultrasonic and performance sensing microcontrollers** Ultra-low-power single-chip MCUs with integrated sensing peripherals

**Companion Products for MSP430FR5969** Review products that are frequently purchased or used with this product.

**Reference Designs for MSP430FR5969** The TI Designs Reference Design Library is a robust reference design library that spans analog, embedded processor, and connectivity. Created by TI experts to help you jump start your system design, all TI Designs include schematic or block diagrams, BOMs, and design files to speed your time to market. Search and download designs at ti.com/tidesigns.


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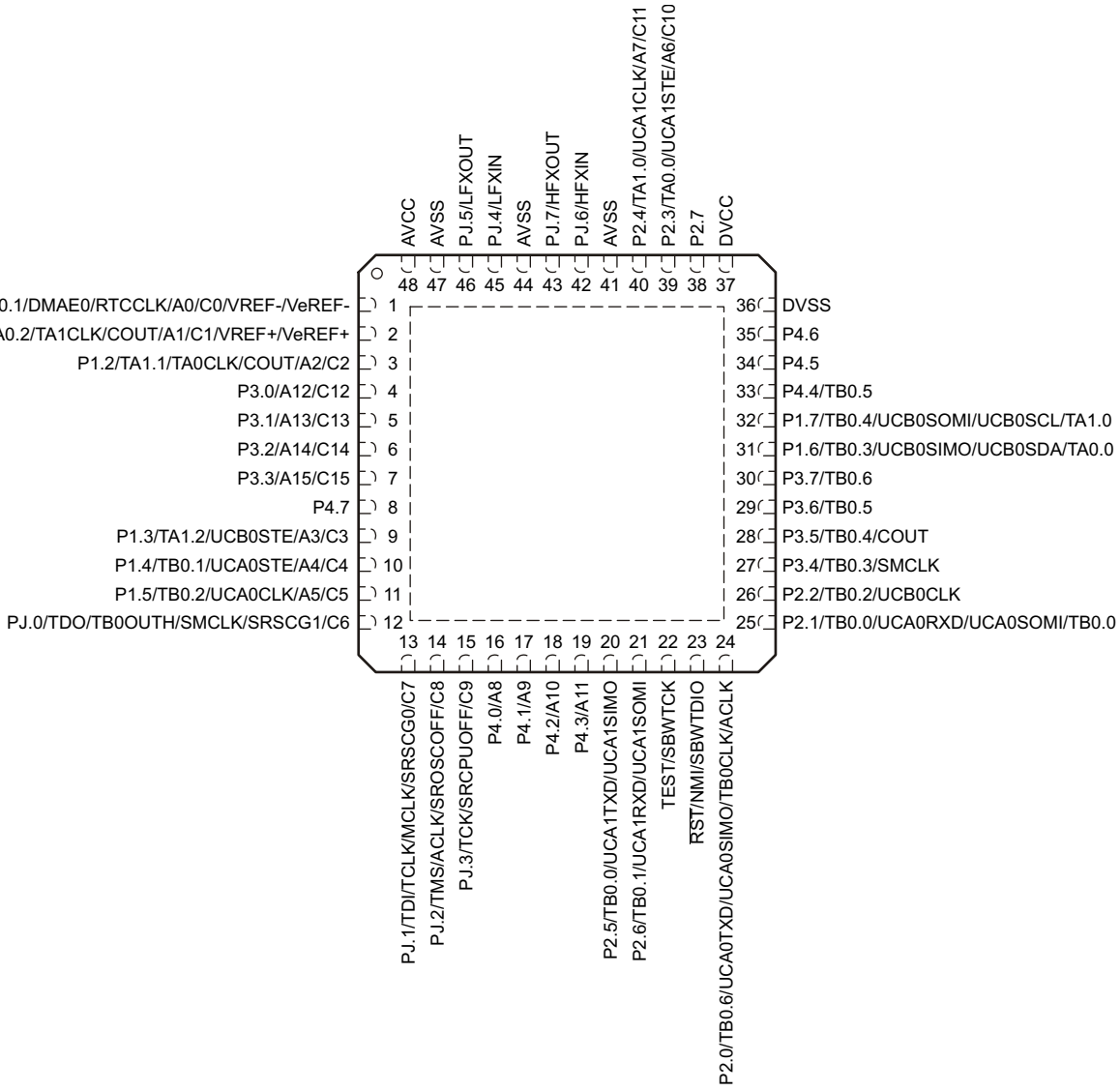
# 4 Terminal Configuration and Functions

## 4.1 Pin Diagrams

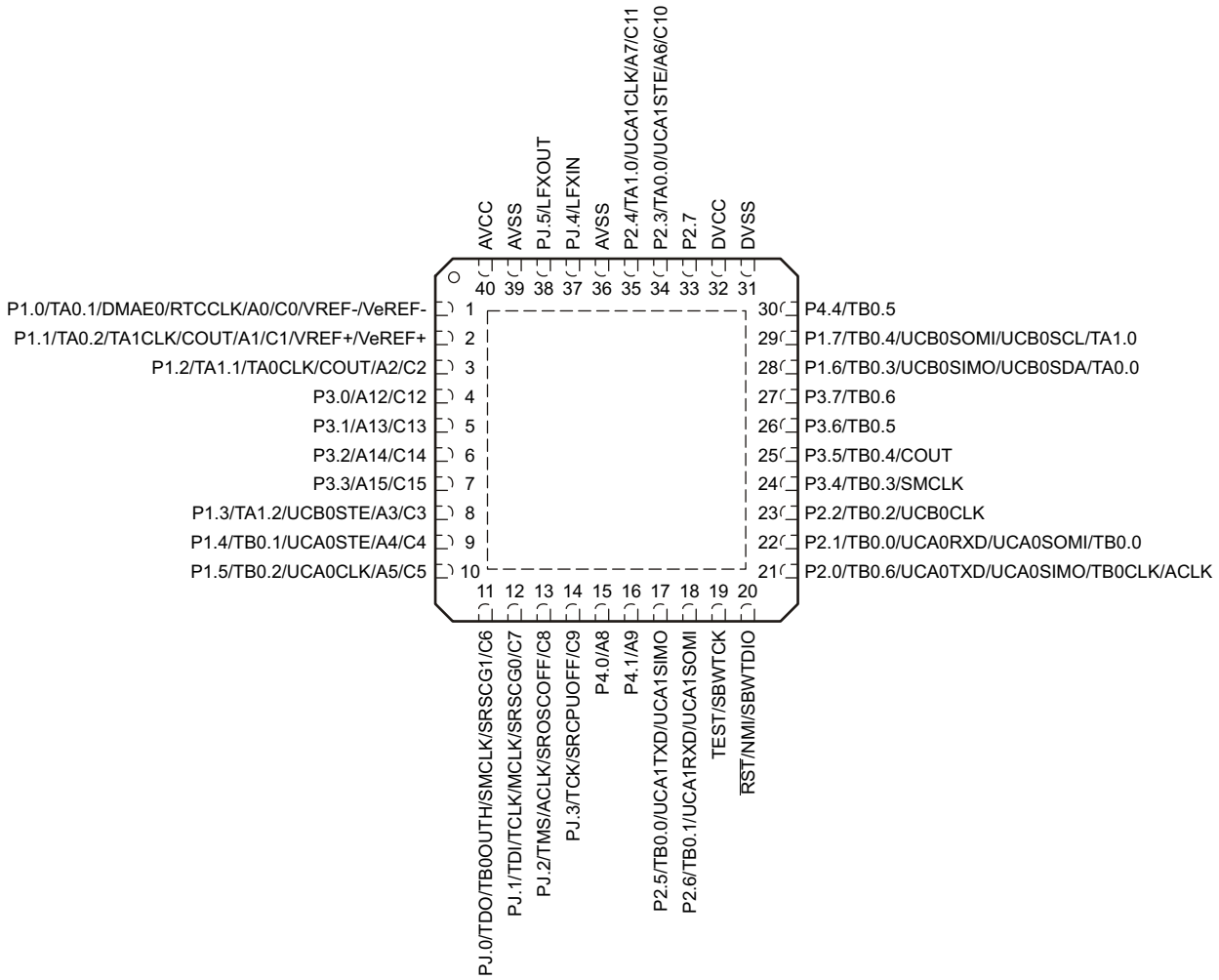
Figure 4-1 shows the 48-pin RGZ package for the MSP430FR596x and MSP430FR596x1 MCUs.




NOTE: TI recommends connecting the QFN package pad to $V_{SS}$.
NOTE: On devices with UART BSL: P2.0: BSLTX; P2.1: BSLRX
NOTE: On devices with $I^2C$ BSL: P1.6: BSLSDA; P1.7: BSLSCL

**Figure 4-1. 48-Pin RGZ Package (Top View) – MSP430FR596x and MSP430FR596x1**

Figure 4-2 shows the 40-pin RHA package for the MSP430FR594x and MSP430FR594x1 MCUs (LFXT only).




NOTE: TI recommends connecting the QFN package pad to $V_{SS}$.
NOTE: On devices with UART BSL: P2.0: BSLTX; P2.1: BSLRX
NOTE: On devices with $I^2C$ BSL: P1.6: BSLSDA; P1.7: BSLSCL

**Figure 4-2. 40-Pin RHA Package (Top View) – MSP430FR594x and MSP430FR594x1**


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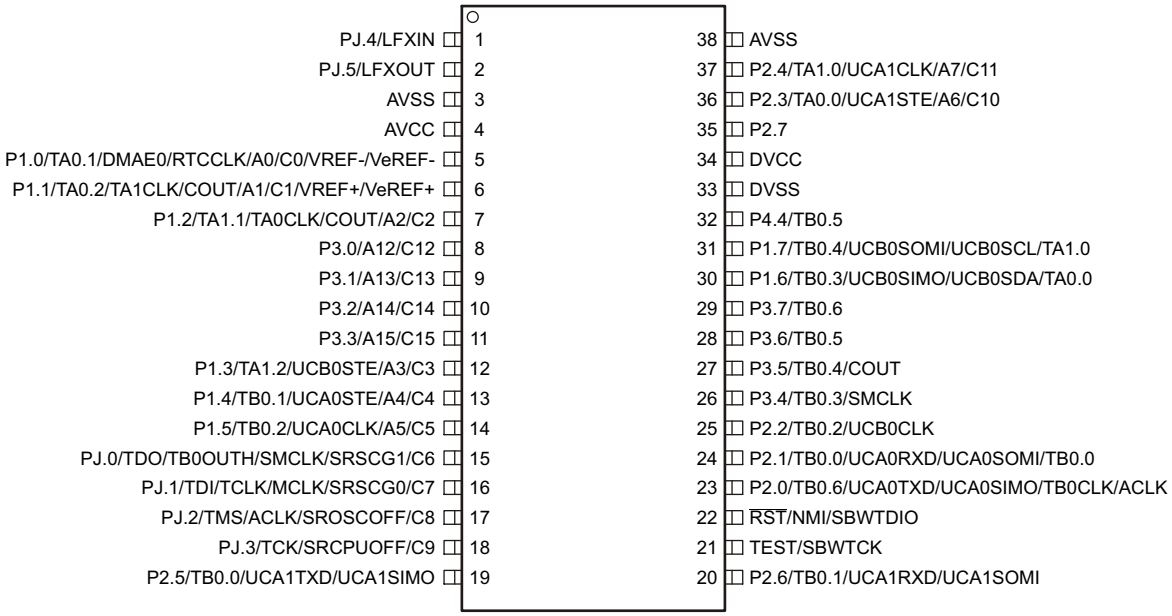
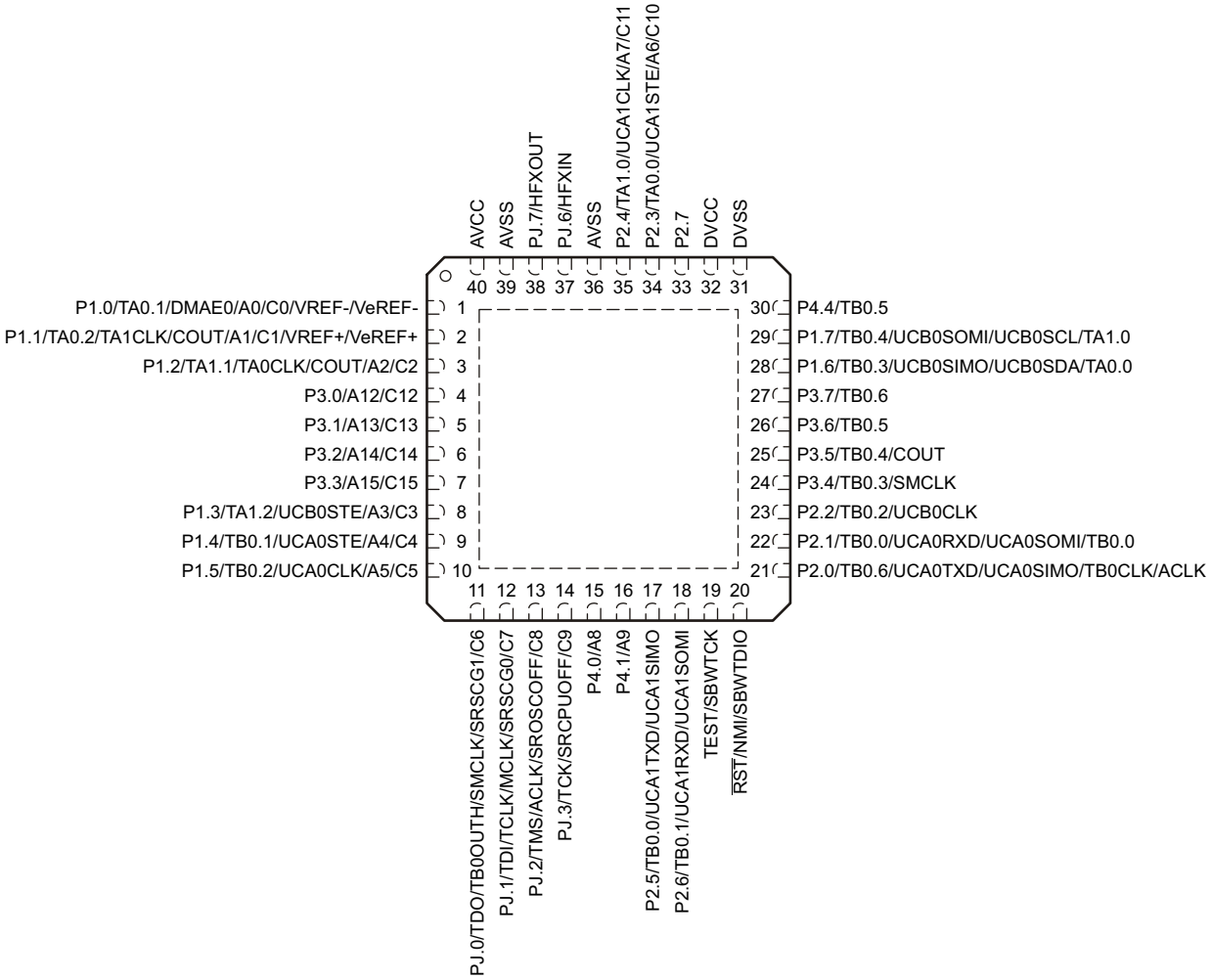
Figure 4-3 shows the 38-pin DA package for the MSP430FR594x MCUs (LFXT only).




NOTE: On devices with UART BSL: P2.0: BSLTX; P2.1: BSLRX

**Figure 4-3. 38-Pin DA Package (Top View) – MSP430FR594x**

Figure 4-4 shows the 40-pin RHA package for the MSP430FR595x MCUs (HFXT only).




NOTE: TI recommends connecting the QFN package pad to $V_{SS}$.
NOTE: On devices with UART BSL: P2.0: BSLTX; P2.1: BSLRX

**Figure 4-4. 40-Pin RHA Package (Top View) – MSP430FR595x**


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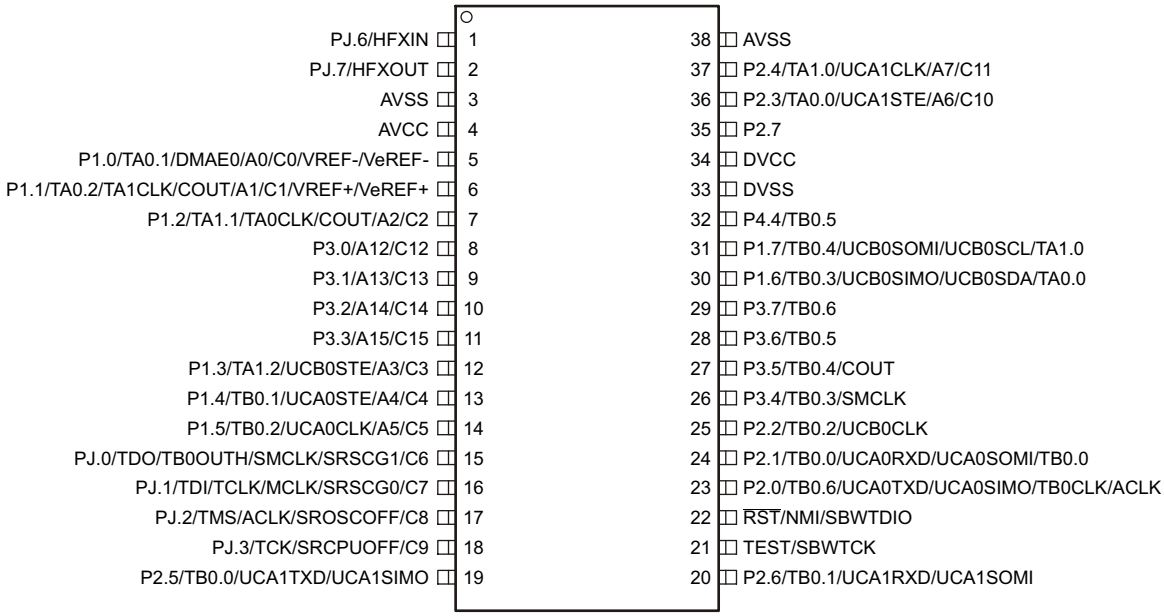
Figure 4-5 shows the 38-pin DA package for the MSP430FR595x MCUs (HFXT only).




NOTE: On devices with UART BSL: P2.0: BSLTX; P2.1: BSLRX

**Figure 4-5. 38-Pin DA Package (Top View) – MSP430FR595x**

## 4.2 Signal Descriptions

Table 4-1 describes the signals for all device variants and package options.

**Table 4-1. Signal Descriptions**

| TERMINAL | | | | I/O[1] | DESCRIPTION |
|---|---|---|---|---|---|
| NAME | NO.[2] | | | | |
| | RGZ | RHA | DA | | |
| P1.0/TA0.1/DMAE0/ RTCCLK/A0/C0/VREF-/ VeREF- | 1 | 1 | 5 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TA0 CCR1 capture: CCI1A input, compare: Out1<br>External DMA trigger<br>RTC clock calibration output (not available on MSP430FR5x5x devices)<br>Analog input A0 for ADC<br>Comparator input C0<br>Output of negative reference voltage<br>Input for an external negative reference voltage to the ADC |
| P1.1/TA0.2/TA1CLK/ COUT/A1/C1/VREF+/ VeREF+ | 2 | 2 | 6 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TA0 CCR2 capture: CCI2A input, compare: Out2<br>TA1 input clock<br>Comparator output<br>Analog input A1 for ADC<br>Comparator input C1<br>Output of positive reference voltage<br>Input for an external positive reference voltage to the ADC |
| P1.2/TA1.1/TA0CLK/ COUT/A2/C2 | 3 | 3 | 7 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TA1 CCR1 capture: CCI1A input, compare: Out1<br>TA0 input clock<br>Comparator output<br>Analog input A2 for ADC<br>Comparator input C2 |
| P3.0/A12/C12 | 4 | 4 | 8 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>Analog input A12 for ADC<br>Comparator input C12 |
| P3.1/A13/C13 | 5 | 5 | 9 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>Analog input A13 for ADC<br>Comparator input C13 |
| P3.2/A14/C14 | 6 | 6 | 10 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>Analog input A14 for ADC<br>Comparator input C14 |
| P3.3/A15/C15 | 7 | 7 | 11 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>Analog input A15 for ADC<br>Comparator input C15 |
| P4.7 | 8 | N/A | N/A | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5 |
| P1.3/TA1.2/UCB0STE/ A3/C3 | 9 | 8 | 12 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TA1 CCR2 capture: CCI2A input, compare: Out2<br>Slave transmit enable – eUSCI_B0 SPI mode<br>Analog input A3 for ADC<br>Comparator input C3 |

(1) I = input, O = output
(2) N/A = not available


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**Table 4-1. Signal Descriptions (continued)**

| TERMINAL | | | | I/O[1] | DESCRIPTION |
|---|---|---|---|---|---|
| NAME | NO.[2] | | | | |
| | RGZ | RHA | DA | | |
| P1.4/TB0.1/UCA0STE/ A4/C4 | 10 | 9 | 13 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR1 capture: CCI1A input, compare: Out1<br>Slave transmit enable – eUSCI_A0 SPI mode<br>Analog input A4 for ADC<br>Comparator input C4 |
| P1.5/TB0.2/UCA0CLK/ A5/C5 | 11 | 10 | 14 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR2 capture: CCI2A input, compare: Out2<br>Clock signal input – eUSCI_A0 SPI slave mode,<br>Clock signal output – eUSCI_A0 SPI master mode<br>Analog input A5 for ADC<br>Comparator input C5 |
| PJ.0/TDO/TB0OUTH/ SMCLK/SRSCG1/C6 | 12 | 11 | 15 | I/O | General-purpose digital I/O<br>Test data output port<br>Switch all PWM outputs high impedance input – TB0<br>SMCLK output<br>Low-Power Debug: CPU Status Register Bit SCG1<br>Comparator input C6 |
| PJ.1/TDI/TCLK/MCLK/ SRSCG0/C7 | 13 | 12 | 16 | I/O | General-purpose digital I/O<br>Test data input or test clock input<br>MCLK output<br>Low-Power Debug: CPU Status Register Bit SCG0<br>Comparator input C7 |
| PJ.2/TMS/ACLK/ SROSCOFF/C8 | 14 | 13 | 17 | I/O | General-purpose digital I/O<br>Test mode select<br>ACLK output<br>Low-Power Debug: CPU Status Register Bit OSCOFF<br>Comparator input C8 |
| PJ.3/TCK/ SRCPUOFF/C9 | 15 | 14 | 18 | I/O | General-purpose digital I/O<br>Test clock<br>Low-Power Debug: CPU Status Register Bit CPUOFF<br>Comparator input C9 |
| P4.0/A8 | 16 | 15 | N/A | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>Analog input A8 for ADC |
| P4.1/A9 | 17 | 16 | N/A | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>Analog input A9 for ADC |
| P4.2/A10 | 18 | N/A | N/A | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>Analog input A10 for ADC |
| P4.3/A11 | 19 | N/A | N/A | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>Analog input A11 for ADC |
| P2.5/TB0.0/UCA1TXD/ UCA1SIMO | 20 | 17 | 19 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR0 capture: CCI0B input, compare: Out0<br>Transmit data – eUSCI_A1 UART mode<br>Slave in, master out – eUSCI_A1 SPI mode |

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**Table 4-1. Signal Descriptions (continued)**

| TERMINAL | | | | I/O[1] | DESCRIPTION |
|---|---|---|---|---|---|
| NAME | NO.[2] | | | | |
| | RGZ | RHA | DA | | |
| P2.6/TB0.1/UCA1RXD/ UCA1SOMI | 21 | 18 | 20 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR1 compare: Out1<br>Receive data – eUSCI_A1 UART mode<br>Slave out, master in – eUSCI_A1 SPI mode |
| TEST/SBWTCK | 22 | 19 | 21 | I | Test mode pin – select digital I/O on JTAG pins<br>Spy-Bi-Wire input clock |
| $\overline{\text{RST}}$/NMI/SBWTDIO | 23 | 20 | 22 | I/O | Reset input active low<br>Nonmaskable interrupt input<br>Spy-Bi-Wire data input/output |
| P2.0/TB0.6/UCA0TXD/ UCA0SIMO/TB0CLK/ ACLK | 24 | 21 | 23 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR6 capture: CCI6B input, compare: Out6<br>Transmit data – eUSCI_A0 UART mode<br>BSL Transmit (UART BSL)<br>Slave in, master out – eUSCI_A0 SPI mode<br>TB0 clock input<br>ACLK output |
| P2.1/TB0.0/UCA0RXD/ UCA0SOMI/TB0.0 | 25 | 22 | 24 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR0 capture: CCI0A input, compare: Out0<br>Receive data – eUSCI_A0 UART mode<br>BSL receive (UART BSL)<br>Slave out, master in – eUSCI_A0 SPI mode<br>TB0 CCR0 capture: CCI0A input, compare: Out0 |
| P2.2/TB0.2/UCB0CLK | 26 | 23 | 25 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR2 compare: Out2<br>Clock signal input – eUSCI_B0 SPI slave mode<br>Clock signal output – eUSCI_B0 SPI master mode |
| P3.4/TB0.3/SMCLK | 27 | 24 | 26 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR3 capture: CCI3A input, compare: Out3<br>SMCLK output |
| P3.5/TB0.4/COUT | 28 | 25 | 27 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR4 capture: CCI4A input, compare: Out4<br>Comparator output |
| P3.6/TB0.5 | 29 | 26 | 28 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR5 capture: CCI5A input, compare: Out5 |
| P3.7/TB0.6 | 30 | 27 | 29 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR6 capture: CCI6A input, compare: Out6 |
| P1.6/TB0.3/UCB0SIMO/ UCB0SDA/TA0.0 | 31 | 28 | 30 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR3 capture: CCI3B input, compare: Out3<br>Slave in, master out – eUSCI_B0 SPI mode<br>$I^2C$ data – eUSCI_B0 $I^2C$ mode<br>BSL Data ($I^2C$ BSL)<br>TA0 CCR0 capture: CCI0A input, compare: Out0 |


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**Table 4-1. Signal Descriptions (continued)**

| TERMINAL | | | | I/O[1] | DESCRIPTION |
|---|---|---|---|---|---|
| NAME | NO.[2] | | | | |
| | RGZ | RHA | DA | | |
| P1.7/TB0.4/UCB0SOMI/ UCB0SCL/TA1.0 | 32 | 29 | 31 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0 CCR4 capture: CCI4B input, compare: Out4<br>Slave out, master in – eUSCI_B0 SPI mode<br>$I^2C$ clock – eUSCI_B0 $I^2C$ mode<br>BSL clock ($I^2C$ BSL)<br>TA1 CCR0 capture: CCI0A input, compare: Out0 |
| P4.4/TB0.5 | 33 | 30 | 32 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TB0CCR5 capture: CCI5B input, compare: Out5 |
| P4.5 | 34 | N/A | N/A | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5 |
| P4.6 | 35 | N/A | N/A | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5 |
| DVSS | 36 | 31 | 33 | | Digital ground supply |
| DVCC | 37 | 32 | 34 | | Digital power supply |
| P2.7 | 38 | 33 | 35 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5 |
| P2.3/TA0.0/UCA1STE/ A6/C10 | 39 | 34 | 36 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TA0 CCR0 capture: CCI0B input, compare: Out0<br>Slave transmit enable – eUSCI_A1 SPI mode<br>Analog input A6 for ADC<br>Comparator input C10 |
| P2.4/TA1.0/UCA1CLK/ A7/C11 | 40 | 35 | 37 | I/O | General-purpose digital I/O with port interrupt and wakeup from LPMx.5<br>TA1 CCR0 capture: CCI0B input, compare: Out0<br>Clock signal input – eUSCI_A1 SPI slave mode<br>Clock signal output – eUSCI_A1 SPI master mode<br>Analog input A7 for ADC<br>Comparator input C11 |
| AVSS | 41 | 36 | 38 | | Analog ground supply |
| PJ.6/HFXIN | 42 | 37 | 1 | I/O | General-purpose digital I/O<br>Input for high-frequency crystal oscillator HFXT (in RHA and DA packages: MSP430FR595x devices only) |
| PJ.7/HFXOUT | 43 | 38 | 2 | I/O | General-purpose digital I/O<br>Output for high-frequency crystal oscillator HFXT (in RHA and DA packages: MSP430FR595x devices only) |
| AVSS | 44 | N/A | N/A | | Analog ground supply |
| PJ.4/LFXIN | 45 | 37 | 1 | I/O | General-purpose digital I/O<br>Input for low-frequency crystal oscillator LFXT (in RHA and DA packages: MSP430FR594x devices only) |
| PJ.5/LFXOUT | 46 | 38 | 2 | I/O | General-purpose digital I/O<br>Output of low-frequency crystal oscillator LFXT (in RHA and DA packages: MSP430FR594x devices only) |
| AVSS | 47 | 39 | 3 | | Analog ground supply |
| AVCC | 48 | 40 | 4 | | Analog power supply |
| QFN Pad | Pad | Pad | N/A | | QFN package exposed thermal pad. TI recommends connection to $V_{SS}$. |

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## 4.3 Pin Multiplexing

Pin multiplexing for these devices is controlled by both register settings and operating modes (for example, if the device is in test mode). For details of the settings for each pin and diagrams of the multiplexed ports, see Section 6.11.

## 4.4 Connection of Unused Pins

Table 4-2 lists the correct termination of all unused pins.

**Table 4-2. Connection of Unused Pins(1)**

| PIN | POTENTIAL | COMMENT |
|---|---|---|
| AVCC | $DV_{CC}$ | |
| AVSS | $DV_{SS}$ | |
| Px.0 to Px.7 | Open | Set to port function, output direction (PxDIR.n = 1) |
| $\overline{RST}$/NMI | $DV_{CC}$ or $V_{CC}$ | 47-kΩ pullup or internal pullup selected with 2.2-nF (10-nF(2)) pulldown |
| PJ.0/TDO<br>PJ.1/TDI<br>PJ.2/TMS<br>PJ.3/TCK | Open | The JTAG pins are shared with general-purpose I/O function (PJ.x). If not used as JTAG pins, these pins should be switched to port function, output direction. When used as JTAG pins, these pins should remain open. |
| TEST | Open | This pin always has an internal pulldown enabled. |

(1) Any unused pin with a secondary function that is shared with general-purpose I/O should follow the Px.0 to Px.7 unused pin connection guidelines.
(2) The pulldown capacitor should not exceed 2.2 nF when using devices in Spy-Bi-Wire mode or in 4-wire JTAG mode with TI tools like FET interfaces or GANG programmers. If JTAG or Spy-Bi-Wire access is not needed, up to a 10-nF pulldown capacitor may be used.


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# 5 Specifications

## 5.1 Absolute Maximum Ratings(1)

over operating free-air temperature range (unless otherwise noted)

| | MIN | MAX | UNIT |
|---|---|---|---|
| Voltage applied at DVCC and AVCC pins to $V_{SS}$ | –0.3 | 4.1 | V |
| Voltage difference between DVCC and AVCC pins(2) | | ±0.3 | V |
| Voltage applied to any pin (3) | –0.3 | $V_{CC}$ + 0.3 V (4.1 Max) | V |
| Diode current at any device pin | | ±2 | mA |
| Storage temperature, $T_{stg}$(4) | –40 | 125 | °C |

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) Voltage differences between DVCC and AVCC exceeding the specified limits may cause malfunction of the device including erroneous writes to RAM and FRAM.
(3) All voltages referenced to $V_{SS}$.
(4) Higher temperature may be applied during board soldering according to the current JEDEC J-STD-020 specification with peak reflow temperatures not higher than classified on the device label on the shipping boxes or reels.

## 5.2 ESD Ratings

| | | | VALUE | UNIT |
|---|---|---|---|---|
| $V_{(ESD)}$ | Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1) | ±1000 | V |
| | | Charged-device model (CDM), per JEDEC specification JESD22-C101(2) | ±250 | |

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process. Pins listed as ±1000 V may actually have higher performance.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process. Pins listed as ±250 V may actually have higher performance.

## 5.3 Recommended Operating Conditions

Typical data are based on $V_{CC}$ = 3.0 V, $T_A$ = 25°C (unless otherwise noted)

| | | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{CC}$ | Supply voltage range applied at all DVCC and AVCC pins(1) (2) (3) | | 1.8(4) | | 3.6 | V |
| $V_{SS}$ | Supply voltage applied at all DVSS and AVSS pins | | | 0 | | V |
| $T_A$ | Operating free-air temperature | | –40 | | 85 | °C |
| $T_J$ | Operating junction temperature | | –40 | | 85 | °C |
| $C_{DVCC}$ | Capacitor value at DVCC(5) | | $1_{-20\%}$ | | | µF |
| $f_{SYSTEM}$ | Processor frequency (maximum MCLK frequency)(6) | No FRAM wait states (NWAITSx = 0) | 0 | | 8(7) | MHz |
| | | With FRAM wait states (NWAITSx = 1)(8) | 0 | | 16(9) | |
| $f_{ACLK}$ | Maximum ACLK frequency | | | | 50 | kHz |
| $f_{SMCLK}$ | Maximum SMCLK frequency | | | | 16(9) | MHz |

(1) TI recommends powering AVCC and DVCC pins from the same source. At a minimum, during power up, power down, and device operation, the voltage difference between AVCC and DVCC must not exceed the limits specified in Absolute Maximum Ratings. Exceeding the specified limits may cause malfunction of the device including erroneous writes to RAM and FRAM.
(2) See Table 5-1 for additional important information.
(3) Modules may have a different supply voltage range specification. See the specification of the respective module in this data sheet.
(4) The minimum supply voltage is defined by the supervisor SVS levels. See Table 5-2 for the values.
(5) Connect a low-ESR capacitor with at least the value specified and a maximum tolerance of 20% as close as possible to the DVCC pin.
(6) Modules may have a different maximum input clock specification. See the specification of the respective module in this data sheet.
(7) DCO settings and HF crystals with a typical value less or equal the specified MAX value are permitted.
(8) Wait states only occur on actual FRAM accesses; that is, on FRAM cache misses. RAM and peripheral accesses are always executed without wait states.
(9) DCO settings and HF crystals with a typical value less or equal the specified MAX value are permitted. If a clock sources with a larger typical value is used, the clock must be divided in the clock system.

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## 5.4 Active Mode Supply Current Into $V_{CC}$ Excluding External Current

over recommended operating free-air temperature (unless otherwise noted)(1) (2)

| PARAMETER | EXECUTION MEMORY | $V_{CC}$ | FREQUENCY ($f_{MCLK} = f_{SMCLK}$) | | | | | | | | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 MHz 0 wait states (NWAITSx = 0) | | 4 MHz 0 wait states (NWAITSx = 0) | | 8 MHz 0 wait states (NWAITSx = 0) | | 12 MHz 1 wait states (NWAITSx = 1) | | 16 MHz 1 wait states (NWAITSx = 1) | | |
| | | | TYP | MAX | TYP | MAX | TYP | MAX | TYP | MAX | TYP | MAX | |
| $I_{AM,\ FRAM_UNI}$ (Unified memory)(3) | FRAM | 3.0 V | 210 | | 640 | | 1220 | | 1475 | | 1845 | | µA |
| $I_{AM,\ FRAM\ (0\%)}$(4) (5) | FRAM 0% cache hit ratio | 3.0 V | 370 | | 1280 | | 2510 | | 2080 | | 2650 | | µA |
| $I_{AM,\ FRAM\ (50\%)}$(4) (5) | FRAM 50% cache hit ratio | 3.0 V | 240 | | 745 | | 1440 | | 1575 | | 1990 | | µA |
| $I_{AM,\ FRAM\ (66\%)}$(4) (5) | FRAM 66% cache hit ratio | 3.0 V | 200 | | 560 | | 1070 | | 1300 | | 1620 | | µA |
| $I_{AM,\ FRAM\ (75\%)}$(4) (5) | FRAM 75% cache hit ratio | 3.0 V | 170 | 255 | 480 | | 890 | 1085 | 1155 | 1310 | 1420 | 1620 | µA |
| $I_{AM,\ FRAM\ (100\%)}$(4) (5) | FRAM 100% cache hit ratio | 3.0 V | 110 | | 235 | | 420 | | 640 | | 730 | | µA |
| $I_{AM,\ RAM}$ (6) | RAM | 3.0 V | 130 | | 320 | | 585 | | 890 | | 1070 | | µA |
| $I_{AM,\ RAM\ only}$ (7) (5) | RAM | 3.0 V | 100 | 180 | 290 | | 555 | | 860 | | 1040 | 1300 | µA |

(1) All inputs are tied to 0 V or to $V_{CC}$. Outputs do not source or sink any current.
(2) Characterized with program executing typical data processing.
$f_{ACLK}$ = 32768 Hz, $f_{MCLK} = f_{SMCLK} = f_{DCO}$ at specified frequency, except for 12 MHz. For 12 MHz, $f_{DCO}$= 24 MHz and $f_{MCLK} = f_{SMCLK} = f_{DCO}/2$.
At MCLK frequencies above 8 MHz, the FRAM requires wait states. When wait states are required, the effective MCLK frequency ($f_{MCLK,eff}$) decreases. The effective MCLK frequency also depends on the cache hit ratio. SMCLK is not affected by the number of wait states or the cache hit ratio.
The following equation can be used to compute $f_{MCLK,eff}$:
$f_{MCLK,eff} = f_{MCLK}$ / [wait states × (1 – cache hit ratio) + 1]
For example, with 1 wait state and 75% cache hit ratio, $f_{MCKL,eff} = f_{MCLK}$ / [1 × (1 – 0.75) + 1] = $f_{MCLK}$ / 1.25.
(3) Represents typical program execution. Program and data reside entirely in FRAM. All execution is from FRAM.
(4) Program resides in FRAM. Data resides in SRAM. Average current dissipation varies with cache hit-to-miss ratio as specified. Cache hit ratio represents number cache accesses divided by the total number of FRAM accesses. For example, a 75% ratio implies three of every four accesses is from cache, and the remaining are FRAM accesses.
(5) See Figure 5-1 for typical curves. Each characteristic equation shown in the graph is computed using the least squares method for best linear fit using the typical data from Section 5.4.
(6) Program and data reside entirely in RAM. All execution is from RAM.
(7) Program and data reside entirely in RAM. All execution is from RAM. FRAM is off.


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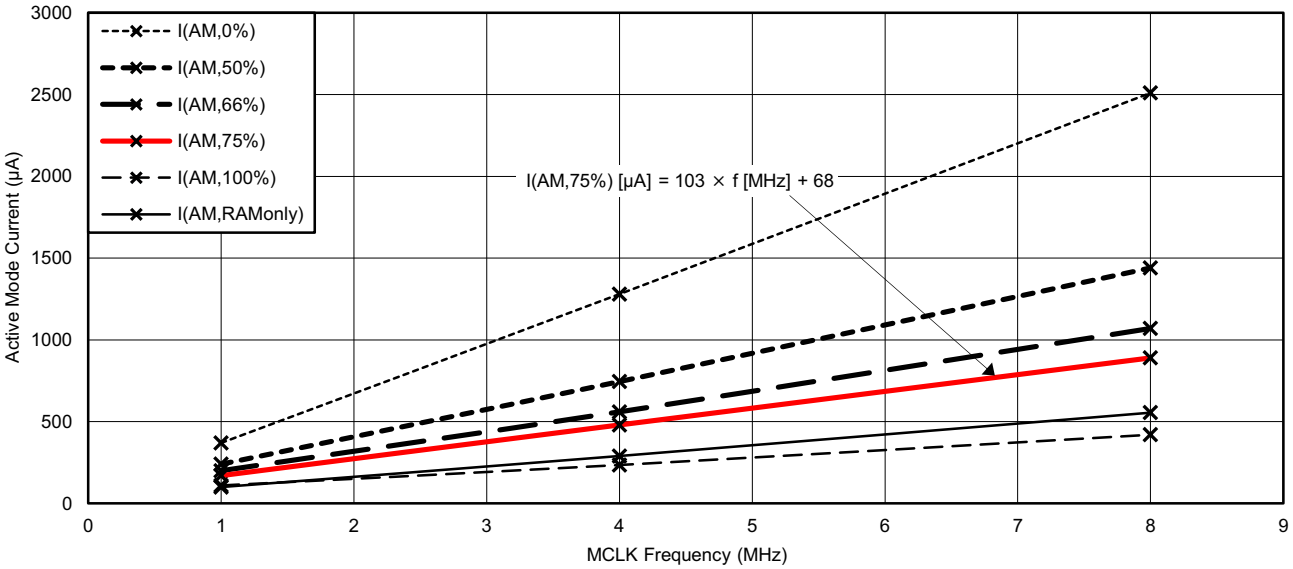
## 5.5 Typical Characteristics – Active Mode Supply Currents




NOTE: I(AM, cache hit ratio): Program resides in FRAM. Data resides in SRAM. Average current dissipation varies with cache hit-to-miss ratio as specified. Cache hit ratio represents number cache accesses divided by the total number of FRAM accesses. For example, a 75% ratio implies three of every four accesses is from cache, and the remaining are FRAM accesses.

NOTE: I(AM, RAMonly): Program and data reside entirely in RAM. All execution is from RAM. FRAM is off.

**Figure 5-1. Typical Active Mode Supply Currents vs MCLK frequency, No Wait States**

## 5.6 Low-Power Mode (LPM0, LPM1) Supply Currents Into $V_{CC}$ Excluding External Current

over recommended operating free-air temperature (unless otherwise noted)(1) (2)

| PARAMETER | $V_{CC}$ | FREQUENCY ($f_{SMCLK}$) | | | | | | | | | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 MHz | | 4 MHz | | 8 MHz | | 12 MHz | | 16 MHz | | |
| | | TYP | MAX | TYP | MAX | TYP | MAX | TYP | MAX | TYP | MAX | |
| $I_{LPM0}$ | 2.2 V | 70 | | 95 | | 150 | | 250 | | 215 | | µA |
| | 3.0 V | 80 | 115 | 105 | | 160 | | 260 | | 225 | 260 | |
| $I_{LPM1}$ | 2.2 V | 35 | | 60 | | 115 | | 215 | | 180 | | µA |
| | 3.0 V | 35 | 60 | 60 | | 115 | | 215 | | 180 | 205 | |

(1) All inputs are tied to 0 V or to $V_{CC}$. Outputs do not source or sink any current.
(2) Current for watchdog timer clocked by SMCLK included.
$f_{ACLK}$ = 32768 Hz, $f_{MCLK}$ = 0 MHz, $f_{SMCLK}$ = $f_{DCO}$ at specified frequency, except for 12 MHz. For 12 MHz, $f_{DCO}$ = 24 MHz and $f_{SMCLK}$ = $f_{DCO}$ / 2.

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## 5.7 Low-Power Mode (LPM2, LPM3, LPM4) Supply Currents (Into $V_{CC}$) Excluding External Current

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (1)

| PARAMETER | | $V_{CC}$ | –40°C | | 25°C | | 60°C | | 85°C | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | TYP | MAX | TYP | MAX | TYP | MAX | TYP | MAX | |
| $I_{LPM2,XT12}$ | Low-power mode 2, 12-pF crystal (2) (3) (4) | 2.2 V | 0.5 | | 0.9 | | 2.2 | | 6.1 | | µA |
| | | 3.0 V | 0.5 | | 0.9 | 1.8 | 2.2 | | 6.1 | 17 | |
| $I_{LPM2,XT3.7}$ | Low-power mode 2, 3.7-pF cyrstal (2) (5) (4) | 2.2 V | 0.5 | | 0.9 | | 2.2 | | 6.0 | | µA |
| | | 3.0 V | 0.5 | | 0.9 | | 2.2 | | 6.0 | | |
| $I_{LPM2,VLO}$ | Low-power mode 2, VLO, includes SVS (6) | 2.2 V | 0.3 | | 0.7 | | 1.9 | | 5.8 | | µA |
| | | 3.0 V | 0.3 | | 0.7 | 1.6 | 1.9 | | 5.8 | 16.7 | |
| $I_{LPM3,XT12}$ | Low-power mode 3, 12-pF crystal, excludes SVS (2) (3) (7) | 2.2 V | 0.5 | | 0.6 | | 0.9 | | 1.85 | | µA |
| | | 3.0 V | 0.5 | | 0.6 | 0.9 | 0.9 | | 1.85 | 4.9 | |
| $I_{LPM3,XT3.7}$ | Low-power mode 3, 3.7-pF cyrstal, excludes SVS (2) (5) (8) (also see Figure 5-2) | 2.2 V | 0.4 | | 0.5 | | 0.8 | | 1.7 | | µA |
| | | 3.0 V | 0.4 | | 0.5 | | 0.8 | | 1.7 | | |
| $I_{LPM3,VLO}$ | Low-power mode 3, VLO, excludes SVS (9) | 2.2 V | 0.3 | | 0.4 | | 0.7 | | 1.6 | | µA |
| | | 3.0 V | 0.3 | | 0.4 | 0.7 | 0.7 | | 1.6 | 4.7 | |
| $I_{LPM4,SVS}$ | Low-power mode 4, includes SVS (10) (also see Figure 5-3) | 2.2 V | 0.4 | | 0.5 | | 0.8 | | 1.7 | | µA |
| | | 3.0 V | 0.4 | | 0.5 | 0.8 | 0.8 | | 1.7 | 4.8 | |
| $I_{LPM4}$ | Low-power mode 4, excludes SVS (11) | 2.2 V | 0.2 | | 0.3 | | 0.6 | | 1.5 | | µA |
| | | 3.0 V | 0.2 | | 0.3 | 0.6 | 0.6 | | 1.5 | 4.6 | |

(1) All inputs are tied to 0 V or to $V_{CC}$. Outputs do not source or sink any current.
(2) Not applicable for devices with HF crystal oscillator only.
(3) Characterized with a Micro Crystal MS1V-T1K crystal with a load capacitance of 12.5 pF. The internal and external load capacitance are chosen to closely match the required 12.5-pF load.
(4) Low-power mode 2, crystal oscillator test conditions:
Current for watchdog timer clocked by ACLK and RTC clocked by XT1 are included. Current for brownout and SVS are included.
CPUOFF = 1, SCG0 = 0 SCG1 = 1, OSCOFF = 0 (LPM2),
$f_{XT1}$ = 32768 Hz, $f_{ACLK} = f_{XT1}$, $f_{MCLK} = f_{SMCLK}$ = 0 MHz
(5) Characterized with a SSP-T7-FL (SMD) crystal with a load capacitance of 3.7 pF. The internal and external load capacitance are chosen to closely match the required 3.7-pF load.
(6) Low-power mode 2, VLO test conditions:
Current for watchdog timer clocked by ACLK is included. RTC disabled (RTCHOLD = 1). Current for brownout and SVS are included.
CPUOFF = 1, SCG0 = 0 SCG1 = 1, OSCOFF = 0 (LPM2),
$f_{XT1}$ = 0 Hz, $f_{ACLK} = f_{VLO}$, $f_{MCLK} = f_{SMCLK}$ = 0 MHz
(7) Low-power mode 3, 12-pF crystal, excludes SVS test conditions:
Current for watchdog timer clocked by ACLK and RTC clocked by XT1 are included. Current for brownout is included. SVS disabled (SVSHE = 0).
CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 0 (LPM3),
$f_{XT1}$ = 32768 Hz, $f_{ACLK} = f_{XT1}$, $f_{MCLK} = f_{SMCLK}$ = 0 MHz
(8) Low-power mode 3, 3.7-pF crystal, excludes SVS test conditions:
Current for watchdog timer clocked by ACLK and RTC clocked by XT1 are included. Current for brownout is included. SVS disabled (SVSHE = 0).
CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 0 (LPM3),
$f_{XT1}$ = 32768 Hz, $f_{ACLK} = f_{XT1}$, $f_{MCLK} = f_{SMCLK}$ = 0 MHz
(9) Low-power mode 3, VLO, excludes SVS test conditions:
Current for watchdog timer clocked by ACLK is included. RTC disabled (RTCHOLD = 1). Current for brownout is included. SVS is disabled (SVSHE = 0).
CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 0 (LPM3),
$f_{XT1}$ = 0 Hz, $f_{ACLK} = f_{VLO}$, $f_{MCLK} = f_{SMCLK}$ = 0 MHz
(10) Low-power mode 4, includes SVS test conditions:
Current for brownout and SVS are included (SVSHE = 1).
CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 1 (LPM4),
$f_{XT1}$ = 0 Hz, $f_{ACLK}$ = 0 Hz, $f_{MCLK} = f_{SMCLK}$ = 0 MHz
(11) Low-power mode 4, excludes SVS test conditions:
Current for brownout is included. SVS is disabled (SVSHE = 0).
CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 1 (LPM4),
$f_{XT1}$ = 0 Hz, $f_{ACLK}$ = 0 Hz, $f_{MCLK} = f_{SMCLK}$ = 0 MHz


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### Low-Power Mode (LPM2, LPM3, LPM4) Supply Currents (Into $V_{CC}$) Excluding External Current *(continued)*

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (1)

| PARAMETER | | $V_{CC}$ | –40°C | | 25°C | | 60°C | | 85°C | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | TYP | MAX | TYP | MAX | TYP | MAX | TYP | MAX | |
| $I_{IDLE,GroupA}$ | Additional idle current if one or more modules from Group A (see Table 6-3) are activated in LPM3 or LPM4. | 3.0V | | | 0.02 | | | | 0.33 | 1.3 | µA |
| $I_{IDLE,GroupB}$ | Additional idle current if one or more modules from Group B (see Table 6-3) are activated in LPM3 or LPM4 | 3.0V | | | 0.015 | | | | 0.25 | 1.0 | µA |

## 5.8 Low-Power Mode (LPM3.5, LPM4.5) Supply Currents (Into $V_{CC}$) Excluding External Current

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)(1)

| PARAMETER | | $V_{CC}$ | –40°C | | 25°C | | 60°C | | 85°C | | UNIT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | TYP | MAX | TYP | MAX | TYP | MAX | TYP | MAX | |
| $I_{LPM3.5,XT12}$ | Low-power mode 3.5, 12-pF crystal, includes SVS(2)(3)(4) | 2.2 V | 0.4 | | 0.45 | | 0.5 | | 0.7 | | µA |
| | | 3.0 V | 0.4 | | 0.45 | 0.7 | 0.5 | | 0.7 | 1.2 | |
| $I_{LPM3.5,XT3.7}$ | Low-power mode 3.5, 3.7-pF cyrstal, excludes SVS(2)(5)(6) (also see Figure 5-4) | 2.2 V | 0.2 | | 0.25 | | 0.3 | | 0.45 | | µA |
| | | 3.0 V | 0.2 | | 0.25 | | 0.3 | | 0.5 | | |
| $I_{LPM4.5,SVS}$ | Low-power mode 4.5, includes SVS(7) (also see Figure 5-5) | 2.2 V | 0.2 | | 0.2 | | 0.2 | | 0.3 | | µA |
| | | 3.0 V | 0.2 | | 0.2 | 0.4 | 0.2 | | 0.3 | 0.55 | |
| $I_{LPM4.5}$ | Low-power mode 4.5, excludes SVS(8) (also see Figure 5-5) | 2.2 V | 0.02 | | 0.02 | | 0.02 | | 0.08 | | µA |
| | | 3.0 V | 0.02 | | 0.02 | | 0.02 | | 0.08 | 0.35 | |

(1) All inputs are tied to 0 V or to $V_{CC}$. Outputs do not source or sink any current.
(2) Not applicable for devices with HF crystal oscillator only.
(3) Characterized with a Micro Crystal MS1V-T1K crystal with a load capacitance of 12.5 pF. The internal and external load capacitance are chosen to closely match the required 12.5-pF load.
(4) Low-power mode 3.5, 12-pF crystal, includes SVS test conditions:
Current for RTC clocked by XT1 is included. Current for brownout and SVS are included (SVSHE = 1). Core regulator is disabled.
PMMREGOFF = 1, CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 1 (LPMx.5),
$f_{XT1}$ = 32768 Hz, $f_{ACLK} = f_{XT1}$, $f_{MCLK} = f_{SMCLK}$ = 0 MHz
(5) Characterized with a SSP-T7-FL (SMD) crystal with a load capacitance of 3.7 pF. The internal and external load capacitance are chosen to closely match the required 3.7-pF load.
(6) Low-power mode 3.5, 3.7-pF crystal, excludes SVS test conditions:
Current for RTC clocked by XT1 is included. Current for brownout is included. SVS is disabled (SVSHE = 0). Core regulator isdisabled.
PMMREGOFF = 1, CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 1 (LPMx.5),
$f_{XT1}$ = 32768 Hz, $f_{ACLK} = f_{XT1}$, $f_{MCLK} = f_{SMCLK}$ = 0 MHz
(7) Low-power mode 4.5, includes SVS test conditions:
Current for brownout and SVS are included (SVSHE = 1). Core regulator is disabled.
PMMREGOFF = 1, CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 1 (LPMx.5),
$f_{XT1}$ = 0 Hz, $f_{ACLK}$ = 0 Hz, $f_{MCLK} = f_{SMCLK}$ = 0 MHz
(8) Low-power mode 4.5, excludes SVS test conditions:
Current for brownout is included. SVS is disabled (SVSHE = 0). Core regulator is disabled.
PMMREGOFF = 1, CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 1 (LPMx.5),
$f_{XT1}$ = 0 Hz, $f_{ACLK}$ = 0 Hz, $f_{MCLK} = f_{SMCLK}$ = 0 MHz

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## 5.9 Typical Characteristics, Low-Power Mode Supply Currents

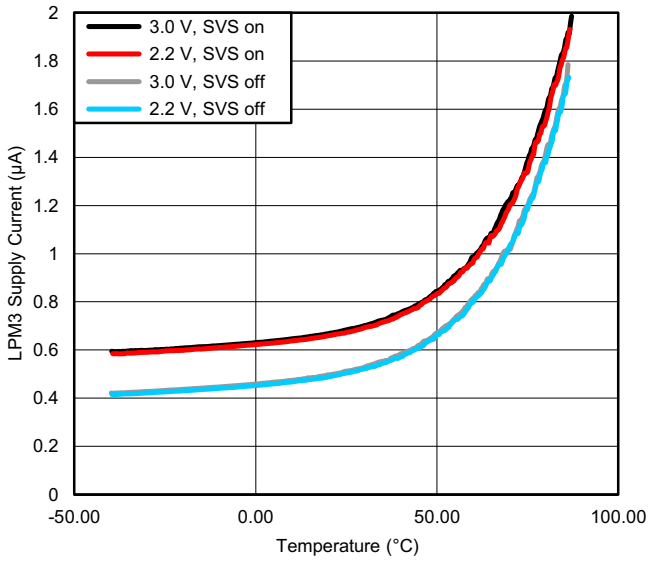


**Figure 5-2. LPM3,XT3.7 Supply Current vs Temperature**

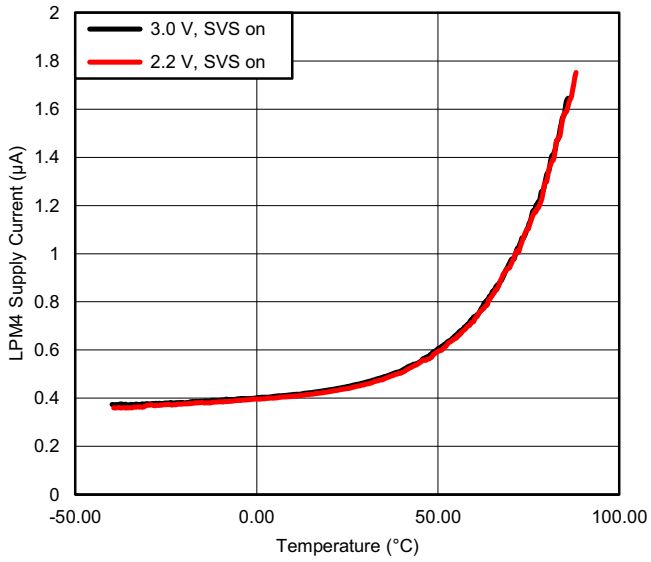


**Figure 5-3. LPM4,SVS Supply Current vs Temperature**

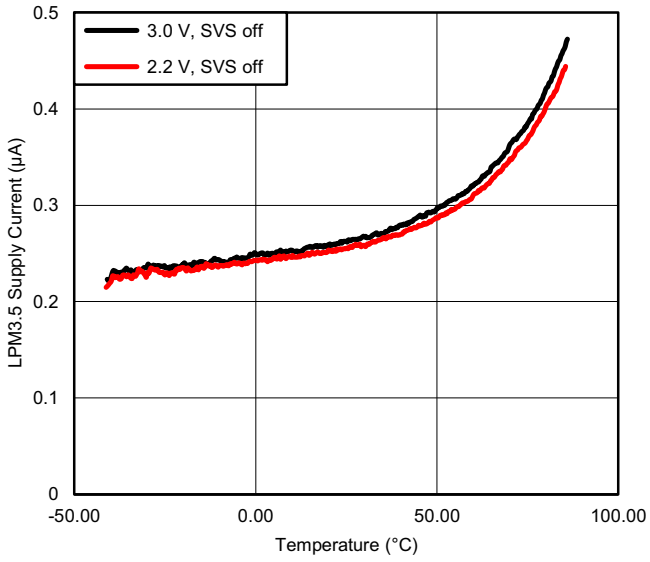


**Figure 5-4. LPM3.5,XT3.7 Supply Current vs Temperature**

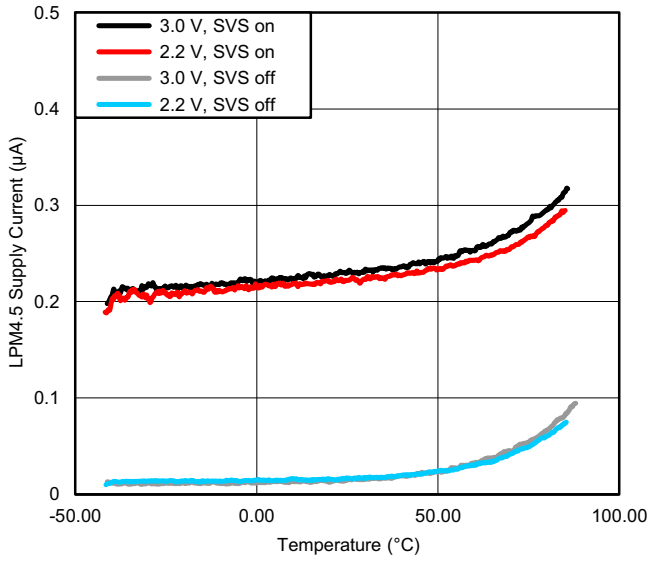


**Figure 5-5. LPM4.5 Supply Current vs Temperature**


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## 5.10 Typical Characteristics, Current Consumption per Module(1)

| MODULE | TEST CONDITIONS | REFERENCE CLOCK | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| Timer_A | | Module input clock | | 3 | | µA/MHz |
| Timer_B | | Module input clock | | 5 | | µA/MHz |
| eUSCI_A | UART mode | Module input clock | | 5.5 | | µA/MHz |
| eUSCI_A | SPI mode | Module input clock | | 3.5 | | µA/MHz |
| eUSCI_B | SPI mode | Module input clock | | 3.5 | | µA/MHz |
| eUSCI_B | $I^2C$ mode, 100 kbaud | Module input clock | | 3.5 | | µA/MHz |
| RTC_B | | 32 kHz | | 100 | | nA |
| MPY | Only from start to end of operation | MCLK | | 25 | | µA/MHz |
| AES | Only from start to end of operation | MCLK | | 21 | | µA/MHz |
| CRC | Only from start to end of operation | MCLK | | 2.5 | | µA/MHz |

(1) For other module currents not listed here, see the module specific parameter sections.

## 5.11 Thermal Resistance Characteristics

| THERMAL METRIC | | PACKAGE | VALUE | UNIT |
|---|---|---|---|---|
| $\theta_{JA}$ | Junction-to-ambient thermal resistance, still air(1) | QFN-48 (RGZ) | 30.6 | °C/W |
| $\theta_{JC(TOP)}$ | Junction-to-case (top) thermal resistance(2) | | 17.2 | °C/W |
| $\theta_{JB}$ | Junction-to-board thermal resistance(3) | | 7.2 | °C/W |
| $\Psi_{JB}$ | Junction-to-board thermal characterization parameter | | 7.2 | °C/W |
| $\Psi_{JT}$ | Junction-to-top thermal characterization parameter | | 0.2 | °C/W |
| $\theta_{JC(BOTTOM)}$ | Junction-to-case (bottom) thermal resistance(4) | | 1.2 | °C/W |
| $\theta_{JA}$ | Junction-to-ambient thermal resistance, still air(1) | QFN-40 (RHA) | 30.1 | °C/W |
| $\theta_{JC(TOP)}$ | Junction-to-case (top) thermal resistance(2) | | 18.7 | °C/W |
| $\theta_{JB}$ | Junction-to-board thermal resistance(3) | | 6.4 | °C/W |
| $\Psi_{JB}$ | Junction-to-board thermal characterization parameter | | 6.3 | °C/W |
| $\Psi_{JT}$ | Junction-to-top thermal characterization parameter | | 0.3 | °C/W |
| $\theta_{JC(BOTTOM)}$ | Junction-to-case (bottom) thermal resistance(4) | | 1.5 | °C/W |
| $\theta_{JA}$ | Junction-to-ambient thermal resistance, still air(1) | TSSOP-38 (DA) | 65.5 | °C/W |
| $\theta_{JC(TOP)}$ | Junction-to-case (top) thermal resistance(2) | | 12.5 | °C/W |
| $\theta_{JB}$ | Junction-to-board thermal resistance(3) | | 32.3 | °C/W |
| $\Psi_{JB}$ | Junction-to-board thermal characterization parameter | | 31.8 | °C/W |
| $\Psi_{JT}$ | Junction-to-top thermal characterization parameter | | 0.3 | °C/W |
| $\theta_{JC(BOTTOM)}$ | Junction-to-case (bottom) thermal resistance(4) | | N/A | °C/W |

(1) The junction-to-ambient thermal resistance under natural convection is obtained in a simulation on a JEDEC-standard, High-K board, as specified in JESD51-7, in an environment described in JESD51-2a.
(2) The junction-to-case (top) thermal resistance is obtained by simulating a cold plate test on the package top. No specific JEDEC-standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.
(3) The junction-to-board thermal resistance is obtained by simulating in an environment with a ring cold plate fixture to control the PCB temperature, as described in JESD51-8.
(4) The junction-to-case (bottom) thermal resistance is obtained by simulating a cold plate test on the exposed (power) pad. No specific JEDEC standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.

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## 5.12 Timing and Switching Characteristics

### 5.12.1 Power Supply Sequencing

TI recommends powering AVCC and DVCC pins from the same source. At a minimum, during power up, power down, and device operation, the voltage difference between AVCC and DVCC must not exceed the limits specified in Absolute Maximum Ratings. Exceeding the specified limits may cause malfunction of the device including erroneous writes to RAM and FRAM.

At power up, the device does not start executing code before the supply voltage reaches $V_{SVSH+}$ if the supply rises monotonically to this level.

Table 5-1 lists the reset power ramp requirements.

**Table 5-1. Brownout and Device Reset Power Ramp Requirements**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{VCC_BOR-}$ | Brownout power-down level(1)(2) | $\lvert dDV_{CC}/d_t \rvert$ < 3 V/s(3) | 0.7 | | 1.66 | V |
| | | $\lvert dDV_{CC}/d_t \rvert$ > 300 V/s(3) | 0 | | | V |
| $V_{VCC_BOR+}$ | Brownout power-up level(2) | $\lvert dDV_{CC}/d_t \rvert$ < 3 V/s(4) | 0.79 | | 1.68 | V |

(1) In case of a supply voltage brownout, the device supply voltages need to ramp down to the specified brownout power-down level $V_{VCC_BOR-}$ before the voltage is ramped up again to ensure a reliable device start-up and performance according to the data sheet including the correct operation of the on-chip SVS module.
(2) Fast supply voltage changes can trigger a BOR reset even within the recommended supply voltage range. To avoid unwanted BOR resets, the supply voltage must change by less than 0.05 V per microsecond (±0.05 V/µs). Following the data sheet recommendation for capacitor $C_{DVCC}$ should limit the slopes accordingly.
(3) The brownout levels are measured with a slowly changing supply. With faster slopes the MIN level required to reset the device properly can decrease to 0 V. Use the graph in Figure 5-6 to estimate the $V_{VCC_BOR-}$ level based on the down slope of the supply voltage. After removing VCC the down slope can be estimated based on the current consumption and the capacitance on DVCC: dV/dt = I/C with dV/dt: slope, I: current, C: capacitance.
(4) The brownout levels are measured with a slowly changing supply.

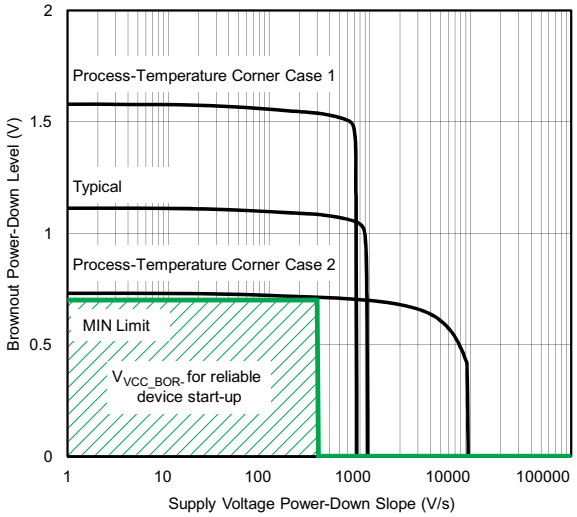


**Figure 5-6. Brownout Power-Down Level vs Supply Voltage Down Slope**


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Table 5-2 lists the characteristics of the SVS.

**Table 5-2. SVS**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $I_{SVSH,LPM}$ | $SVS_H$ current consumption, low power modes | | | 170 | 300 | nA |
| $V_{SVSH-}$ | $SVS_H$ power-down level(1) | | 1.75 | 1.80 | 1.85 | V |
| $V_{SVSH+}$ | $SVS_H$ power-up level(1) | | 1.77 | 1.88 | 1.99 | V |
| $V_{SVSH_hys}$ | $SVS_H$ hysteresis | | 40 | | 120 | mV |
| $t_{PD,SVSH,\ AM}$ | $SVS_H$ propagation delay, active mode | $dV_{Vcc}/dt$ = –10 mV/µs | | | 10 | µs |

(1) For additional information, see the Dynamic Voltage Scaling Power Solution for MSP430 Devices With Single-Channel LDO Reference Design.

### 5.12.2 Reset Timing

Table 5-11 lists the required reset input timing.

**Table 5-3. Reset Input**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| | | $V_{CC}$ | MIN | MAX | UNIT |
|---|---|---|---|---|---|
| $t_{(RST)}$ | External reset pulse duration on $\overline{RST}$(1) | 2.2 V, 3.0 V | 2 | | µs |

(1) Not applicable if $\overline{RST}$/NMI pin configured as NMI.

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### 5.12.3 Clock Specifications

Table 5-4 lists the characteristics of the LFXT.

**Table 5-4. Low-Frequency Crystal Oscillator, LFXT(1)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $I_{VCC.LFXT}$ | Current consumption | $f_{OSC}$ = 32768 Hz, LFXTBYPASS = 0, LFXTDRIVE = {0}, $T_A$ = 25°C, $C_{L,eff}$ = 3.7 pF, ESR ≈ 44 kΩ | 3.0 V | | 180 | | nA |
| | | $f_{OSC}$ = 32768 Hz, LFXTBYPASS = 0, LFXTDRIVE = {1}, $T_A$ = 25°C, $C_{L,eff}$ = 6 pF, ESR ≈ 40 kΩ | | | 185 | | |
| | | $f_{OSC}$ = 32768 Hz, LFXTBYPASS = 0, LFXTDRIVE = {2}, $T_A$ = 25°C, $C_{L,eff}$ = 9 pF, ESR ≈ 40 kΩ | | | 225 | | |
| | | $f_{OSC}$ = 32768 Hz, LFXTBYPASS = 0, LFXTDRIVE = {3}, $T_A$ = 25°C, $C_{L,eff}$ = 12.5 pF, ESR ≈ 40 kΩ | | | 330 | | |
| $f_{LFXT}$ | LFXT oscillator crystal frequency | LFXTBYPASS = 0 | | | 32768 | | Hz |
| $DC_{LFXT}$ | LFXT oscillator duty cycle | Measured at ACLK, $f_{LFXT}$ = 32768 Hz | | 30% | | 70% | |
| $f_{LFXT,SW}$ | LFXT oscillator logic-level square-wave input frequency | LFXTBYPASS = 1(2) (3) | | 10.5 | 32.768 | 50 | kHz |
| $DC_{LFXT,\ SW}$ | LFXT oscillator logic-level square-wave input duty cycle | LFXTBYPASS = 1 | | 30% | | 70% | |
| $OA_{LFXT}$ | Oscillation allowance for LF crystals(4) | LFXTBYPASS = 0, LFXTDRIVE = {1}, $f_{LFXT}$ = 32768 Hz, $C_{L,eff}$ = 6 pF | | | 210 | | kΩ |
| | | LFXTBYPASS = 0, LFXTDRIVE = {3}, $f_{LFXT}$ = 32768 Hz, $C_{L,eff}$ = 12.5 pF | | | 300 | | |
| $C_{LFXIN}$ | Integrated load capacitance at LFXIN terminal(5) (6) | | | | 2 | | pF |
| $C_{LFXOUT}$ | Integrated load capacitance at LFXOUT terminal(5) (6) | | | | 2 | | pF |

(1) To improve EMI on the LFXT oscillator, observe the following guidelines.
- Keep the trace between the device and the crystal as short as possible.
- Design a good ground plane around the oscillator pins.
- Prevent crosstalk from other clock or data lines into oscillator pins LFXIN and LFXOUT.
- Avoid running PCB traces underneath or adjacent to the LFXIN and LFXOUT pins.
- Use assembly materials and processes that avoid any parasitic load on the oscillator LFXIN and LFXOUT pins.
- If conformal coating is used, ensure that it does not induce capacitive or resistive leakage between the oscillator pins.

(2) When LFXTBYPASS is set, LFXT circuits are automatically powered down. Input signal is a digital square wave with parametrics defined in the Schmitt-trigger Inputs section of this data sheet. Duty cycle requirements are defined by $DC_{LFXT,\ SW}$.

(3) Maximum frequency of operation of the entire device cannot be exceeded.

(4) Oscillation allowance is based on a safety factor of 5 for recommended crystals. The oscillation allowance is a function of the LFXTDRIVE settings and the effective load. In general, comparable oscillator allowance can be achieved based on the following guidelines, but should be evaluated based on the actual crystal selected for the application:
- For LFXTDRIVE = {0}, $C_{L,eff}$ = 3.7 pF.
- For LFXTDRIVE = {1}, $C_{L,eff}$ = 6 pF
- For LFXTDRIVE = {2}, 6 pF ≤ $C_{L,eff}$ ≤ 9 pF
- For LFXTDRIVE = {3}, 9 pF ≤ $C_{L,eff}$ ≤ 12.5 pF

(5) This represents all the parasitic capacitance present at the LFXIN and LFXOUT terminals, respectively, including parasitic bond and package capacitance. The effective load capacitance, $C_{L,eff}$ can be computed as $C_{IN} \times C_{OUT} / (C_{IN} + C_{OUT})$, where $C_{IN}$ and $C_{OUT}$ are the total capacitance at the LFXIN and LFXOUT terminals, respectively.

(6) Requires external capacitors at both terminals to meet the effective load capacitance specified by crystal manufacturers. Recommended effective load capacitance values supported are 3.7 pF, 6 pF, 9 pF, and 12.5 pF. Maximum shunt capacitance of 1.6 pF. The PCB adds additional capacitance, so it must also be considered in the overall capacitance. Verify that the recommended effective load capacitance of the selected crystal is met.


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**Table 5-4. Low-Frequency Crystal Oscillator, LFXT(1) (continued)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $t_{START,LFXT}$ | Start-up time(7) | $f_{OSC}$ = 32768 Hz, LFXTBYPASS = 0, LFXTDRIVE = {0}, $T_A$ = 25°C, $C_{L,eff}$ = 3.7 pF | 3.0 V | | 800 | | ms |
| | | $f_{OSC}$ = 32768 Hz, LFXTBYPASS = 0, LFXTDRIVE = {3}, $T_A$ = 25°C, $C_{L,eff}$ = 12.5 pF | 3.0 V | | 1000 | | |
| $f_{Fault,LFXT}$ | Oscillator fault frequency(8) (9) | | | 0 | | 3500 | Hz |

(7) Includes start-up counter of 1024 clock cycles.
(8) Frequencies above the MAX specification do not set the fault flag. Frequencies between the MIN and MAX specification may set the flag. A static condition or stuck at fault condition sets the flag.
(9) Measured with logic-level input frequency but also applies to operation with crystals.

Table 5-5 lists the characteristics of the HFXT.

**Table 5-5. High-Frequency Crystal Oscillator, HFXT(1)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $I_{DVCC.HFXT}$ | HFXT oscillator crystal current HF mode at typical ESR | $f_{OSC}$ = 4 MHz, HFXTBYPASS = 0, HFXTDRIVE = 0, HFFREQ = 1(2) $T_A$ = 25°C, $C_{L,eff}$ = 18 pF, Typical ESR, $C_{shunt}$ | 3.0 V | | 75 | | µA |
| | | $f_{OSC}$ = 8 MHz, HFXTBYPASS = 0, HFXTDRIVE = 1, HFFREQ = 1, $T_A$ = 25°C, $C_{L,eff}$ = 18 pF, Typical ESR, $C_{shunt}$ | | | 120 | | |
| | | $f_{OSC}$ = 16 MHz, HFXTBYPASS = 0, HFXTDRIVE = 2, HFFREQ = 2, $T_A$ = 25°C, $C_{L,eff}$ = 18 pF, Typical ESR, $C_{shunt}$ | | | 190 | | |
| | | $f_{OSC}$ = 24 MHz, HFXTBYPASS = 0, HFXTDRIVE = 3, HFFREQ = 3, $T_A$ = 25°C, $C_{L,eff}$ = 18 pF, Typical ESR, $C_{shunt}$ | | | 250 | | |
| $f_{HFXT}$ | HFXT oscillator crystal frequency, crystal mode | HFXTBYPASS = 0, HFFREQ = 1(2)(3) | | 4 | | 8 | MHz |
| | | HFXTBYPASS = 0, HFFREQ = 2(3) | | 8.01 | | 16 | |
| | | HFXTBYPASS = 0, HFFREQ = 3(3) | | 16.01 | | 24 | |
| $DC_{HFXT}$ | HFXT oscillator duty cycle | Measured at SMCLK, $f_{HFXT}$ = 16 MHz | | 40% | 50% | 60% | |
| $f_{HFXT,SW}$ | HFXT oscillator logic-level square-wave input frequency, bypass mode | HFXTBYPASS = 1, HFFREQ = 0(4)(3) | | 0.9 | | 4 | MHz |
| | | HFXTBYPASS = 1, HFFREQ = 1(4)(3) | | 4.01 | | 8 | |
| | | HFXTBYPASS = 1, HFFREQ = 2(4)(3) | | 8.01 | | 16 | |
| | | HFXTBYPASS = 1, HFFREQ = 3(4)(3) | | 16.01 | | 24 | |
| $DC_{HFXT, SW}$ | HFXT oscillator logic-level square-wave input duty cycle | HFXTBYPASS = 1 | | 40% | | 60% | |

(1) To improve EMI on the HFXT oscillator, observe the following guidelines.
- Keep the traces between the device and the crystal as short as possible.
- Design a good ground plane around the oscillator pins.
- Prevent crosstalk from other clock or data lines into oscillator pins HFXIN and HFXOUT.
- Avoid running PCB traces underneath or adjacent to the HFXIN and HFXOUT pins.
- Use assembly materials and processes that avoid any parasitic load on the oscillator HFXIN and HFXOUT pins.
- If conformal coating is used, ensure that it does not induce capacitive or resistive leakage between the oscillator pins.

(2) HFFREQ = {0} is not supported for HFXT crystal mode of operation.
(3) Maximum frequency of operation of the entire device cannot be exceeded.
(4) When HFXTBYPASS is set, HFXT circuits are automatically powered down. Input signal is a digital square wave with parametrics defined in the Schmitt-trigger Inputs section of this data sheet. Duty cycle requirements are defined by $DC_{HFXT, SW}$.

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**Table 5-5. High-Frequency Crystal Oscillator, HFXT(1) (continued)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $t_{START,HFXT}$ | Start-up time(5) | $f_{OSC}$ = 4 MHz, HFXTBYPASS = 0, HFXTDRIVE = 0, HFFREQ = 1, $T_A$ = 25°C, $C_{L,eff}$ = 16 pF | 3.0 V | | 1.6 | | ms |
| | | $f_{OSC}$ = 24 MHz , HFXTBYPASS = 0, HFXTDRIVE = 3, HFFREQ = 3, $T_A$ = 25°C, $C_{L,eff}$ = 16 pF | 3.0 V | | 0.6 | | |
| $C_{HFXIN}$ | Integrated load capacitance at HFXIN terminal(6) (7) | | | | 2 | | pF |
| $C_{HFXOUT}$ | Integrated load capacitance at HFXOUT terminal(6) (7) | | | | 2 | | pF |
| $f_{Fault,HFXT}$ | Oscillator fault frequency(8) (9) | | | 0 | | 800 | kHz |

(5) Includes start-up counter of 1024 clock cycles.
(6) This represents all the parasitic capacitance present at the HFXIN and HFXOUT terminals, respectively, including parasitic bond and package capacitance. The effective load capacitance, $C_{L,eff}$ can be computed as $C_{IN} \times C_{OUT} / (C_{IN} + C_{OUT})$, where $C_{IN}$ and $C_{OUT}$ are the total capacitance at the HFXIN and HFXOUT terminals, respectively.
(7) Requires external capacitors at both terminals to meet the effective load capacitance specified by crystal manufacturers. Recommended effective load capacitance values supported are 14 pF, 16 pF, and 18 pF. Maximum shunt capacitance of 7 pF. The PCB adds additional capacitance, so it must also be considered in the overall capacitance. Verify that the recommended effective load capacitance of the selected crystal is met.
(8) Frequencies above the MAX specification do not set the fault flag. Frequencies between the MIN and MAX might set the flag. A static condition or stuck at fault condition set the flag.
(9) Measured with logic-level input frequency but also applies to operation with crystals.


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Table 5-6 lists the characteristics of the DCO.

**Table 5-6. DCO**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $f_{DCO1}$ | DCO frequency range 1 MHz, trimmed | Measured at SMCLK, divide by 1, DCORSEL = 0, DCOFSEL = 0, DCORSEL = 1, DCOFSEL = 0 | | | 1 | ±3.5% | MHz |
| $f_{DCO2.7}$ | DCO frequency range 2.7 MHz, trimmed | Measured at SMCLK, divide by 1, DCORSEL = 0, DCOFSEL = 1 | | | 2.667 | ±3.5% | MHz |
| $f_{DCO3.5}$ | DCO frequency range 3.5 MHz, trimmed | Measured at SMCLK, divide by 1, DCORSEL = 0, DCOFSEL = 2 | | | 3.5 | ±3.5% | MHz |
| $f_{DCO4}$ | DCO frequency range 4 MHz, trimmed | Measured at SMCLK, divide by 1, DCORSEL = 0, DCOFSEL = 3 | | | 4 | ±3.5% | MHz |
| $f_{DCO5.3}$ | DCO frequency range 5.3 MHz, trimmed | Measured at SMCLK, divide by 1, DCORSEL = 0, DCOFSEL = 4, DCORSEL = 1, DCOFSEL = 1 | | | 5.333 | ±3.5% | MHz |
| $f_{DCO7}$ | DCO frequency range 7 MHz, trimmed | Measured at SMCLK, divide by 1, DCORSEL = 0, DCOFSEL = 5, DCORSEL = 1, DCOFSEL = 2 | | | 7 | ±3.5% | MHz |
| $f_{DCO8}$ | DCO frequency range 8 MHz, trimmed | Measured at SMCLK, divide by 1, DCORSEL = 0, DCOFSEL = 6, DCORSEL = 1, DCOFSEL = 3 | | | 8 | ±3.5% | MHz |
| $f_{DCO16}$ | DCO frequency range 16 MHz, trimmed | Measured at SMCLK, divide by 1, DCORSEL = 1, DCOFSEL = 4 | | | 16 | ±3.5%(1) | MHz |
| $f_{DCO21}$ | DCO frequency range 21 MHz, trimmed | Measured at SMCLK, divide by 2, DCORSEL = 1, DCOFSEL = 5 | | | 21 | ±3.5%(1) | MHz |
| $f_{DCO24}$ | DCO frequency range 24 MHz, trimmed | Measured at SMCLK, divide by 2, DCORSEL = 1, DCOFSEL = 6 | | | 24 | ±3.5%(1) | MHz |
| $f_{DCO,DC}$ | Duty cycle | Measured at SMCLK, divide by 1, no external divide, all DCORSEL/DCOFSEL settings except DCORSEL = 1, DCOFSEL = 5 and DCORSEL = 1, DCOFSEL = 6 | | 48% | 50% | 52% | |
| $t_{DCO,\ JITTER}$ | DCO jitter | Based on $f_{signal}$ = 10 kHz and DCO used for 12-bit SAR ADC sampling source. This achieves >74 dB SNR due to jitter (that is, it is limited by ADC performance). | | | 2 | 3 | ns |
| $df_{DCO}/dT$ | DCO temperature drift(2) | | 3.0 V | | 0.01 | | %/ºC |

(1) After a wakeup from LPM1, LPM2, LPM3, or LPM4, the DCO frequency $f_{DCO}$ might exceed the specified frequency range for a few clock cycles by up to 5% before settling into the specified steady-state frequency range.
(2) Calculated using the box method: (MAX(–40ºC to 85ºC) – MIN(–40ºC to 85ºC)) / MIN(–40ºC to 85ºC) / (85ºC – (–40ºC))

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Table 5-7 lists the characteristics of the VLO.

**Table 5-7. Internal Very-Low-Power Low-Frequency Oscillator (VLO)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $I_{VLO}$ | Current consumption | | | 100 | | nA |
| $f_{VLO}$ | VLO frequency | Measured at ACLK | 6 | 9.4 | 14 | kHz |
| $df_{VLO}/d_T$ | VLO frequency temperature drift | Measured at ACLK(1) | | 0.2 | | %/°C |
| $df_{VLO}/dV_{CC}$ | VLO frequency supply voltage drift | Measured at ACLK(2) | | 0.7 | | %/V |
| $f_{VLO,DC}$ | Duty cycle | Measured at ACLK | 40% | 50% | 60% | |

(1) Calculated using the box method: (MAX(–40ºC to 85°C) – MIN(–40ºC to 85°C)) / MIN(–40ºC to 85°C) / (85°C – (–40°C))
(2) Calculated using the box method: (MAX(1.8 V to 3.6 V) – MIN(1.8 V to 3.6 V)) / MIN(1.8 V to 3.6 V) / (3.6 V – 1.8 V)

Table 5-8 lists the characteristics of the MODOSC.

**Table 5-8. Module Oscillator (MODOSC)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $I_{MODOSC}$ | Current consumption | Enabled | | 25 | | µA |
| $f_{MODOSC}$ | MODOSC frequency | | 4.0 | 4.8 | 5.4 | MHz |
| $f_{MODOSC}/dT$ | MODOSC frequency temperature drift(1) | | | 0.08 | | %/°C |
| $f_{MODOSC}/dV_{CC}$ | MODOSC frequency supply voltage drift(2) | | | 1.4 | | %/V |
| $DC_{MODOSC}$ | Duty cycle | Measured at SMCLK, divide by 1 | 40% | 50% | 60% | |

(1) Calculated using the box method: (MAX(–40ºC to 85°C) – MIN(–40ºC to 85°C)) / MIN(–40ºC to 85°C) / (85°C – (–40°C))
(2) Calculated using the box method: (MAX(1.8 V to 3.6 V) – MIN(1.8 V to 3.6 V)) / MIN(1.8 V to 3.6 V) / (3.6 V – 1.8 V)


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### 5.12.4 Wake-up Characteristics

Table 5-9 list the device wake-up times.

**Table 5-9. Wake-up Times From Low-Power Modes and Reset**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $t_{WAKE-UP\ FRAM}$ | (Additional) wake-up time to activate the FRAM in AM if previously disabled by the FRAM controller or from an LPM if immediate activation is selected for wakeup | | | | 6 | 10 | µs |
| $t_{WAKE-UP\ LPM0}$ | Wake-up time from LPM0 to active mode(1) | | 2.2 V, 3.0 V | | | 400 + 1.5 / $f_{DCO}$ | ns |
| $t_{WAKE-UP\ LPM1}$ | Wake-up time from LPM1 to active mode(1) | | 2.2 V, 3.0 V | | 6 | | µs |
| $t_{WAKE-UP\ LPM2}$ | Wake-up time from LPM2 to active mode(1) | | 2.2 V, 3.0 V | | 6 | | µs |
| $t_{WAKE-UP\ LPM3}$ | Wake-up time from LPM3 to active mode(1) | | 2.2 V, 3.0 V | | 7 | 10 | µs |
| $t_{WAKE-UP\ LPM4}$ | Wake-up time from LPM4 to active mode(1) | | 2.2 V, 3.0 V | | 7 | 10 | µs |
| $t_{WAKE-UP\ LPM3.5}$ | Wake-up time from LPM3.5 to active mode(2) | | 2.2 V, 3.0 V | | 250 | 350 | µs |
| $t_{WAKE-UP\ LPM4.5}$ | Wake-up time from LPM4.5 to active mode(2) | SVSHE = 1 | 2.2 V, 3.0 V | | 250 | 350 | µs |
| | | SVSHE = 0 | 2.2 V, 3.0 V | | 1 | 1.5 | ms |
| $t_{WAKE-UP-RST}$ | Wake-up time from a $\overline{RST}$ pin triggered reset to active mode(2) | | 2.2 V, 3.0 V | | 250 | 350 | µs |
| $t_{WAKE-UP-BOR}$ | Wake-up time from power-up to active mode (2) | | 2.2 V, 3.0 V | | 1 | 1.5 | ms |

(1) The wake-up time is measured from the edge of an external wake-up signal (for example, port interrupt or wake-up event) to the first externally observable MCLK clock edge. MCLK is sourced by the DCO and the MCLK divider is set to divide-by-1 (DIVMx = 000b, $f_{MCLK} = f_{DCO}$). This time includes the activation of the FRAM during wakeup.
(2) The wake-up time is measured from the edge of an external wake-up signal (for example, port interrupt or wake-up event) until the first instruction of the user program is executed.

Table 5-10 list the typical wake-up charges.

**Table 5-10. Typical Wake-up Charge(1)**

also see Figure 5-7 and Figure 5-8

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $Q_{WAKE-UP\ FRAM}$ | Charge used for activating the FRAM in AM or during wakeup from LPM0 if previously disabled by the FRAM controller. | | | 15.1 | | nAs |
| $Q_{WAKE-UP\ LPM0}$ | Charge used for wakeup from LPM0 to active mode (with FRAM active) | | | 4.4 | | nAs |
| $Q_{WAKE-UP\ LPM1}$ | Charge used for wakeup from LPM1 to active mode (with FRAM active) | | | 15.1 | | nAs |
| $Q_{WAKE-UP\ LPM2}$ | Charge used for wakeup from LPM2 to active mode (with FRAM active) | | | 15.3 | | nAs |
| $Q_{WAKE-UP\ LPM3}$ | Charge used for wakeup from LPM3 to active mode (with FRAM active) | | | 16.5 | | nAs |
| $Q_{WAKE-UP\ LPM4}$ | Charge used for wakeup from LPM4 to active mode (with FRAM active) | | | 16.5 | | nAs |
| $Q_{WAKE-UP\ LPM3.5}$ | Charge used for wakeup from LPM3.5 to active mode(2) | | | 76 | | nAs |
| $Q_{WAKE-UP\ LPM4.5}$ | Charge used for wakeup from LPM4.5 to active mode(2) | SVSHE = 1 | | 77 | | nAs |
| | | SVSHE = 0 | | 77.5 | | nAs |
| $Q_{WAKE-UP-RESET}$ | Charge used for reset from $\overline{RST}$ or BOR event to active mode(2) | | | 75 | | nAs |

(1) Charge used during the wake-up time from a given low-power mode to active mode. This does not include the energy required in active mode (for example, for an interrupt service routine).
(2) Charge required until start of user code. This does not include the energy required to reconfigure the device.

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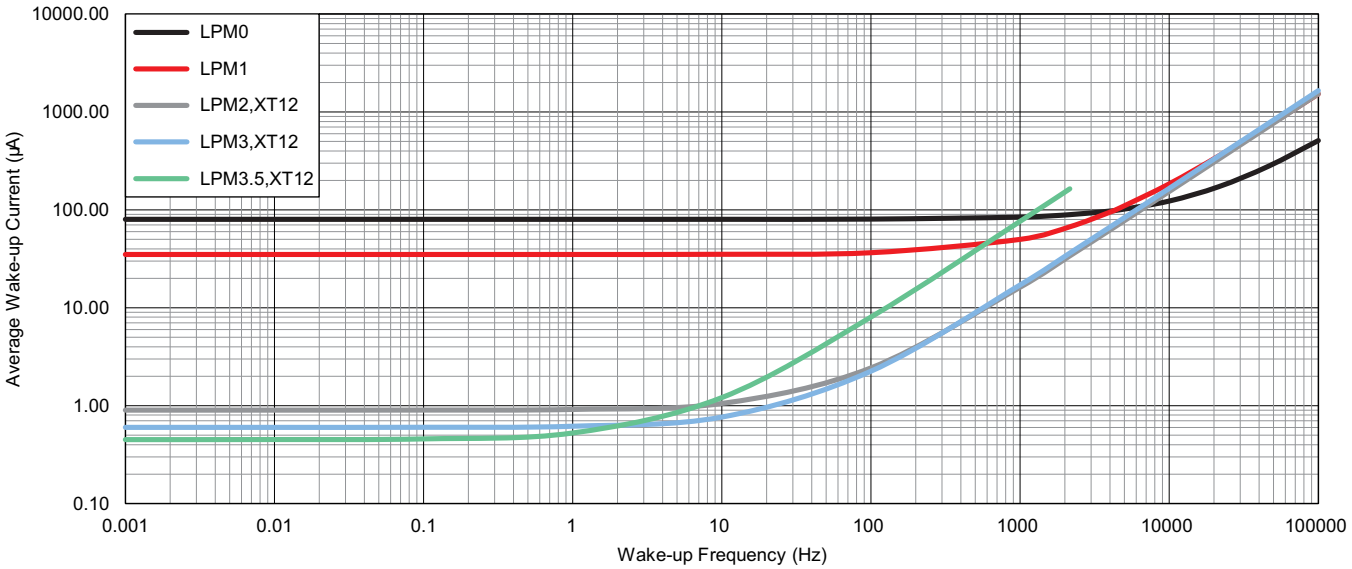
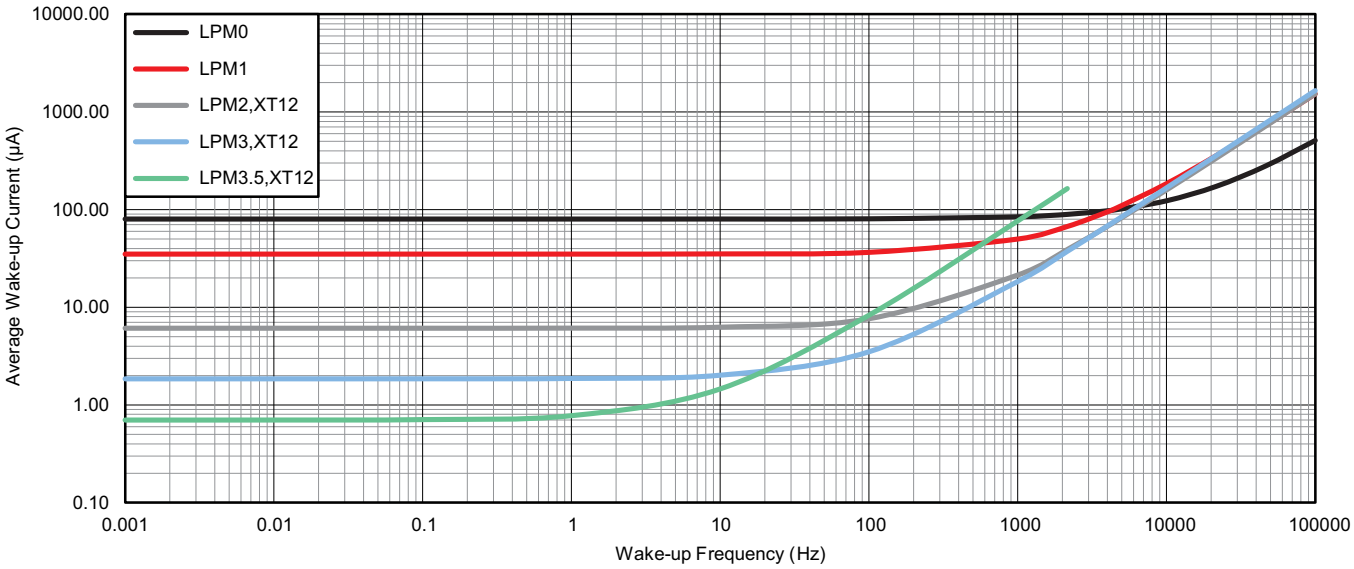
### 5.12.4.1 Typical Characteristics, Average LPM Currents vs Wake-up Frequency




NOTE: The average wakeup current does not include the energy required in active mode; for example, for an interrupt service routine or to reconfigure the device.

**Figure 5-7. Average LPM Currents vs Wake-up Frequency at 25°C**




NOTE: The average wakeup current does not include the energy required in active mode; for example, for an interrupt service routine or to reconfigure the device.

**Figure 5-8. Average LPM Currents vs Wake-up Frequency at 85°C**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### 5.12.5 Digital I/Os

Table 5-11 lists the characteristics of the digital inputs.

**Table 5-11. Digital Inputs**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $V_{IT+}$ | Positive-going input threshold voltage | | 2.2 V | 1.2 | | 1.65 | V |
| | | | 3.0 V | 1.65 | | 2.25 | |
| $V_{IT-}$ | Negative-going input threshold voltage | | 2.2 V | 0.55 | | 1.00 | V |
| | | | 3.0 V | 0.75 | | 1.35 | |
| $V_{hys}$ | Input voltage hysteresis ($V_{IT+} - V_{IT-}$) | | 2.2 V | 0.44 | | 0.98 | V |
| | | | 3.0 V | 0.60 | | 1.30 | |
| $R_{Pull}$ | Pullup or pulldown resistor | For pullup: $V_{IN} = V_{SS}$<br>For pulldown: $V_{IN} = V_{CC}$ | | 20 | 35 | 50 | kΩ |
| $C_{I,dig}$ | Input capacitance, digital only port pins | $V_{IN} = V_{SS}$ or $V_{CC}$ | | | 3 | | pF |
| $C_{I,ana}$ | Input capacitance, port pins with shared analog functions(1) | $V_{IN} = V_{SS}$ or $V_{CC}$ | | | 5 | | pF |
| $I_{lkg(Px.y)}$ | High-impedance input leakage current | See (2)(3) | 2.2 V, 3.0 V | –20 | | +20 | nA |
| $t_{(int)}$ | External interrupt timing (external trigger pulse duration to set interrupt flag)(4) | Ports with interrupt capability (see Section 1.4 and Section 4.2) | 2.2 V, 3.0 V | 20 | | | ns |
| $t_{(RST)}$ | External reset pulse duration on $\overline{RST}$(5) | | 2.2 V, 3.0 V | 2 | | | µs |

(1) If the port pins PJ.4/LFXIN and PJ.5/LFXOUT are used as digital I/Os, they are connected by a 4-pF capacitor and a 35-MΩ resistor in series. At frequencies of approximately 1 kHz and lower, the 4-pF capacitor can add to the pin capacitance of PJ.4/LFXIN and/or PJ.5/LFXOUT.
(2) The input leakage current is measured with $V_{SS}$ or $V_{CC}$ applied to the corresponding pins, unless otherwise noted.
(3) The input leakage of the digital port pins is measured individually. The port pin is selected for input, and the pullup or pulldown resistor is disabled.
(4) An external signal sets the interrupt flag every time the minimum interrupt pulse duration $t_{(int)}$ is met. It may be set by trigger signals shorter than $t_{(int)}$.
(5) Not applicable if $\overline{RST}$/NMI pin configured as NMI.

Table 5-12 lists the characteristics of the digital outputs.

**Table 5-12. Digital Outputs**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (also see Figure 5-9, Figure 5-10, Figure 5-11, and Figure 5-12)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $V_{OH}$ | High-level output voltage | $I_{(OHmax)}$ = –1 mA(1) | 2.2 V | $V_{CC}$ – 0.25 | | $V_{CC}$ | V |
| | | $I_{(OHmax)}$ = –3 mA(2) | | $V_{CC}$ – 0.60 | | $V_{CC}$ | |
| | | $I_{(OHmax)}$ = –2 mA(1) | 3.0 V | $V_{CC}$ – 0.25 | | $V_{CC}$ | |
| | | $I_{(OHmax)}$ = –6 mA(2) | | $V_{CC}$ – 0.60 | | $V_{CC}$ | |
| $V_{OL}$ | Low-level output voltage | $I_{(OLmax)}$ = 1 mA(1) | 2.2 V | $V_{SS}$ | | $V_{SS}$ + 0.25 | V |
| | | $I_{(OLmax)}$ = 3 mA(2) | | $V_{SS}$ | | $V_{SS}$ + 0.60 | |
| | | $I_{(OLmax)}$ = 2 mA(1) | 3.0 V | $V_{SS}$ | | $V_{SS}$ + 0.25 | |
| | | $I_{(OLmax)}$ = 6 mA(2) | | $V_{SS}$ | | $V_{SS}$ + 0.60 | |
| $f_{Px.y}$ | Port output frequency (with load)(3) | $C_L$ = 20 pF, $R_L$ (4) (5) | 2.2 V | 16 | | | MHz |
| | | | 3.0 V | 16 | | | |
| $f_{Port_CLK}$ | Clock output frequency(3) | ACLK, MCLK, or SMCLK at configured output port, $C_L$ = 20 pF(5) | 2.2 V | 16 | | | MHz |
| | | | 3.0 V | 16 | | | |
| $t_{rise,dig}$ | Port output rise time, digital only port pins | $C_L$ = 20 pF | 2.2 V | | 4 | 15 | ns |
| | | | 3.0 V | | 3 | 15 | |
| $t_{fall,dig}$ | Port output fall time, digital only port pins | $C_L$ = 20 pF | 2.2 V | | 4 | 15 | ns |
| | | | 3.0 V | | 3 | 15 | |
| $t_{rise,ana}$ | Port output rise time, port pins with shared analog functions | $C_L$ = 20 pF | 2.2 V | | 6 | 15 | ns |
| | | | 3.0 V | | 4 | 15 | |
| $t_{fall,ana}$ | Port output fall time, port pins with shared analog functions | $C_L$ = 20 pF | 2.2 V | | 6 | 15 | ns |
| | | | 3.0 V | | 4 | 15 | |

(1) The maximum total current, $I_{(OHmax)}$ and $I_{(OLmax)}$, for all outputs combined should not exceed ±48 mA to hold the maximum voltage drop specified.
(2) The maximum total current, $I_{(OHmax)}$ and $I_{(OLmax)}$, for all outputs combined should not exceed ±100 mA to hold the maximum voltage drop specified.
(3) The port can output frequencies at least up to the specified limit, and the port might support higher frequencies.
(4) A resistive divider with 2 × R1 and R1 = 1.6 kΩ between $V_{CC}$ and $V_{SS}$ is used as load. The output is connected to the center tap of the divider. $C_L$ = 20 pF is connected from the output to $V_{SS}$.
(5) The output voltage reaches at least 10% and 90% $V_{CC}$ at the specified toggle frequency.


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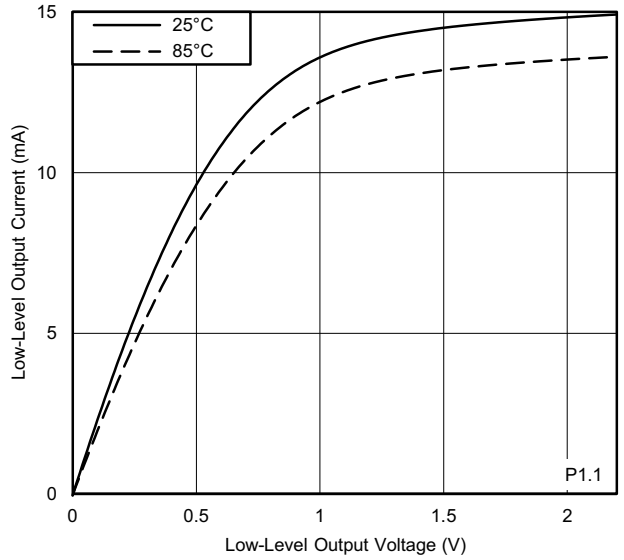
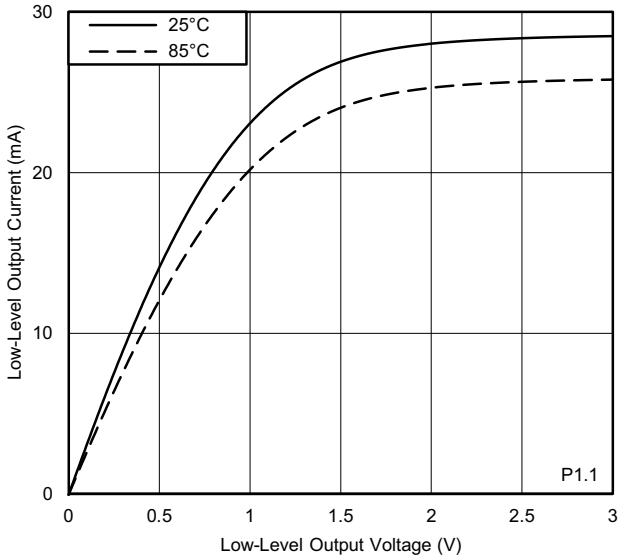
### 5.12.5.1 Typical Characteristics, Digital Outputs at 3.0 V and 2.2 V



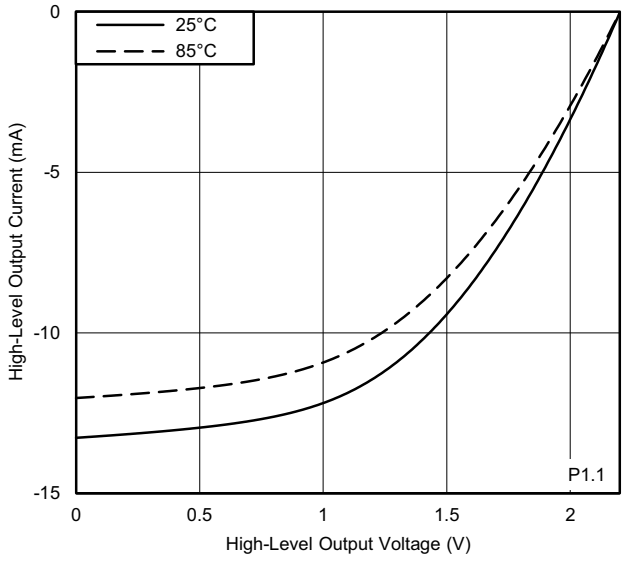

$V_{CC}$ = 2.2 V

**Figure 5-9. Typical Low-Level Output Current vs Low-Level Output Voltage**



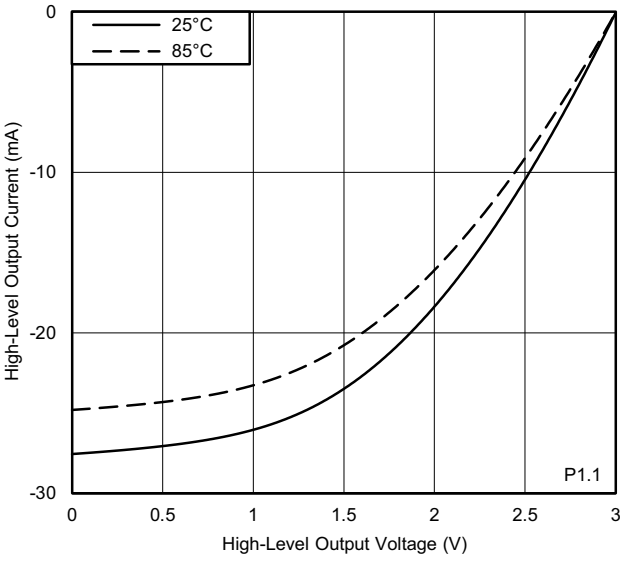

$V_{CC}$ = 3.0 V

**Figure 5-10. Typical Low-Level Output Current vs Low-Level Output Voltage**




$V_{CC}$ = 2.2 V

**Figure 5-11. Typical High-Level Output Current vs High-Level Output Voltage**




$V_{CC}$ = 3.0 V

**Figure 5-12. Typical High-Level Output Current vs High-Level Output Voltage**

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Table 5-13 lists the frequencies of the pin oscillator.

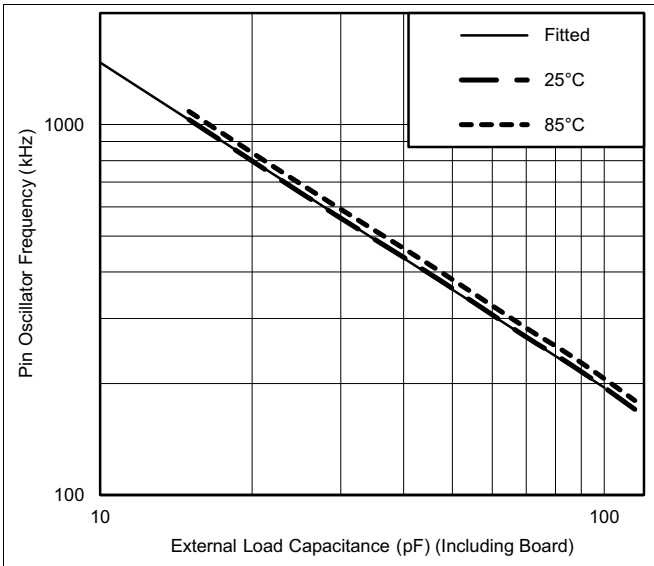
**Table 5-13. Pin-Oscillator Frequency, Ports Px**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Figure 5-13 and Figure 5-14)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $fo_{Px.y}$ | Pin-oscillator frequency | Px.y, $C_L$ = 10 pF(1) | 3.0 V | | 1640 | | kHz |
| | | Px.y, $C_L$ = 20 pF(1) | | | 870 | | |

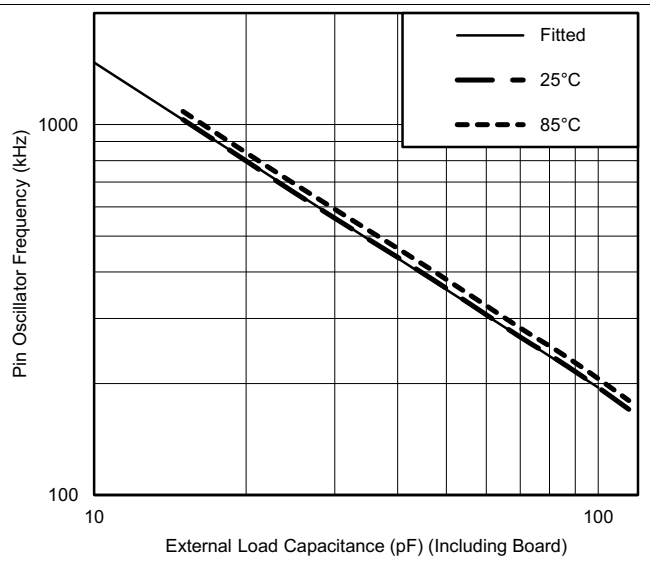
(1) $C_L$ is the external load capacitance connected from the output to $V_{SS}$ and includes all parasitic effects such as PCB traces.

### 5.12.5.2 Typical Characteristics, Pin-Oscillator Frequency




$V_{CC}$ = 2.2 V One output active at a time.

**Figure 5-13. Typical Oscillation Frequency vs Load Capacitance**




$V_{CC}$ = 3.0 V One output active at a time.

**Figure 5-14. Typical Oscillation Frequency vs Load Capacitance**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### 5.12.6 Timer_A and Timer_B

Table 5-14 lists the characteristics of the Timer_A.

**Table 5-14. Timer_A**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $f_{TA}$ | Timer_A input clock frequency | Internal: SMCLK or ACLK,<br>External: TACLK,<br>Duty cycle = 50% ±10% | 2.2 V,<br>3.0 V | | | 16 | MHz |
| $t_{TA,cap}$ | Timer_A capture timing | All capture inputs, minimum pulse duration required for capture | 2.2 V,<br>3.0 V | 20 | | | ns |

Table 5-15 lists the characteristics of the Timer_B.

**Table 5-15. Timer_B**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $f_{TB}$ | Timer_B input clock frequency | Internal: SMCLK or ACLK,<br>External: TBCLK,<br>Duty cycle = 50% ±10% | 2.2 V,<br>3.0 V | | | 16 | MHz |
| $t_{TB,cap}$ | Timer_B capture timing | All capture inputs, minimum pulse duration required for capture | 2.2 V,<br>3.0 V | 20 | | | ns |

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### 5.12.7 eUSCI

Table 5-16 lists the supported clock frequencies of the eUSCI in UART mode.

**Table 5-16. eUSCI (UART Mode) Clock Frequency**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | MAX | UNIT |
|---|---|---|---|---|---|
| $f_{eUSCI}$ | eUSCI input clock frequency | Internal: SMCLK or ACLK,<br>External: UCLK,<br>Duty cycle = 50% ±10% | | 16 | MHz |
| $f_{BITCLK}$ | BITCLK clock frequency<br>(equals baud rate in MBaud) | | | 4 | MHz |

Table 5-17 lists the deglitch times of the eUSCI in UART mode.

**Table 5-17. eUSCI (UART Mode)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $t_t$ | UART receive deglitch time(1) | UCGLITx = 0 | 2.2 V, 3.0 V | 5 | | 30 | ns |
| | | UCGLITx = 1 | | 20 | | 90 | |
| | | UCGLITx = 2 | | 35 | | 160 | |
| | | UCGLITx = 3 | | 50 | | 220 | |

(1) Pulses on the UART receive input (UCxRX) shorter than the UART receive deglitch time are suppressed. Thus the selected deglitch time can limit the maximum usable baud rate. To ensure that pulses are correctly recognized, their duration should exceed the maximum specification of the deglitch time.

Table 5-18 lists the supported clock frequencies of the eUSCI in SPI master mode.

**Table 5-18. eUSCI (SPI Master Mode) Clock Frequency**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | MAX | UNIT |
|---|---|---|---|---|---|
| $f_{eUSCI}$ | eUSCI input clock frequency | Internal: SMCLK or ACLK,<br>Duty cycle = 50% ±10% | | 16 | MHz |


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Table 5-19 lists the characteristics of the eUSCI in SPI master mode.

**Table 5-19. eUSCI (SPI Master Mode)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see note (1))

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | MAX | UNIT |
|---|---|---|---|---|---|---|
| $t_{STE,LEAD}$ | STE lead time, STE active to clock | UCSTEM = 1, UCMODEx = 01 or 10 | | 1 | | UCxCLK cycles |
| $t_{STE,LAG}$ | STE lag time, last clock to STE inactive | UCSTEM = 1, UCMODEx = 01 or 10 | | 1 | | UCxCLK cycles |
| $t_{STE,ACC}$ | STE access time, STE active to SIMO data out | UCSTEM = 0, UCMODEx = 01 or 10 | 2.2 V, 3.0 V | | 60 | ns |
| $t_{STE,DIS}$ | STE disable time, STE inactive to SOMI high impedance | UCSTEM = 0, UCMODEx = 01 or 10 | 2.2 V, 3.0 V | | 60 | ns |
| $t_{SU,MI}$ | SOMI input data setup time | | 2.2 V | 35 | | ns |
| | | | 3.0 V | 35 | | ns |
| $t_{HD,MI}$ | SOMI input data hold time | | 2.2 V | 0 | | ns |
| | | | 3.0 V | 0 | | ns |
| $t_{VALID,MO}$ | SIMO output data valid time(2) | UCLK edge to SIMO valid, $C_L$ = 20 pF | 2.2 V | | 10 | ns |
| | | | 3.0 V | | 10 | ns |
| $t_{HD,MO}$ | SIMO output data hold time(3) | $C_L$ = 20 pF | 2.2 V | 0 | | ns |
| | | | 3.0 V | 0 | | ns |

(1) $f_{UCxCLK} = 1 / 2t_{LO/HI}$ with $t_{LO/HI} = \max(t_{VALID,MO(eUSCI)} + t_{SU,SI(Slave)}, t_{SU,MI(eUSCI)} + t_{VALID,SO(Slave)})$
For the slave parameters $t_{SU,SI(Slave)}$ and $t_{VALID,SO(Slave)}$, see the SPI parameters of the attached slave.

(2) Specifies the time to drive the next valid data to the SIMO output after the output changing UCLK clock edge. See the timing diagrams in Figure 5-15 and Figure 5-16.

(3) Specifies how long data on the SIMO output is valid after the output changing UCLK clock edge. Negative values indicate that the data on the SIMO output can become invalid before the output changing clock edge observed on UCLK. See the timing diagrams in Figure 5-15 and Figure 5-16.

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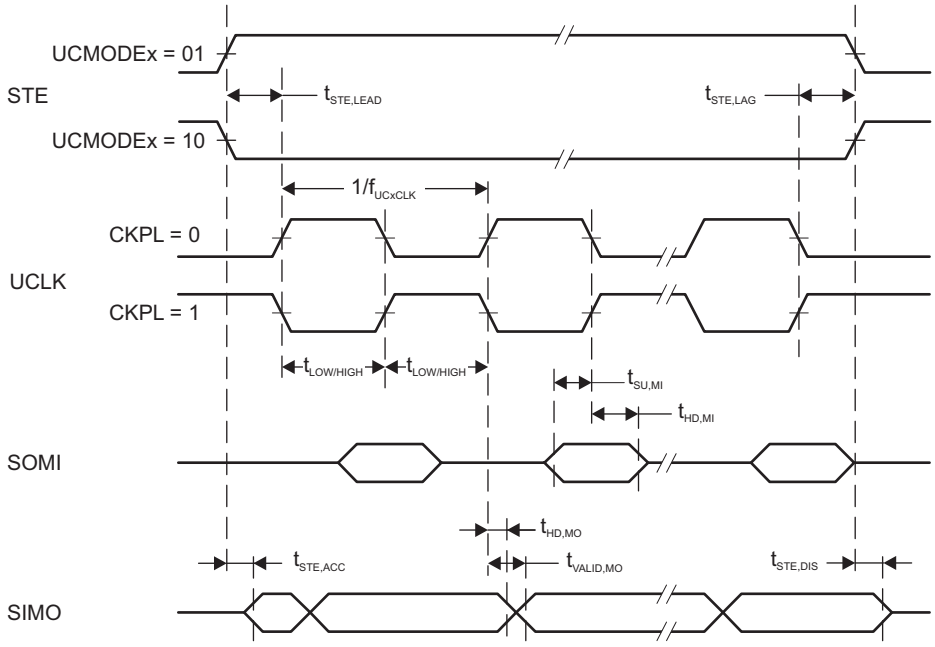


**Figure 5-15. SPI Master Mode, CKPH = 0**

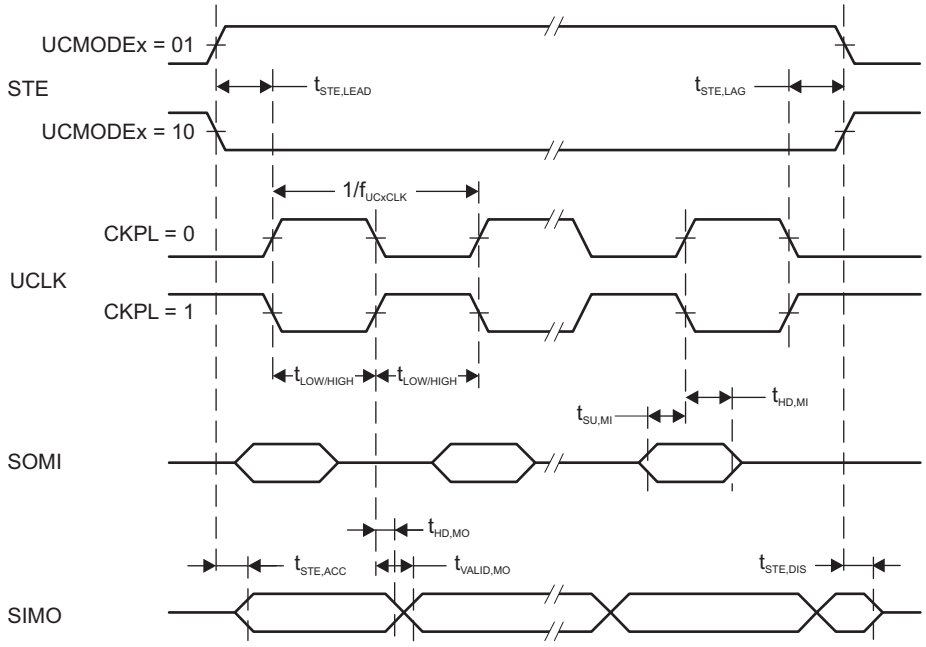


**Figure 5-16. SPI Master Mode, CKPH = 1**


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Table 5-20 lists the characteristics of the eUSCI in SPI slave mode.

**Table 5-20. eUSCI (SPI Slave Mode)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Note (1))

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | MAX | UNIT |
|---|---|---|---|---|---|---|
| $t_{STE,LEAD}$ | STE lead time, STE active to clock | | 2.2 V | 45 | | ns |
| | | | 3.0 V | 40 | | |
| $t_{STE,LAG}$ | STE lag time, last clock to STE inactive | | 2.2 V | 0 | | ns |
| | | | 3.0 V | 0 | | |
| $t_{STE,ACC}$ | STE access time, STE active to SOMI data out | | 2.2 V | | 45 | ns |
| | | | 3.0 V | | 40 | |
| $t_{STE,DIS}$ | STE disable time, STE inactive to SOMI high impedance | | 2.2 V | | 40 | ns |
| | | | 3.0 V | | 35 | |
| $t_{SU,SI}$ | SIMO input data setup time | | 2.2 V | 4 | | ns |
| | | | 3.0 V | 4 | | |
| $t_{HD,SI}$ | SIMO input data hold time | | 2.2 V | 7 | | ns |
| | | | 3.0 V | 7 | | |
| $t_{VALID,SO}$ | SOMI output data valid time(2) | UCLK edge to SOMI valid, $C_L$ = 20 pF | 2.2 V | | 35 | ns |
| | | | 3.0 V | | 35 | |
| $t_{HD,SO}$ | SOMI output data hold time(3) | $C_L$ = 20 pF | 2.2 V | 0 | | ns |
| | | | 3.0 V | 0 | | |

(1) $f_{UCxCLK} = 1/2t_{LO/HI}$ with $t_{LO/HI} \geq \max(t_{VALID,MO(Master)} + t_{SU,SI(eUSCI)}, t_{SU,MI(Master)} + t_{VALID,SO(eUSCI)})$
For the master parameters $t_{SU,MI(Master)}$ and $t_{VALID,MO(Master)}$, see the SPI parameters of the attached master.
(2) Specifies the time to drive the next valid data to the SOMI output after the output changing UCLK clock edge. See the timing diagrams in Figure 5-17 and Figure 5-18.
(3) Specifies how long data on the SOMI output is valid after the output changing UCLK clock edge. See the timing diagrams in Figure 5-17 and Figure 5-18.

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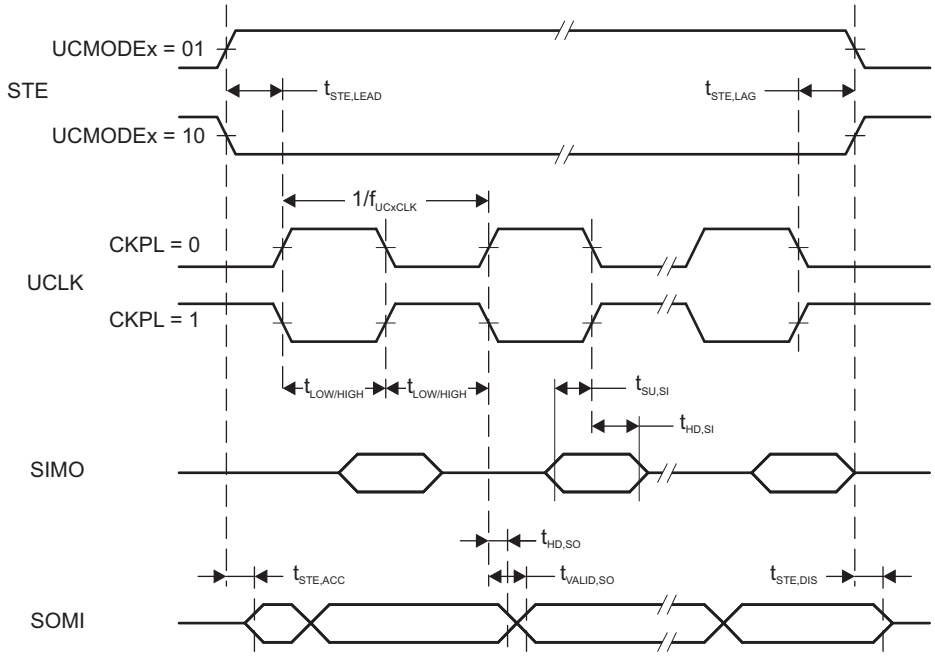


**Figure 5-17. SPI Slave Mode, CKPH = 0**

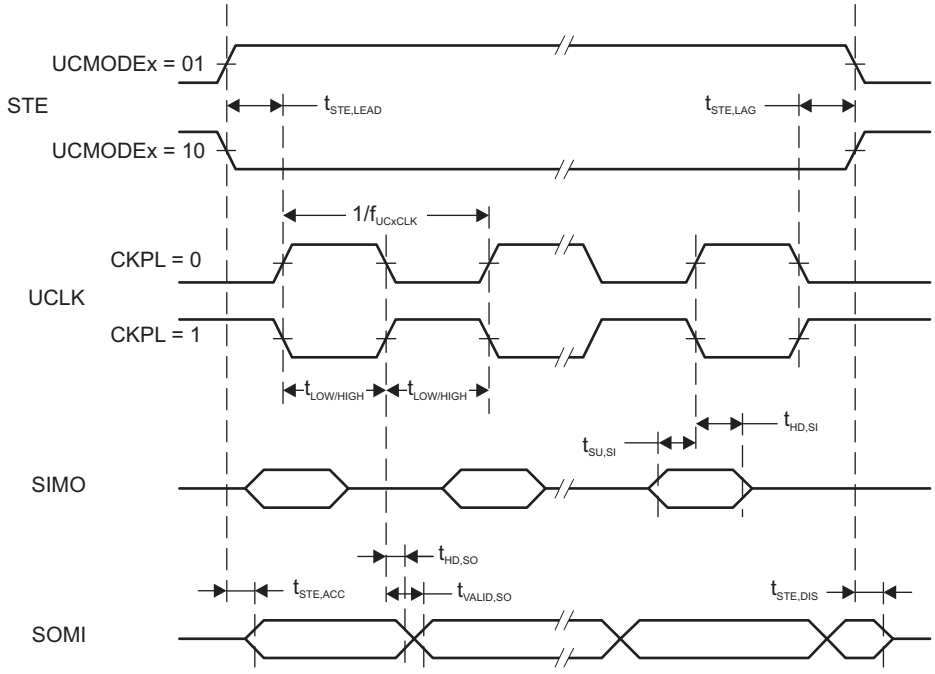


**Figure 5-18. SPI Slave Mode, CKPH = 1**


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Table 5-21 lists the characteristics of the eUSCI in I²C mode.

**Table 5-21. eUSCI (I²C Mode)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Figure 5-19)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $f_{eUSCI}$ | eUSCI input clock frequency | Internal: SMCLK or ACLK, External: UCLK, Duty cycle = 50% ±10% | | | | 16 | MHz |
| $f_{SCL}$ | SCL clock frequency | | 2.2 V, 3.0 V | 0 | | 400 | kHz |
| $t_{HD,STA}$ | Hold time (repeated) START | $f_{SCL}$ = 100 kHz | 2.2 V, 3.0 V | 4.0 | | | µs |
| | | $f_{SCL}$ > 100 kHz | | 0.6 | | | |
| $t_{SU,STA}$ | Setup time for a repeated START | $f_{SCL}$ = 100 kHz | 2.2 V, 3.0 V | 4.7 | | | µs |
| | | $f_{SCL}$ > 100 kHz | | 0.6 | | | |
| $t_{HD,DAT}$ | Data hold time | | 2.2 V, 3.0 V | 0 | | | ns |
| $t_{SU,DAT}$ | Data setup time | | 2.2 V, 3.0 V | 100 | | | ns |
| $t_{SU,STO}$ | Setup time for STOP | $f_{SCL}$ = 100 kHz | 2.2 V, 3.0 V | 4.0 | | | µs |
| | | $f_{SCL}$ > 100 kHz | | 0.6 | | | |
| $t_{BUF}$ | Bus free time between a STOP and START condition | $f_{SCL}$ = 100 kHz | | 4.7 | | | µs |
| | | $f_{SCL}$ > 100 kHz | | 1.3 | | | |
| $t_{SP}$ | Pulse duration of spikes suppressed by input filter | UCGLITx = 0 | 2.2 V, 3.0 V | 50 | | 250 | ns |
| | | UCGLITx = 1 | | 25 | | 125 | |
| | | UCGLITx = 2 | | 12.5 | | 62.5 | |
| | | UCGLITx = 3 | | 6.3 | | 31.5 | |
| $t_{TIMEOUT}$ | Clock low time-out | UCCLTOx = 1 | 2.2 V, 3.0 V | | 27 | | ms |
| | | UCCLTOx = 2 | | | 30 | | |
| | | UCCLTOx = 3 | | | 33 | | |

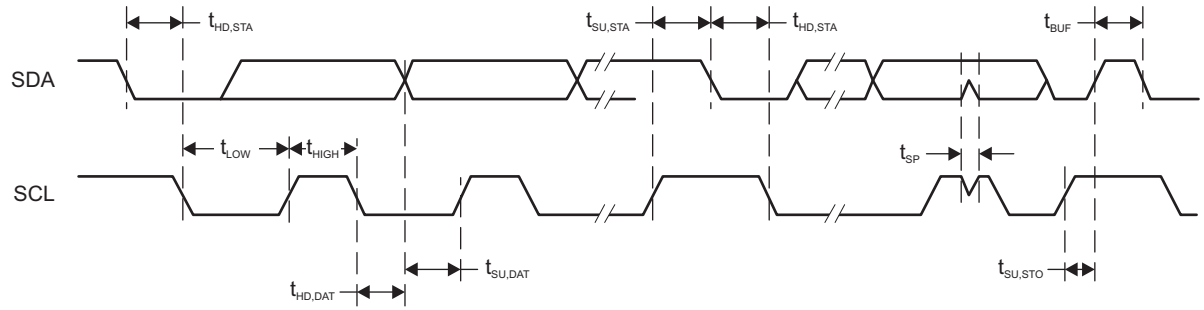


**Figure 5-19. I²C Mode Timing**

### 5.12.8 ADC

Table 5-22 lists the input requirements of the ADC.

**Table 5-22. 12-Bit ADC, Power Supply and Input Range Conditions**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| V(Ax) | Analog input voltage range(1) | All ADC12 analog input pins Ax | | 0 | | AVCC | V |
| I(ADC12_B) single-ended mode | Operating supply current into AVCC plus DVCC terminals(2) (3) | $f_{ADC12CLK}$ = MODCLK, ADC12ON = 1, ADC12PWRMD = 0, ADC12DIF = 0, REFON = 0, ADC12SHTx = 0, ADC12DIV = 0 | 3.0 V | | 145 | 185 | µA |
| | | | 2.2 V | | 140 | 180 | |
| I(ADC12_B) differential mode | Operating supply current into AVCC plus DVCC terminals(2) (3) | $f_{ADC12CLK}$ = MODCLK, ADC12ON = 1, ADC12PWRMD = 0, ADC12DIF = 1, REFON = 0, ADC12SHTx= 0, ADC12DIV = 0 | 3.0 V | | 175 | 225 | µA |
| | | | 2.2 V | | 170 | 220 | |
| $C_I$ | Input capacitance | Only one terminal Ax can be selected at one time | 2.2 V | | 10 | 15 | pF |
| $R_I$ | Input MUX ON resistance | 0 V ≤ V(Ax) ≤ AVCC | >2 V | | 0.5 | 4 | kΩ |
| | | | <2 V | | 1 | 10 | kΩ |

(1) The analog input voltage range must be within the selected reference voltage range $V_{R+}$ to $V_{R-}$ for valid conversion results.
(2) The internal reference supply current is not included in current consumption parameter $I_{(ADC12_B)}$.
(3) Approximately 60% (typical) of the total current into the AVCC and DVCC terminals is from AVCC.


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Table 5-23 lists the timing parameters of the ADC.

**Table 5-23. 12-Bit ADC, Timing Parameters**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $f_{ADC12CLK}$ | Frequency for specified performance | For specified performance of ADC12 linearity parameters with ADC12PWRMD = 0.<br>If ADC12PWRMD = 1, the maximum is 1/4 of the value shown here. | | 0.45 | | 5.4 | MHz |
| $f_{ADC12CLK}$ | Frequency for reduced performance | Linearity parameters have reduced performance | | | 32.768 | | kHz |
| $f_{ADC12OSC}$ | Internal oscillator(1) | ADC12DIV = 0, $f_{ADC12CLK} = f_{ADC12OSC}$ from MODCLK | | 4 | 4.8 | 5.4 | MHz |
| $t_{CONVERT}$ | Conversion time | REFON = 0, Internal oscillator, $f_{ADC12CLK} = f_{ADC12OSC}$ from MODCLK, ADC12WINC = 0 | | 2.6 | | 3.5 | µs |
| | | External $f_{ADC12CLK}$ from ACLK, MCLK, or SMCLK, ADC12SSEL ≠ 0 | | See (2) | | | |
| $t_{ADC12ON}$ | Turnon settling time of the ADC | See (3) | | | | 100 | ns |
| $t_{ADC12OFF}$ | Time ADC must be off before it can be turned on again | $t_{ADC12OFF}$ must be met to make sure that $t_{ADC12ON}$ time holds. | | 100 | | | ns |
| $t_{Sample}$ | Sampling time | $R_S$ = 400 Ω, $R_I$ = 4 kΩ, $C_I$ = 15 pF, $C_{pext}$= 8 pF(4) | All pulse sample mode (ADC12SHP = 1) and extended sample mode (ADC12SHP = 0) with buffered reference (ADC12VRSEL = 0x1, 0x3, 0x5, 0x7, 0x9, 0xB, 0xD, 0xF) | 1 | | | µs |
| | | | Extended sample mode (ADC12SHP = 0) with unbuffered reference (ADC12VRSEL= 0x0, 0x2, 0x4, 0x6, 0xC, 0xE) | See (5) | | | µs |

(1) The ADC12OSC is sourced directly from MODOSC inside the UCS.
(2) 14 × 1 / $f_{ADC12CLK}$. If ADC12WINC = 1, then 15 × 1 / $f_{ADC12CLK}$
(3) The condition is that the error in a conversion started after $t_{ADC12ON}$ is less than ±0.5 LSB. The reference and input signal are already settled.
(4) Approximately 10 Tau (τ) are needed to get an error of less than ±0.5 LSB: $t_{sample} = \ln(2^{n+2}) \times (R_S + R_I) \times (C_I + C_{pext})$, $R_S < 10$ kΩ, where n = ADC resolution = 12, $R_S$= external source resistance, $C_{pext}$ = external parasitic capacitance.
(5) 6 × 1 / $f_{ADC12CLK}$

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Table 5-24 lists the linearity parameters of the ADC when using an external reference.

**Table 5-24. 12-Bit ADC, Linearity Parameters With External Reference(1)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| Resolution | Number of no missing code output-code bits | | 12 | | | bits |
| $E_I$ | Integral linearity error (INL) for differential input | 1.2 V ≤ $V_{R+} - V_{R-}$ ≤ $AV_{CC}$ | | | ±1.8 | LSB |
| $E_I$ | Integral linearity error (INL) for single ended inputs | 1.2 V ≤ $V_{R+} - V_{R-}$ ≤ $AV_{CC}$ | | | ±2.2 | LSB |
| $E_D$ | Differential linearity error (DNL) | | –0.99 | | +1.0 | LSB |
| $E_O$ | Offset error(2) (3) | ADC12VRSEL = 0x2 or 0x4 without TLV calibration, TLV calibration data can be used to improve the parameter(4) | | ±0.5 | ±1.5 | mV |
| $E_{G,ext}$ | Gain error | With external voltage reference without internal buffer (ADC12VRSEL = 0x2 or 0x4) without TLV calibration, TLV calibration data can be used to improve the parameter(4), $V_{R+}$ = 2.5 V, $V_{R-}$ = AVSS | | ±0.8 | ±2.5 | LSB |
| | | With external voltage reference with internal buffer (ADC12VRSEL = 0x3), $V_{R+}$ = 2.5 V, $V_{R-}$ = AVSS | | ±1 | ±20 | |
| $E_{T,ext}$ | Total unadjusted error | With external voltage reference without internal buffer (ADC12VRSEL = 0x2 or 0x4) without TLV calibration, TLV calibration data can be used to improve the parameter(4), $V_{R+}$ = 2.5 V, $V_{R-}$ = AVSS | | ±1.4 | ±3.5 | LSB |
| | | With external voltage reference with internal buffer (ADC12VRSEL = 0x3), $V_{R+}$ = 2.5 V, $V_{R-}$ = AVSS | | ±1.4 | ±21.0 | |

(1) See Table 5-26 and Table 5-32 for more information on internal reference performance, and see *Designing With the MSP430FR59xx and MSP430FR58xx ADC* for details on optimizing ADC performance for your application with the choice of internal or external reference.
(2) Offset is measured as the input voltage (at which ADC output transitions from 0 to 1) minus 0.5 LSB.
(3) Offset increases as $I_R$ drop increases when $V_{R-}$ is AVSS.
(4) For details, see the device descriptor in the *MSP430FR58xx, MSP430FR59xx, MSP430FR68xx, and MSP430FR69xx Family User's Guide*.


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Table 5-25 lists the dynamic performance characteristics of the ADC with differential inputs and an external reference.

**Table 5-25. 12-Bit ADC, Dynamic Performance for Differential Inputs With External Reference(1)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| SNR | Signal-to-noise | $V_{R+}$ = 2.5 V, $V_{R-}$ = AVSS | 68 | 71 | | dB |
| ENOB | Effective number of bits(2) | $V_{R+}$ = 2.5 V, $V_{R-}$ = AVSS | 10.7 | 11.2 | | bits |

(1) See Table 5-26 and Table 5-32 for more information on internal reference performance, and see *Designing With the MSP430FR59xx and MSP430FR58xx ADC* for details on optimizing ADC performance for your application with the choice of internal or external reference.
(2) ENOB = (SINAD – 1.76) / 6.02

Table 5-26 lists the dynamic performance characteristics of the ADC with differential inputs and an internal reference.

**Table 5-26. 12-Bit ADC, Dynamic Performance for Differential Inputs With Internal Reference(1)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| ENOB | Effective number of bits(2) | $V_{R+}$ = 2.5 V, $V_{R-}$ = AVSS | 10.3 | 10.7 | | Bits |

(1) See Table 5-32 for more information on internal reference performance, and see *Designing With the MSP430FR59xx and MSP430FR58xx ADC* for details on optimizing ADC performance for your application with the choice of internal or external reference.
(2) ENOB = (SINAD – 1.76) / 6.02

Table 5-27 lists the dynamic performance characteristics of the ADC with single-ended inputs and an external reference.

**Table 5-27. 12-Bit ADC, Dynamic Performance for Single-Ended Inputs With External Reference(1)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| SNR | Signal-to-noise | $V_{R+}$ = 2.5 V, $V_{R-}$ = AVSS | 64 | 68 | | dB |
| ENOB | Effective number of bits(2) | $V_{R+}$ = 2.5 V, $V_{R-}$ = AVSS | 10.2 | 10.7 | | bits |

(1) See Table 5-28 and Table 5-32 for more information on internal reference performance, and see *Designing With the MSP430FR59xx and MSP430FR58xx ADC* for details on optimizing ADC performance for your application with the choice of internal or external reference.
(2) ENOB = (SINAD – 1.76) / 6.02

Table 5-28 lists the dynamic performance characteristics of the ADC with single-ended inputs and an internal reference.

**Table 5-28. 12-Bit ADC, Dynamic Performance for Single-Ended Inputs With Internal Reference(1)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| ENOB | Effective number of bits(2) | $V_{R+}$ = 2.5 V, $V_{R-}$ = AVSS | 9.4 | 10.4 | | bits |

(1) See Table 5-32 for more information on internal reference performance, and see *Designing With the MSP430FR59xx and MSP430FR58xx ADC* for details on optimizing ADC performance for your application with the choice of internal or external reference.
(2) ENOB = (SINAD – 1.76) / 6.02

Table 5-29 lists the dynamic performance characteristics of the ADC using a 32.678-kHz clock.

**Table 5-29. 12-Bit ADC, Dynamic Performance With 32.768-kHz Clock**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | TYP | UNIT |
|---|---|---|---|---|
| ENOB | Effective number of bits(1) | Reduced performance with $f_{ADC12CLK}$ from ACLK LFXT 32.768 kHz, $V_{R+}$ = 2.5 V, $V_{R-}$ = AVSS | 10 | bits |

(1) ENOB = (SINAD – 1.76) / 6.02

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Table 5-30 lists the characteristics of the temperature sensor and built-in $V_{1/2}$ of the ADC.

**Table 5-30. 12-Bit ADC, Temperature Sensor and Built-In $V_{1/2}$**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{SENSOR}$ | See (1) (2) (also see Figure 5-20) | ADC12ON = 1, ADC12TCMAP = 1, $T_A$ = 0°C | | 700 | | mV |
| $TC_{SENSOR}$ | See (2) | ADC12ON = 1, ADC12TCMAP = 1 | | 2.5 | | mV/°C |
| $t_{SENSOR(sample)}$ | Sample time required if ADCTCMAP = 1 and channel (MAX – 1) is selected(3) | ADC12ON = 1, ADC12TCMAP = 1, Error of conversion result ≤ 1 LSB | 30 | | | µs |
| $V_{1/2}$ | AVCC voltage divider for ADC12BATMAP = 1 on MAX input channel | ADC12ON = 1, ADC12BATMAP = 1 | 47.5% | 50% | 52.5% | |
| $I_{V\ 1/2}$ | Current for battery monitor during sample time | ADC12ON = 1, ADC12BATMAP = 1 | | 38 | 63 | µA |
| $t_{V\ 1/2\ (sample)}$ | Sample time required if ADC12BATMAP = 1 and channel MAX is selected(4) | ADC12ON = 1, ADC12BATMAP = 1 | 1.7 | | | µs |

(1) The temperature sensor offset can be as much as ±30°C. TI recommends a single-point calibration to minimize the offset error of the built-in temperature sensor.
(2) The device descriptor structure contains calibration values for 30°C ±3°C and 85°C ±3°C for each available reference voltage level. The sensor voltage can be computed as $V_{SENSE} = TC_{SENSOR} \times (\text{Temperature, °C}) + V_{SENSOR}$, where $TC_{SENSOR}$ and $V_{SENSOR}$ can be computed from the calibration values for higher accuracy.
(3) The typical equivalent impedance of the sensor is 250 kΩ. The sample time required includes the sensor-on time $t_{SENSOR(on)}$.
(4) The on-time $t_{V1/2(on)}$ is included in the sampling time $t_{V1/2(sample)}$; no additional on time is needed.

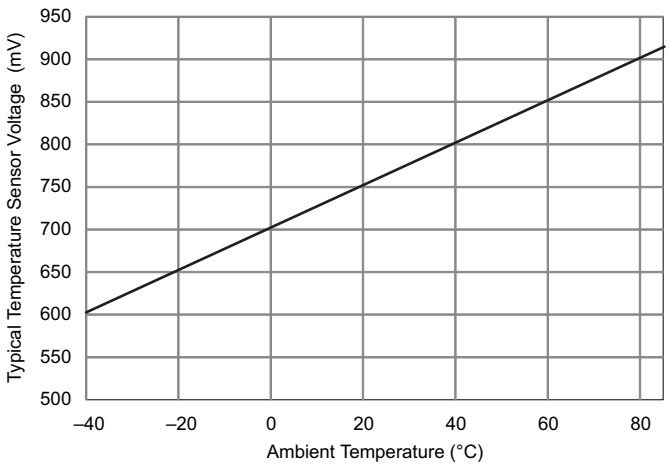


**Figure 5-20. Typical Temperature Sensor Voltage**


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Table 5-31 lists the external reference requirements for the ADC.

**Table 5-31. 12-Bit ADC, External Reference(1)**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{R+}$ | Positive external reference voltage input VeREF+ or VeREF- based on ADC12VRSEL bit | $V_{R+} > V_{R-}$ | 1.2 | | $AV_{CC}$ | V |
| $V_{R-}$ | Negative external reference voltage input VeREF+ or VeREF- based on ADC12VRSEL bit | $V_{R+} > V_{R-}$ | 0 | | 1.2 | V |
| $V_{R+} - V_{R-}$ | Differential external reference voltage input | $V_{R+} > V_{R-}$ | 1.2 | | $AV_{CC}$ | V |
| $I_{VeREF+}$, $I_{VeREF-}$ | Static input current, singled-ended input mode | 1.2 V ≤ $V_{eREF+}$ ≤ $V_{AVCC}$, $V_{eREF-}$ = 0 V<br>$f_{ADC12CLK}$ = 5 MHz, ADC12SHTx = 1h, ADC12DIF = 0, ADC12PWRMD = 0 | | | ±10 | µA |
| | | 1.2 V ≤ $V_{eREF+}$ ≤ $V_{AVCC}$ , $V_{eREF-}$ = 0 V<br>$f_{ADC12CLK}$ = 5 MHz, ADC12SHTx = 8h, ADC12DIF = 0, ADC12PWRMD = 01 | | | ±2.5 | |
| $I_{VeREF+}$, $I_{VeREF-}$ | Static input current, differential input mode | 1.2 V ≤ $V_{eREF+}$ ≤ $V_{AVCC}$, $V_{eREF-}$ = 0 V<br>$f_{ADC12CLK}$ = 5 MHz, ADC12SHTx = 1h, ADC12DIF = 1, ADC12PWRMD = 0 | | | ±20 | µA |
| | | 1.2 V ≤ $V_{eREF+}$ ≤ $V_{AVCC}$ , $V_{eREF-}$ = 0 V<br>$f_{ADC12CLK}$ = 5 MHz, ADC12SHTx = 8h, ADC12DIF = 1, ADC12PWRMD = 1 | | | ±5 | |
| $I_{VeREF+}$ | Peak input current with single-ended input | 0 V ≤ $V_{eREF+}$ ≤ $V_{AVCC}$, ADC12DIF = 0 | | | 1.5 | mA |
| $I_{VeREF+}$ | Peak input current with differential input | 0 V ≤ $V_{eREF+}$ ≤ $V_{AVCC}$, ADC12DIF = 1 | | | 3 | mA |
| $C_{VeREF+/-}$ | Capacitance at VeREF+ or VeREF- terminal | See (2) | 10 | | | µF |

(1) The external reference is used during ADC conversion to charge and discharge the capacitance array. The input capacitance, $C_I$, is also the dynamic load for an external reference during conversion. The dynamic impedance of the reference supply should follow the recommendations on analog-source impedance to allow the charge to settle for 12-bit accuracy.

(2) Connect two decoupling capacitors, 10 µF and 470 nF, to VeREF to decouple the dynamic current required for an external reference source if it is used for the ADC12_B. Also see the *MSP430FR58xx, MSP430FR59xx, MSP430FR68xx, and MSP430FR69xx Family User's Guide*.

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### 5.12.9 Reference

Table 5-32 lists the characteristics of the built-in voltage reference.

**Table 5-32. REF, Built-In Reference**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $V_{REF+}$ | Positive built-in reference voltage output | REFVSEL = {2} for 2.5 V, REFON = 1 | 2.7 V | | 2.5 | ±1.5% | V |
| | | REFVSEL = {1} for 2.0 V, REFON = 1 | 2.2 V | | 2.0 | ±1.5% | |
| | | REFVSEL = {0} for 1.2 V, REFON = 1 | 1.8 V | | 1.2 | ±1.8% | |
| Noise | RMS noise at VREF(1) | From 0.1 Hz to 10 Hz, REFVSEL = {0} | | | 110 | 600 | µV |
| $V_{OS_BUF_INT}$ | VREF ADC BUF_INT buffer offset(2) | $T_A$ = 25°C , ADC ON, REFVSEL = {0}, REFON = 1, REFOUT = 0 | | –12 | | +12 | mV |
| $V_{OS_BUF_EXT}$ | VREF ADC BUF_EXT buffer offset(2) | $T_A$ = 25°C, REFVSEL = {0} , REFOUT = 1, REFON = 1 or ADC ON | | –12 | | +12 | mV |
| $AV_{CC(min)}$ | AVCC minimum voltage, Positive built-in reference active | REFVSEL = {0} for 1.2 V | | 1.8 | | | V |
| | | REFVSEL = {1} for 2.0 V | | 2.2 | | | |
| | | REFVSEL = {2} for 2.5 V | | 2.7 | | | |
| $I_{REF+}$ | Operating supply current into AVCC terminal(3) | REFON = 1 | 3 V | | 8 | 15 | µA |
| $I_{REF+_ADC_BUF}$ | Operating supply current into AVCC terminal(3) | ADC ON, REFOUT = 0, REFVSEL = {0, 1, 2}, ADC12PWRMD = 0, | 3 V | | 225 | 355 | µA |
| | | ADC ON, REFOUT = 1, REFVSEL = {0, 1, 2}, ADC12PWRMD = 0 | | | 1030 | 1660 | |
| | | ADC ON, REFOUT = 0, REFVSEL = {0, 1, 2}, ADC12PWRMD = 1 | | | 120 | 185 | |
| | | ADC ON, REFOUT = 1, REFVSEL = {0, 1, 2}, ADC12PWRMD = 1 | | | 545 | 895 | |
| | | ADC OFF, REFON = 1, REFOUT = 1, REFVSEL = {0, 1, 2} | | | 1085 | 1780 | |
| $I_{O(VREF+)}$ | VREF maximum load current, VREF+ terminal | REFVSEL = {0, 1, 2}, AVCC = AVCC(min) for each reference level, REFON = REFOUT = 1 | | –1000 | | +10 | µA |
| ΔVout/ΔIo (VREF+) | Load-current regulation, VREF+ terminal | REFVSEL = {0, 1, 2}, $I_{O(VREF+)}$ = +10 µA or –1000 µA, $AV_{CC}$ = $AV_{CC(min)}$ for each reference level, REFON = REFOUT = 1 | | | | 2500 | µV/mA |
| $C_{VREF+/-}$ | Capacitance at VREF+ and VREF- terminals | REFON = REFOUT = 1 | | 0 | | 100 | pF |
| $TC_{REF+}$ | Temperature coefficient of built-in reference | REFVSEL = {0, 1, 2}, REFON = REFOUT = 1, $T_A$ = –40°C to 85°C(4) | | | 18 | 50 | ppm/K |
| PSRR_DC | Power supply rejection ratio (DC) | $AV_{CC}$ = $AV_{CC(min)}$ to $AV_{CC(max)}$, $T_A$ = 25°C, REFVSEL = {0, 1, 2}, REFON = REFOUT = 1 | | | 120 | 400 | µV/V |
| PSRR_AC | Power supply rejection ratio (AC) | $dAV_{CC}$= 0.1 V at 1 kHz | | | 3.0 | | mV/V |
| $t_{SETTLE}$ | Settling time of reference voltage(5) | $AV_{CC}$ = $AV_{CC\ (min)}$ to $AV_{CC(max)}$, REFVSEL = {0, 1, 2}, REFON = 0 → 1 | | | 75 | 80 | µs |

(1) Internal reference noise affects ADC performance when ADC uses internal reference. See *Designing With the MSP430FR59xx and MSP430FR58xx ADC* for details on optimizing ADC performance for your application with the choice of internal versus external reference.
(2) Buffer offset affects ADC gain error and thus total unadjusted error.
(3) The internal reference current is supplied through the AVCC terminal.
(4) Calculated using the box method: (MAX(–40°C to 85°C) – MIN(–40°C to 85°C)) / MIN(–40°C to 85°C)/(85°C – (–40°C)).
(5) The condition is that the error in a conversion started after $t_{REFON}$ is less than ±0.5 LSB.


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### 5.12.10 Comparator

Table 5-33 lists the characteristics of the comparator.

**Table 5-33. Comparator_E**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | $V_{CC}$ | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| $I_{AVCC_COMP}$ | Comparator operating supply current into AVCC, excludes reference resistor ladder | CEPWRMD = 00, CEON = 1, CERSx = 00 (fast) | 2.2 V, 3.0 V | | 11 | 20 | µA |
| | | CEPWRMD = 01, CEON = 1, CERSx = 00 (medium) | | | 9 | 17 | |
| | | CEPWRMD = 10, CEON = 1, CERSx = 00 (slow), $T_A$ = 30°C | | | | 0.5 | |
| | | CEPWRMD = 10, CEON = 1, CERSx = 00 (slow), $T_A$ = 85°C | | | | 1.3 | |
| $I_{AVCC_REF}$ | Quiescent current of resistor ladder into AVCC, including REF module current | CEREFLx = 01, CERSx = 10, REFON = 0, CEON = 0, CEREFACC = 0 | 2.2 V, 3.0 V | | 12 | 15 | µA |
| | | CEREFLx = 01, CERSx = 10, REFON = 0, CEON = 0, CEREFACC = 1 | | | 5 | 7 | |
| $V_{REF}$ | Reference voltage level | CERSx = 11, CEREFLx = 01, CEREFACC = 0 | 1.8 V | 1.17 | 1.2 | 1.23 | V |
| | | CERSx = 11, CEREFLx = 10, CEREFACC = 0 | 2.2 V | 1.92 | 2.0 | 2.08 | |
| | | CERSx = 11, CEREFLx = 11, CEREFACC = 0 | 2.7 V | 2.40 | 2.5 | 2.60 | |
| | | CERSx = 11, CEREFLx = 01, CEREFACC = 1 | 1.8 V | 1.10 | 1.2 | 1.245 | |
| | | CERSx = 11, CEREFLx = 10, CEREFACC = 1 | 2.2 V | 1.90 | 2.0 | 2.08 | |
| | | CERSx = 11, CEREFLx = 11, CEREFACC = 1 | 2.7 V | 2.35 | 2.5 | 2.60 | |
| $V_{IC}$ | Common-mode input range | | | 0 | | $V_{CC}$ – 1 | V |
| $V_{OFFSET}$ | Input offset voltage | CEPWRMD = 00 | | –32 | | 32 | mV |
| | | CEPWRMD = 01 | | –32 | | 32 | |
| | | CEPWRMD = 10 | | –30 | | 30 | |
| $C_{IN}$ | Input capacitance | CEPWRMD = 00 or CEPWRMD = 01 | | | 9 | | pF |
| | | CEPWRMD = 10 | | | 9 | | |
| $R_{SIN}$ | Series input resistance | On (switch closed) | | | 1 | 3 | kΩ |
| | | Off (switch open) | | 50 | | | MΩ |
| $t_{PD}$ | Propagation delay, response time | CEPWRMD = 00, CEF = 0, Overdrive ≥ 20 mV | | | 260 | 330 | ns |
| | | CEPWRMD = 01, CEF = 0, Overdrive ≥ 20 mV | | | 350 | 460 | |
| | | CEPWRMD = 10, CEF = 0, Overdrive ≥ 20 mV | | | | 15 | µs |
| $t_{PD,filter}$ | Propagation delay with filter active | CEPWRMD = 00 or 01, CEF = 1, Overdrive ≥ 20 mV, CEFDLY = 00 | | | 700 | 1000 | ns |
| | | CEPWRMD = 00 or 01, CEF = 1, Overdrive ≥ 20 mV, CEFDLY = 01 | | | 1.0 | 1.8 | µs |
| | | CEPWRMD = 00 or 01, CEF = 1, Overdrive ≥ 20 mV, CEFDLY = 10 | | | 2.0 | 3.5 | |
| | | CEPWRMD = 00 or 01, CEF = 1, Overdrive ≥ 20 mV, CEFDLY = 11 | | | 4.0 | 7.0 | |
| $t_{EN_CMP}$ | Comparator enable time | CEON = 0 → 1, VIN+, VIN- from pins, Overdrive ≥ 20 mV, CEPWRMD = 00 | | | 0.9 | 1.5 | µs |
| | | CEON = 0 → 1, VIN+, VIN- from pins, Overdrive ≥ 20 mV, CEPWRMD = 01 | | | 0.9 | 1.5 | |
| | | CEON = 0 → 1, VIN+, VIN- from pins, Overdrive ≥ 20 mV, CEPWRMD = 10 | | | 15 | 100 | |
| $t_{EN_CMP_VREF}$ | Comparator and reference ladder and reference voltage enable time | CEON = 0 → 1, CEREFLX = 10, CERSx = 10 or 11, CEREF0 = CEREF1 = 0x0F, Overdrive ≥ 20 mV | | | 350 | 1500 | µs |
| $V_{CE_REF}$ | Reference voltage for a given tap | VIN = reference into resistor ladder, n = 0 to 31 | | VIN × (n + 0.5) / 32 | VIN × (n + 1) / 32 | VIN × (n + 1.5) / 32 | V |

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### 5.12.11 FRAM

Table 5-34 lists the characteristics of the FRAM.

**Table 5-34. FRAM**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| | Read and write endurance | | $10^{15}$ | | | cycles |
| $t_{Retention}$ | Data retention duration | $T_J$ = 25°C | 100 | | | years |
| | | $T_J$ = 70°C | 40 | | | |
| | | $T_J$ = 85°C | 10 | | | |
| $I_{WRITE}$ | Current to write into FRAM | | | $I_{READ}$ (1) | | nA |
| $I_{ERASE}$ | Erase current | | | n/a (2) | | nA |
| $t_{WRITE}$ | Write time | | | $t_{READ}$ (3) | | ns |
| $t_{READ}$ | Read time | NWAITSx = 0 | | 1 / $f_{SYSTEM}$ (4) | | ns |
| | | NWAITSx = 1 | | 2 / $f_{SYSTEM}$ (4) | | |

(1) Writing to FRAM does not require a setup sequence or additional power when compared to reading from FRAM. The FRAM read current $I_{READ}$ is included in the active mode current consumption numbers $I_{AM,FRAM}$.
(2) FRAM does not require a special erase sequence.
(3) Writing into FRAM is as fast as reading.
(4) The maximum read (and write) speed is specified by $f_{SYSTEM}$ using the appropriate wait state settings (NWAITSx).

## 5.13 Emulation and Debug

Table 5-35 lists the characteristics of the JTAG and Spy-Bi-Wire interface.

**Table 5-35. JTAG and Spy-Bi-Wire Interface**

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $I_{JTAG}$ | Supply current adder when JTAG active (but not clocked) | 2.2 V, 3.0 V | | 40 | 100 | µA |
| $f_{SBW}$ | Spy-Bi-Wire input frequency | 2.2 V, 3.0 V | 0 | | 10 | MHz |
| $t_{SBW,Low}$ | Spy-Bi-Wire low clock pulse duration | 2.2 V, 3.0 V | 0.04 | | 15 | µs |
| $t_{SBW,\ En}$ | Spy-Bi-Wire enable time (TEST high to acceptance of first clock edge) (1) | 2.2 V, 3.0 V | | | 110 | µs |
| $t_{SBW,Rst}$ | Spy-Bi-Wire return to normal operation time | | 15 | | 100 | µs |
| $f_{TCK}$ | TCK input frequency, 4-wire JTAG (2) | 2.2 V | 0 | | 16 | MHz |
| | | 3.0 V | 0 | | 16 | MHz |
| $R_{internal}$ | Internal pulldown resistance on TEST | 2.2 V, 3.0 V | 20 | 35 | 50 | kΩ |
| $f_{TCLK}$ | TCLK/MCLK frequency during JTAG access, no FRAM access (limited by $f_{SYSTEM}$) | | | | 16 | MHz |
| $t_{TCLK,Low/High}$ | TCLK low or high clock pulse duration, no FRAM access | | | | 25 | ns |
| $f_{TCLK,FRAM}$ | TCLK/MCLK frequency during JTAG access, including FRAM access (limited by $f_{SYSTEM}$ with no FRAM wait states) | | | | 4 | MHz |
| $t_{TCLK,FRAM,Low/High}$ | TCLK low or high clock pulse duration, including FRAM accesses | | | | 100 | ns |

(1) Tools that access the Spy-Bi-Wire and BSL interfaces must wait for the $t_{SBW,En}$ time after the first transition of the TEST/SBWTCK pin (low to high), before the second transition of the pin (high to low) during the entry sequence.
(2) $f_{TCK}$ may be restricted to meet the timing requirements of the module selected.


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# 6 Detailed Description

## 6.1 Overview

The Texas Instruments MSP430FR59xx family of ultra-low-power microcontrollers consists of several devices featuring different sets of peripherals. The architecture, combined with seven low-power modes is optimized to achieve extended battery life for example in portable measurement applications. The devices features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency.

The MSP430FR59xx devices are microcontroller configurations with up to five 16-bit timers, Comparator, universal serial communication interfaces (eUSCI) supporting UART, SPI, and $I^2C$, hardware multiplier, AES accelerator, DMA, real-time clock module with alarm capabilities, up to 40 I/O pins, and an high-performance 12-bit analog-to-digital converter (ADC).

## 6.2 CPU

The MSP430 CPU has a 16-bit RISC architecture that is highly transparent to the application. All operations, other than program-flow instructions, are performed as register operations in conjunction with seven addressing modes for source operand and four addressing modes for destination operand.

The CPU is integrated with 16 registers that provide reduced instruction execution time. The register-to-register operation execution time is one cycle of the CPU clock.

Four of the registers, R0 to R3, are dedicated as program counter, stack pointer, status register, and constant generator, respectively. The remaining registers are general-purpose registers.

Peripherals are connected to the CPU using data, address, and control buses, and can be handled with all instructions.

The instruction set consists of the original 51 instructions with three formats and seven address modes and additional instructions for the expanded address range. Each instruction can operate on word and byte data.

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## 6.3 Operating Modes

The MSP430FR59xx MCUs have one active mode and seven software-selectable low-power modes of operation (see Table 6-1). An interrupt event can wake up the device from a low-power mode (LPM0 to LPM4), service the request, and restore back to the low-power mode on return from the interrupt program. Low-power modes LPM3.5 and LPM4.5 disable the core supply to minimize power consumption.

**Table 6-1. Operating Modes**

| MODE | AM | | LPM0 | LPM1 | LPM2 | LPM3 | LPM4 | LPM3.5 | LPM4.5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ACTIVE | ACTIVE, FRAM OFF(1) | CPU Off(2) | CPU OFF | STANDBY | STANDBY | OFF | RTC ONLY | SHUTDOWN WITH SVS | SHUTDOWN WITHOUT SVS |
| Maximum system clock | 16 MHz | | 16 MHz | 16 MHz | 50 kHz | 50 kHz | 0(3) | 50 kHz | 0(3) | |
| Typical current consumption, $T_A$ = 25°C | 103 µA/MHz | 65 µA/MHz | 70 µA at 1 MHz | 35 µA at 1 MHz | 0.7 µA | 0.4 µA | 0.3 µA | 0.25 µA | 0.2 µA | 0.02 µA |
| Typical wake-up time | N/A | | instant | 6 µs | 6 µs | 7 µs | 7 µs | 250 µs | 250 µs | 1000 µs |
| Wake-up events | N/A | | all | all | LF<br>I/O<br>Comp | LF<br>I/O<br>Comp | I/O<br>Comp | RTC<br>I/O | I/O | |
| CPU | **on** | | off | off | off | off | off | reset | reset | |
| FRAM | **on** | off(1) | standby<br>(or off(1)) | off | off | off | off | off | off | |
| Peripherals in high-frequency state(4) | **yes** | | **yes** | **yes** | no | no | no | reset | reset | |
| Peripherals in low-frequency state(4) | **yes** | | **yes** | **yes** | **yes** | **yes**(5) | no | RTC | reset | |
| Peripherals in unclocked state(4) | **yes** | | **yes** | **yes** | **yes** | **yes**(5) | **yes**(5) | reset | reset | |
| MCLK | **on**<br>(16 $MHz_{MAX}$) | | off | off | off | off | off | off | off | |
| SMCLK | optional(6)<br>(16 $MHz_{MAX}$) | | optional(6)<br>(16 $MHz_{MAX}$) | optional(6)<br>(16 $MHz_{MAX}$) | off | off | off | off | off | |
| ACLK | **on**<br>(50 $kHz_{MAX}$) | | **on**<br>(50 $kHz_{MAX}$) | **on**<br>(50 $kHz_{MAX}$) | **on**<br>(50 $kHz_{MAX}$) | **on**<br>(50 $kHz_{MAX}$) | off | off | off | |
| External clock | optional<br>(16 $MHz_{MAX}$) | | optional<br>(16 $MHz_{MAX}$) | optional<br>(16 $MHz_{MAX}$) | optional<br>(50 $kHz_{MAX}$) | optional<br>(50 $kHz_{MAX}$) | optional<br>(50 $kHz_{MAX}$) | off | off | |
| Full retention | **yes** | | **yes** | **yes** | **yes** | **yes** | **yes** | no | no | |

(1) FRAM disabled in FRAM controller
(2) Disabling the FRAM through the FRAM controller allows the application to lower the LPM current consumption but the wake-up time increases as soon as FRAM is accessed (for example, to fetch an interrupt vector). For a wakeup that does not involve the FRAM (for example, DMA transfer to RAM), the wakeup is not delayed.
(3) All clocks disabled
(4) See Table 6-2 for a detailed description of peripherals in high-frequency, low-frequency, or unclocked state.
(5) See Section 6.3.1, which describes the use of peripherals in LPM3 and LPM4.
(6) Controlled by SMCLKOFF.


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**Table 6-1. Operating Modes (continued)**

| MODE | AM | | LPM0 | LPM1 | LPM2 | LPM3 | LPM4 | LPM3.5 | LPM4.5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ACTIVE | ACTIVE, FRAM OFF(1) | CPU Off(2) | CPU OFF | STANDBY | STANDBY | OFF | RTC ONLY | SHUTDOWN WITH SVS | SHUTDOWN WITHOUT SVS |
| SVS | always | | always | always | optional(7) | optional(7) | optional(7) | optional(7) | on(8) | off(9) |
| Brownout | **always** | | **always** | **always** | **always** | **always** | **always** | **always** | **always** | |

(7) Activated SVS (SVSHE = 1) results in higher current consumption. SVS is not included in typical current consumption.
(8) SVSHE = 1
(9) SVSHE = 0

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### 6.3.1 Peripherals in Low-Power Modes

Peripherals can be in different states that impact the achievable power modes of the device. The states depend on the operational modes of the peripherals. The states are:

- A peripheral is in a "high frequency state" if it requires or uses a clock with a "high" frequency of more than 50 kHz.
- A peripheral is in a "low frequency state" if it requires or uses a clock with a "low" frequency of 50 kHz or less.
- A peripheral is in an "unclocked state" if it does not require nor use an internal clock.

If the CPU requests a power mode that does not support the current state of all active peripherals, the device cannot enter the requested power mode but does enter a power mode that still supports the current state of the peripherals, unless an external clock is used. If an external clock is used, the application must ensure the correct frequency range for the requested power mode.

**Table 6-2. Peripheral States**

| PERIPHERAL | IN HIGH-FREQUENCY STATE(1) | IN LOW-FREQUENCY STATE(2) | IN UNCLOCKED STATE(3) |
|---|---|---|---|
| WDT | Clocked by SMCLK | Clocked by ACLK | Not applicable |
| DMA(4) | Not applicable | Not applicable | Waiting for a trigger |
| RTC_B | Not applicable | Clocked by LFXT | Not applicable |
| Timer_A, TAx | Clocked by SMCLK or clocked by external clock >50 kHz | Clocked by ACLK or clocked by external clock ≤50 kHz | Clocked by external clock ≤50 kHz |
| Timer_B, TBx | Clocked by SMCLK or clocked by external clock >50 kHz | Clocked by ACLK or clocked by external clock ≤50 kHz | Clocked by external clock ≤50 kHz |
| eUSCI_Ax in UART mode | Clocked by SMCLK | Clocked by ACLK | Waiting for first edge of START bit |
| eUSCI_Ax in SPI master mode | Clocked by SMCLK | Clocked by ACLK | Not applicable |
| eUSCI_Ax in SPI slave mode | Clocked by external clock >50 kHz | Clocked by external clock ≤50 kHz | Clocked by external clock ≤50 kHz |
| eUSCI_Bx in $I^2C$ master mode | Clocked by SMCLK or clocked by external clock >50 kHz | Clocked by ACLK or clocked by external clock ≤50 kHz | Not applicable |
| eUSCI_Bx in $I^2C$ slave mode | Clocked by external clock >50 kHz | Clocked by external clock ≤50 kHz | Waiting for START condition or clocked by external clock ≤50 kHz |
| eUSCI_Bx in SPI master mode | Clocked by SMCLK | Clocked by ACLK | Not applicable |
| eUSCI_Bx in SPI slave mode | Clocked by external clock >50 kHz | Clocked by external clock ≤50 kHz | Clocked by external clock ≤50 kHz |
| ADC12_B | Clocked by SMCLK or by MODOSC | Clocked by ACLK | Waiting for a trigger |
| REF_A | Not applicable | Not applicable | Always |
| COMP_E | Not applicable | Not applicable | Always |
| CRC(5) | Not applicable | Not applicable | Not applicable |
| MPY(5) | Not applicable | Not applicable | Not applicable |
| AES(5) | Not applicable | Not applicable | Not applicable |

(1) Peripherals are in a state that requires or uses a clock with a "high" frequency of more than 50 kHz.
(2) Peripherals are in a state that requires or uses a clock with a "low" frequency of 50 kHz or less.
(3) Peripherals are in a state that does not require or does not use an internal clock.
(4) The DMA always transfers data in active mode but can wait for a trigger in any low power mode. A DMA trigger during a low power mode will cause a temporary transition into active mode for the time of the transfer.
(5) Operates only during active mode and will eventually delay the transition into a low power mode until its operation is completed.


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#### 6.3.1.1 Idle Currents of Peripherals in LPM3 and LPM4

Most peripherals can be activated to be operational in LPM3 if clocked by ACLK. Some modules are operational in LPM4, because they do not require a clock to operate (for example, the comparator). Activating a peripheral in LPM3 or LPM4 increases the current consumption due to its active supply current contribution but also due to an additional idle current. To limit the idle current adder, certain peripherals are grouped together. To achieve optimal current consumption, use modules within one group and limit the number of groups with active modules. Table 6-3 lists the grouping of the peripherals. Modules not listed in this table are either already included in the standard LPM3 current consumption or cannot be used in LPM3 or LPM4.

The idle current adder is very small at room temperature (25°C) but increases at high temperatures (85°C), See the $I_{IDLE}$ current parameters in Section 5.7 for details.

**Table 6-3. Peripheral Groups**

| Group A | Group B |
|---|---|
| Timer TA1 | Timer TA0 |
| Timer TA2 | Timer TA3 |
| Timer TB0 | Comparator |
| eUSCI_A0 | ADC12_B |
| eUSCI_A1 | REF_A |
| eUSCI_B0 | |

## 6.4 Interrupt Vector Table and Signatures

The interrupt vectors, the power-up start address and signatures are in the address range 0FFFFh to 0FF80h. Figure 6-1 summarizes the content of this address range.

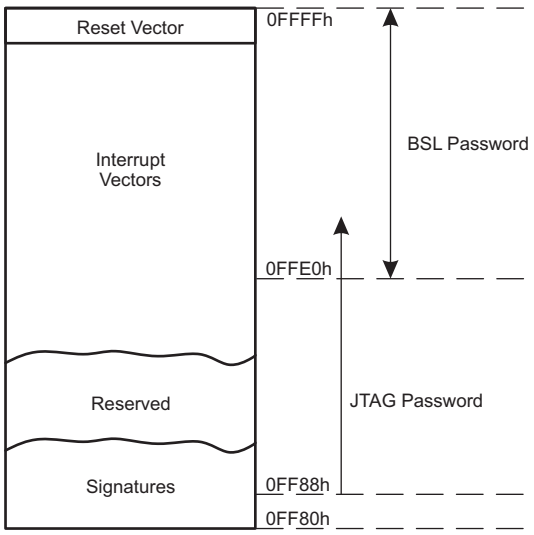


**Figure 6-1. Interrupt Vectors, Signatures and Passwords**

The power-up start address or reset vector is at 0FFFFh to 0FFFEh. It contains a 16-bit address that points to the start address of the application program.

The interrupt vectors start at 0FFFDh and extend to lower addresses. Each vector contains the 16-bit address of the appropriate interrupt-handler instruction sequence. Table 6-4 lists the device specific interrupt vector locations.

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The vectors programmed into the address range from 0FFFFh to 0FFE0h are used as BSL password (if enabled by the corresponding signature).

The signatures are located at 0FF80h extending to higher addresses. Signatures are evaluated during device start-up. Table 6-5 lists the device specific signature locations.

A JTAG password can be programmed starting from address 0FF88h and extending to higher addresses. The password can extend into the interrupt vector locations using the interrupt vector addresses as additional bits for the password. The length of the JTAG password depends on the JTAG signature.

See the *System Resets, Interrupts, and Operating Modes, System Control Module (SYS)* chapter in the *MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide* for details.

**Table 6-4. Interrupt Sources, Flags, and Vectors**

| INTERRUPT SOURCE | INTERRUPT FLAG | SYSTEM INTERRUPT | WORD ADDRESS | PRIORITY |
|---|---|---|---|---|
| **System Reset**<br>Power up, Brownout, Supply Supervisor<br>External Reset RST<br>Watchdog Time-out (Watchdog mode)<br>WDT, FRCTL MPU, CS, PMM Password Violation<br>FRAM uncorrectable bit error detection<br>MPU segment violation<br>FRAM access time error<br>Software POR, BOR | SVSHIFG<br>PMMRSTIFG<br>WDTIFG<br>WDTPW, FRCTLPW, MPUPW, CSPW, PMMPW<br>UBDIFG<br>MPUSEGIIFG, MPUSEG1IFG, MPUSEG2IFG, MPUSEG3IFG<br>ACCTEIFG<br>PMMPORIFG, PMMBORIFG<br>(SYSRSTIV)(1) (2) | Reset | 0FFFEh | highest |
| **System NMI**<br>Vacant Memory Access<br>JTAG Mailbox<br>FRAM bit error detection<br>MPU segment violation | VMAIFG<br>JMBNIFG, JMBOUTIFG<br>CBDIFG, UBDIFG<br>MPUSEGIIFG, MPUSEG1IFG, MPUSEG2IFG, MPUSEG3IFG<br>(SYSSNIV)(1) (3) | (Non)maskable | 0FFFCh | |
| **User NMI**<br>External NMI<br>Oscillator Fault | NMIIFG, OFIFG<br>(SYSUNIV)(1) (3) | (Non)maskable | 0FFFAh | |
| Comparator_E | CEIFG, CEIIFG<br>(CEIV)(1) | Maskable | 0FFF8h | |
| TB0 | TB0CCR0.CCIFG | Maskable | 0FFF6h | |
| TB0 | TB0CCR1.CCIFG ... TB0CCR6.CCIFG, TB0CTL.TBIFG<br>(TB0IV)(1) | Maskable | 0FFF4h | |
| Watchdog Timer (Interval Timer Mode) | WDTIFG | Maskable | 0FFF2h | |
| eUSCI_A0 Receive or Transmit | UCA0IFG: UCRXIFG, UCTXIFG (SPI mode)<br>UCA0IFG: UCSTTIFG, UCTXCPTIFG, UCRXIFG, UCTXIFG (UART mode)<br>(UCA0IV)(1) | Maskable | 0FFF0h | |
| eUSCI_B0 Receive or Transmit | UCB0IFG: UCRXIFG, UCTXIFG (SPI mode)<br>UCB0IFG: UCALIFG, UCNACKIFG, UCSTTIFG, UCSTPIFG, UCRXIFG0, UCTXIFG0, UCRXIFG1, UCTXIFG1, UCRXIFG2, UCTXIFG2, UCRXIFG3, UCTXIFG3, UCCNTIFG, UCBIT9IFG ($I^2C$ mode)<br>(UCB0IV)(1) | Maskable | 0FFEEh | |
| ADC12_B | ADC12IFG0 to ADC12IFG31<br>ADC12LOIFG, ADC12INIFG, ADC12HIIFG, ADC12RDYIFG, ADC21OVIFG, ADC12TOVIFG<br>(ADC12IV)(1) | Maskable | 0FFECh | |
| TA0 | TA0CCR0.CCIFG | Maskable | 0FFEAh | |
| TA0 | TA0CCR1.CCIFG, TA0CCR2.CCIFG, TA0CTL.TAIFG<br>(TA0IV)(1) | Maskable | 0FFE8h | |

(1) Multiple source flags
(2) A reset is generated if the CPU tries to fetch instructions from within peripheral space
(3) (Non)maskable: the individual interrupt enable bit can disable an interrupt event, but the general interrupt enable cannot disable it.


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**Table 6-4. Interrupt Sources, Flags, and Vectors (continued)**

| INTERRUPT SOURCE | INTERRUPT FLAG | SYSTEM INTERRUPT | WORD ADDRESS | PRIORITY |
|---|---|---|---|---|
| eUSCI_A1 Receive or Transmit | UCA1IFG: UCRXIFG, UCTXIFG (SPI mode)<br>UCA1IFG: UCSTTIFG, UCTXCPTIFG, UCRXIFG, UCTXIFG (UART mode)<br>(UCA1IV)(1) | Maskable | 0FFE6h | |
| DMA | DMA0CTL.DMAIFG, DMA1CTL.DMAIFG, DMA2CTL.DMAIFG<br>(DMAIV)(1) | Maskable | 0FFE4h | |
| TA1 | TA1CCR0.CCIFG | Maskable | 0FFE2h | |
| TA1 | TA1CCR1.CCIFG, TA1CCR2.CCIFG, TA1CTL.TAIFG<br>(TA1IV)(1) | Maskable | 0FFE0h | |
| I/O Port P1 | P1IFG.0 to P1IFG.7<br>(P1IV)(1) | Maskable | 0FFDEh | |
| TA2 | TA2CCR0.CCIFG | Maskable | 0FFDCh | |
| TA2 | TA2CCR1.CCIFG<br>TA2CTL.TAIFG<br>(TA2IV)(1) | Maskable | 0FFDAh | |
| I/O Port P2 | P2IFG.0 to P2IFG.7<br>(P2IV)(1) | Maskable | 0FFD8h | |
| TA3 | TA3CCR0.CCIFG | Maskable | 0FFD6h | |
| TA3 | TA3CCR1.CCIFG<br>TA3CTL.TAIFG<br>(TA3IV)(1) | Maskable | 0FFD4h | |
| I/O Port P3 | P3IFG.0 to P3IFG.7<br>(P3IV)(1) | Maskable | 0FFD2h | |
| I/O Port P4 | P4IFG.0 to P4IFG.2<br>(P4IV)(1) | Maskable | 0FFD0h | |
| RTC_B | RTCRDYIFG, RTCTEVIFG, RTCAIFG, RT0PSIFG, RT1PSIFG, RTCOFIFG<br>(RTCIV)(1) | Maskable | 0FFCEh | |
| AES | AESRDYIFG | Maskable | 0FFCCh | lowest |

**Table 6-5. Signatures**

| SIGNATURE | WORD ADDRESS |
|---|---|
| IP Encapsulation Signature 2 | 0FF8Ah |
| IP Encapsulation Signature 1(1) | 0FF88h |
| BSL Signature 2 | 0FF86h |
| BSL Signature 1 | 0FF84h |
| JTAG Signature 2 | 0FF82h |
| JTAG Signature 1 | 0FF80h |

(1) Must not contain 0AAAAh if used as JTAG password and IP encapsulation functionality is not desired.

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## 6.5 Memory Organization

Table 6-6 summarizes the memory map for all device variants.

**Table 6-6. Memory Organization(1)**

| | | MSP430FR59x9 | MSP430FR59x8 | MSP430FR59x7 |
|---|---|---|---|---|
| Memory (FRAM)<br>Main: interrupt vectors and signatures<br>Main: code memory | Total Size | 63KB<br>00FFFFh to 00FF80h<br>013FFFh to 004400h | 47KB<br>00FFFFh to 00FF80h<br>00FF7Fh to 004400h | 32KB<br>00FFFFh to 00FF80h<br>00FF7Fh to 008000h |
| RAM | | 2KB<br>0023FFh to 001C00h | 2KB<br>0023FFh to 001C00h | 1KB<br>001FFFh to 001C00h |
| Device Descriptor Info (TLV) (FRAM) | | 256 B<br>001AFFh to 001A00h | 256 B<br>001AFFh to 001A00h | 256 B<br>001AFFh to 001A00h |
| Information memory (FRAM) | Info A | 128 B<br>0019FFh to 001980h | 128 B<br>0019FFh to 001980h | 128 B<br>0019FFh to 001980h |
| | Info B | 128 B<br>00197Fh to 001900h | 128 B<br>00197Fh to 001900h | 128 B<br>00197Fh to 001900h |
| | Info C | 128 B<br>0018FFh to 001880h | 128 B<br>0018FFh to 001880h | 128 B<br>0018FFh to 001880h |
| | Info D | 128 B<br>00187Fh to 001800h | 128 B<br>00187Fh to 001800h | 128 B<br>00187Fh to 001800h |
| Bootloader (BSL) memory (ROM) | BSL 3 | 512 B<br>0017FFh to 001600h | 512 B<br>0017FFh to 001600h | 512 B<br>0017FFh to 001600h |
| | BSL 2 | 512 B<br>0015FFh to 001400h | 512 B<br>0015FFh to 001400h | 512 B<br>0015FFh to 001400h |
| | BSL 1 | 512 B<br>0013FFh to 001200h | 512 B<br>0013FFh to 001200h | 512 B<br>0013FFh to 001200h |
| | BSL 0 | 512 B<br>0011FFh to 001000h | 512 B<br>0011FFh to 001000h | 512 B<br>0011FFh to 001000h |
| Peripherals | Size | 4KB<br>000FFFh to 0h | 4KB<br>000FFFh to 0h | 4KB<br>000FFFh to 0h |

(1) All address space not listed is considered vacant memory.

## 6.6 Bootloader (BSL)

The BSL enables users to program the FRAM or RAM using a UART serial interface (FRxxxx devices) or an $I^2C$ interface (FRxxxx1 devices). Access to the device memory through the BSL is protected by an user-defined password. Table 6-7 list the BSL pins requirements. BSL entry requires a specific entry sequence on the $\overline{RST}$/NMI/SBWTDIO and TEST/SBWTCK pins. For a complete description of the features of the BSL and its implementation, see the *MSP430 FRAM Device Bootloader (BSL) User's Guide*.

**Table 6-7. BSL Pin Requirements and Functions**

| DEVICE SIGNAL | BSL FUNCTION |
|---|---|
| $\overline{RST}$/NMI/SBWTDIO | Entry sequence signal |
| TEST/SBWTCK | Entry sequence signal |
| P2.0 | Devices with UART BSL (FRxxxx): Data transmit |
| P2.1 | Devices with UART BSL (FRxxxx): Data receive |
| P1.6 | Devices with $I^2C$ BSL (FRxxxx1): Data |
| P1.7 | Devices with $I^2C$ BSL (FRxxxx1): Clock |
| VCC | Power supply |
| VSS | Ground supply |


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## 6.7 JTAG Operation

### 6.7.1 JTAG Standard Interface

The MSP430 family supports the standard JTAG interface which requires four signals for sending and receiving data. The JTAG signals are shared with general-purpose I/O. The TEST/SBWTCK pin is used to enable the JTAG signals. In addition to these signals, the RST/NMI/SBWTDIO is required to interface with MSP430 development tools and device programmers. Table 6-8 lists the JTAG pin requirements. For further details on interfacing to development tools and device programmers, see the *MSP430 Hardware Tools User's Guide*. For a complete description of the features of the JTAG interface and its implementation, see *MSP430 Programming With the JTAG Interface*.

**Table 6-8. JTAG Pin Requirements and Functions**

| DEVICE SIGNAL | DIRECTION | FUNCTION |
|---|---|---|
| PJ.3/TCK | IN | JTAG clock input |
| PJ.2/TMS | IN | JTAG state control |
| PJ.1/TDI/TCLK | IN | JTAG data input, TCLK input |
| PJ.0/TDO | OUT | JTAG data output |
| TEST/SBWTCK | IN | Enable JTAG pins |
| RST/NMI/SBWTDIO | IN | External reset |
| VCC | | Power supply |
| VSS | | Ground supply |

### 6.7.2 Spy-Bi-Wire Interface

In addition to the standard JTAG interface, the MSP430 family supports the 2-wire Spy-Bi-Wire interface. Spy-Bi-Wire can be used to interface with MSP430 development tools and device programmers. Table 6-9 lists the Spy-Bi-Wire interface pin requirements. For further details on interfacing to development tools and device programmers, see the *MSP430 Hardware Tools User's Guide*. For a complete description of the features of the JTAG interface and its implementation, see *MSP430 Programming With the JTAG Interface*.

**Table 6-9. Spy-Bi-Wire Pin Requirements and Functions**

| DEVICE SIGNAL | DIRECTION | FUNCTION |
|---|---|---|
| TEST/SBWTCK | IN | Spy-Bi-Wire clock input |
| RST/NMI/SBWTDIO | IN, OUT | Spy-Bi-Wire data input and output |
| VCC | | Power supply |
| VSS | | Ground supply |

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## 6.8 FRAM

The FRAM can be programmed through the JTAG port, Spy-Bi-Wire (SBW), the BSL, or in-system by the CPU. Features of the FRAM include:

- Ultra-low-power ultra-fast-write nonvolatile memory
- Byte and word access capability
- Programmable wait state generation
- Error correction coding (ECC)

**NOTE**

**Wait States**

For MCLK frequencies > 8 MHz, wait states must be configured following the flow described in the *Wait State Control* section of the *FRAM Controller (FRCTRL)* chapter in the *MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide*.

For important software design information regarding FRAM including but not limited to partitioning the memory layout according to application-specific code, constant, and data space requirements, the use of FRAM to optimize application energy consumption, and the use of the Memory Protection Unit (MPU) to maximize application robustness by protecting the program code against unintended write accesses, see *MSP430™ FRAM Technology – How To and Best Practices*.

## 6.9 Memory Protection Unit Including IP Encapsulation

The FRAM can be protected from inadvertent CPU execution, read access, or write access by the MPU. Features of the MPU include:

- IP encapsulation with programmable boundaries in steps of 1KB (prevents reads from "outside"; for example, JTAG or non-IP software).
- Main memory partitioning is programmable up to three segments in steps of 1KB.
- Each segment's access rights can be individually selected (main and information memory).
- Access violation flags with interrupt capability for easy servicing of access violations.


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## 6.10 Peripherals

Peripherals are connected to the CPU through data, address, and control buses. Peripherals can be handled using all instructions. For complete module descriptions, see the *MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide*.

### 6.10.1 Digital I/O

Up to four 8-bit I/O ports are implemented:

- All individual I/O bits are independently programmable.
- Any combination of input, output, and interrupt conditions is possible.
- Programmable pullup or pulldown on all ports.
- Edge-selectable interrupt and LPM3.5 and LPM4.5 wake-up input capability is available for all ports.
- Read and write access to port control registers is supported by all instructions.
- Ports can be accessed byte-wise or word-wise in pairs.
- All pins of ports P1, P2, P3, P4, and PJ support Capacitive Touch I/O functionality.
- No cross-currents during start-up.

**NOTE**

**Configuration of Digital I/Os After BOR Reset**

To prevent any cross currents during start-up of the device, all port pins are high-impedance with Schmitt triggers, and their module functions disabled. To enable the I/O functionality after a BOR reset, the ports must be configured first and then the LOCKLPM5 bit must be cleared. For details, see the *Configuration After Reset* section of the *Digital I/O* chapter in the *MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide*.

### 6.10.2 Oscillator and Clock System (CS)

The clock system includes support for a 32-kHz watch-crystal oscillator (XT1), an internal very-low-power low-frequency oscillator (VLO), an integrated internal digitally controlled oscillator (DCO), and a high-frequency crystal oscillator XT2. The clock system module is designed to meet the requirements of both low system cost and low power consumption. A fail-safe mechanism exists for all crystal sources. The clock system module provides the following clock signals:

- Auxiliary clock (ACLK). ACLK can be sourced from a 32-kHz watch crystal (LFXT1), the internal low-frequency oscillator (VLO), or a digital external low-frequency (<50 kHz) clock source.
- Main clock (MCLK), the system clock used by the CPU. MCLK can be sourced from a high-frequency crystal (HFXT2), the internal digitally controlled oscillator DCO, a 32-kHz watch crystal (LFXT1), the internal low-frequency oscillator (VLO), or a digital external clock source.
- Sub-Main clock (SMCLK), the subsystem clock used by the peripheral modules. SMCLK can be sourced by same sources made available to MCLK.

### 6.10.3 Power-Management Module (PMM)

The primary functions of the PMM are:

- Supply regulated voltages to the core logic
- Supervise voltages that are connected to the device (at DVCC pins)
- Give reset signals to the device during power on and power off

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### 6.10.4 Hardware Multiplier (MPY)

The multiplication operation is supported by a dedicated peripheral module. The module performs operations with 32-, 24-, 16-, and 8-bit operands. The module supports signed multiplication, unsigned multiplication, signed multiply-and-accumulate, and unsigned multiply-and-accumulate operations.

### 6.10.5 Real-Time Clock (RTC_B) (Only MSP430FR596x and MSP430FR594x)

The RTC_B module contains an integrated real-time clock (RTC). The RTC integrates an internal calendar that compensates for months with less than 31 days and includes leap year correction. The RTC_B also supports flexible alarm functions and offset-calibration hardware. RTC operation is available in LPM3.5 modes to minimize power consumption.

### 6.10.6 Watchdog Timer (WDT_A)

The primary function of the WDT_A module is to perform a controlled system restart if a software problem occurs. If the selected time interval expires, a system reset is generated. If the watchdog function is not needed in an application, the module can be configured as an interval timer and can generate interrupts at selected time intervals. Table 6-10 lists the clock sources for the WDT_A module.

**Table 6-10. WDT_A Clocks**

| WDTSSEL | NORMAL OPERATION (WATCHDOG AND INTERVAL TIMER MODE) |
|---|---|
| 00 | SMCLK |
| 01 | ACLK |
| 10 | VLOCLK |
| 11 | LFMODCLK |

### 6.10.7 System Module (SYS)

The SYS module manages many of the system functions within the device. These system functions include power on reset (POR) and power up clear (PUC) handling, NMI source selection and management, reset interrupt vector generators, bootloader (BSL) entry mechanisms, and configuration management (device descriptors). The SYS module also includes a data exchange mechanism through JTAG called a JTAG mailbox that can be used in the application. Table 6-11 lists the SYS module interrupt vector registers.


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**Table 6-11. System Module Interrupt Vector Registers**

| INTERRUPT VECTOR REGISTER | ADDRESS | INTERRUPT EVENT | VALUE | PRIORITY |
|---|---|---|---|---|
| SYSRSTIV, System Reset | 019Eh | No interrupt pending | 00h | |
| | | Brownout (BOR) | 02h | Highest |
| | | RSTIFG $\overline{\text{RST}}$/NMI (BOR) | 04h | |
| | | PMMSWBOR software BOR (BOR) | 06h | |
| | | LPMx.5 wakeup (BOR) | 08h | |
| | | Security violation (BOR) | 0Ah | |
| | | Reserved | 0Ch | |
| | | SVSHIFG SVSH event (BOR) | 0Eh | |
| | | Reserved | 10h | |
| | | Reserved | 12h | |
| | | PMMSWPOR software POR (POR) | 14h | |
| | | WDTIFG watchdog time-out (PUC) | 16h | |
| | | WDTPW password violation (PUC) | 18h | |
| | | FRCTLPW password violation (PUC) | 1Ah | |
| | | Uncorrectable FRAM bit error detection (PUC) | 1Ch | |
| | | Peripheral area fetch (PUC) | 1Eh | |
| | | PMMPW PMM password violation (PUC) | 20h | |
| | | MPUPW MPU password violation (PUC) | 22h | |
| | | CSPW CS password violation (PUC) | 24h | |
| | | MPUSEGPIFG encapsulated IP memory segment violation (PUC) | 26h | |
| | | MPUSEGIIFG information memory segment violation (PUC) | 28h | |
| | | MPUSEG1IFG segment 1 memory violation (PUC) | 2Ah | |
| | | MPUSEG2IFG segment 2 memory violation (PUC) | 2Ch | |
| | | MPUSEG3IFG segment 3 memory violation (PUC) | 2Eh | |
| | | ACCTEIFG access time error (PUC) (1) | 30h | |
| | | Reserved | 32h to 3Eh | Lowest |
| SYSSNIV, System NMI | 019Ch | No interrupt pending | 00h | |
| | | Reserved | 02h | Highest |
| | | Uncorrectable FRAM bit error detection | 04h | |
| | | Reserved | 06h | |
| | | MPUSEGPIFG encapsulated IP memory segment violation | 08h | |
| | | MPUSEGIIFG information memory segment violation | 0Ah | |
| | | MPUSEG1IFG segment 1 memory violation | 0Ch | |
| | | MPUSEG2IFG segment 2 memory violation | 0Eh | |
| | | MPUSEG3IFG segment 3 memory violation | 10h | |
| | | VMAIFG vacant memory access | 12h | |
| | | JMBINIFG JTAG mailbox input | 14h | |
| | | JMBOUTIFG JTAG mailbox output | 16h | |
| | | Correctable FRAM bit error detection | 18h | |
| | | Reserved | 1Ah to 1Eh | Lowest |

(1) Indicates incorrect wait state settings.

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**Table 6-11. System Module Interrupt Vector Registers (continued)**

| INTERRUPT VECTOR REGISTER | ADDRESS | INTERRUPT EVENT | VALUE | PRIORITY |
|---|---|---|---|---|
| SYSUNIV, User NMI | 019Ah | No interrupt pending | 00h | |
| | | NMIIFG NMI pin | 02h | Highest |
| | | OFIFG oscillator fault | 04h | |
| | | Reserved | 06h | |
| | | Reserved | 08h | |
| | | Reserved | 0Ah to 1Eh | Lowest |

### 6.10.8 DMA Controller

The DMA controller allows movement of data from one memory address to another without CPU intervention. For example, the DMA controller can be used to move data from the ADC12_B conversion memory to RAM. Using the DMA controller can increase the throughput of peripheral modules. The DMA controller reduces system power consumption by allowing the CPU to remain in sleep mode, without having to wake to move data to or from a peripheral. Table 6-12 lists the available triggers for the DMA.

**Table 6-12. DMA Trigger Assignments(1)**

| TRIGGER | CHANNEL 0 | CHANNEL 1 | CHANNEL 2 |
|---|---|---|---|
| 0 | DMAREQ | DMAREQ | DMAREQ |
| 1 | TA0CCR0 CCIFG | TA0CCR0 CCIFG | TA0CCR0 CCIFG |
| 2 | TA0CCR2 CCIFG | TA0CCR2 CCIFG | TA0CCR2 CCIFG |
| 3 | TA1CCR0 CCIFG | TA1CCR0 CCIFG | TA1CCR0 CCIFG |
| 4 | TA1CCR2 CCIFG | TA1CCR2 CCIFG | TA1CCR2 CCIFG |
| 5 | TA2CCR0 CCIFG | TA2CCR0 CCIFG | TA2CCR0 CCIFG |
| 6 | TA3CCR0 CCIFG | TA3CCR0 CCIFG | TA3CCR0 CCIFG |
| 7 | TB0CCR0 CCIFG | TB0CCR0 CCIFG | TB0CCR0 CCIFG |
| 8 | TB0CCR2 CCIFG | TB0CCR2 CCIFG | TB0CCR2 CCIFG |
| 9 | Reserved | Reserved | Reserved |
| 10 | Reserved | Reserved | Reserved |
| 11 | AES Trigger 0 | AES Trigger 0 | AES Trigger 0 |
| 12 | AES Trigger 1 | AES Trigger 1 | AES Trigger 1 |
| 13 | AES Trigger 2 | AES Trigger 2 | AES Trigger 2 |
| 14 | UCA0RXIFG | UCA0RXIFG | UCA0RXIFG |
| 15 | UCA0TXIFG | UCA0TXIFG | UCA0TXIFG |
| 16 | UCA1RXIFG | UCA1RXIFG | UCA1RXIFG |
| 17 | UCA1TXIFG | UCA1TXIFG | UCA1TXIFG |
| 18 | UCB0RXIFG (SPI)<br>UCB0RXIFG0 ($I^2C$) | UCB0RXIFG (SPI)<br>UCB0RXIFG0 ($I^2C$) | UCB0RXIFG (SPI)<br>UCB0RXIFG0 ($I^2C$) |
| 19 | UCB0TXIFG (SPI)<br>UCB0TXIFG0 ($I^2C$) | UCB0TXIFG (SPI)<br>UCB0TXIFG0 ($I^2C$) | UCB0TXIFG (SPI)<br>UCB0TXIFG0 ($I^2C$) |
| 20 | UCB0RXIFG1 ($I^2C$) | UCB0RXIFG1 ($I^2C$) | UCB0RXIFG1 ($I^2C$) |
| 21 | UCB0TXIFG1 ($I^2C$) | UCB0TXIFG1 ($I^2C$) | UCB0TXIFG1 ($I^2C$) |
| 22 | UCB0RXIFG2 ($I^2C$) | UCB0RXIFG2 ($I^2C$) | UCB0RXIFG2 ($I^2C$) |
| 23 | UCB0TXIFG2 ($I^2C$) | UCB0TXIFG2 ($I^2C$) | UCB0TXIFG2 ($I^2C$) |
| 24 | UCB0RXIFG3 ($I^2C$) | UCB0RXIFG3 ($I^2C$) | UCB0RXIFG3 ($I^2C$) |
| 25 | UCB0TXIFG3 ($I^2C$) | UCB0TXIFG3 ($I^2C$) | UCB0TXIFG3 ($I^2C$) |
| 26 | ADC12 end of conversion | ADC12 end of conversion | ADC12 end of conversion |
| 27 | Reserved | Reserved | Reserved |

(1) If a reserved trigger source is selected, no trigger is generated.


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**Table 6-12. DMA Trigger Assignments[(1)] (continued)**

| TRIGGER | CHANNEL 0 | CHANNEL 1 | CHANNEL 2 |
|---|---|---|---|
| 28 | Reserved | Reserved | Reserved |
| 29 | MPY ready | MPY ready | MPY ready |
| 30 | DMA2IFG | DMA0IFG | DMA1IFG |
| 31 | DMAE0 | DMAE0 | DMAE0 |

### 6.10.9 Enhanced Universal Serial Communication Interface (eUSCI)

The eUSCI modules are used for serial data communication. The eUSCI module supports synchronous communication protocols such as SPI (3 or 4 pin) and $I^2C$, and asynchronous communication protocols such as UART, enhanced UART with automatic baudrate detection, and IrDA.

The eUSCI_An module provides support for SPI (3 or 4 pin), UART, enhanced UART, and IrDA.

The eUSCI_Bn module provides support for SPI (3 or 4 pin) and $I^2C$.

Two eUSCI_A modules and one eUSCI_B module are implemented.

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### 6.10.10 TA0, TA1

TA0 and TA1 are 16-bit timers and counters (Timer_A type) with three capture/compare registers each. TA0 and TA can support multiple captures or compares, PWM outputs, and interval timing (see Table 6-13 and Table 6-14). TA0 and TA have extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each of the capture/compare registers.

**Table 6-13. TA0 Signal Connections**

| INPUT PORT PIN | DEVICE INPUT SIGNAL | MODULE INPUT SIGNAL | MODULE BLOCK | MODULE OUTPUT SIGNAL | DEVICE OUTPUT SIGNAL | OUTPUT PORT PIN |
|---|---|---|---|---|---|---|
| P1.2 | TA0CLK | TACLK | Timer | N/A | N/A | |
| | ACLK (internal) | ACLK | | | | |
| | SMCLK (internal) | SMCLK | | | | |
| P1.2 | $\overline{\text{TA0CLK}}$ | INCLK | | | | |
| P1.6 | TA0.0 | CCI0A | CCR0 | TA0 | TA0.0 | P1.6 |
| P2.3 | TA0.0 | CCI0B | | | | P2.3 |
| | DVSS | GND | | | | |
| | DVCC | $V_{CC}$ | | | | |
| P1.0 | TA0.1 | CCI1A | CCR1 | TA1 | TA0.1 | P1.0 |
| | COUT (internal) | CCI1B | | | | ADC12(internal) ADC12SHSx = {1} |
| | DVSS | GND | | | | |
| | DVCC | $V_{CC}$ | | | | |
| P1.1 | TA0.2 | CCI2A | CCR2 | TA2 | TA0.2 | P1.1 |
| | ACLK (internal) | CCI2B | | | | |
| | DVSS | GND | | | | |
| | DVCC | $V_{CC}$ | | | | |

**Table 6-14. TA1 Signal Connections**

| INPUT PORT PIN | DEVICE INPUT SIGNAL | MODULE INPUT SIGNAL | MODULE BLOCK | MODULE OUTPUT SIGNAL | DEVICE OUTPUT SIGNAL | OUTPUT PORT PIN |
|---|---|---|---|---|---|---|
| P1.1 | TA1CLK | TACLK | Timer | N/A | N/A | |
| | ACLK (internal) | ACLK | | | | |
| | SMCLK (internal) | SMCLK | | | | |
| P1.1 | $\overline{\text{TA1CLK}}$ | INCLK | | | | |
| P1.7 | TA1.0 | CCI0A | CCR0 | TA0 | TA1.0 | P1.7 |
| P2.4 | TA1.0 | CCI0B | | | | P2.4 |
| | DVSS | GND | | | | |
| | DVCC | $V_{CC}$ | | | | |
| P1.2 | TA1.1 | CCI1A | CCR1 | TA1 | TA1.1 | P1.2 |
| | COUT (internal) | CCI1B | | | | ADC12(internal) ADC12SHSx = {4} |
| | DVSS | GND | | | | |
| | DVCC | $V_{CC}$ | | | | |
| P1.3 | TA1.2 | CCI2A | CCR2 | TA2 | TA1.2 | P1.3 |
| | ACLK (internal) | CCI2B | | | | |
| | DVSS | GND | | | | |
| | DVCC | $V_{CC}$ | | | | |


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### 6.10.11 TA2, TA3

TA2 and TA3 are 16-bit timers and counters (Timer_A type) with two capture/compare registers each and with internal connections only. TA2 and TA3 can support multiple captures or compares, PWM outputs, and interval timing (see Table 6-15 and Table 6-16). TA2 and TA3 have extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each of the capture/compare registers.

**Table 6-15. TA2 Signal Connections**

| DEVICE INPUT SIGNAL | MODULE INPUT NAME | MODULE BLOCK | MODULE OUTPUT SIGNAL | DEVICE OUTPUT SIGNAL |
|---|---|---|---|---|
| COUT (internal) | TACLK | Timer | N/A | |
| ACLK (internal) | ACLK | | | |
| SMCLK (internal) | SMCLK | | | |
| From Capacitive Touch I/O 0 (internal) | INCLK | | | |
| TA3 CCR0 output (internal) | CCI0A | CCR0 | TA0 | TA3 CCI0A input |
| ACLK (internal) | CCI0B | | | |
| DVSS | GND | | | |
| DVCC | $V_{CC}$ | | | |
| From Capacitive Touch I/O 0 (internal) | CCI1A | CCR1 | TA1 | ADC12(internal) ADC12SHSx = {5} |
| COUT (internal) | CCI1B | | | |
| DVSS | GND | | | |
| DVCC | $V_{CC}$ | | | |

**Table 6-16. TA3 Signal Connections**

| DEVICE INPUT SIGNAL | MODULE INPUT NAME | MODULE BLOCK | MODULE OUTPUT SIGNAL | DEVICE OUTPUT SIGNAL |
|---|---|---|---|---|
| COUT (internal) | TACLK | Timer | N/A | |
| ACLK (internal) | ACLK | | | |
| SMCLK (internal) | SMCLK | | | |
| From Capacitive Touch I/O 1 (internal) | INCLK | | | |
| TA2 CCR0 output (internal) | CCI0A | CCR0 | TA0 | TA2 CCI0A input |
| ACLK (internal) | CCI0B | | | |
| DVSS | GND | | | |
| DVCC | $V_{CC}$ | | | |
| From Capacitive Touch I/O 1 (internal) | CCI1A | CCR1 | TA1 | ADC12(internal) ADC12SHSx = {6} |
| COUT (internal) | CCI1B | | | |
| DVSS | GND | | | |
| DVCC | $V_{CC}$ | | | |

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### 6.10.12 TB0

TB0 is a 16-bit timer and counter (Timer_B type) with seven capture/compare registers. TB0 can support multiple captures or compares, PWM outputs, and interval timing (see Table 6-17). TB0 has extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each of the capture/compare registers.

**Table 6-17. TB0 Signal Connections**

| INPUT PORT PIN | DEVICE INPUT SIGNAL | MODULE INPUT SIGNAL | MODULE BLOCK | MODULE OUTPUT SIGNAL | DEVICE OUTPUT SIGNAL | OUTPUT PORT PIN |
|---|---|---|---|---|---|---|
| P2.0 | TB0CLK | TBCLK | Timer | N/A | N/A | |
| | ACLK (internal) | ACLK | | | | |
| | SMCLK (internal) | SMCLK | | | | |
| P2.0 | $\overline{\text{TB0CLK}}$ | INCLK | | | | |
| P2.1 | TB0.0 | CCI0A | CCR0 | TB0 | TB0.0 | P2.1 |
| P2.5 | TB0.0 | CCI0B | | | | P2.5 |
| | DVSS | GND | | | | ADC12 (internal) ADC12SHSx = {2} |
| | DVCC | $V_{CC}$ | | | | |
| P1.4 | TB0.1 | CCI1A | CCR1 | TB1 | TB0.1 | P1.4 |
| | COUT (internal) | CCI1B | | | | P2.6 |
| | DVSS | GND | | | | ADC12 (internal) ADC12SHSx = {3} |
| | DVCC | $V_{CC}$ | | | | |
| P1.5 | TB0.2 | CCI2A | CCR2 | TB2 | TB0.2 | P1.5 |
| | ACLK (internal) | CCI2B | | | | P2.2 |
| | DVSS | GND | | | | |
| | DVCC | $V_{CC}$ | | | | |
| P3.4 | TB0.3 | CCI3A | CCR3 | TB3 | TB0.3 | P3.4 |
| P1.6 | TB0.3 | CCI3B | | | | P1.6 |
| | DVSS | GND | | | | |
| | DVCC | $V_{CC}$ | | | | |
| P3.5 | TB0.4 | CCI4A | CCR4 | TB4 | TB0.4 | P3.5 |
| P1.7 | TB0.4 | CCI4B | | | | P1.7 |
| | DVSS | GND | | | | |
| | DVCC | $V_{CC}$ | | | | |
| P3.6 | TB0.5 | CCI5A | CCR5 | TB5 | TB0.5 | P3.6 |
| P4.4 | TB0.5 | CCI5B | | | | P4.4 |
| | DVSS | GND | | | | |
| | DVCC | $V_{CC}$ | | | | |
| P3.7 | TB0.6 | CCI6A | CCR6 | TB6 | TB0.6 | P3.7 |
| P2.0 | TB0.6 | CCI6B | | | | P2.0 |
| | DVSS | GND | | | | |
| | DVCC | $V_{CC}$ | | | | |


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### 6.10.13 ADC12_B

The ADC12_B module supports fast 12-bit analog-to-digital conversions with differential and single-ended inputs. The module implements a 12-bit SAR core, sample select control, reference generator, and a conversion result buffer. A window comparator with lower and upper limits allows CPU-independent result monitoring with three window comparator interrupt flags.

Table 6-18 lists the external trigger sources.

**Table 6-18. ADC12_B Trigger Signal Connections**

| ADC12SHSx | | CONNECTED TRIGGER SOURCE |
|---|---|---|
| BINARY | DECIMAL | |
| 000 | 0 | Software (ADC12SC) |
| 001 | 1 | TA0 CCR1 output |
| 010 | 2 | TB0 CCR0 output |
| 011 | 3 | TB0 CCR1 output |
| 100 | 4 | TA1 CCR1 output |
| 101 | 5 | TA2 CCR1 output |
| 110 | 6 | TA3 CCR1 output |
| 111 | 7 | Reserved (DVSS) |

Table 6-19 lists the available multiplexing between internal and external analog inputs.

**Table 6-19. ADC12_B External and Internal Signal Mapping**

| CONTROL BIT IN ADC12CTL3 REGISTER | EXTERNAL ADC INPUT (CONTROL BIT = 0) | INTERNAL ADC INPUT (CONTROL BIT = 1) |
|---|---|---|
| ADC12BATMAP | A31 | Battery monitor |
| ADC12TCMAP | A30 | Temperature sensor |
| ADC12CH0MAP | A29 | N/A(1) |
| ADC12CH1MAP | A28 | N/A(1) |
| ADC12CH2MAP | A27 | N/A(1) |
| ADC12CH3MAP | A26 | N/A(1) |

(1) N/A = No internal signal is available on this device.

### 6.10.14 Comparator_E

The primary function of the Comparator_E module is to support precision slope analog-to-digital conversions, battery voltage supervision, and monitoring of external analog signals.

### 6.10.15 CRC16

The CRC16 module produces a signature based on a sequence of entered data values and can be used for data checking. The CRC16 module signature is based on the CRC-CCITT standard.

### 6.10.16 AES256 Accelerator

The AES accelerator module performs encryption and decryption of 128-bit data with 128-, 192-, or 256-bit keys according to the Advanced Encryption Standard (AES) (FIPS PUB 197) in hardware.

### 6.10.17 True Random Seed

The Device Descriptor (TLV) (see Section 6.12) contains a 128-bit true random seed that can be used to implement a deterministic random number generator.

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### 6.10.18 Shared Reference (REF)

The REF module generates all of the critical reference voltages that can be used by the various analog peripherals in the device.

### 6.10.19 Embedded Emulation

#### 6.10.19.1 Embedded Emulation Module (EEM)

The EEM supports real-time in-system debugging. The S version of the EEM has the following features:

- Three hardware triggers or breakpoints on memory access
- One hardware trigger or breakpoint on CPU register write access
- Up to four hardware triggers that can be combined to form complex triggers or breakpoints
- One cycle counter
- Clock control on module level

#### 6.10.19.2 EnergyTrace++ Technology

The devices implement circuitry to support EnergyTrace++ technology. The EnergyTrace++ technology allows you to observe information about the internal states of the microcontroller. These states include the CPU Program Counter (PC), the ON or OFF status of the peripherals and the system clocks (regardless of the clock source), and the low-power mode currently in use. These states can always be read by a debug tool, even when the microcontroller sleeps in LPMx.5 modes.

The activity of the following modules can be observed:

- MPY is calculating.
- WDT is counting.
- RTC is counting.
- ADC: a sequence, sample, or conversion is active.
- REF: REFBG or REFGEN active and BG in static mode.
- COMP is on.
- AES is encrypting or decrypting.
- eUSCI_A0 is transferring (receiving or transmitting) data.
- eUSCI_A1 is transferring (receiving or transmitting) data.
- eUSCI_B0 is transferring (receiving or transmitting) data.
- TB0 is counting.
- TA0 is counting.
- TA1 is counting.
- TA2 is counting.
- TA3 is counting.


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### 6.10.20 Peripheral File Map

Table 6-20 lists the base address for each peripheral. For complete module register descriptions, see the *MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide*.

**Table 6-20. Peripherals**

| MODULE NAME | BASE ADDRESS | OFFSET ADDRESS RANGE |
|---|---|---|
| Special Functions (see Table 6-21) | 0100h | 000h to 01Fh |
| PMM (see Table 6-22) | 0120h | 000h to 01Fh |
| FRAM Control (see Table 6-23) | 0140h | 000h to 00Fh |
| CRC16 (see Table 6-24) | 0150h | 000h to 007h |
| Watchdog (see Table 6-25) | 015Ch | 000h to 001h |
| CS (see Table 6-26) | 0160h | 000h to 00Fh |
| SYS (see Table 6-27) | 0180h | 000h to 01Fh |
| Shared Reference (see Table 6-28) | 01B0h | 000h to 001h |
| Port P1, P2 (see Table 6-29) | 0200h | 000h to 01Fh |
| Port P3, P4 (see Table 6-30) | 0220h | 000h to 01Fh |
| Port PJ (see Table 6-31) | 0320h | 000h to 01Fh |
| TA0 (see Table 6-32) | 0340h | 000h to 02Fh |
| TA1 (see Table 6-33) | 0380h | 000h to 02Fh |
| TB0 (see Table 6-34) | 03C0h | 000h to 02Fh |
| TA2 (see Table 6-35) | 0400h | 000h to 02Fh |
| Capacitive Touch I/O 0 (see Table 6-36) | 0430h | 000h to 00Fh |
| TA3 (see Table 6-37) | 0440h | 000h to 02Fh |
| Capacitive Touch I/O 1 (see Table 6-38) | 0470h | 000h to 00Fh |
| Real-Time Clock (RTC_B) (see Table 6-39) | 04A0h | 000h to 01Fh |
| 32-Bit Hardware Multiplier (see Table 6-40) | 04C0h | 000h to 02Fh |
| DMA General Control (see Table 6-41) | 0500h | 000h to 00Fh |
| DMA Channel 0 (see Table 6-41) | 0510h | 000h to 00Fh |
| DMA Channel 1 (see Table 6-41) | 0520h | 000h to 00Fh |
| DMA Channel 2 (see Table 6-41) | 0530h | 000h to 00Fh |
| MPU Control (see Table 6-42) | 05A0h | 000h to 00Fh |
| eUSCI_A0 (see Table 6-43) | 05C0h | 000h to 01Fh |
| eUSCI_A1 (see Table 6-44) | 05E0h | 000h to 01Fh |
| eUSCI_B0 (see Table 6-45) | 0640h | 000h to 02Fh |
| ADC12_B (see Table 6-46) | 0800h | 000h to 09Fh |
| Comparator_E (see Table 6-47) | 08C0h | 000h to 00Fh |
| AES (see Table 6-48) | 09C0h | 000h to 00Fh |

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**Table 6-21. Special Function Registers (Base Address: 0100h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| SFR interrupt enable | SFRIE1 | 00h |
| SFR interrupt flag | SFRIFG1 | 02h |
| SFR reset pin control | SFRRPCR | 04h |

**Table 6-22. PMM Registers (Base Address: 0120h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| PMM control 0 | PMMCTL0 | 00h |
| PMM interrupt flags | PMMIFG | 0Ah |
| PM5 control 0 | PM5CTL0 | 10h |

**Table 6-23. FRAM Control Registers (Base Address: 0140h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| FRAM control 0 | FRCTL0 | 00h |
| General control 0 | GCCTL0 | 04h |
| General control 1 | GCCTL1 | 06h |

**Table 6-24. CRC16 Registers (Base Address: 0150h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| CRC data input | CRC16DI | 00h |
| CRC data input reverse byte | CRCDIRB | 02h |
| CRC initialization and result | CRCINIRES | 04h |
| CRC result reverse byte | CRCRESR | 06h |

**Table 6-25. Watchdog Registers (Base Address: 015Ch)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| Watchdog timer control | WDTCTL | 00h |

**Table 6-26. CS Registers (Base Address: 0160h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| CS control 0 | CSCTL0 | 00h |
| CS control 1 | CSCTL1 | 02h |
| CS control 2 | CSCTL2 | 04h |
| CS control 3 | CSCTL3 | 06h |
| CS control 4 | CSCTL4 | 08h |
| CS control 5 | CSCTL5 | 0Ah |
| CS control 6 | CSCTL6 | 0Ch |

**Table 6-27. SYS Registers (Base Address: 0180h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| System control | SYSCTL | 00h |
| JTAG mailbox control | SYSJMBC | 06h |
| JTAG mailbox input 0 | SYSJMBI0 | 08h |
| JTAG mailbox input 1 | SYSJMBI1 | 0Ah |
| JTAG mailbox output 0 | SYSJMBO0 | 0Ch |
| JTAG mailbox output 1 | SYSJMBO1 | 0Eh |


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**Table 6-27. SYS Registers (Base Address: 0180h) (continued)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| User NMI vector generator | SYSUNIV | 1Ah |
| System NMI vector generator | SYSSNIV | 1Ch |
| Reset vector generator | SYSRSTIV | 1Eh |

**Table 6-28. Shared Reference Registers (Base Address: 01B0h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| Shared reference control | REFCTL | 00h |

**Table 6-29. Port P1, P2 Registers (Base Address: 0200h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| Port P1 input | P1IN | 00h |
| Port P1 output | P1OUT | 02h |
| Port P1 direction | P1DIR | 04h |
| Port P1 resistor enable | P1REN | 06h |
| Port P1 selection 0 | P1SEL0 | 0Ah |
| Port P1 selection 1 | P1SEL1 | 0Ch |
| Port P1 interrupt vector word | P1IV | 0Eh |
| Port P1 complement selection | P1SELC | 16h |
| Port P1 interrupt edge select | P1IES | 18h |
| Port P1 interrupt enable | P1IE | 1Ah |
| Port P1 interrupt flag | P1IFG | 1Ch |
| Port P2 input | P2IN | 01h |
| Port P2 output | P2OUT | 03h |
| Port P2 direction | P2DIR | 05h |
| Port P2 resistor enable | P2REN | 07h |
| Port P2 selection 0 | P2SEL0 | 0Bh |
| Port P2 selection 1 | P2SEL1 | 0Dh |
| Port P2 complement selection | P2SELC | 17h |
| Port P2 interrupt vector word | P2IV | 1Eh |
| Port P2 interrupt edge select | P2IES | 19h |
| Port P2 interrupt enable | P2IE | 1Bh |
| Port P2 interrupt flag | P2IFG | 1Dh |

**Table 6-30. Port P3, P4 Registers (Base Address: 0220h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| Port P3 input | P3IN | 00h |
| Port P3 output | P3OUT | 02h |
| Port P3 direction | P3DIR | 04h |
| Port P3 resistor enable | P3REN | 06h |
| Port P3 selection 0 | P3SEL0 | 0Ah |
| Port P3 selection 1 | P3SEL1 | 0Ch |
| Port P3 interrupt vector word | P3IV | 0Eh |
| Port P3 complement selection | P3SELC | 16h |
| Port P3 interrupt edge select | P3IES | 18h |
| Port P3 interrupt enable | P3IE | 1Ah |
| Port P3 interrupt flag | P3IFG | 1Ch |

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**Table 6-30. Port P3, P4 Registers (Base Address: 0220h) (continued)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| Port P4 input | P4IN | 01h |
| Port P4 output | P4OUT | 03h |
| Port P4 direction | P4DIR | 05h |
| Port P4 resistor enable | P4REN | 07h |
| Port P4 selection 0 | P4SEL0 | 0Bh |
| Port P4 selection 1 | P4SEL1 | 0Dh |
| Port P4 complement selection | P4SELC | 17h |
| Port P4 interrupt vector word | P4IV | 1Eh |
| Port P4 interrupt edge select | P4IES | 19h |
| Port P4 interrupt enable | P4IE | 1Bh |
| Port P4 interrupt flag | P4IFG | 1Dh |

**Table 6-31. Port J Registers (Base Address: 0320h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| Port PJ input | PJIN | 00h |
| Port PJ output | PJOUT | 02h |
| Port PJ direction | PJDIR | 04h |
| Port PJ resistor enable | PJREN | 06h |
| Port PJ selection 0 | PJSEL0 | 0Ah |
| Port PJ selection 1 | PJSEL1 | 0Ch |
| Port PJ complement selection | PJSELC | 16h |

**Table 6-32. TA0 Registers (Base Address: 0340h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| TA0 control | TA0CTL | 00h |
| Capture/compare control 0 | TA0CCTL0 | 02h |
| Capture/compare control 1 | TA0CCTL1 | 04h |
| Capture/compare control 2 | TA0CCTL2 | 06h |
| Capture/compare control 3 | TA0CCTL3 | 08h |
| Capture/compare control 4 | TA0CCTL4 | 0Ah |
| TA0 counter | TA0R | 10h |
| Capture/compare 0 | TA0CCR0 | 12h |
| Capture/compare 1 | TA0CCR1 | 14h |
| Capture/compare 2 | TA0CCR2 | 16h |
| Capture/compare 3 | TA0CCR3 | 18h |
| Capture/compare 4 | TA0CCR4 | 1Ah |
| TA0 expansion 0 | TA0EX0 | 20h |
| TA0 interrupt vector | TA0IV | 2Eh |

**Table 6-33. TA1 Registers (Base Address: 0380h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| TA1 control | TA1CTL | 00h |
| Capture/compare control 0 | TA1CCTL0 | 02h |
| Capture/compare control 1 | TA1CCTL1 | 04h |
| Capture/compare control 2 | TA1CCTL2 | 06h |
| TA1 counter | TA1R | 10h |


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**Table 6-33. TA1 Registers (Base Address: 0380h) (continued)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| Capture/compare 0 | TA1CCR0 | 12h |
| Capture/compare 1 | TA1CCR1 | 14h |
| Capture/compare 2 | TA1CCR2 | 16h |
| TA1 expansion 0 | TA1EX0 | 20h |
| TA1 interrupt vector | TA1IV | 2Eh |

**Table 6-34. TB0 Registers (Base Address: 03C0h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| TB0 control | TB0CTL | 00h |
| Capture/compare control 0 | TB0CCTL0 | 02h |
| Capture/compare control 1 | TB0CCTL1 | 04h |
| Capture/compare control 2 | TB0CCTL2 | 06h |
| Capture/compare control 3 | TB0CCTL3 | 08h |
| Capture/compare control 4 | TB0CCTL4 | 0Ah |
| Capture/compare control 5 | TB0CCTL5 | 0Ch |
| Capture/compare control 6 | TB0CCTL6 | 0Eh |
| TB0 counter | TB0R | 10h |
| Capture/compare 0 | TB0CCR0 | 12h |
| Capture/compare 1 | TB0CCR1 | 14h |
| Capture/compare 2 | TB0CCR2 | 16h |
| Capture/compare 3 | TB0CCR3 | 18h |
| Capture/compare 4 | TB0CCR4 | 1Ah |
| Capture/compare 5 | TB0CCR5 | 1Ch |
| Capture/compare 6 | TB0CCR6 | 1Eh |
| TB0 expansion 0 | TB0EX0 | 20h |
| TB0 interrupt vector | TB0IV | 2Eh |

**Table 6-35. TA2 Registers (Base Address: 0400h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| TA2 control | TA2CTL | 00h |
| Capture/compare control 0 | TA2CCTL0 | 02h |
| Capture/compare control 1 | TA2CCTL1 | 04h |
| TA2 counter | TA2R | 10h |
| Capture/compare 0 | TA2CCR0 | 12h |
| Capture/compare 1 | TA2CCR1 | 14h |
| TA2 expansion 0 | TA2EX0 | 20h |
| TA2 interrupt vector | TA2IV | 2Eh |

**Table 6-36. Capacitive Touch I/O 0 Registers (Base Address: 0430h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| Capacitive Touch I/O 0 control | CAPTIO0CTL | 0Eh |

**Table 6-37. TA3 Registers (Base Address: 0440h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| TA3 control | TA3CTL | 00h |
| Capture/compare control 0 | TA3CCTL0 | 02h |

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**Table 6-37. TA3 Registers (Base Address: 0440h) (continued)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| Capture/compare control 1 | TA3CCTL1 | 04h |
| TA3 counter | TA3R | 10h |
| Capture/compare 0 | TA3CCR0 | 12h |
| Capture/compare 1 | TA3CCR1 | 14h |
| TA3 expansion 0 | TA3EX0 | 20h |
| TA3 interrupt vector | TA3IV | 2Eh |

**Table 6-38. Capacitive Touch I/O 1 Registers (Base Address: 0470h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| Capacitive touch I/O 1 control | CAPTIO1CTL | 0Eh |

**Table 6-39. RTC_B Real-Time Clock Registers (Base Address: 04A0h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| RTC control 0 | RTCCTL0 | 00h |
| RTC control 1 | RTCCTL1 | 01h |
| RTC control 2 | RTCCTL2 | 02h |
| RTC control 3 | RTCCTL3 | 03h |
| RTC prescaler 0 control | RTCPS0CTL | 08h |
| RTC prescaler 1 control | RTCPS1CTL | 0Ah |
| RTC prescaler 0 | RTCPS0 | 0Ch |
| RTC prescaler 1 | RTCPS1 | 0Dh |
| RTC interrupt vector word | RTCIV | 0Eh |
| RTC seconds | RTCSEC/RTCNT1 | 10h |
| RTC minutes | RTCMIN/RTCNT2 | 11h |
| RTC hours | RTCHOUR/RTCNT3 | 12h |
| RTC day of week | RTCDOW/RTCNT4 | 13h |
| RTC days | RTCDAY | 14h |
| RTC month | RTCMON | 15h |
| RTC year low | RTCYEARL | 16h |
| RTC year high | RTCYEARH | 17h |
| RTC alarm minutes | RTCAMIN | 18h |
| RTC alarm hours | RTCAHOUR | 19h |
| RTC alarm day of week | RTCADOW | 1Ah |
| RTC alarm days | RTCADAY | 1Bh |
| Binary-to-BCD conversion | BIN2BCD | 1Ch |
| BCD-to-binary conversion | BCD2BIN | 1Eh |

**Table 6-40. 32-Bit Hardware Multiplier Registers (Base Address: 04C0h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| 16-bit operand 1 – multiply | MPY | 00h |
| 16-bit operand 1 – signed multiply | MPYS | 02h |
| 16-bit operand 1 – multiply accumulate | MAC | 04h |
| 16-bit operand 1 – signed multiply accumulate | MACS | 06h |
| 16-bit operand 2 | OP2 | 08h |
| 16 × 16 result low word | RESLO | 0Ah |
| 16 × 16 result high word | RESHI | 0Ch |


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**Table 6-40. 32-Bit Hardware Multiplier Registers (Base Address: 04C0h) (continued)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| 16 × 16 sum extension | SUMEXT | 0Eh |
| 32-bit operand 1 – multiply low word | MPY32L | 10h |
| 32-bit operand 1 – multiply high word | MPY32H | 12h |
| 32-bit operand 1 – signed multiply low word | MPYS32L | 14h |
| 32-bit operand 1 – signed multiply high word | MPYS32H | 16h |
| 32-bit operand 1 – multiply accumulate low word | MAC32L | 18h |
| 32-bit operand 1 – multiply accumulate high word | MAC32H | 1Ah |
| 32-bit operand 1 – signed multiply accumulate low word | MACS32L | 1Ch |
| 32-bit operand 1 – signed multiply accumulate high word | MACS32H | 1Eh |
| 32-bit operand 2 – low word | OP2L | 20h |
| 32-bit operand 2 – high word | OP2H | 22h |
| 32 × 32 result 0 – least significant word | RES0 | 24h |
| 32 × 32 result 1 | RES1 | 26h |
| 32 × 32 result 2 | RES2 | 28h |
| 32 × 32 result 3 – most significant word | RES3 | 2Ah |
| MPY32 control 0 | MPY32CTL0 | 2Ch |

**Table 6-41. DMA Registers (Base Address DMA General Control: 0500h, DMA Channel 0: 0510h, DMA Channel 1: 0520h, DMA Channel 2: 0530h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| DMA channel 0 control | DMA0CTL | 00h |
| DMA channel 0 source address low | DMA0SAL | 02h |
| DMA channel 0 source address high | DMA0SAH | 04h |
| DMA channel 0 destination address low | DMA0DAL | 06h |
| DMA channel 0 destination address high | DMA0DAH | 08h |
| DMA channel 0 transfer size | DMA0SZ | 0Ah |
| DMA channel 1 control | DMA1CTL | 00h |
| DMA channel 1 source address low | DMA1SAL | 02h |
| DMA channel 1 source address high | DMA1SAH | 04h |
| DMA channel 1 destination address low | DMA1DAL | 06h |
| DMA channel 1 destination address high | DMA1DAH | 08h |
| DMA channel 1 transfer size | DMA1SZ | 0Ah |
| DMA channel 2 control | DMA2CTL | 00h |
| DMA channel 2 source address low | DMA2SAL | 02h |
| DMA channel 2 source address high | DMA2SAH | 04h |
| DMA channel 2 destination address low | DMA2DAL | 06h |
| DMA channel 2 destination address high | DMA2DAH | 08h |
| DMA channel 2 transfer size | DMA2SZ | 0Ah |
| DMA module control 0 | DMACTL0 | 00h |
| DMA module control 1 | DMACTL1 | 02h |
| DMA module control 2 | DMACTL2 | 04h |
| DMA module control 3 | DMACTL3 | 06h |
| DMA module control 4 | DMACTL4 | 08h |
| DMA interrupt vector | DMAIV | 0Eh |

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**Table 6-42. MPU Control Registers (Base Address: 05A0h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| MPU control 0 | MPUCTL0 | 00h |
| MPU control 1 | MPUCTL1 | 02h |
| MPU segmentation border 2 | MPUSEGB2 | 04h |
| MPU segmentation border 1 | MPUSEGB1 | 06h |
| MPU access management | MPUSAM | 08h |
| MPU IP control 0 | MPUIPC0 | 0Ah |
| MPU IP encapsulation segment border 2 | MPUIPSEGB2 | 0Ch |
| MPU IP encapsulation segment border 1 | MPUIPSEGB1 | 0Eh |

**Table 6-43. eUSCI_A0 Registers (Base Address: 05C0h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| eUSCI_A control word 0 | UCA0CTLW0 | 00h |
| eUSCI _A control word 1 | UCA0CTLW1 | 02h |
| eUSCI_A baud rate 0 | UCA0BR0 | 06h |
| eUSCI_A baud rate 1 | UCA0BR1 | 07h |
| eUSCI_A modulation control | UCA0MCTLW | 08h |
| eUSCI_A status word | UCA0STATW | 0Ah |
| eUSCI_A receive buffer | UCA0RXBUF | 0Ch |
| eUSCI_A transmit buffer | UCA0TXBUF | 0Eh |
| eUSCI_A LIN control | UCA0ABCTL | 10h |
| eUSCI_A IrDA transmit control | UCA0IRTCTL | 12h |
| eUSCI_A IrDA receive control | UCA0IRRCTL | 13h |
| eUSCI_A interrupt enable | UCA0IE | 1Ah |
| eUSCI_A interrupt flags | UCA0IFG | 1Ch |
| eUSCI_A interrupt vector word | UCA0IV | 1Eh |

**Table 6-44. eUSCI_A1 Registers (Base Address:05E0h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| eUSCI_A control word 0 | UCA1CTLW0 | 00h |
| eUSCI _A control word 1 | UCA1CTLW1 | 02h |
| eUSCI_A baud rate 0 | UCA1BR0 | 06h |
| eUSCI_A baud rate 1 | UCA1BR1 | 07h |
| eUSCI_A modulation control | UCA1MCTLW | 08h |
| eUSCI_A status word | UCA1STATW | 0Ah |
| eUSCI_A receive buffer | UCA1RXBUF | 0Ch |
| eUSCI_A transmit buffer | UCA1TXBUF | 0Eh |
| eUSCI_A LIN control | UCA1ABCTL | 10h |
| eUSCI_A IrDA transmit control | UCA1IRTCTL | 12h |
| eUSCI_A IrDA receive control | UCA1IRRCTL | 13h |
| eUSCI_A interrupt enable | UCA1IE | 1Ah |
| eUSCI_A interrupt flags | UCA1IFG | 1Ch |
| eUSCI_A interrupt vector word | UCA1IV | 1Eh |


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**Table 6-45. eUSCI_B0 Registers (Base Address: 0640h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| eUSCI_B control word 0 | UCB0CTLW0 | 00h |
| eUSCI_B control word 1 | UCB0CTLW1 | 02h |
| eUSCI_B bit rate 0 | UCB0BR0 | 06h |
| eUSCI_B bit rate 1 | UCB0BR1 | 07h |
| eUSCI_B status word | UCB0STATW | 08h |
| eUSCI_B byte counter threshold | UCB0TBCNT | 0Ah |
| eUSCI_B receive buffer | UCB0RXBUF | 0Ch |
| eUSCI_B transmit buffer | UCB0TXBUF | 0Eh |
| eUSCI_B I2C own address 0 | UCB0I2COA0 | 14h |
| eUSCI_B I2C own address 1 | UCB0I2COA1 | 16h |
| eUSCI_B I2C own address 2 | UCB0I2COA2 | 18h |
| eUSCI_B I2C own address 3 | UCB0I2COA3 | 1Ah |
| eUSCI_B received address | UCB0ADDRX | 1Ch |
| eUSCI_B address mask | UCB0ADDMASK | 1Eh |
| eUSCI I2C slave address | UCB0I2CSA | 20h |
| eUSCI interrupt enable | UCB0IE | 2Ah |
| eUSCI interrupt flags | UCB0IFG | 2Ch |
| eUSCI interrupt vector word | UCB0IV | 2Eh |

**Table 6-46. ADC12_B Registers (Base Address: 0800h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| ADC12_B control 0 | ADC12CTL0 | 00h |
| ADC12_B control 1 | ADC12CTL1 | 02h |
| ADC12_B control 2 | ADC12CTL2 | 04h |
| ADC12_B control 3 | ADC12CTL3 | 06h |
| ADC12_B window comparator low threshold | ADC12LO | 08h |
| ADC12_B window comparator high threshold | ADC12HI | 0Ah |
| ADC12_B interrupt flag 0 | ADC12IFGR0 | 0Ch |
| ADC12_B interrupt flag 1 | ADC12IFGR1 | 0Eh |
| ADC12_B interrupt flag 2 | ADC12IFGR2 | 10h |
| ADC12_B interrupt enable 0 | ADC12IER0 | 12h |
| ADC12_B interrupt enable 1 | ADC12IER1 | 14h |
| ADC12_B interrupt enable 2 | ADC12IER2 | 16h |
| ADC12_B interrupt vector | ADC12IV | 18h |
| ADC12_B memory control 0 | ADC12MCTL0 | 20h |
| ADC12_B memory control 1 | ADC12MCTL1 | 22h |
| ADC12_B memory control 2 | ADC12MCTL2 | 24h |
| ADC12_B memory control 3 | ADC12MCTL3 | 26h |
| ADC12_B memory control 4 | ADC12MCTL4 | 28h |
| ADC12_B memory control 5 | ADC12MCTL5 | 2Ah |
| ADC12_B memory control 6 | ADC12MCTL6 | 2Ch |
| ADC12_B memory control 7 | ADC12MCTL7 | 2Eh |
| ADC12_B memory control 8 | ADC12MCTL8 | 30h |
| ADC12_B memory control 9 | ADC12MCTL9 | 32h |
| ADC12_B memory control 10 | ADC12MCTL10 | 34h |
| ADC12_B memory control 11 | ADC12MCTL11 | 36h |
| ADC12_B memory control 12 | ADC12MCTL12 | 38h |

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**Table 6-46. ADC12_B Registers (Base Address: 0800h) (continued)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| ADC12_B memory control 13 | ADC12MCTL13 | 3Ah |
| ADC12_B memory control 14 | ADC12MCTL14 | 3Ch |
| ADC12_B memory control 15 | ADC12MCTL15 | 3Eh |
| ADC12_B memory control 16 | ADC12MCTL16 | 40h |
| ADC12_B memory control 17 | ADC12MCTL17 | 42h |
| ADC12_B memory control 18 | ADC12MCTL18 | 44h |
| ADC12_B memory control 19 | ADC12MCTL19 | 46h |
| ADC12_B memory control 20 | ADC12MCTL20 | 48h |
| ADC12_B memory control 21 | ADC12MCTL21 | 4Ah |
| ADC12_B memory control 22 | ADC12MCTL22 | 4Ch |
| ADC12_B memory control 23 | ADC12MCTL23 | 4Eh |
| ADC12_B memory control 24 | ADC12MCTL24 | 50h |
| ADC12_B memory control 25 | ADC12MCTL25 | 52h |
| ADC12_B memory control 26 | ADC12MCTL26 | 54h |
| ADC12_B memory control 27 | ADC12MCTL27 | 56h |
| ADC12_B memory control 28 | ADC12MCTL28 | 58h |
| ADC12_B memory control 29 | ADC12MCTL29 | 5Ah |
| ADC12_B memory control 30 | ADC12MCTL30 | 5Ch |
| ADC12_B memory control 31 | ADC12MCTL31 | 5Eh |
| ADC12_B memory 0 | ADC12MEM0 | 60h |
| ADC12_B memory 1 | ADC12MEM1 | 62h |
| ADC12_B memory 2 | ADC12MEM2 | 64h |
| ADC12_B memory 3 | ADC12MEM3 | 66h |
| ADC12_B memory 4 | ADC12MEM4 | 68h |
| ADC12_B memory 5 | ADC12MEM5 | 6Ah |
| ADC12_B memory 6 | ADC12MEM6 | 6Ch |
| ADC12_B memory 7 | ADC12MEM7 | 6Eh |
| ADC12_B memory 8 | ADC12MEM8 | 70h |
| ADC12_B memory 9 | ADC12MEM9 | 72h |
| ADC12_B memory 10 | ADC12MEM10 | 74h |
| ADC12_B memory 11 | ADC12MEM11 | 76h |
| ADC12_B memory 12 | ADC12MEM12 | 78h |
| ADC12_B memory 13 | ADC12MEM13 | 7Ah |
| ADC12_B memory 14 | ADC12MEM14 | 7Ch |
| ADC12_B memory 15 | ADC12MEM15 | 7Eh |
| ADC12_B memory 16 | ADC12MEM16 | 80h |
| ADC12_B memory 17 | ADC12MEM17 | 82h |
| ADC12_B memory 18 | ADC12MEM18 | 84h |
| ADC12_B memory 19 | ADC12MEM19 | 86h |
| ADC12_B memory 20 | ADC12MEM20 | 88h |
| ADC12_B memory 21 | ADC12MEM21 | 8Ah |
| ADC12_B memory 22 | ADC12MEM22 | 8Ch |
| ADC12_B memory 23 | ADC12MEM23 | 8Eh |
| ADC12_B memory 24 | ADC12MEM24 | 90h |
| ADC12_B memory 25 | ADC12MEM25 | 92h |
| ADC12_B memory 26 | ADC12MEM26 | 94h |
| ADC12_B memory 27 | ADC12MEM27 | 96h |


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**Table 6-46. ADC12_B Registers (Base Address: 0800h) (continued)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| ADC12_B memory 28 | ADC12MEM28 | 98h |
| ADC12_B memory 29 | ADC12MEM29 | 9Ah |
| ADC12_B memory 30 | ADC12MEM30 | 9Ch |
| ADC12_B memory 31 | ADC12MEM31 | 9Eh |

**Table 6-47. Comparator_E Registers (Base Address: 08C0h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| Comparator_E control 0 | CECTL0 | 00h |
| Comparator_E control 1 | CECTL1 | 02h |
| Comparator_E control 2 | CECTL2 | 04h |
| Comparator_E control 3 | CECTL3 | 06h |
| Comparator_E interrupt | CEINT | 0Ch |
| Comparator_E interrupt vector word | CEIV | 0Eh |

**Table 6-48. AES Accelerator Registers (Base Address: 09C0h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|---|---|---|
| AES accelerator control 0 | AESACTL0 | 00h |
| AES accelerator control 1 | AESACTL1 | 02h |
| AES accelerator status | AESASTAT | 04h |
| AES accelerator key | AESAKEY | 06h |
| AES accelerator data in | AESADIN | 008h |
| AES accelerator data out | AESADOUT | 00Ah |
| AES accelerator XORed data in | AESAXDIN | 00Ch |
| AES accelerator XORed data in (no trigger) | AESAXIN | 00Eh |

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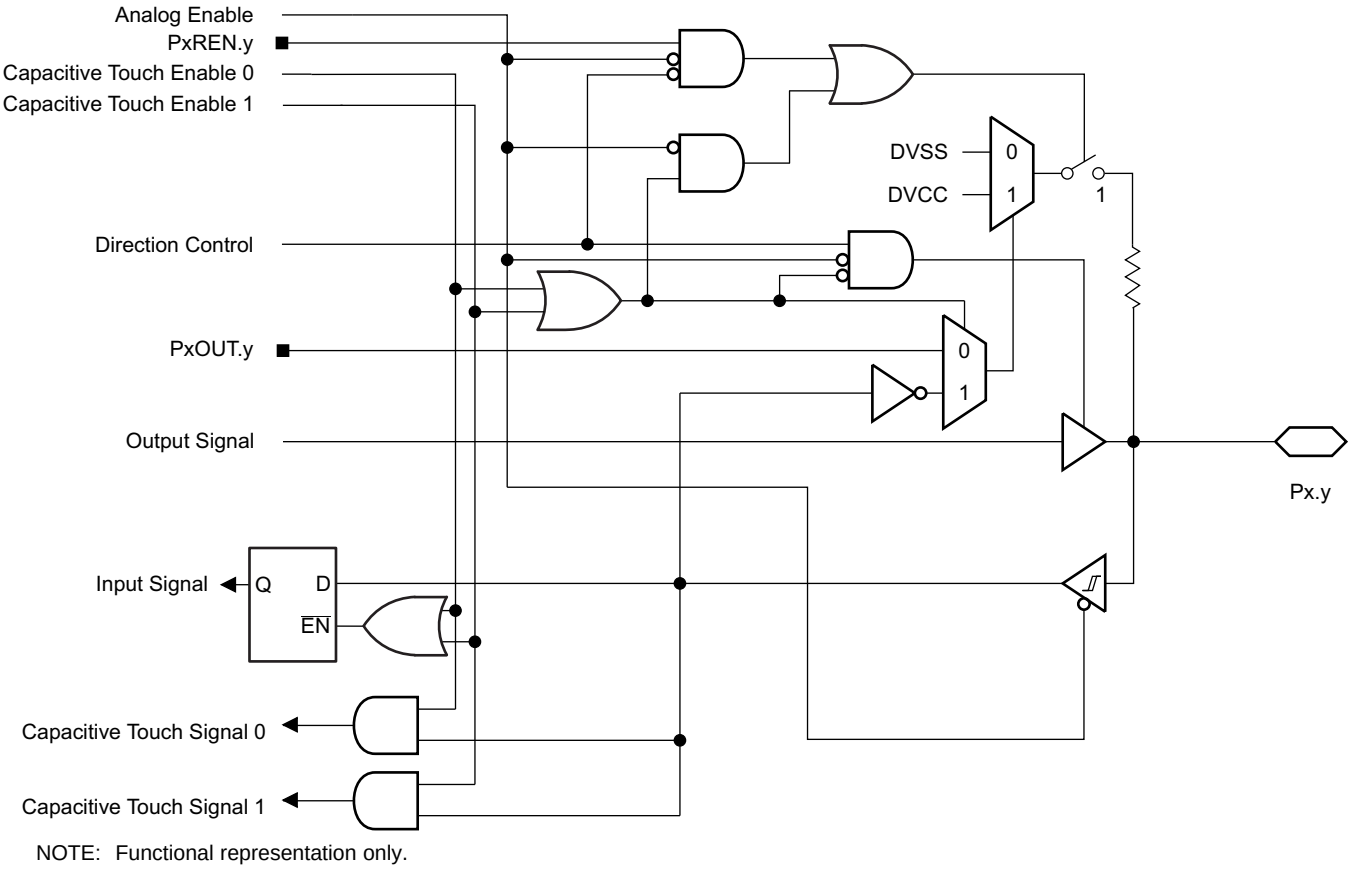
## 6.11 Input/Output Diagrams

### 6.11.1 Capacitive Touch Functionality Ports P1, P2, P3, P4, and PJ

All port pins provide the Capacitive Touch I/O functionality as shown in Figure 6-2. The Capacitive Touch I/O functionality is controlled using the Capacitive Touch I/O control registers CAPTIO0CTL and CAPTIO1CTL as described in the *MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide*. The Capacitive Touch I/O functionality is not shown in the individual pin diagrams in the following sections.




NOTE: Functional representation only.

**Figure 6-2. Capacitive Touch Diagram**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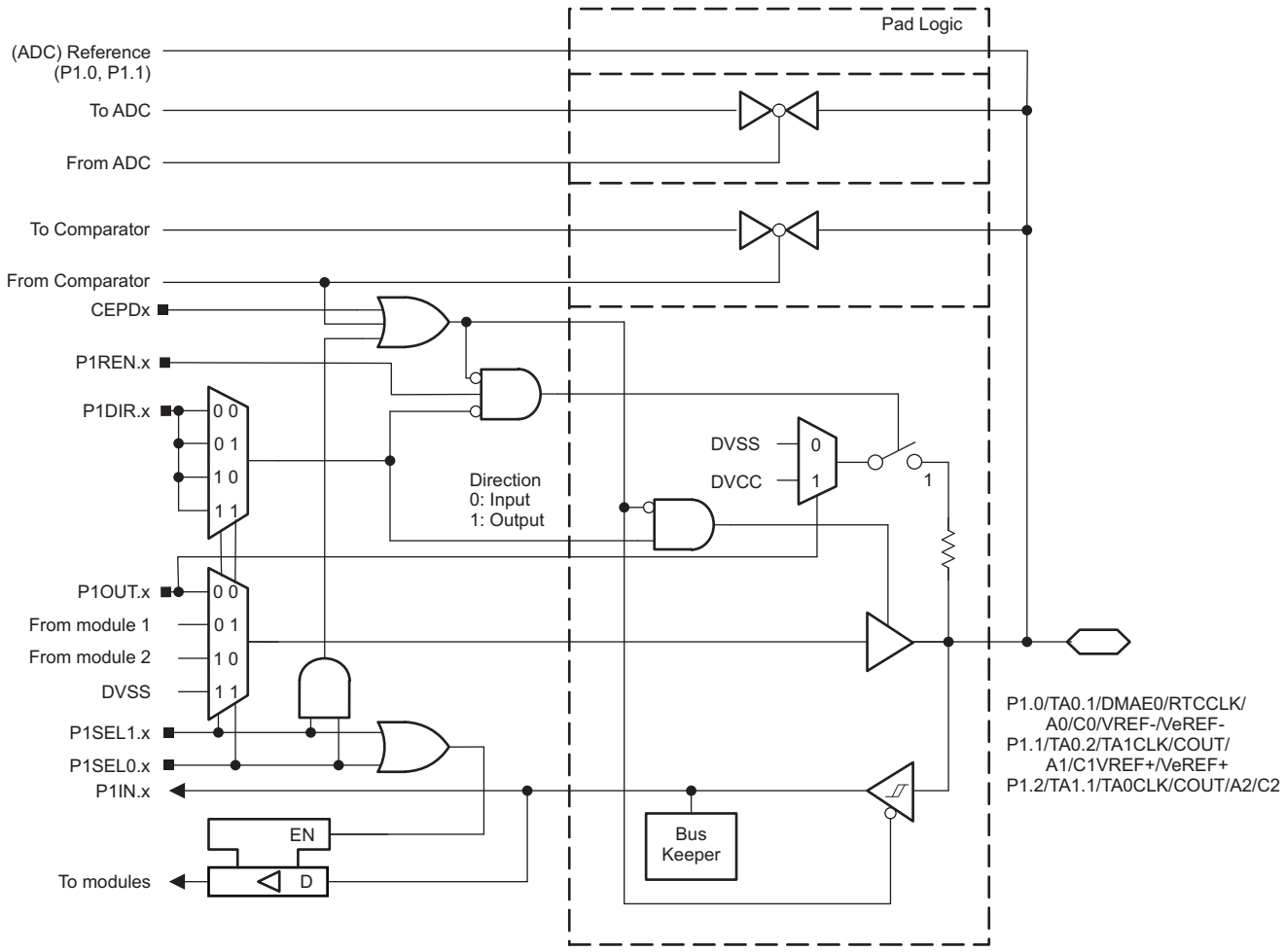
### 6.11.2 Port P1 (P1.0 to P1.2) Input/Output With Schmitt Trigger

Figure 6-3 shows the port diagram. Table 6-49 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-3. Port P1 (P1.0 to P1.2) Diagram**

**Table 6-49. Port P1 (P1.0 to P1.2) Pin Functions**

| PIN NAME (P1.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | |
|---|---|---|---|---|---|
| | | | P1DIR.x | P1SEL1.x | P1SEL0.x |
| P1.0/TA0.1/DMAE0/RTCCLK/A0/C0/ VREF-/VeREF- | 0 | P1.0 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TA0.CCI1A | 0 | 0 | 1 |
| | | TA0.1 | 1 | | |
| | | DMAE0 | 0 | 1 | 0 |
| | | RTCCLK(2)(3) | 1 | | |
| | | A0, C0, VREF-, VeREF-(4)(5) | X | 1 | 1 |
| P1.1/TA0.2/TA1CLK/COUT/A1/C1/ VREF+/VeREF+ | 1 | P1.1 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TA0.CCI2A | 0 | 0 | 1 |
| | | TA0.2 | 1 | | |
| | | TA1CLK | 0 | 1 | 0 |
| | | COUT(6) | 1 | | |
| | | A1, C1, VREF+, VeREF+(4)(5) | X | 1 | 1 |
| P1.2/TA1.1/TA0CLK/COUT/A2/C2 | 2 | P1.2 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TA1.CCI1A | 0 | 0 | 1 |
| | | TA1.1 | 1 | | |
| | | TA0CLK | 0 | 1 | 0 |
| | | COUT(7) | 1 | | |
| | | A2, C2(4)(5) | X | 1 | 1 |

(1) X = Don't care
(2) Not available on MSP430FR5x5x devices
(3) Do not use this pin as RTCCLK output if the DMAE0 functionality is used on any other pin. Select an alternative RTCCLK output pin.
(4) Setting P1SEL1.x and P1SEL0.x disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.
(5) Setting the CEPDx bit of the comparator disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals. Selecting the Cx input pin to the comparator multiplexer with the input select bits in the comparator module automatically disables output driver and input buffer for that pin, regardless of the state of the associated CEPDx bit.
(6) Do not use this pin as COUT output if the TA1CLK functionality is used on any other pin. Select an alternative COUT output pin.
(7) Do not use this pin as COUT output if the TA0CLK functionality is used on any other pin. Select an alternative COUT output pin.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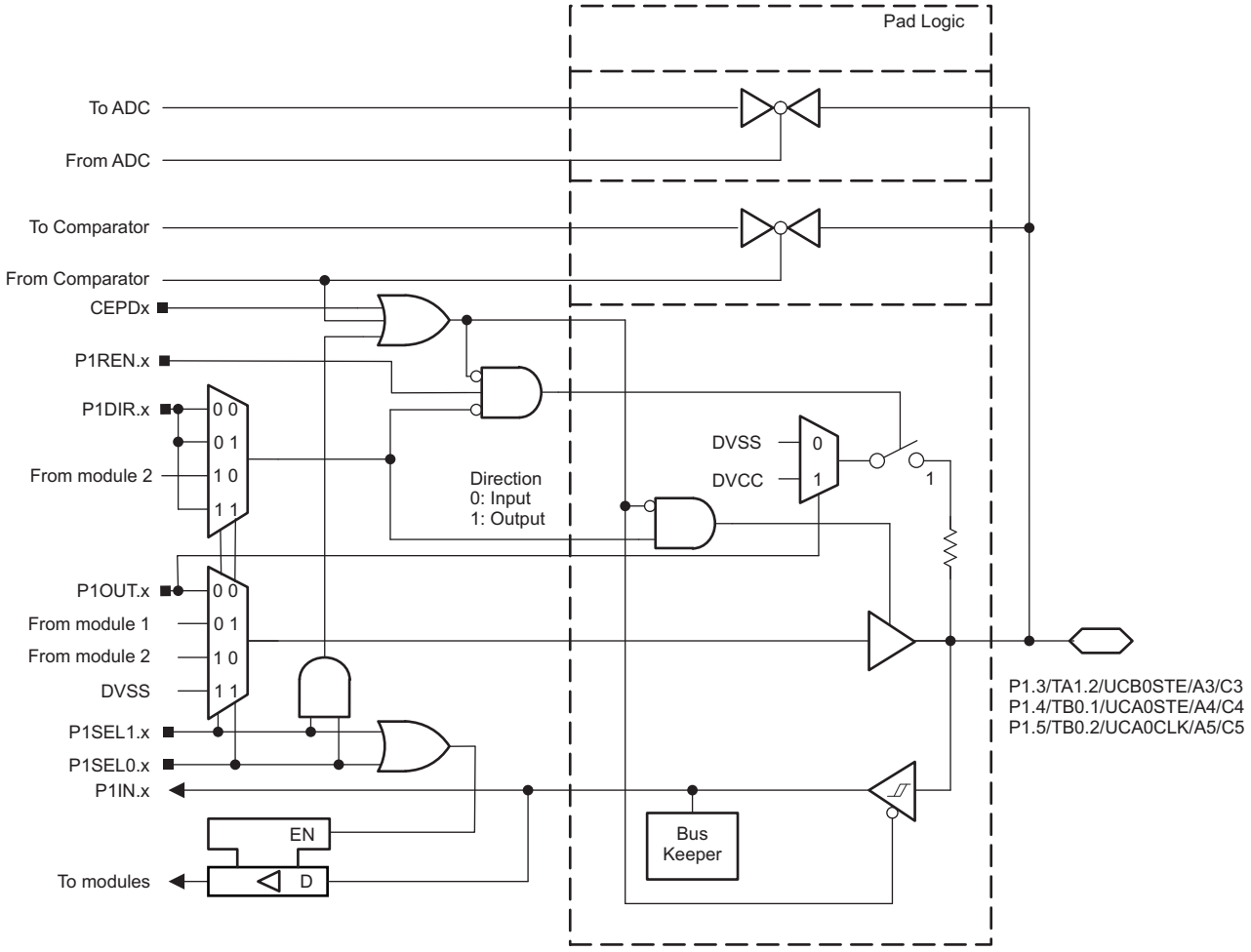
### 6.11.3 Port P1 (P1.3 to P1.5) Input/Output With Schmitt Trigger

Figure 6-4 shows the port diagram. Table 6-50 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-4. Port P1 (P1.3 to P1.5) Diagram**

**Table 6-50. Port P1 (P1.3 to P1.5) Pin Functions**

| PIN NAME (P1.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | |
|---|---|---|---|---|---|
| | | | P1DIR.x | P1SEL1.x | P1SEL0.x |
| P1.3/TA1.2/UCB0STE/A3/C3 | 3 | P1.3 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TA1.CCI2A | 0 | 0 | 1 |
| | | TA1.2 | 1 | | |
| | | UCB0STE | X(2) | 1 | 0 |
| | | A3, C3(3)(4) | X | 1 | 1 |
| P1.4/TB0.1/UCA0STE/A4/C4 | 4 | P1.4 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI1A | 0 | 0 | 1 |
| | | TB0.1 | 1 | | |
| | | UCA0STE | X(5) | 1 | 0 |
| | | A4, C4(3)(4) | X | 1 | 1 |
| P1.5/TB0.2/UCA0CLK/A5/C5 | 5 | P1.5(I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI2A | 0 | 0 | 1 |
| | | TB0.2 | 1 | | |
| | | UCA0CLK | X(5) | 1 | 0 |
| | | A5, C5(3)(4) | X | 1 | 1 |

(1) X = Don't care
(2) Direction controlled by eUSCI_B0 module.
(3) Setting P1SEL1.x and P1SEL0.x disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.
(4) Setting the CEPDx bit of the comparator disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals. Selecting the Cx input pin to the comparator multiplexer with the input select bits in the comparator module automatically disables output driver and input buffer for that pin, regardless of the state of the associated CEPDx bit.
(5) Direction controlled by eUSCI_A0 module.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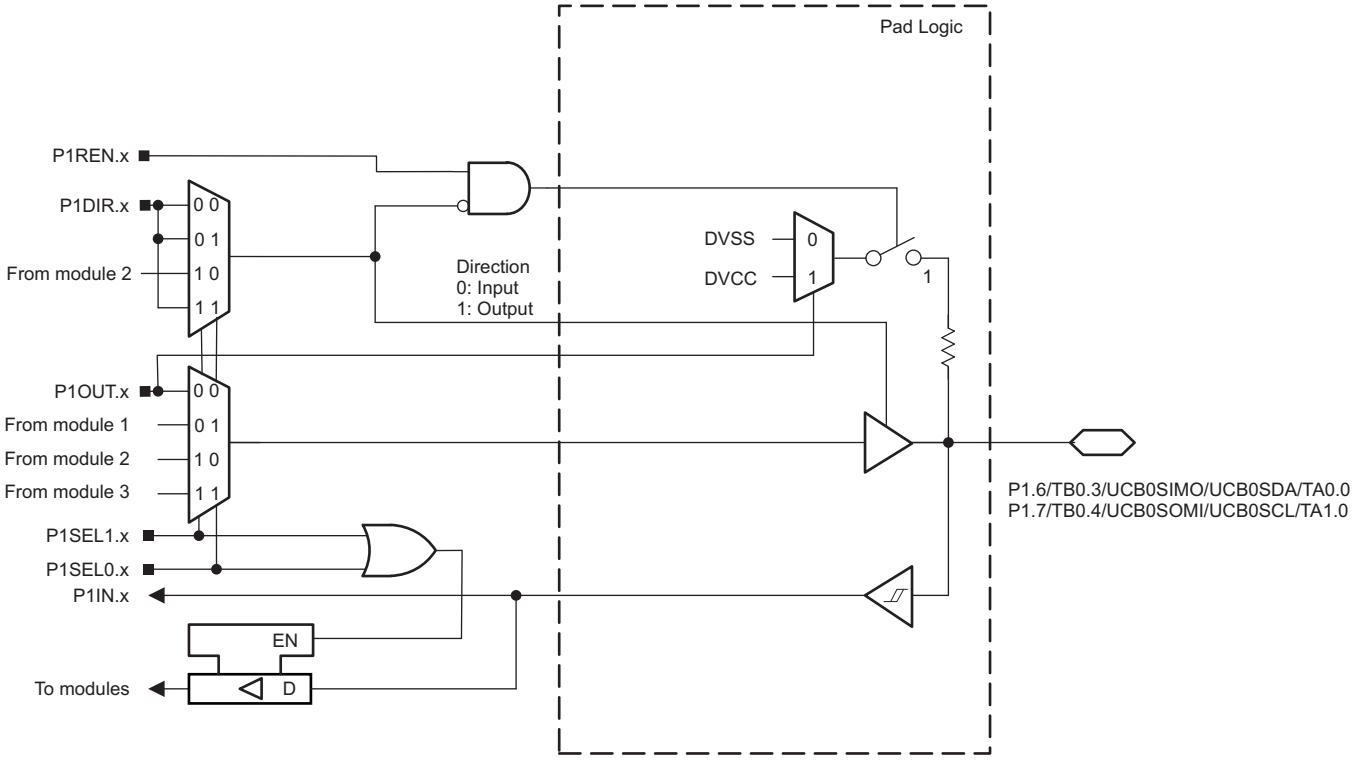
### 6.11.4 Port P1 (P1.6 and P1.7) Input/Output With Schmitt Trigger

Figure 6-5 shows the port diagram. Table 6-51 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-5. Port P1 (P1.6 and P1.7) Diagram**

**Table 6-51. Port P1 (P1.6 and P1.7) Pin Functions**

| PIN NAME (P1.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | |
|---|---|---|---|---|---|
| | | | P1DIR.x | P1SEL1.x | P1SEL0.x |
| P1.6/TB0.3/UCB0SIMO/UCB0SDA/ TA0.0 | 6 | P1.6 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI3B | 0 | 0 | 1 |
| | | TB0.3 | 1 | | |
| | | UCB0SIMO/UCB0SDA | X(2) | 1 | 0 |
| | | TA0.CCI0A | 0 | 1 | 1 |
| | | TA0.0 | 1 | | |
| P1.7/TB0.4/UCB0SOMI/UCB0SCL/ TA1.0 | 7 | P1.7 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI4B | 0 | 0 | 1 |
| | | TB0.4 | 1 | | |
| | | UCB0SOMI/UCB0SCL | X(3) | 1 | 0 |
| | | TA1.CCI0A | 0 | 1 | 1 |
| | | TA1.0 | 1 | | |

(1) X = Don't care
(2) Direction controlled by eUSCI_B0 module.
(3) Direction controlled by eUSCI_A0 module.

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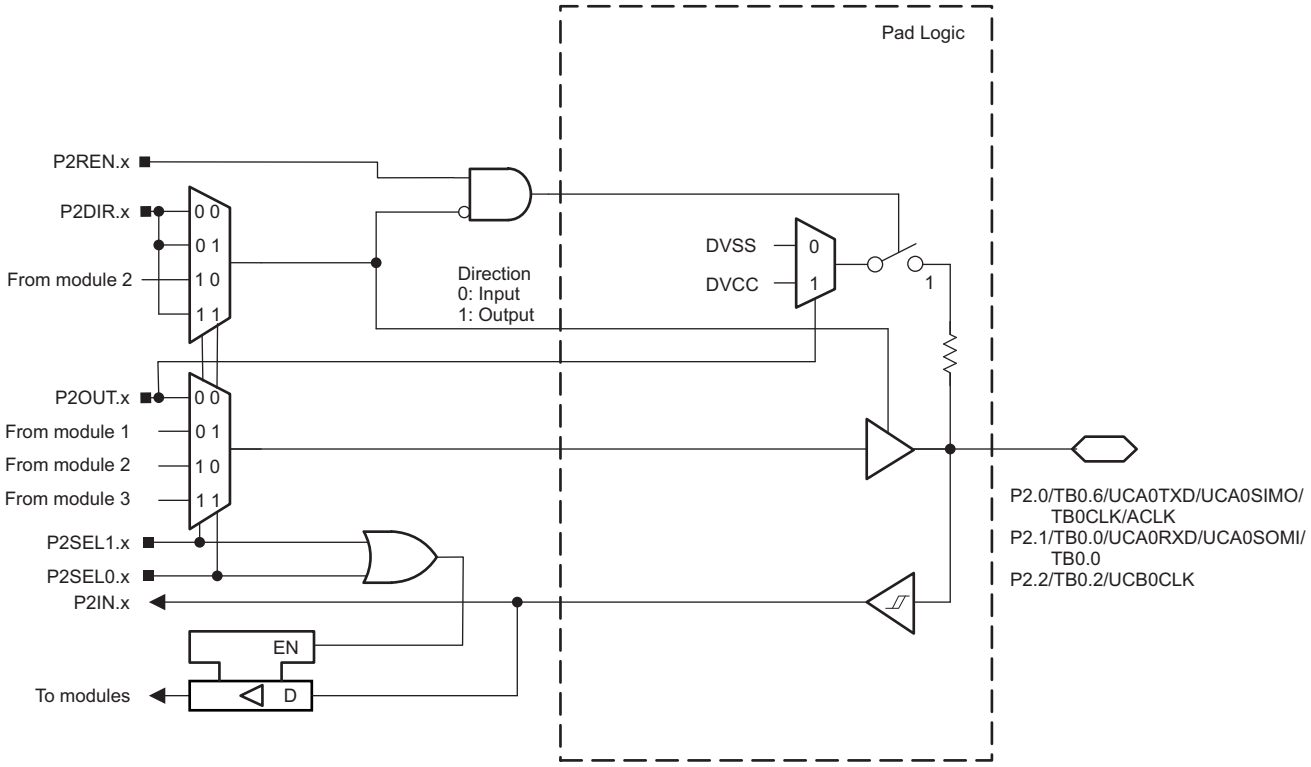
### 6.11.5 Port P2 (P2.0 to P2.2) Input/Output With Schmitt Trigger

Figure 6-6 shows the port diagram. Table 6-52 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-6. Port P2 (P2.0 to P2.2) Diagram**

**Table 6-52. Port P2 (P2.0 to P2.2) Pin Functions**

| PIN NAME (P2.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | |
|---|---|---|---|---|---|
| | | | P2DIR.x | P2SEL1.x | P2SEL0.x |
| P2.0/TB0.6/UCA0TXD/UCA0SIMO/ TB0CLK/ACLK | 0 | P2.0 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI6B | 0 | 0 | 1 |
| | | TB0.6 | 1 | | |
| | | UCA0TXD/UCA0SIMO | X(2) | 1 | 0 |
| | | TB0CLK | 0 | 1 | 1 |
| | | ACLK(3) | 1 | | |
| P2.1/TB0.0/UCA0RXD/UCA0SOMI/ TB0.0 | 1 | P2.1 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI0A | 0 | X | 1 |
| | | TB0.0 | 1 | | |
| | | UCA0RXD/UCA0SOMI | X(2) | 1 | 0 |

(1) X = Don't care
(2) Direction controlled by eUSCI_A0 module.
(3) Do not use this pin as ACLK output if the TB0CLK functionality is used on any other pin. Select an alternative ACLK output pin.


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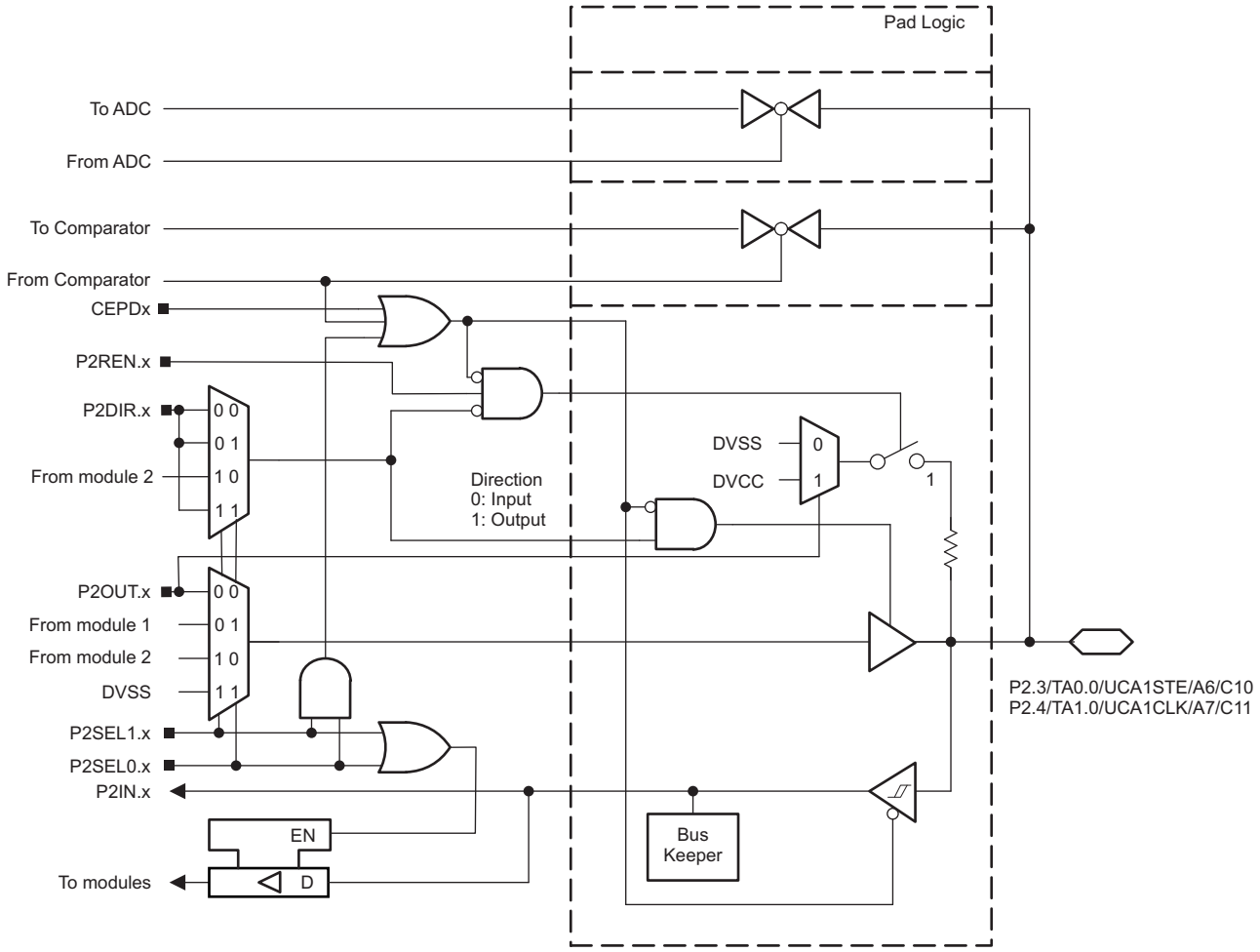
**Table 6-52. Port P2 (P2.0 to P2.2) Pin Functions (continued)**

| PIN NAME (P2.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | |
|---|---|---|---|---|---|
| | | | P2DIR.x | P2SEL1.x | P2SEL0.x |
| P2.2/TB0.2/UCB0CLK | 2 | P2.2 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | TB0.2 | 1 | | |
| | | UCB0CLK | X (4) | 1 | 0 |
| | | N/A | 0 | 1 | 1 |
| | | Internally tied to DVSS | 1 | | |

(4) Direction controlled by eUSCI_B0 module.

### 6.11.6 Port P2 (P2.3 and P2.4) Input/Output With Schmitt Trigger




NOTE: Functional representation only.

**Figure 6-7. Port P2 (P2.3 and P2.4) Diagram**


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**Table 6-53. Port P2 (P2.3 and P2.4) Pin Functions**

| PIN NAME (P2.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | |
|---|---|---|---|---|---|
| | | | P2DIR.x | P2SEL1.x | P2SEL0.x |
| P2.3/TA0.0/UCA1STE/A6/C10 | 3 | P2.3 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TA0.CCI0B | 0 | 0 | 1 |
| | | TA0.0 | 1 | | |
| | | UCA1STE | X (2) | 1 | 0 |
| | | A6, C10(3)(4) | X | 1 | 1 |
| P2.4/TA1.0/UCA1CLK/A7/C11 | 4 | P2.4 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TA1.CCI0B | 0 | 0 | 1 |
| | | TA1.0 | 1 | | |
| | | UCA1CLK | X (2) | 1 | 0 |
| | | A7, C11(3)(4) | X | 1 | 1 |

(1) X = Don't care
(2) Direction controlled by eUSCI_A1 module.
(3) Setting P2SEL1.x and P2SEL0.x disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.
(4) Setting the CEPDx bit of the comparator disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals. Selecting the Cx input pin to the comparator multiplexer with the input select bits in the comparator module automatically disables output driver and input buffer for that pin, regardless of the state of the associated CEPDx bit.

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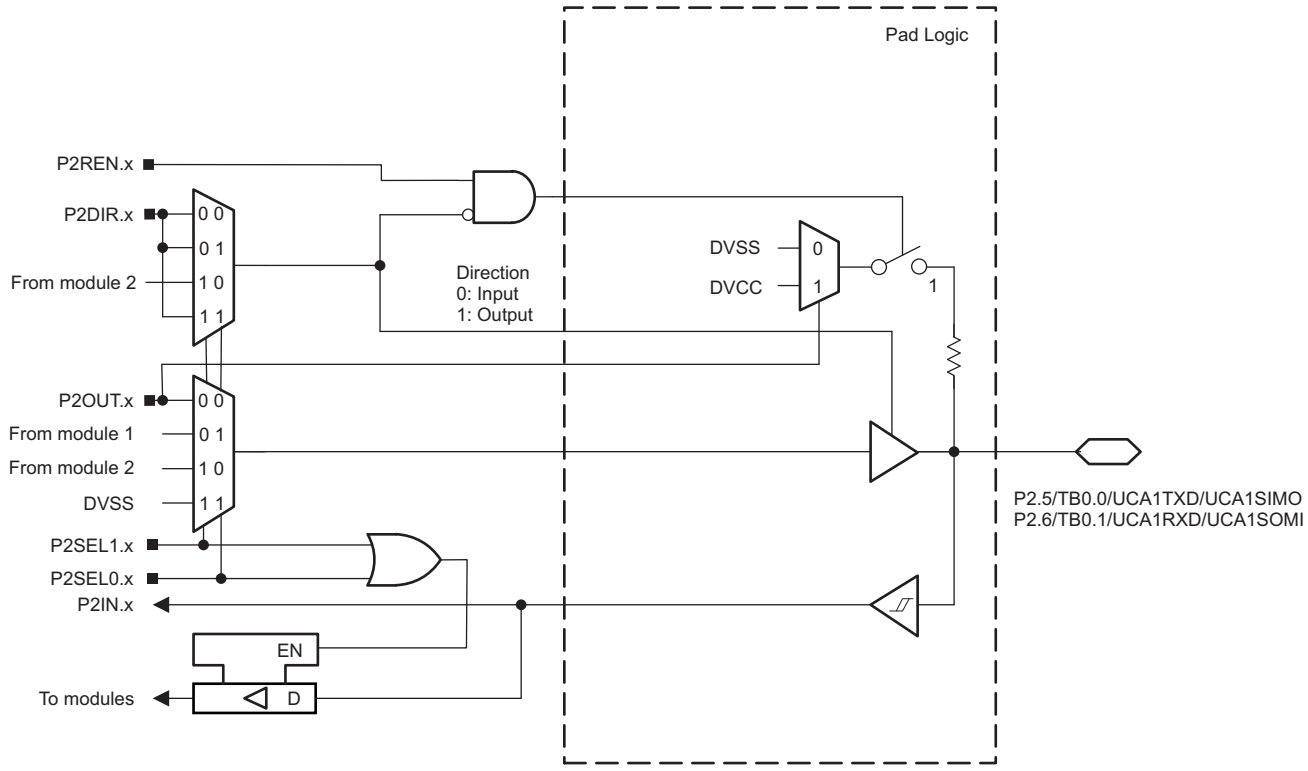
### 6.11.7 Port P2 (P2.5 and P2.6) Input/Output With Schmitt Trigger

Figure 6-8 shows the port diagram. Table 6-54 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-8. Port P2 (P2.5 and P2.6) Diagram**

**Table 6-54. Port P2 (P2.5 and P2.6) Pin Functions**

| PIN NAME (P2.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | |
|---|---|---|---|---|---|
| | | | P2DIR.x | P2SEL1.x | P2SEL0.x |
| P2.5/TB0.0/UCA1TXD/UCA1SIMO | 5 | P2.5(I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI0B | 0 | 0 | 1 |
| | | TB0.0 | 1 | | |
| | | UCA1TXD/UCA1SIMO | X(2) | 1 | 0 |
| | | N/A | 0 | 1 | 1 |
| | | Internally tied to DVSS | 1 | | |
| P2.6/TB0.1/UCA1RXD/UCA1SOMI | 6 | P2.6(I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | TB0.1 | 1 | | |
| | | UCA1RXD/UCA1SOMI | X(2) | 1 | 0 |
| | | N/A | 0 | 1 | 1 |
| | | Internally tied to DVSS | 1 | | |

(1) X = Don't care
(2) Direction controlled by eUSCI_A1 module.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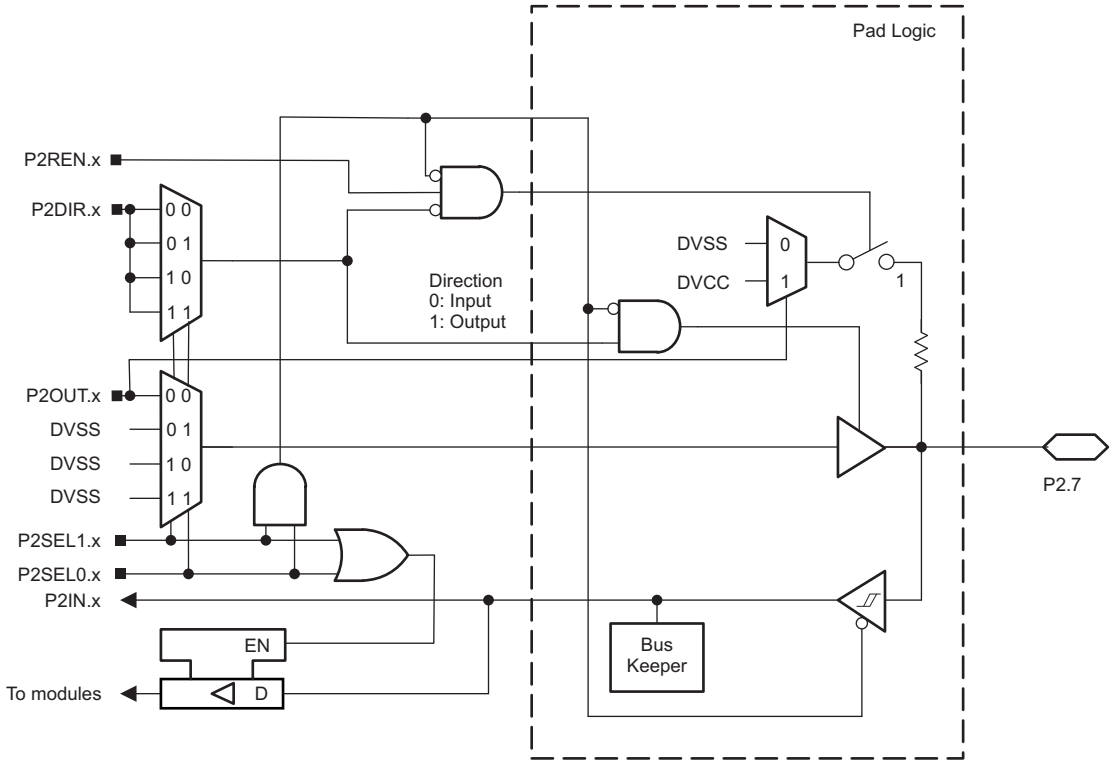
### 6.11.8 Port P2 (P2.7) Input/Output With Schmitt Trigger

Figure 6-9 shows the port diagram. Table 6-55 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-9. Port P2 (P2.7) Diagram**

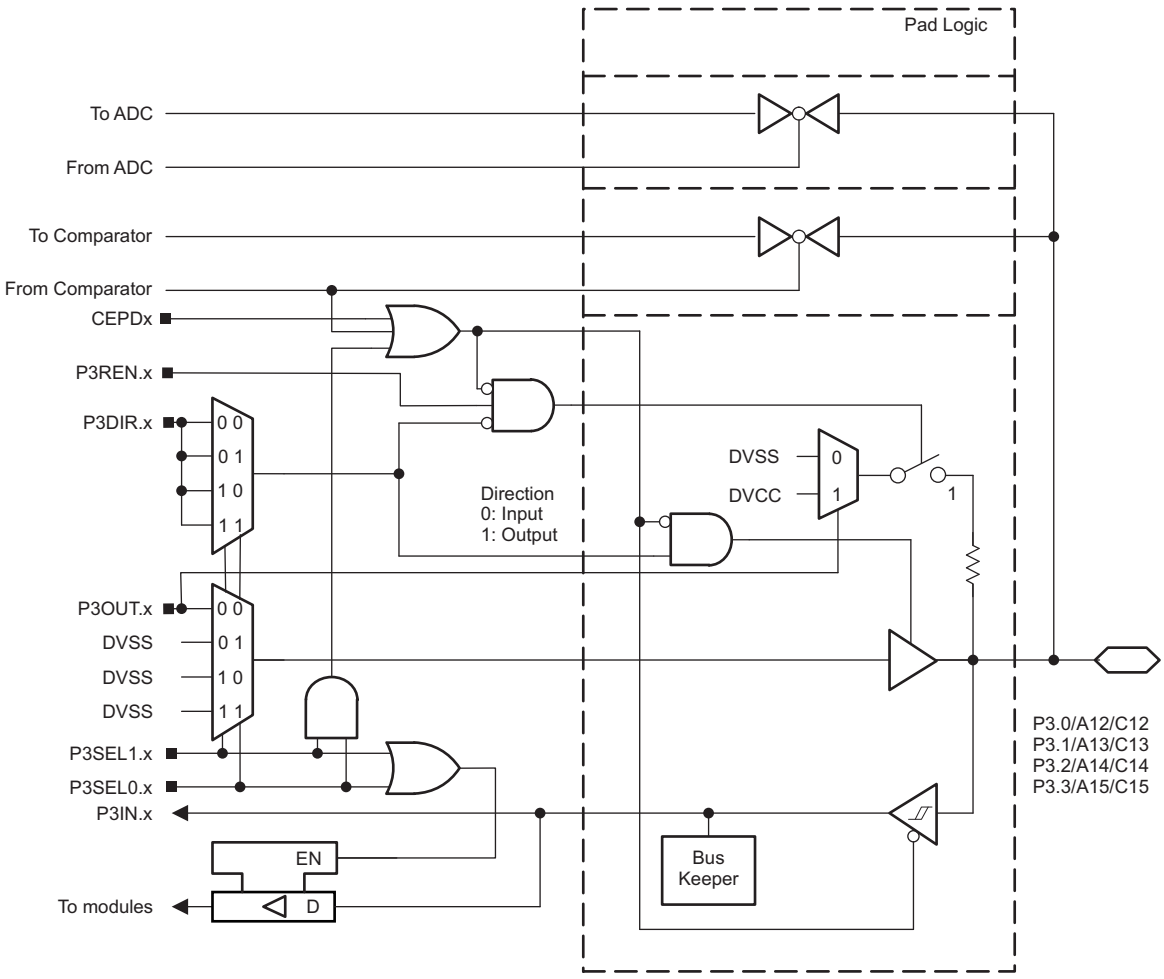
**Table 6-55. Port P2 (P2.7) Pin Functions**

| PIN NAME (P2.x) | x | FUNCTION | CONTROL BITS AND SIGNALS[1] | | |
|---|---|---|---|---|---|
| | | | P2DIR.x | P2SEL1.x | P2SEL0.x |
| P2.7 | 7 | P2.7(I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | X |
| | | Internally tied to DVSS | 1 | | |

(1) X = Don't care

### 6.11.9 Port P3 (P3.0 to P3.3) Input/Output With Schmitt Trigger

Figure 6-10 shows the port diagram. Table 6-56 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-10. Port P3 (P3.0 to P3.3) Diagram**


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**Table 6-56. Port P3 (P3.0 to P3.3) Pin Functions**

| PIN NAME (P3.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | |
|---|---|---|---|---|---|
| | | | P3DIR.x | P3SEL1.x | P3SEL0.x |
| P3.0/A12/C12 | 0 | P3.0 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | |
| | | A12/C12(2)(3) | X | 1 | 1 |
| P3.1/A13/C13 | 1 | P3.1 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | |
| | | A13/C13(2)(3) | X | 1 | 1 |
| P3.2/A14/C14 | 2 | P3.2 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | |
| | | A14/C14(2)(3) | X | 1 | 1 |
| P3.3/A15/C15 | 3 | P3.3 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | |
| | | A15/C15(2)(3) | X | 1 | 1 |

(1) X = Don't care
(2) Setting P3SEL1.x and P3SEL0.x disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.
(3) Setting the CEPDx bit of the comparator disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals. Selecting the Cx input pin to the comparator multiplexer with the input select bits in the comparator module automatically disables output driver and input buffer for that pin, regardless of the state of the associated CEPDx bit.

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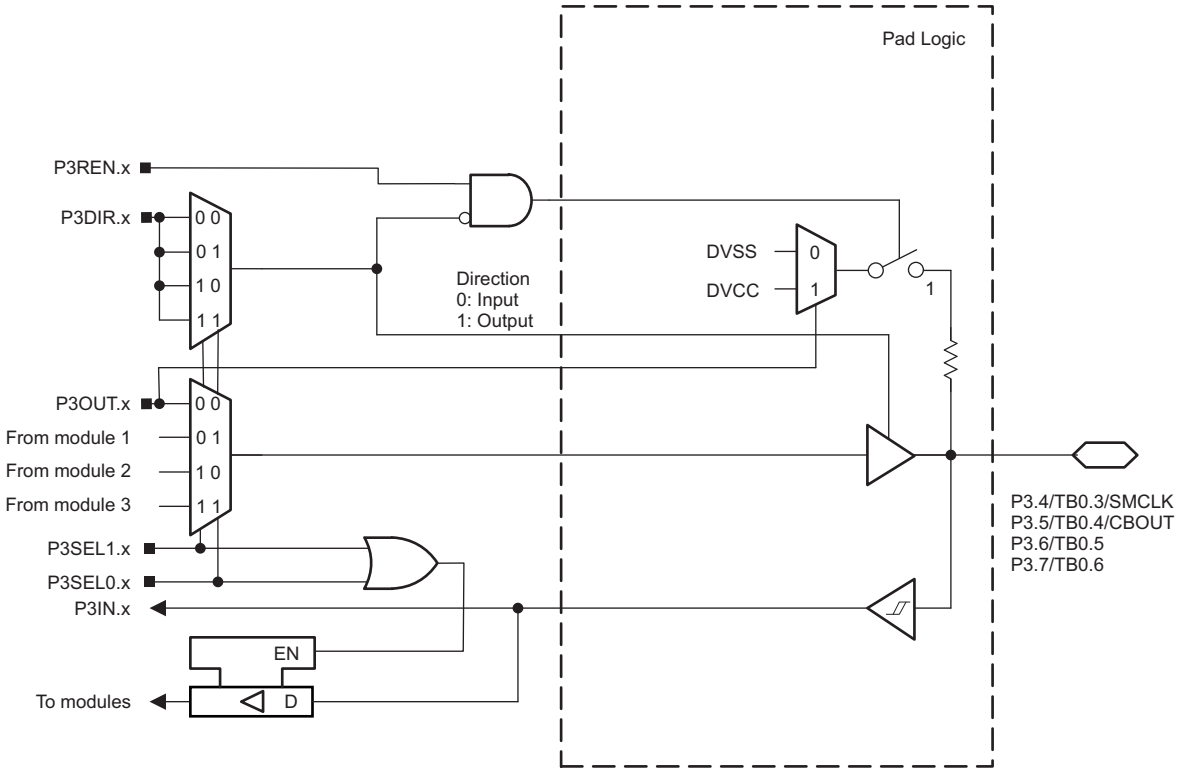
### 6.11.10 Port P3 (P3.4 to P3.7) Input/Output With Schmitt Trigger

Figure 6-11 shows the port diagram. Table 6-57 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-11. Port P3 (P3.4 to P3.7) Diagram**


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**Table 6-57. Port P3 (P3.4 to P3.7) Pin Functions**

| PIN NAME (P3.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | |
|---|---|---|---|---|---|
| | | | P3DIR.x | P3SEL1.x | P3SEL0.x |
| P3.4/TB0.3/SMCLK | 4 | P3.4 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI3A | 0 | 0 | 1 |
| | | TB0.3 | 1 | | |
| | | N/A | 0 | 1 | X |
| | | SMCLK | 1 | | |
| P3.5/TB0.4/COUT | 5 | P3.5 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI4A | 0 | 0 | 1 |
| | | TB0.4 | 1 | | |
| | | N/A | 0 | 1 | X |
| | | COUT | 1 | | |
| P3.6/TB0.5 | 6 | P3.6 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI5A | 0 | 0 | 1 |
| | | TB0.5 | 1 | | |
| | | N/A | 0 | 1 | X |
| | | Internally tied to DVSS | 1 | | |
| P3.7/TB0.6 | 7 | P3.7 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI6A | 0 | 0 | 1 |
| | | TB0.6 | 1 | | |
| | | N/A | 0 | 1 | X |
| | | Internally tied to DVSS | 1 | | |

(1) X = Don't care

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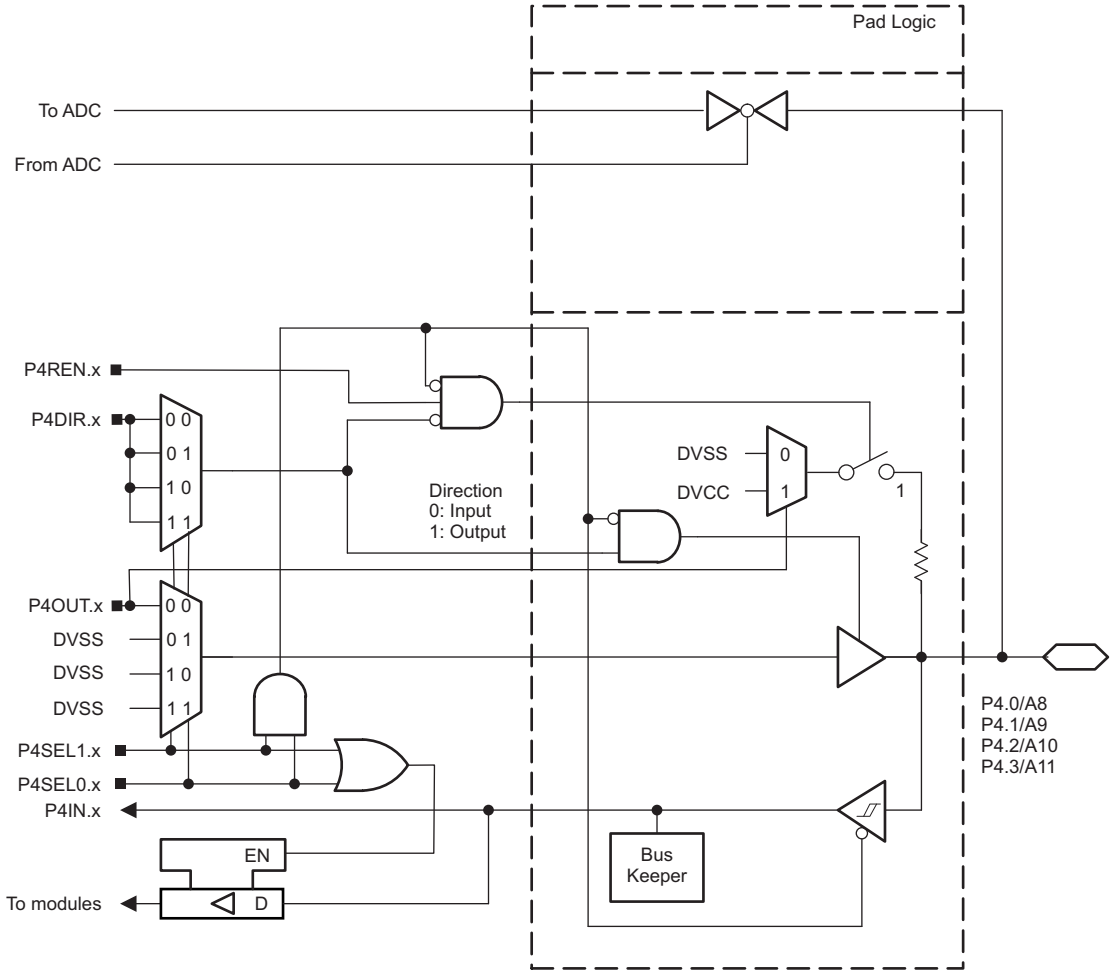
### 6.11.11 Port P4 (P4.0 to P4.3) Input/Output With Schmitt Trigger

Figure 6-12 shows the port diagram. Table 6-58 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-12. Port P4 (P4.0 to P4.3) Diagram**


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**Table 6-58. Port P4 (P4.0 to P4.3) Pin Functions**

| PIN NAME (P4.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | |
|---|---|---|---|---|---|
| | | | P4DIR.x | P4SEL1.x | P4SEL0.x |
| P4.0/A8 | 0 | P4.0 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | |
| | | A8(2) | X | 1 | 1 |
| P4.1/A9 | 1 | P4.1 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | |
| | | A9(2) | X | 1 | 1 |
| P4.2/A10 | 2 | P4.2 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | |
| | | A10(2) | X | 1 | 1 |
| P4.3/A11 | 3 | P4.3 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | |
| | | A11(2) | X | 1 | 1 |

(1) X = Don't care
(2) Setting P4SEL1.x and P4SEL0.x disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

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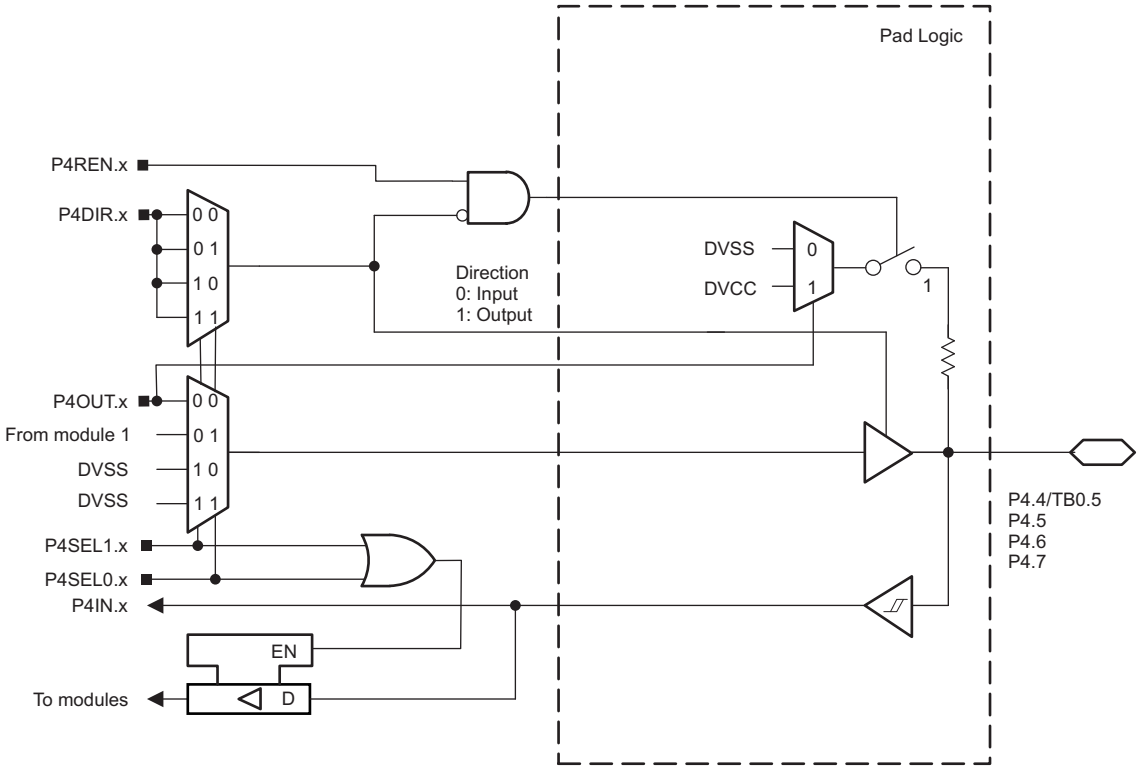
### 6.11.12 Port P4 (P4.4 to P4.7) Input/Output With Schmitt Trigger

Figure 6-13 shows the port diagram. Table 6-59 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-13. Port P4 (P4.4 to P4.7) Diagram**


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**Table 6-59. Port P4 (P4.4 to P4.7) Pin Functions**

| PIN NAME (P4.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | |
|---|---|---|---|---|---|
| | | | P4DIR.x | P4SEL1.x | P4SEL0.x |
| P4.4/TB0.5 | 4 | P4.4 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | TB0.CCI5B | 0 | 0 | 1 |
| | | TB0.5 | 1 | | |
| | | N/A | 0 | 1 | X |
| | | Internally tied to DVSS | 1 | | |
| P4.5 | 5 | P4.5 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | X |
| | | Internally tied to DVSS | 1 | | |
| P4.6 | 6 | P4.6 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | X |
| | | Internally tied to DVSS | 1 | | |
| P4.7 | 7 | P4.7 (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A | 0 | 0 | 1 |
| | | Internally tied to DVSS | 1 | | |
| | | N/A | 0 | 1 | X |
| | | Internally tied to DVSS | 1 | | |

(1) X = Don't care

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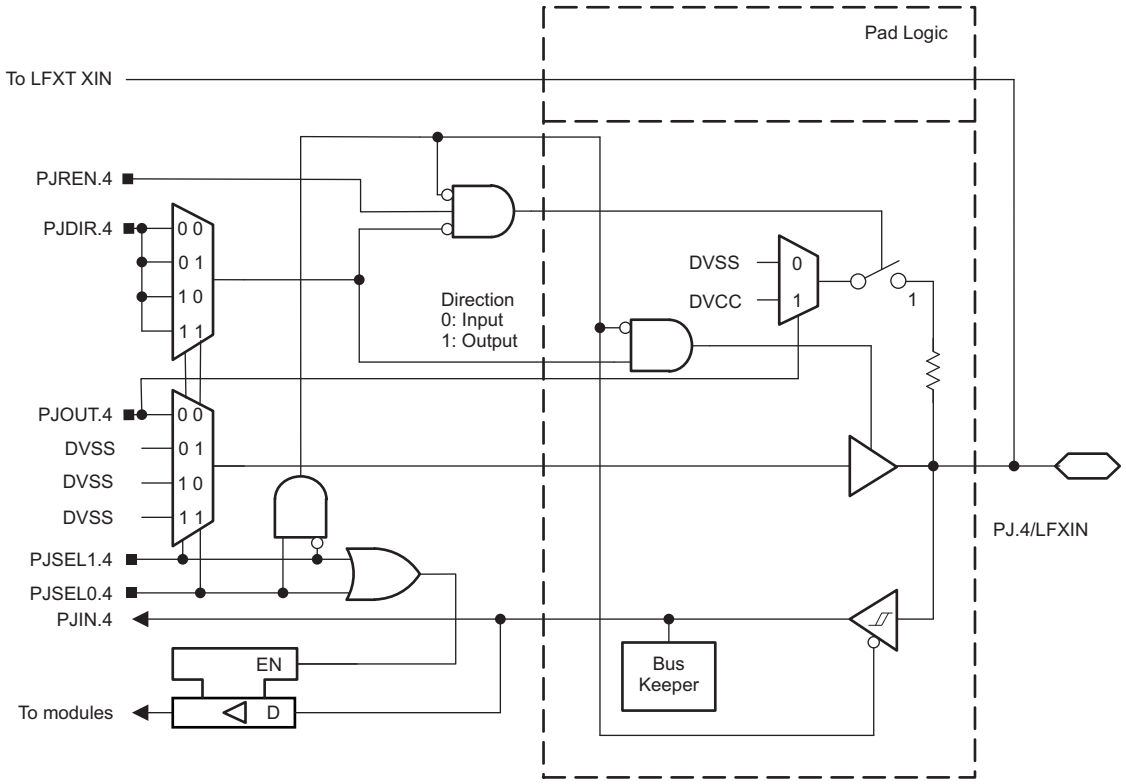
### 6.11.13 Port PJ, PJ.4 and PJ.5 Input/Output With Schmitt Trigger

Figure 6-14 and Figure 6-15 show the port diagrams. Table 6-60 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-14. Port PJ (PJ.4) Diagram**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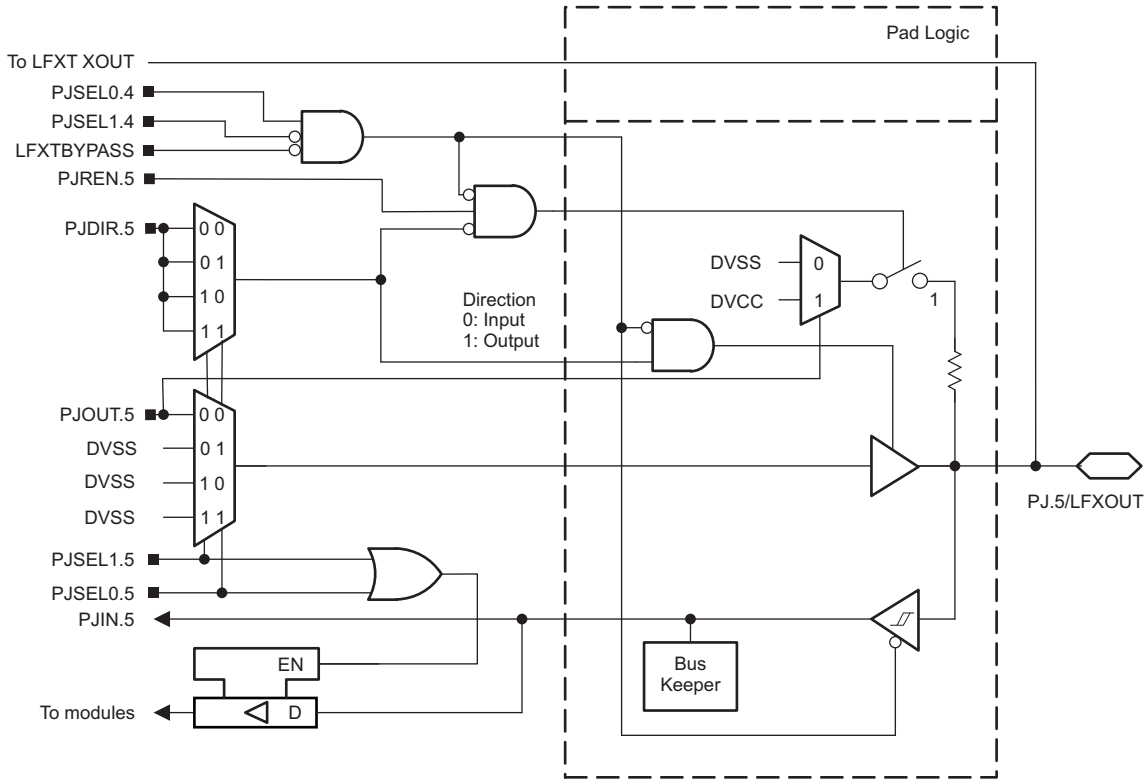


NOTE: Functional representation only.

**Figure 6-15. Port PJ (PJ.5) Diagram**

**Table 6-60. Port PJ (PJ.4 and PJ.5) Pin Functions**

| PIN NAME (PJ.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | PJDIR.x | PJSEL1.5 | PJSEL0.5 | PJSEL1.4 | PJSEL0.4 | LFXT BYPASS |
| PJ.4/LFXIN | 4 | PJ.4 (I/O) | I: 0; O: 1 | X | X | 0 | 0 | X |
| | | N/A | 0 | X | X | 1 | X | X |
| | | Internally tied to DVSS | 1 | | | | | |
| | | LFXIN crystal mode(2) | X | X | X | 0 | 1 | 0 |
| | | LFXIN bypass mode(2) | X | X | X | 0 | 1 | 1 |
| PJ.5/LFXOUT | 5 | PJ.5 (I/O) | I: 0; O: 1 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | 1 | X | |
| | | | | | | X | X | 1(3) |
| | | N/A | 0 | see(4) | see(4) | 0 | 0 | 0 |
| | | | | | | 1 | X | |
| | | | | | | X | X | 1(3) |
| | | Internally tied to DVSS | 1 | see(4) | see(4) | 0 | 0 | 0 |
| | | | | | | 1 | X | |
| | | | | | | X | X | 1(3) |
| | | LFXOUT crystal mode(2) | X | X | X | 0 | 1 | 0 |

(1) X = Don't care
(2) If PJSEL1.4 = 0 and PJSEL0.4 = 1, the general-purpose I/O is disabled. When LFXTBYPASS = 0, PJ.4 and PJ.5 are configured for crystal operation and PJSEL1.5 and PJSEL0.5 are don't care. When LFXTBYPASS = 1, PJ.4 is configured for bypass operation and PJ.5 is configured as general-purpose I/O.
(3) When PJ.4 is configured in bypass mode, PJ.5 is configured as general-purpose I/O.
(4) If PJSEL0.5 = 1 or PJSEL1.5 = 1, the general-purpose I/O functionality is disabled. No input function is available. Configured as output, the pin is actively pulled to zero.


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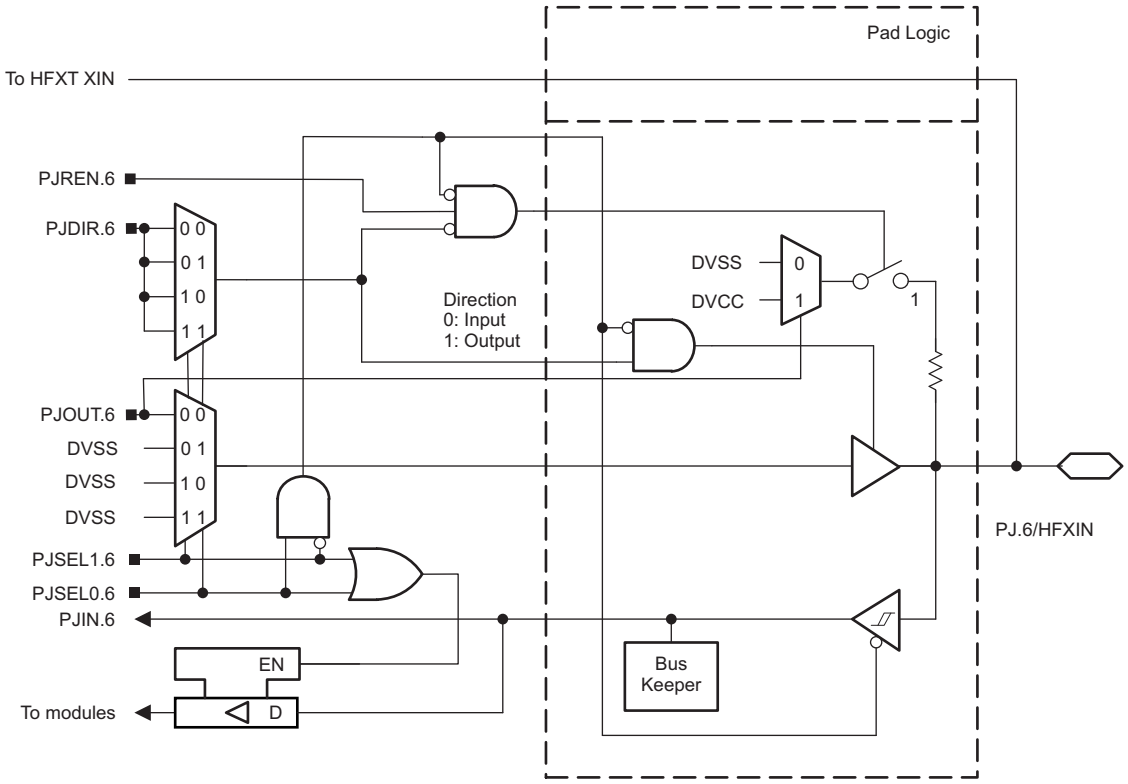
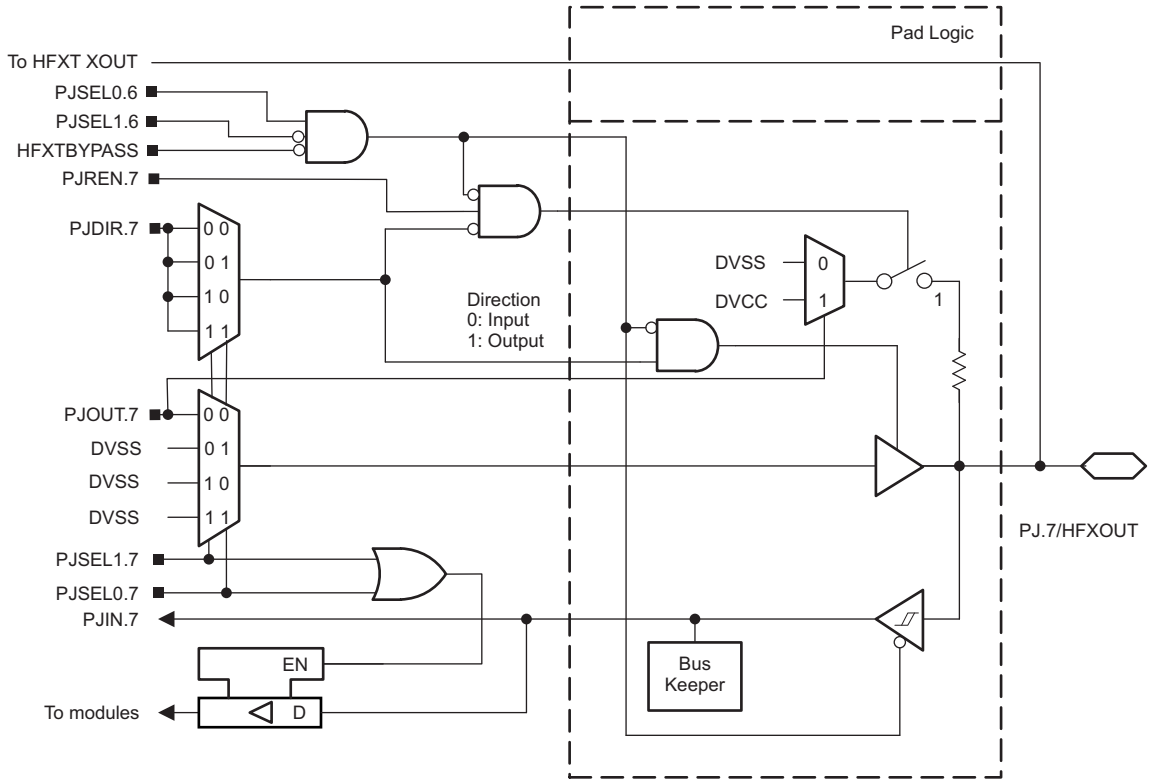
### 6.11.14 Port PJ (PJ.6 and PJ.7) Input/Output With Schmitt Trigger

Figure 6-16 and Figure 6-17 show the port diagrams. Table 6-61 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-16. Port PJ (PJ.6) Diagram**




NOTE: Functional representation only.

**Figure 6-17. Port PJ (PJ.7) Diagram**


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**Table 6-61. Port PJ (PJ.6 and PJ.7) Pin Functions**

| PIN NAME (PJ.x) | x | FUNCTION | CONTROL BITS AND SIGNALS(1) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | PJDIR.x | PJSEL1.7 | PJSEL0.7 | PJSEL1.6 | PJSEL0.6 | HFXT BYPASS |
| PJ.6/HFXIN | 6 | PJ.6 (I/O) | I: 0; O: 1 | X | X | 0 | 0 | X |
| | | N/A | 0 | X | X | 1 | X | X |
| | | Internally tied to DVSS | 1 | | | | | |
| | | HFXIN crystal mode(2) | X | X | X | 0 | 1 | 0 |
| | | HFXIN bypass mode(2) | X | X | X | 0 | 1 | 1 |
| PJ.7/HFXOUT | 7 | PJ.7 (I/O)(3) | I: 0; O: 1 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | 1 | X | |
| | | | | | | X | X | 1(4) |
| | | N/A | 0 | see (3) | see (3) | 0 | 0 | 0 |
| | | | | | | 1 | X | |
| | | | | | | X | X | 1(4) |
| | | Internally tied to DVSS | 1 | see (3) | see (3) | 0 | 0 | 0 |
| | | | | | | 1 | X | |
| | | | | | | X | X | 1(4) |
| | | HFXOUT crystal mode(2) | X | X | X | 0 | 1 | 0 |

(1) X = Don't care
(2) Setting PJSEL1.6 = 0 and PJSEL0.6 = 1 causes the general-purpose I/O to be disabled. When HFXTBYPASS = 0, PJ.6 and PJ.7 are configured for crystal operation and PJSEL1.6 and PJSEL0.7 are do not care. When HFXTBYPASS = 1, PJ.6 is configured for bypass operation, and PJ.7 is configured as general-purpose I/O.
(3) With PJSEL0.7 = 1 or PJSEL1.7 = 1 the general-purpose I/O functionality is disabled. No input function is available. When configured as output, the pin is actively pulled to zero.
(4) When PJ.6 is configured in bypass mode, PJ.7 is configured as general-purpose I/O.

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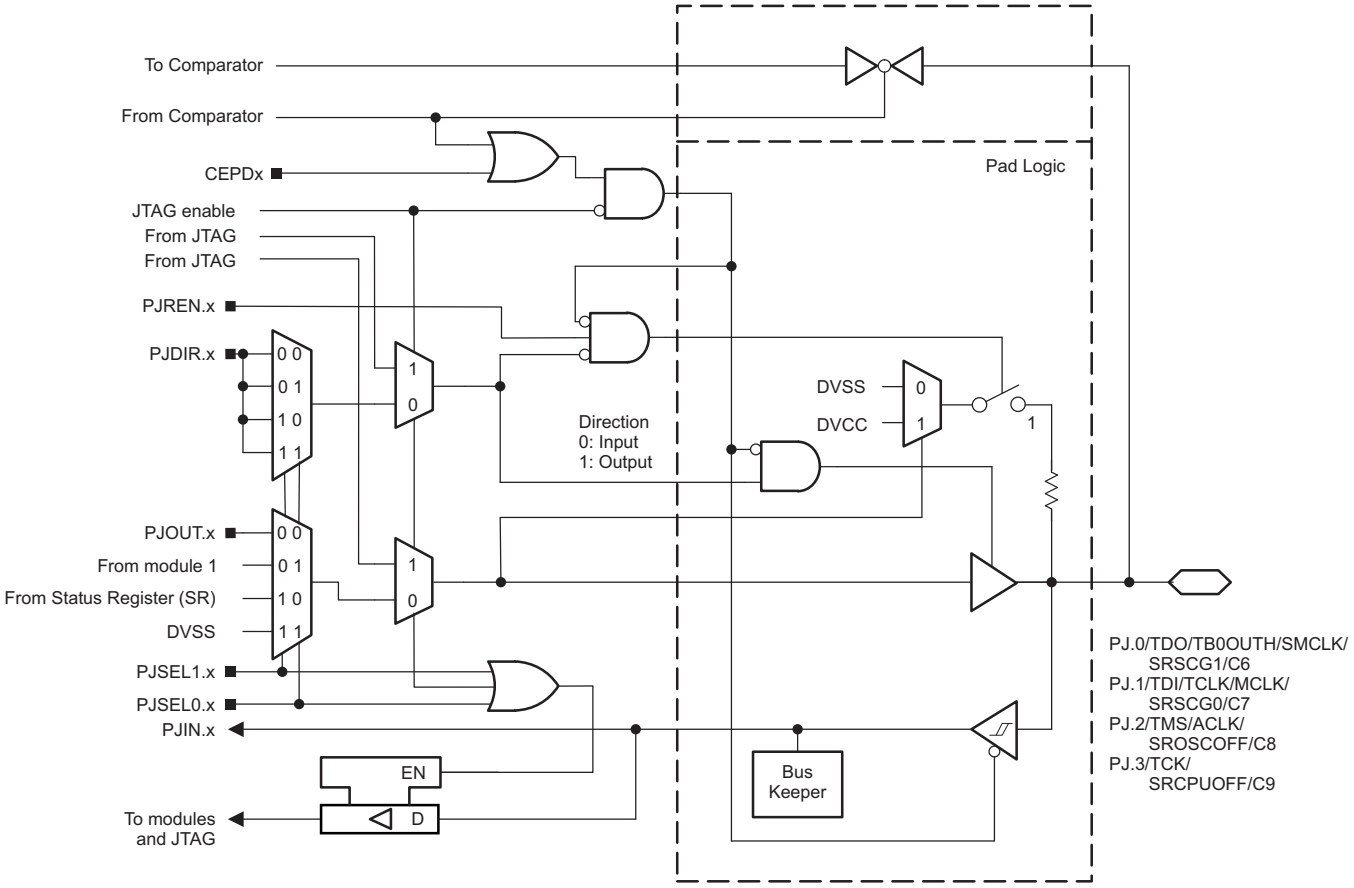
### 6.11.15 Port PJ (PJ.0 to PJ.3) JTAG Pins TDO, TMS, TCK, TDI/TCLK, Input/Output With Schmitt Trigger

Figure 6-18 shows the port diagram. Table 6-62 summarizes the selection of the pin function.




NOTE: Functional representation only.

**Figure 6-18. Port PJ (PJ.0 to PJ.3) Diagram**


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**Table 6-62. Port PJ (PJ.0 to PJ.3) Pin Functions**

| PIN NAME (PJ.x) | x | FUNCTION | CONTROL BITS/ SIGNALS(1) | | | |
|---|---|---|---|---|---|---|
| | | | PJDIR.x | PJSEL1.x | PJSEL0.x | CEPDx (Cx) |
| PJ.0/TDO/TB0OUTH/ SMCLK/SRSCG1/C6 | 0 | PJ.0 (I/O)(2) | I: 0; O: 1 | 0 | 0 | 0 |
| | | TDO(3) | X | X | X | 0 |
| | | TB0OUTH | 0 | 0 | 1 | 0 |
| | | SMCLK(4) | 1 | | | |
| | | N/A | 0 | 1 | 0 | 0 |
| | | CPU Status Register Bit SCG1 | 1 | | | |
| | | N/A | 0 | 1 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | | |
| | | C6(5) | X | X | X | 1 |
| PJ.1/TDI/TCLK/MCLK/ SRSCG0/C7 | 1 | PJ.1 (I/O)(2) | I: 0; O: 1 | 0 | 0 | 0 |
| | | TDI/TCLK(3) (6) | X | X | X | 0 |
| | | N/A | 0 | 0 | 1 | 0 |
| | | MCLK | 1 | | | |
| | | N/A | 0 | 1 | 0 | 0 |
| | | CPU Status Register Bit SCG0 | 1 | | | |
| | | N/A | 0 | 1 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | | |
| | | C7(5) | X | X | X | 1 |
| PJ.2/TMS/ACLK/ SROSCOFF/C8 | 2 | PJ.2 (I/O)(2) | I: 0; O: 1 | 0 | 0 | 0 |
| | | TMS(3) (6) | X | X | X | 0 |
| | | N/A | 0 | 0 | 1 | 0 |
| | | ACLK | 1 | | | |
| | | N/A | 0 | 1 | 0 | 0 |
| | | CPU Status Register Bit OSCOFF | 1 | | | |
| | | N/A | 0 | 1 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | | |
| | | C8(5) | X | X | X | 1 |
| PJ.3/TCK/SRCPUOFF/C9 | 3 | PJ.3 (I/O)(2) | I: 0; O: 1 | 0 | 0 | 0 |
| | | TCK(3) (6) | X | X | X | 0 |
| | | N/A | 0 | 0 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | | |
| | | N/A | 0 | 1 | 0 | 0 |
| | | CPU Status Register Bit CPUOFF | 1 | | | |
| | | N/A | 0 | 1 | 1 | 0 |
| | | Internally tied to DVSS | 1 | | | |
| | | C9(5) | X | X | X | 1 |

(1) X = Don't care
(2) Default condition
(3) The pin direction is controlled by the JTAG module. JTAG mode selection is made via the SYS module or by the Spy-Bi-Wire four-wire entry sequence. Neither PJSEL1.x and PJSEL0.x nor CEPDx bits have an effect in these cases.
(4) Do not use this pin as SMCLK output if the TB0OUTH functionality is used on any other pin. Select an alternative SMCLK output pin.
(5) Setting the CEPDx bit of the comparator disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals. Selecting the Cx input pin to the comparator multiplexer with the input select bits in the comparator module automatically disables output driver and input buffer for that pin, regardless of the state of the associated CEPDx bit.
(6) In JTAG mode, pullups are activated automatically on TMS, TCK, and TDI/TCLK. PJREN.x are don't care.

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## 6.12 Device Descriptor (TLV)

Table 6-63 lists the Device IDs of the MSP430FR59xx(1) devices. Table 6-64 lists the contents of the device descriptor tag-length-value (TLV) structure for MSP430FR59xx(1) devices including AES.

**Table 6-63. Device IDs**

| DEVICE | DEVICE ID | |
|---|---|---|
| | 01A05h | 01A04h |
| MSP430FR5969(1) | 081h | 069h |
| MSP430FR5968 | 081h | 068h |
| MSP430FR5967 | 081h | 067h |
| MSP430FR5949 | 081h | 061h |
| MSP430FR5948 | 081h | 060h |
| MSP430FR5947(1) | 081h | 05Fh |
| MSP430FR5959 | 081h | 065h |
| MSP430FR5958 | 081h | 064h |
| MSP430FR5957 | 081h | 063h |

**Table 6-64. Device Descriptor(1)**

| DESCRIPTION | | MSP430FR59xx (UART BSL) | | MSP430FR59xx1 (I2C BSL) | |
|---|---|---|---|---|---|
| | | ADDRESS | VALUE | ADDRESS | VALUE |
| Info Block | Info length | 01A00h | 06h | 01A00h | 06h |
| | CRC length | 01A01h | 06h | 01A01h | 06h |
| | CRC value | 01A02h | Per unit | 01A02h | Per unit |
| | | 01A03h | Per unit | 01A03h | Per unit |
| | Device ID | 01A04h | See Table 6-63. | 01A04h | See Table 6-63. |
| | | 01A05h | | | |
| | Hardware revision | 01A06h | Per unit | 01A06h | Per unit |
| | Firmware revision | 01A07h | Per unit | 01A07h | Per unit |
| Die Record | Die record tag | 01A08h | 08h | 01A08h | 08h |
| | Die record length | 01A09h | 0Ah | 01A09h | 0Ah |
| | Lot/Wafer ID | 01A0Ah | Per unit | 01A0Ah | Per unit |
| | | 01A0Bh | Per unit | 01A0Bh | Per unit |
| | | 01A0Ch | Per unit | 01A0Ch | Per unit |
| | | 01A0Dh | Per unit | 01A0Dh | Per unit |
| | Die X position | 01A0Eh | Per unit | 01A0Eh | Per unit |
| | | 01A0Fh | Per unit | 01A0Fh | Per unit |
| | Die Y position | 01A10h | Per unit | 01A10h | Per unit |
| | | 01A11h | Per unit | 01A11h | Per unit |
| | Test results | 01A12h | Per unit | 01A12h | Per unit |
| | | 01A13h | Per unit | 01A13h | Per unit |

(1) NA = Not applicable, Per unit = content can differ from device to device


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**Table 6-64. Device Descriptor(1) (continued)**

| DESCRIPTION | | MSP430FR59xx (UART BSL) | | MSP430FR59xx1 (I2C BSL) | |
|---|---|---|---|---|---|
| | | ADDRESS | VALUE | ADDRESS | VALUE |
| ADC12 Calibration | ADC12 calibration tag | 01A14h | 11h | 01A14h | 11h |
| | ADC12 calibration length | 01A15h | 10h | 01A15h | 10h |
| | ADC gain factor(2) | 01A16h | Per unit | 01A16h | Per unit |
| | | 01A17h | Per unit | 01A17h | Per unit |
| | ADC offset(3) | 01A18h | Per unit | 01A18h | Per unit |
| | | 01A19h | Per unit | 01A19h | Per unit |
| | ADC 1.2-V reference Temperature sensor 30°C | 01A1Ah | Per unit | 01A1Ah | Per unit |
| | | 01A1Bh | Per unit | 01A1Bh | Per unit |
| | ADC 1.2-V reference Temperature sensor 85°C | 01A1Ch | Per unit | 01A1Ch | Per unit |
| | | 01A1Dh | Per unit | 01A1Dh | Per unit |
| | ADC 2.0-V reference Temperature sensor 30°C | 01A1Eh | Per unit | 01A1Eh | Per unit |
| | | 01A1Fh | Per unit | 01A1Fh | Per unit |
| | ADC 2.0-V reference Temperature sensor 85°C | 01A20h | Per unit | 01A20h | Per unit |
| | | 01A21h | Per unit | 01A21h | Per unit |
| | ADC 2.5-V reference Temperature sensor 30°C | 01A22h | Per unit | 01A22h | Per unit |
| | | 01A23h | Per unit | 01A23h | Per unit |
| | ADC 2.5-V reference Temperature sensor 85°C | 01A24h | Per unit | 01A24h | Per unit |
| | | 01A25h | Per unit | 01A25h | Per unit |
| REF Calibration | REF calibration tag | 01A26h | 12h | 01A26h | 12h |
| | REF calibration length | 01A27h | 06h | 01A27h | 06h |
| | REF 1.2-V reference | 01A28h | Per unit | 01A28h | Per unit |
| | | 01A29h | Per unit | 01A29h | Per unit |
| | REF 2.0-V reference | 01A2Ah | Per unit | 01A2Ah | Per unit |
| | | 01A2Bh | Per unit | 01A2Bh | Per unit |
| | REF 2.5-V reference | 01A2Ch | Per unit | 01A2Ch | Per unit |
| | | 01A2Dh | Per unit | 01A2Dh | Per unit |

(2) ADC gain: the gain correction factor is measured at room temperature using a 2.5-V external voltage reference without internal buffer (ADC12VRSEL=0x2, 0x4, or 0xE). Other settings (for example, using internal reference) can result in different correction factors.
(3) ADC offset: the offset correction factor is measured at room temperature using ADC12VRSEL= 0x2 or 0x4, an external reference, VR+ = external 2.5 V, VR- = AVSS.

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**Table 6-64. Device Descriptor[1] (continued)**

| DESCRIPTION | | MSP430FR59xx (UART BSL) | | MSP430FR59xx1 (I2C BSL) | |
|---|---|---|---|---|---|
| | | ADDRESS | VALUE | ADDRESS | VALUE |
| Random Number | 128-bit random number tag | 01A2Eh | 15h | 01A2Eh | 15h |
| | Random number length | 01A2Fh | 10h | 01A2Fh | 10h |
| | 128-bit random number[4] | 01A30h | Per unit | 01A30h | Per unit |
| | | 01A31h | Per unit | 01A31h | Per unit |
| | | 01A32h | Per unit | 01A32h | Per unit |
| | | 01A33h | Per unit | 01A33h | Per unit |
| | | 01A34h | Per unit | 01A34h | Per unit |
| | | 01A35h | Per unit | 01A35h | Per unit |
| | | 01A36h | Per unit | 01A36h | Per unit |
| | | 01A37h | Per unit | 01A37h | Per unit |
| | | 01A38h | Per unit | 01A38h | Per unit |
| | | 01A39h | Per unit | 01A39h | Per unit |
| | | 01A3Ah | Per unit | 01A3Ah | Per unit |
| | | 01A3Bh | Per unit | 01A3Bh | Per unit |
| | | 01A3Ch | Per unit | 01A3Ch | Per unit |
| | | 01A3Dh | Per unit | 01A3Dh | Per unit |
| | | 01A3Eh | Per unit | 01A3Eh | Per unit |
| | | 01A3Fh | Per unit | 01A3Fh | Per unit |
| BSL Configuration | BSL tag | 01A40h | 1Ch | 01A40h | 1Ch |
| | BSL length | 01A41h | 02h | 01A41h | 02h |
| | BSL Interface | 01A42h | 00h | 01A42h | 01h |
| | BSL interface configuration | 01A43h | 00h | 01A43h | 48h |

(4) 128-bit random number: The random number is generated during production test using the CryptGenRandom() function from Microsoft®.

## 6.13 Identification

### 6.13.1 Revision Identification

The device revision information is shown as part of the top-side marking on the device package. The device-specific errata sheet describes these markings. For links to the errata sheets for the devices in this data sheet, see Section 8.4.

The hardware revision is also stored in the Device Descriptor structure in the Info Block section. For details on this value, see the "Hardware Revision" entries in Section 6.12.

### 6.13.2 Device Identification

The device type can be identified from the top-side marking on the device package. The device-specific errata sheet describes these markings. For links to the errata sheets for the devices in this data sheet, see Section 8.4.

A device identification value is also stored in the Device Descriptor structure in the Info Block section. For details on this value, see the "Device ID" entries in Section 6.12.

### 6.13.3 JTAG Identification

Programming through the JTAG interface, including reading and identifying the JTAG ID, is described in detail in the *MSP430 Programming With the JTAG Interface*.


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# 7 Applications, Implementation, and Layout

**NOTE**

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

## 7.1 Device Connection and Layout Fundamentals

This section describes the recommended guidelines when designing with the MSP430. These guidelines ensure that the device has proper connections for powering, programming, debugging, and optimum analog performance.

### *7.1.1 Power Supply Decoupling and Bulk Capacitors*

TI recommends connecting a combination of a 1-µF capacitor and a 100-nF low-ESR ceramic decoupling capacitor to each AVCC and DVCC pin. Higher-value capacitors may be used but can affect supply rail ramp-up time. Decoupling capacitors must be placed as close as possible to the pins that they decouple (within a few millimeters). Additionally, TI recommends separated grounds with a single-point connection for better noise isolation from digital to analog circuits on the board and to achieve high analog accuracy.

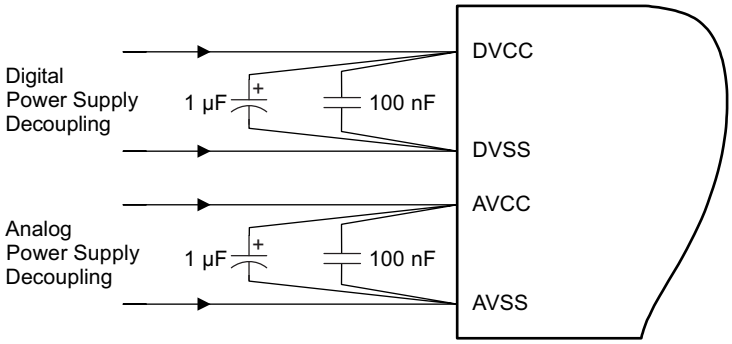


**Figure 7-1. Power Supply Decoupling**

### *7.1.2 External Oscillator*

Depending on the device variant (see Section 3), the device can support a low-frequency crystal (32 kHz) on the LFXT pins, a high-frequency crystal on the HFXT pins, or both. External bypass capacitors for the crystal oscillator pins are required.

It is also possible to apply digital clock signals to the LFXIN and HFXIN input pins that meet the specifications of the respective oscillator if the appropriate LFXTBYPASS or HFXTBYPASS mode is selected. In this case, the associated LFXOUT and HFXOUT pins can be used for other purposes. If the LFXIN and HFXIN are left unused, they must be terminated according to Section 4.4.

Figure 7-2 shows a typical connection diagram.

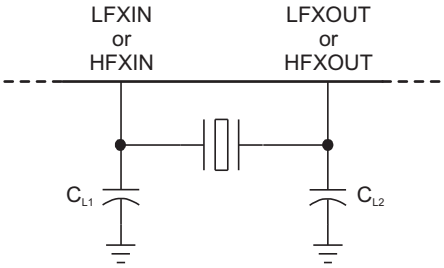


**Figure 7-2. Typical Crystal Connection**

See *MSP430 32-kHz Crystal Oscillators* for more information on selecting, testing, and designing a crystal oscillator with the MSP430 devices.

### 7.1.3 JTAG

With the proper connections, the debugger and a hardware JTAG interface (such as the MSP-FET or MSP-FET430UIF) can be used to program and debug code on the target board. In addition, the connections also support the MSP-GANG production programmers, thus providing an easy way to program prototype boards, if desired. Figure 7-3 shows the connections between the 14-pin JTAG connector and the target device required to support in-system programming and debugging for 4-wire JTAG communication. Figure 7-4 shows the connections for 2-wire JTAG mode (Spy-Bi-Wire).

The connections for the MSP-FET and MSP-FET430UIF interface modules and the MSP-GANG are identical. Both can supply VCC to the target board (through pin 2). In addition, the MSP-FET and MSP-FET430UIF interface modules and MSP-GANG have a VCC sense feature that, if used, requires an alternate connection (pin 4 instead of pin 2). The VCC-sense feature senses the local VCC present on the target board (that is, a battery or other local power supply) and adjusts the output signals accordingly. Figure 7-3 and Figure 7-4 show a jumper block that supports both scenarios of supplying VCC to the target board. If this flexibility is not required, the desired VCC connections may be hard-wired to eliminate the jumper block. Pins 2 and 4 must not be connected at the same time.

For additional design information regarding the JTAG interface, see the *MSP430 Hardware Tools User's Guide*.


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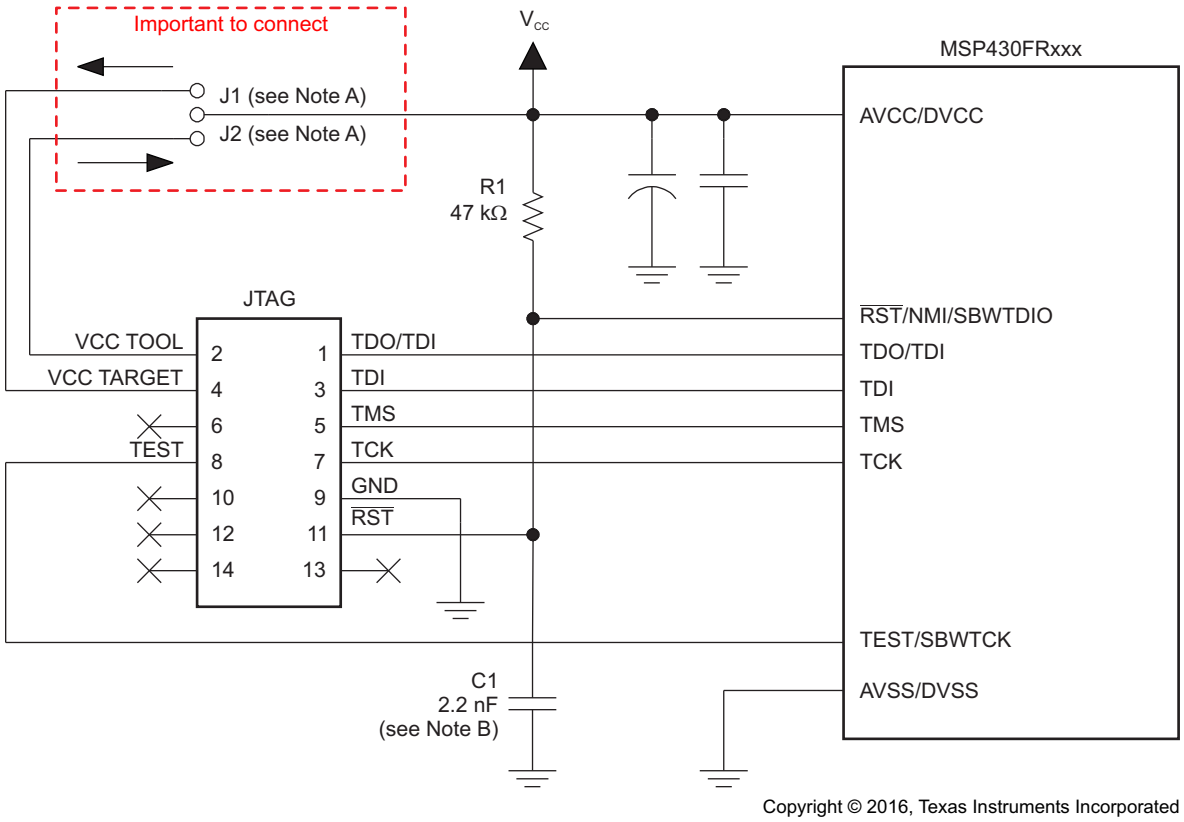


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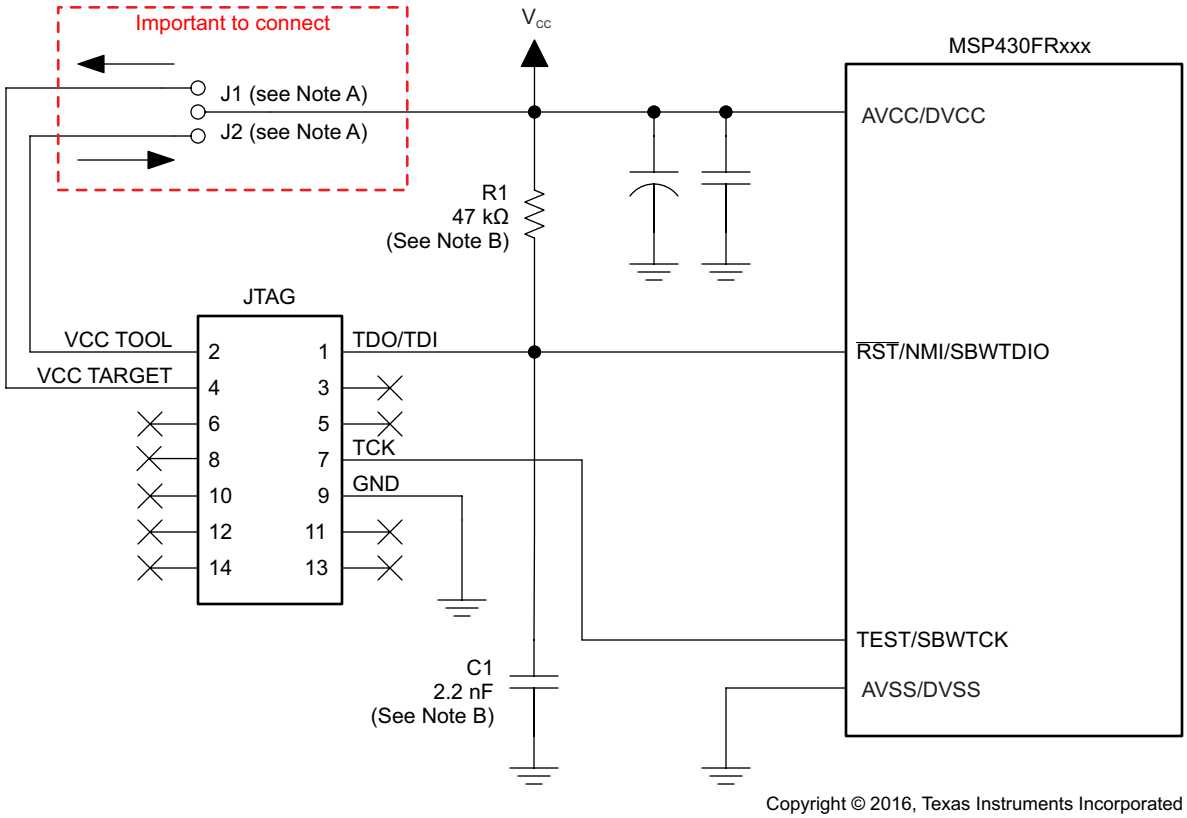
A. If a local target power supply is used, make connection J1. If power from the debug or programming adapter is used, make connection J2.

B. The upper limit for C1 is 2.2 nF when using current TI tools.

**Figure 7-3. Signal Connections for 4-Wire JTAG Communication**




A. Make connection J1 if a local target power supply is used, or make connection J2 if the target is powered from the debug or programming adapter.

B. The device $\overline{\text{RST}}$/NMI/SBWTDIO pin is used in 2-wire mode for bidirectional communication with the device during JTAG access, and any capacitance that is attached to this signal may affect the ability to establish a connection with the device. The upper limit for C1 is 2.2 nF when using current TI tools.

**Figure 7-4. Signal Connections for 2-Wire JTAG Communication (Spy-Bi-Wire)**

### 7.1.4 Reset

The reset pin can be configured as a reset function (default) or as an NMI function in the Special Function Register (SFR), SFRRPCR.

In reset mode, the $\overline{\text{RST}}$/NMI pin is active low, and a pulse applied to this pin that meets the reset timing specifications generates a BOR-type device reset.

Setting SYSNMI causes the $\overline{\text{RST}}$/NMI pin to be configured as an external NMI source. The external NMI is edge sensitive, and its edge is selectable by SYSNMIIES. Setting the NMIIE enables the interrupt of the external NMI. When an external NMI event occurs, the NMIIFG is set.

The $\overline{\text{RST}}$/NMI pin can have either a pullup or pulldown that is enabled or not. SYSRSTUP selects either pullup or pulldown, and SYSRSTRE causes the pullup (default) or pulldown to be enabled (default) or not. If the $\overline{\text{RST}}$/NMI pin is unused, it is required either to select and enable the internal pullup or to connect an external 47-kΩ pullup resistor to the $\overline{\text{RST}}$/NMI pin with a 2.2-nF pulldown capacitor. The pulldown capacitor should not exceed 2.2 nF when using devices in Spy-Bi-Wire mode or in 4-wire JTAG mode with TI tools like FET interfaces or GANG programmers. If JTAG or Spy-Bi-Wire access is not needed, up to a 10-nF pulldown capacitor may be used.

See the *MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide* for more information on the referenced control registers and bits.

### 7.1.5 Unused Pins

For details on the connection of unused pins, see Section 4.4.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### 7.1.6 General Layout Recommendations

- Proper grounding and short traces for external crystal to reduce parasitic capacitance. See *MSP430 32-kHz Crystal Oscillators* for recommended layout guidelines.
- Proper bypass capacitors on DVCC, AVCC, and reference pins if used.
- Avoid routing any high-frequency signal close to an analog signal line. For example, keep digital switching signals such as PWM or JTAG signals away from the oscillator circuit.
- Proper ESD level protection should be considered to protect the device from unintended high-voltage electrostatic discharge. See *MSP430 System-Level ESD Considerations* for guidelines.

### 7.1.7 Do's and Don'ts

TI recommends powering AVCC and DVCC pins from the same source. At a minimum, during power up, power down, and device operation, the voltage difference between AVCC and DVCC must not exceed the limits specified in Section 5.1. Exceeding the specified limits may cause malfunction of the device including erroneous writes to RAM and FRAM.

## 7.2 Peripheral- and Interface-Specific Design Information

### 7.2.1 ADC12_B Peripheral

#### 7.2.1.1 Partial Schematic

Figure 7-5 shows the recommended decoupling circuit when an external voltage reference is used.

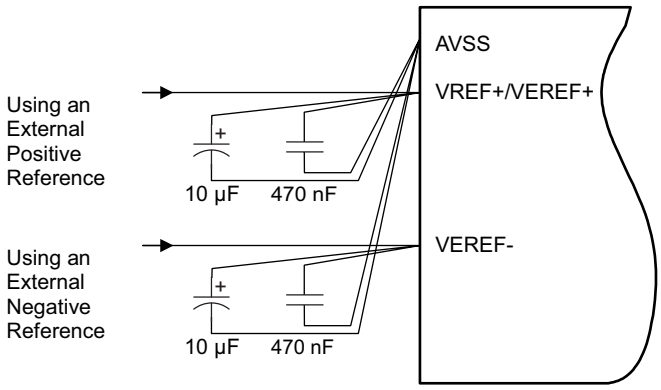


**Figure 7-5. ADC12_B Grounding and Noise Considerations**

#### 7.2.1.2 Design Requirements

As with any high-resolution ADC, appropriate printed-circuit-board layout and grounding techniques should be followed to eliminate ground loops, unwanted parasitic effects, and noise.

Ground loops are formed when return current from the ADC flows through paths that are common with other analog or digital circuitry. If care is not taken, this current can generate small unwanted offset voltages that can add to or subtract from the reference or input voltages of the ADC. The general guidelines in Section 7.1.1 combined with the connections in Section 7.2.1.1 prevent this.

In addition to grounding, ripple and noise spikes on the power-supply lines that are caused by digital switching or switching power supplies can corrupt the conversion result. TI recommends a noise-free design using separate analog and digital ground planes with a single-point connection to achieve high accuracy.

Figure 7-5 shows the recommended decoupling circuit when an external voltage reference is used. The internal reference module has a maximum drive current as specified in the Reference module's $I_{O(VREF+)}$ specification.

The reference voltage must be a stable voltage for accurate measurements. The capacitor values that are selected in the general guidelines filter out the high- and low-frequency ripple before the reference voltage enters the device. In this case, the 10-µF capacitor is used to buffer the reference pin and filter low-frequency ripple. A 470-nF bypass capacitor is used to filter high-frequency noise.

#### 7.2.1.3 Detailed Design Procedure

For additional design information, see Designing With the MSP430FR58xx, FR59xx, FR68xx, and FR69xx ADC.

#### 7.2.1.4 Layout Guidelines

Component that are shown in the partial schematic (see Figure 7-5) should be placed as close as possible to the respective device pins. Avoid long traces, because they add additional parasitic capacitance, inductance, and resistance on the signal.

Avoid routing analog input signals close to a high-frequency pin (for example, a high-frequency PWM), because the high-frequency switching can be coupled into the analog signal.

If differential mode is used for the ADC12_B, the analog differential input signals must be routed closely together to minimize the effect of noise on the resulting signal.


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# 8 Device and Documentation Support

## 8.1 Getting Started and Next Steps

For more information on the MSP430 family of devices and the tools and libraries that are available to help with your development, visit the Getting Started page.

## 8.2 Device Nomenclature

To designate the stages in the product development cycle, TI assigns prefixes to the part numbers of all MSP MCU devices. Each MSP MCU commercial family member has one of two prefixes: MSP or XMS. These prefixes represent evolutionary stages of product development from engineering prototypes (XMS) through fully qualified production devices (MSP).

**XMS** – Experimental device that is not necessarily representative of the final device's electrical specifications

**MSP** – Fully qualified production device

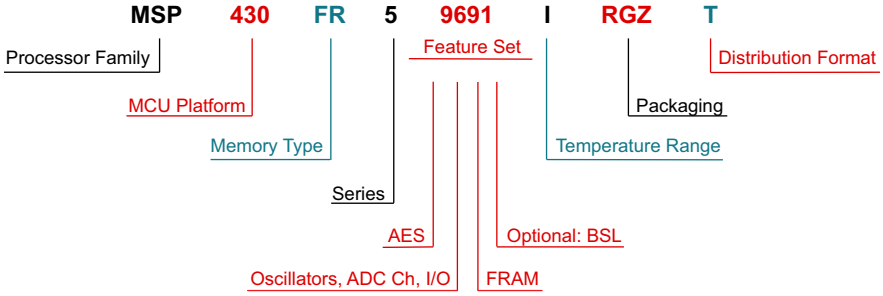
XMS devices are shipped against the following disclaimer:

"Developmental product is intended for internal evaluation purposes."

MSP devices have been characterized fully, and the quality and reliability of the device have been demonstrated fully. TI's standard warranty applies.

Predictions show that prototype devices (XMS) have a greater failure rate than the standard production devices. TI recommends that these devices not be used in any production system because their expected end-use failure rate still is undefined. Only qualified production devices are to be used.

TI device nomenclature also includes a suffix with the device family name. This suffix indicates the temperature range, package type, and distribution format. Figure 8-1 provides a legend for reading the complete device name.




| | | | | |
|---|---|---|---|---|
| **Processor Family** | MSP = Mixed-Signal Processor<br>XMS = Experimental Silicon | | | |
| **MCU Platform** | 430 = TI's 16-bit MSP430 Low-Power Microcontroller Platform | | | |
| **Memory Type** | FR = FRAM | | | |
| **Series** | 5 = FRAM 5 series up to 16 MHz without LCD | | | |
| **Feature Set** | **First Digit: AES**<br>9 = AES<br>8 = No AES | **Second Digit: Oscillators, ADC Channels, I/O**<br>6 = DCO/HFXT/LFXT, 16, 40<br>5 = DCO/HFXT, 14/12, 33/31<br>4 = DCO/LFXT, 14/12, 33/31 | **Third Digit: FRAM (KB)**<br>9 = 64<br>8 = 48<br>7 = 32 | **Optional Fourth Digit: BSL**<br>1 = $I^2C$<br>No value = UART |
| **Temperature Range** | I = –40°C to 85°C | | | |
| **Packaging** | www.ti.com/packaging | | | |
| **Distribution Format** | T = Small reel<br>R = Large reel<br>No markings = Tube or tray | | | |

NOTE: This figure does not represent a complete list of the available features and options, and it does not indicate that all of these features and options are available for a given device or family.

**Figure 8-1. Device Nomenclature – Part Number Decoder**

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## 8.3 Tools and Software

Table 8-1 lists the debug features supported by the MSP430FR59xx microcontrollers. See the *Code Composer Studio for MSP430 User's Guide* for details on the available features.

**Table 8-1. Hardware Features**

| MSP430 ARCHITECTURE | 4-WIRE JTAG | 2-WIRE JTAG | BREAK-POINTS (N) | RANGE BREAK-POINTS | CLOCK CONTROL | STATE SEQUENCER | TRACE BUFFER | LPMx.5 DEBUGGING SUPPORT | EnergyTrace++ TECHNOLOGY |
|---|---|---|---|---|---|---|---|---|---|
| MSP430Xv2 | Yes | Yes | 3 | Yes | Yes | No | No | Yes | Yes |

EnergyTrace™ technology is supported with Code Composer Studio version 6.0 and newer. EnergyTrace technology requires specialized debugger circuitry, which is supported with the second-generation onboard eZ-FET flash emulation tool and second-generation stand-alone MSP-FET JTAG emulator. For additional information, see:

*Advanced Debugging Using the Enhanced Emulation Module (EEM) With Code Composer Studio*

*MSP430™ Advanced Power Optimizations: ULP Advisor™ and EnergyTrace™ Technology*

### Design Kits and Evaluation Modules

**MSP430FR5969 LaunchPad™ Development Kit** The MSP-EXP430FR5969 LaunchPad Development Kit is an easy-to-use microcontroller development board for the MSP430FR5969 MCU. It contains everything needed to start developing quickly on the MSP430FRxx FRAM platform, including onboard emulation for programming, debugging, and energy measurements.

**48-pin Target Development Board and MSP-FET Programmer Bundle for MSP430FRxx FRAM MCUs**
The MSP-FET430U48C is a powerful design kit for quick application development on the MSP MCU. The board includes a USB debugging interface used to program and debug the MSP MCU in system through the JTAG interface or the pin-saving Spy-Bi-Wire (2-wire JTAG) protocol. The FRAM can be erased and programmed in seconds with only a few keystrokes, and because the MSP FRAM consumes very little power, no external supply is required.

**MSP-TS430RGZ48C - 48-pin Target Development Board for MSP430FRxx FRAM MCUs** The MSP-TS430RGZ48C is a stand-alone 48-pin ZIF socket target board used to program and debug the MSP430 MCU in system through the JTAG interface or the Spy-Bi-Wire (2-wire JTAG) protocol.

### Software

**MSP430Ware™ Software** MSP430Ware software is a collection of code examples, data sheets, and other design resources for all MSP430 devices delivered in a convenient package. In addition to providing a complete collection of existing MSP430 MCU design resources, MSP430Ware software also includes a high-level API called MSP Driver Library. This library makes it easy to program MSP430 hardware. MSP430Ware software is available as a component of CCS or as a stand-alone package.

**MSP430FR59xx, MSP430FR58xx Code Examples** C Code examples are available for every MSP device that configures each of the integrated peripherals for various application needs.

**FRAM Embedded Software Utilities for MSP Ultra-Low-Power Microcontrollers** The TI FRAM Utilities software is designed to grow as a collection of embedded software utilities that leverage the ultra-low-power and virtually unlimited write endurance of FRAM. The utilities are available for MSP430FRxx FRAM microcontrollers and provide example code to help start application development.

**Capacitive Touch Software Library** Free C libraries for enabling capacitive touch capabilities on MSP430 MCUs. The MSP430 MCU version of the library features several capacitive touch implementations including the RO and RC method.


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**MSP Driver Library** The abstracted API of MSP Driver Library provides easy-to-use function calls that free you from directly manipulating the bits and bytes of the MSP430 hardware. Thorough documentation is delivered through a helpful API Guide, which includes details on each function call and the recognized parameters. Developers can use Driver Library functions to write complete projects with minimal overhead.

**MSP EnergyTrace™ Technology** EnergyTrace technology for MSP430 microcontrollers is an energy-based code analysis tool that measures and displays the energy profile of the application and helps to optimize it for ultra-low-power consumption.

**ULP (Ultra-Low Power) Advisor** ULP Advisor™ software is a tool for guiding developers to write more efficient code to fully use the unique ultra-low-power features of MSP and MSP432 microcontrollers. Aimed at both experienced and new microcontroller developers, ULP Advisor checks your code against a thorough ULP checklist to help minimize the energy consumption of your application. At build time, ULP Advisor provides notifications and remarks to highlight areas of your code that can be further optimized for lower power.

**IEC60730 Software Package** The IEC60730 MSP430 software package was developed to help customers comply with IEC 60730-1:2010 (Automatic Electrical Controls for Household and Similar Use – Part 1: General Requirements) for up to Class B products, which includes home appliances, arc detectors, power converters, power tools, e-bikes, and many others. The IEC60730 MSP430 software package can be embedded in customer applications running on MSP430s to help simplify the customer's certification efforts of functional safety-compliant consumer devices to IEC 60730-1:2010 Class B.

**Fixed Point Math Library for MSP** The MSP IQmath and Qmath Libraries are a collection of highly optimized and high-precision mathematical functions for C programmers to seamlessly port a floating-point algorithm into fixed-point code on MSP430 and MSP432 devices. These routines are typically used in computationally intensive real-time applications where optimal execution speed, high accuracy, and ultra-low energy are critical. By using the IQmath and Qmath libraries, it is possible to achieve execution speeds considerably faster and energy consumption considerably lower than equivalent code written using floating-point math.

**Floating Point Math Library for MSP430** Continuing to innovate in the low-power and low-cost microcontroller space, TI provides MSPMATHLIB. Leveraging the intelligent peripherals of our devices, this floating-point math library of scalar functions that are up to 26 times faster than the standard MSP430 math functions. Mathlib is easy to integrate into your designs. This library is free and is integrated in both Code Composer Studio IDE and IAR Embedded Workbench IDE.

### Development Tools

**Code Composer Studio™ Integrated Development Environment for MSP Microcontrollers** Code Composer Studio (CCS) integrated development environment (IDE) supports all MSP microcontroller devices. CCS comprises a suite of embedded software utilities used to develop and debug embedded applications. CCS includes an optimizing C/C++ compiler, source code editor, project build environment, debugger, profiler, and many other features.

**Command-Line Programmer** MSP Flasher is an open-source shell-based interface for programming MSP microcontrollers through a FET programmer or eZ430 using JTAG or Spy-Bi-Wire (SBW) communication. MSP Flasher can download binary files (.txt or .hex) directly to the MSP microcontroller without an IDE.

**MSP MCU Programmer and Debugger** The MSP-FET is a powerful emulation development tool – often called a debug probe – which lets users quickly begin application development on MSP low-power MCUs. Creating MCU software usually requires downloading the resulting binary program to the MSP device for validation and debugging.

**MSP-GANG Production Programmer** The MSP Gang Programmer is an MSP430 or MSP432 device programmer that can program up to eight identical MSP430 or MSP432 flash or FRAM devices at the same time. The MSP Gang Programmer connects to a host PC using a standard RS-232 or USB connection and provides flexible programming options that let the user fully customize the process.

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## 8.4 Documentation Support

The following documents describe the MSP430FR59xx MCUs. Copies of these documents are available on the Internet at www.ti.com.

### Receiving Notification of Document Updates

To receive notification of documentation updates—including silicon errata—go to the product folder for your device on ti.com (for links to product folders, see Section 8.5). In the upper right corner, click the "Alert me" button. This registers you to receive a weekly digest of product information that has changed (if any). For change details, check the revision history of any revised document.

### Errata

**MSP430FR5969 Device Erratasheet** Describes the known exceptions to the functional specifications.

**MSP430FR59691 Device Erratasheet** Describes the known exceptions to the functional specifications.

**MSP430FR5968 Device Erratasheet** Describes the known exceptions to the functional specifications.

**MSP430FR5967 Device Erratasheet** Describes the known exceptions to the functional specifications.

**MSP430FR5959 Device Erratasheet** Describes the known exceptions to the functional specifications.

**MSP430FR5958 Device Erratasheet** Describes the known exceptions to the functional specifications.

**MSP430FR5957 Device Erratasheet** Describes the known exceptions to the functional specifications.

**MSP430FR5949 Device Erratasheet** Describes the known exceptions to the functional specifications.

**MSP430FR5948 Device Erratasheet** Describes the known exceptions to the functional specifications.

**MSP430FR5947 Device Erratasheet** Describes the known exceptions to the functional specifications.

**MSP430FR59471 Device Erratasheet** Describes the known exceptions to the functional specifications.

### User's Guides

**MSP430FR58xx, MSP430FR59xx, and MSP430FR6xx Family User's Guide** Detailed description of all modules and peripherals available in this device family.

**MSP430 FRAM Device Bootloader (BSL) User's Guide** The bootloader (BSL, formerly known as the bootstrap loader) provides a method to program memory during MSP430 MCU project development and updates. It can be activated by a utility that sends commands using a serial protocol. The BSL lets the user control the activity of the MSP430 and to exchange data using a personal computer or other device.

**MSP430 Programming With the JTAG Interface** This document describes the functions that are required to erase, program, and verify the memory module of the MSP430 flash-based and FRAM-based microcontroller families using the JTAG communication port. In addition, it describes how to program the JTAG access security fuse that is available on all MSP430 devices. This document describes device access using both the standard 4-wire JTAG interface and the 2-wire JTAG interface, which is also referred to as Spy-Bi-Wire (SBW).

**MSP430 Hardware Tools User's Guide** This manual describes the hardware of the TI MSP-FET430 Flash Emulation Tool (FET). The FET is the program development tool for the MSP430 ultra-low-power microcontroller. Both available interface types, the parallel port interface and the USB interface, are described.


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### Application Reports

**MSP430 FRAM Technology – How To and Best Practices** FRAM is a nonvolatile memory technology that behaves similar to SRAM while enabling a whole host of new applications, but also changing the way firmware should be designed. This application report outlines the how to and best practices of using FRAM technology in MSP430 from an embedded software development perspective. It discusses how to implement a memory layout according to application-specific code, constant, data space requirements, and the use of FRAM to optimize application energy consumption.

**MSP430 32-kHz Crystal Oscillators** Selection of the right crystal, correct load circuit, and proper board layout are important for a stable crystal oscillator. This application report summarizes crystal oscillator function and explains the parameters to select the correct crystal for MSP430 ultra-low-power operation. In addition, hints and examples for correct board layout are given. The document also contains detailed information on the possible oscillator tests to ensure stable oscillator operation in mass production.

**MSP430 System-Level ESD Considerations** System-Level ESD has become increasingly demanding with silicon technology scaling towards lower voltages and the need for designing cost-effective and ultra-low-power components. This application report addresses three different ESD topics to help board designers and OEMs understand and design robust system-level designs.

## 8.5 Related Links

Table 8-2 lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

**Table 8-2. Related Links**

| PARTS | PRODUCT FOLDER | ORDER NOW | TECHNICAL DOCUMENTS | TOOLS & SOFTWARE | SUPPORT & COMMUNITY |
|---|---|---|---|---|---|
| MSP430FR5969 | Click here | Click here | Click here | Click here | Click here |
| MSP430FR59691 | Click here | Click here | Click here | Click here | Click here |
| MSP430FR5968 | Click here | Click here | Click here | Click here | Click here |
| MSP430FR5967 | Click here | Click here | Click here | Click here | Click here |
| MSP430FR5959 | Click here | Click here | Click here | Click here | Click here |
| MSP430FR5958 | Click here | Click here | Click here | Click here | Click here |
| MSP430FR5957 | Click here | Click here | Click here | Click here | Click here |
| MSP430FR5949 | Click here | Click here | Click here | Click here | Click here |
| MSP430FR5948 | Click here | Click here | Click here | Click here | Click here |
| MSP430FR5947 | Click here | Click here | Click here | Click here | Click here |
| MSP430FR59471 | Click here | Click here | Click here | Click here | Click here |

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## 8.6 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

TI E2E™ Community

*TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas, and help solve problems with fellow engineers.

TI Embedded Processors Wiki

*Texas Instruments Embedded Processors Wiki*. Established to help developers get started with embedded processors from Texas Instruments and to foster innovation and growth of general knowledge about the hardware and software surrounding these devices.

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## 8.8 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

## 8.9 Export Control Notice

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## 8.10 Glossary

**TI Glossary** This glossary lists and explains terms, acronyms, and definitions.


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# 9 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

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## PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead/Ball Finish (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSP430FR59471IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR59471 | Samples |
| MSP430FR59471IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR59471 | Samples |
| MSP430FR5947IDA | ACTIVE | TSSOP | DA | 38 | 40 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5947 | Samples |
| MSP430FR5947IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5947 | Samples |
| MSP430FR5947IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5947 | Samples |
| MSP430FR5947IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5947 | Samples |
| MSP430FR5948IDA | ACTIVE | TSSOP | DA | 38 | 40 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5948 | Samples |
| MSP430FR5948IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5948 | Samples |
| MSP430FR5948IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5948 | Samples |
| MSP430FR5948IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5948 | Samples |
| MSP430FR5949IDA | ACTIVE | TSSOP | DA | 38 | 40 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5949 | Samples |
| MSP430FR5949IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5949 | Samples |
| MSP430FR5949IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5949 | Samples |
| MSP430FR5949IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5949 | Samples |
| MSP430FR5957IDA | ACTIVE | TSSOP | DA | 38 | 40 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5957 | Samples |
| MSP430FR5957IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5957 | Samples |
| MSP430FR5957IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5957 | Samples |

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead/Ball Finish (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSP430FR5957IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5957 | Samples |
| MSP430FR5958IDA | ACTIVE | TSSOP | DA | 38 | 40 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5958 | Samples |
| MSP430FR5958IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5958 | Samples |
| MSP430FR5958IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5958 | Samples |
| MSP430FR5958IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5958 | Samples |
| MSP430FR5959IDA | ACTIVE | TSSOP | DA | 38 | 40 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5959 | Samples |
| MSP430FR5959IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5959 | Samples |
| MSP430FR5959IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5959 | Samples |
| MSP430FR5959IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5959 | Samples |
| MSP430FR5967IRGZR | ACTIVE | VQFN | RGZ | 48 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5967 | Samples |
| MSP430FR5967IRGZT | ACTIVE | VQFN | RGZ | 48 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5967 | Samples |
| MSP430FR5968IRGZR | ACTIVE | VQFN | RGZ | 48 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5968 | Samples |
| MSP430FR5968IRGZT | ACTIVE | VQFN | RGZ | 48 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5968 | Samples |
| MSP430FR59691IRGZR | ACTIVE | VQFN | RGZ | 48 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR59691 | Samples |
| MSP430FR59691IRGZT | ACTIVE | VQFN | RGZ | 48 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR59691 | Samples |
| MSP430FR5969IRGZR | ACTIVE | VQFN | RGZ | 48 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5969 | Samples |
| MSP430FR5969IRGZT | ACTIVE | VQFN | RGZ | 48 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-3-260C-168 HR | -40 to 85 | FR5969 | Samples |

**(1)** The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.
**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.
**OBSOLETE:** TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

**Important Information and Disclaimer:**The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

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**OTHER QUALIFIED VERSIONS OF MSP430FR5969 :**

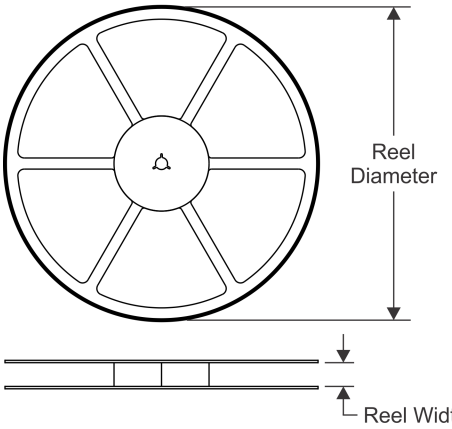
- Space: MSP430FR5969-SP

NOTE: Qualified Version Definitions:

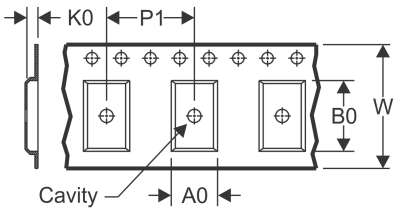
- Space - Radiation tolerant, ceramic packaging and qualified for use in Space-based application

## TAPE AND REEL INFORMATION

**REEL DIMENSIONS**

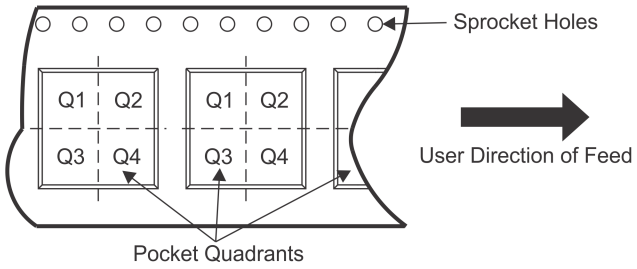



**TAPE DIMENSIONS**




| | |
|---|---|
| A0 | Dimension designed to accommodate the component width |
| B0 | Dimension designed to accommodate the component length |
| K0 | Dimension designed to accommodate the component thickness |
| W | Overall width of the carrier tape |
| P1 | Pitch between successive cavity centers |

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**

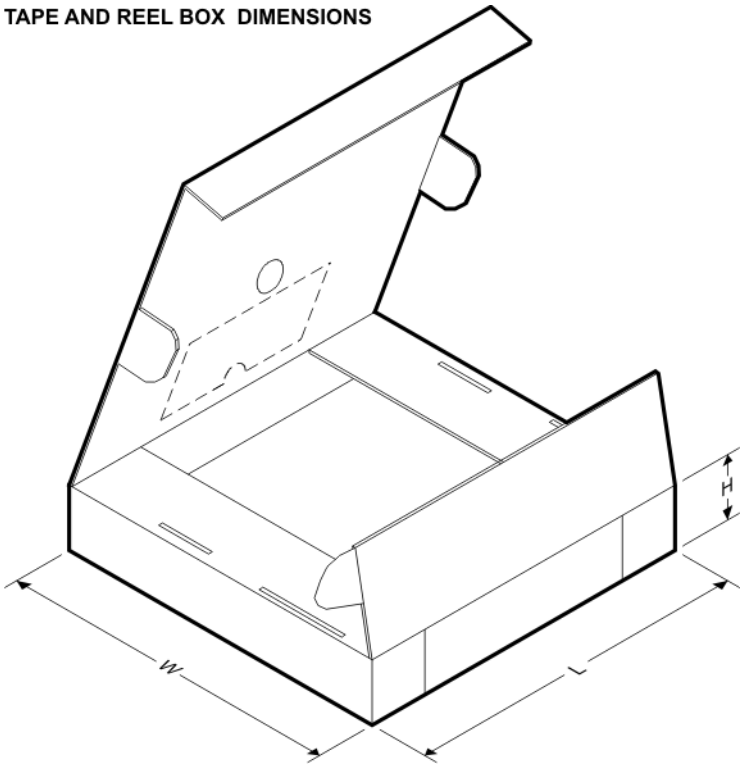



*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSP430FR59471IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR59471IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5947IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430FR5947IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5947IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5948IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430FR5948IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5948IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5949IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430FR5949IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5957IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430FR5957IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5957IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5958IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430FR5958IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5958IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5959IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430FR5959IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |

| Device | Package Type | Package Drawing | Pins | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSP430FR5959IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5967IRGZR | VQFN | RGZ | 48 | 2500 | 330.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5967IRGZR | VQFN | RGZ | 48 | 2500 | 330.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5967IRGZT | VQFN | RGZ | 48 | 250 | 180.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5967IRGZT | VQFN | RGZ | 48 | 250 | 180.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5968IRGZR | VQFN | RGZ | 48 | 2500 | 330.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5968IRGZR | VQFN | RGZ | 48 | 2500 | 330.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5968IRGZT | VQFN | RGZ | 48 | 250 | 180.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5968IRGZT | VQFN | RGZ | 48 | 250 | 180.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR59691IRGZR | VQFN | RGZ | 48 | 2500 | 330.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR59691IRGZR | VQFN | RGZ | 48 | 2500 | 330.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR59691IRGZT | VQFN | RGZ | 48 | 250 | 180.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR59691IRGZT | VQFN | RGZ | 48 | 250 | 180.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5969IRGZR | VQFN | RGZ | 48 | 2500 | 330.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5969IRGZR | VQFN | RGZ | 48 | 2500 | 330.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5969IRGZT | VQFN | RGZ | 48 | 250 | 180.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430FR5969IRGZT | VQFN | RGZ | 48 | 250 | 180.0 | 16.4 | 7.3 | 7.3 | 1.1 | 12.0 | 16.0 | Q2 |

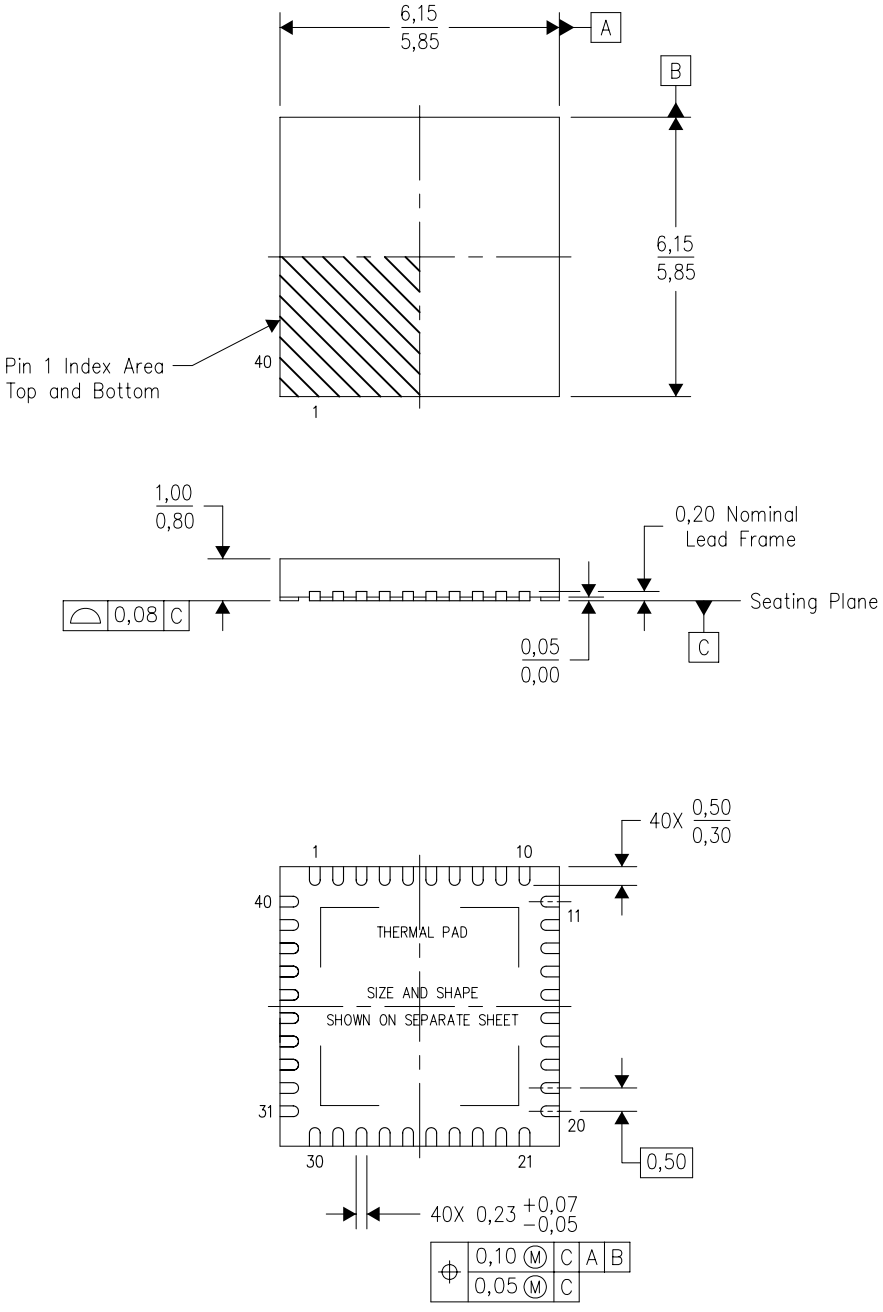
**TAPE AND REEL BOX DIMENSIONS**




*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| MSP430FR59471IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430FR59471IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5947IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430FR5947IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430FR5947IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5948IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430FR5948IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430FR5948IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5949IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430FR5949IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5957IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430FR5957IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430FR5957IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5958IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430FR5958IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430FR5958IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5959IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430FR5959IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430FR5959IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5967IRGZR | VQFN | RGZ | 48 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430FR5967IRGZR | VQFN | RGZ | 48 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430FR5967IRGZT | VQFN | RGZ | 48 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5967IRGZT | VQFN | RGZ | 48 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5968IRGZR | VQFN | RGZ | 48 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430FR5968IRGZR | VQFN | RGZ | 48 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430FR5968IRGZT | VQFN | RGZ | 48 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5968IRGZT | VQFN | RGZ | 48 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR59691IRGZR | VQFN | RGZ | 48 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430FR59691IRGZR | VQFN | RGZ | 48 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430FR59691IRGZT | VQFN | RGZ | 48 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR59691IRGZT | VQFN | RGZ | 48 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5969IRGZR | VQFN | RGZ | 48 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430FR5969IRGZR | VQFN | RGZ | 48 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430FR5969IRGZT | VQFN | RGZ | 48 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430FR5969IRGZT | VQFN | RGZ | 48 | 250 | 210.0 | 185.0 | 35.0 |

RHA (S–PVQFN–N40) PLASTIC QUAD FLATPACK NO–LEAD




Bottom View

4204276/E 06/11

NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. QFN (Quad Flatpack No–Lead) Package configuration.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance.
E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
F. Package complies to JEDEC MO–220 variation VJJD–2.

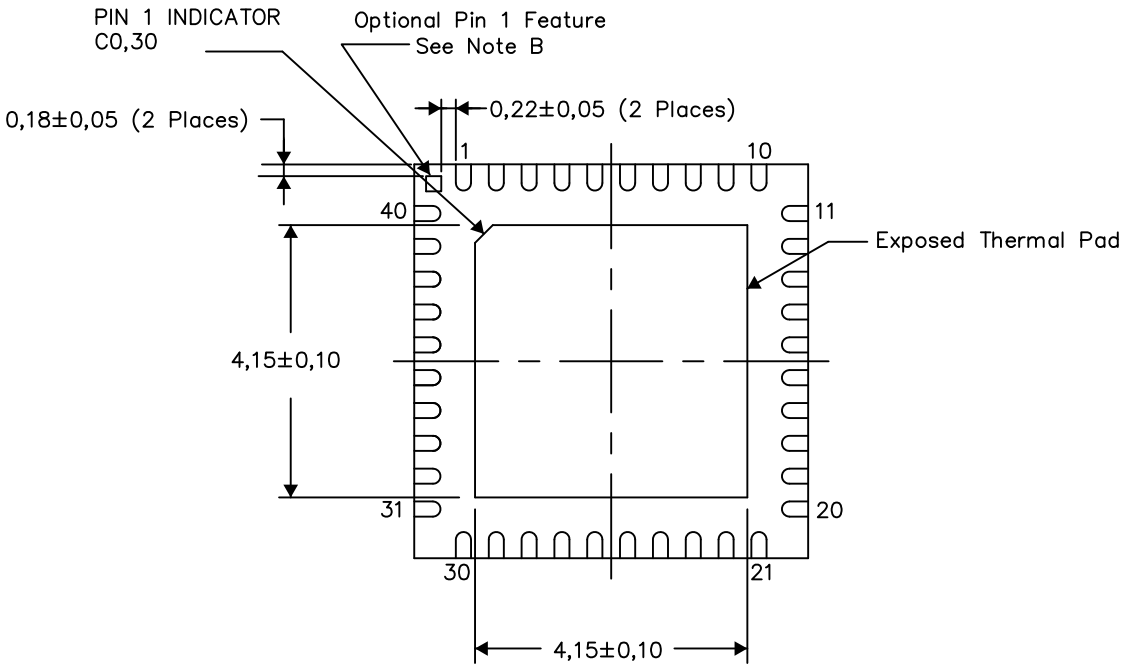
RHA (S–PVQFN–N40) PLASTIC QUAD FLATPACK NO–LEAD

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No–Lead (QFN) package and its advantages, refer to Application Report, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.




Bottom View

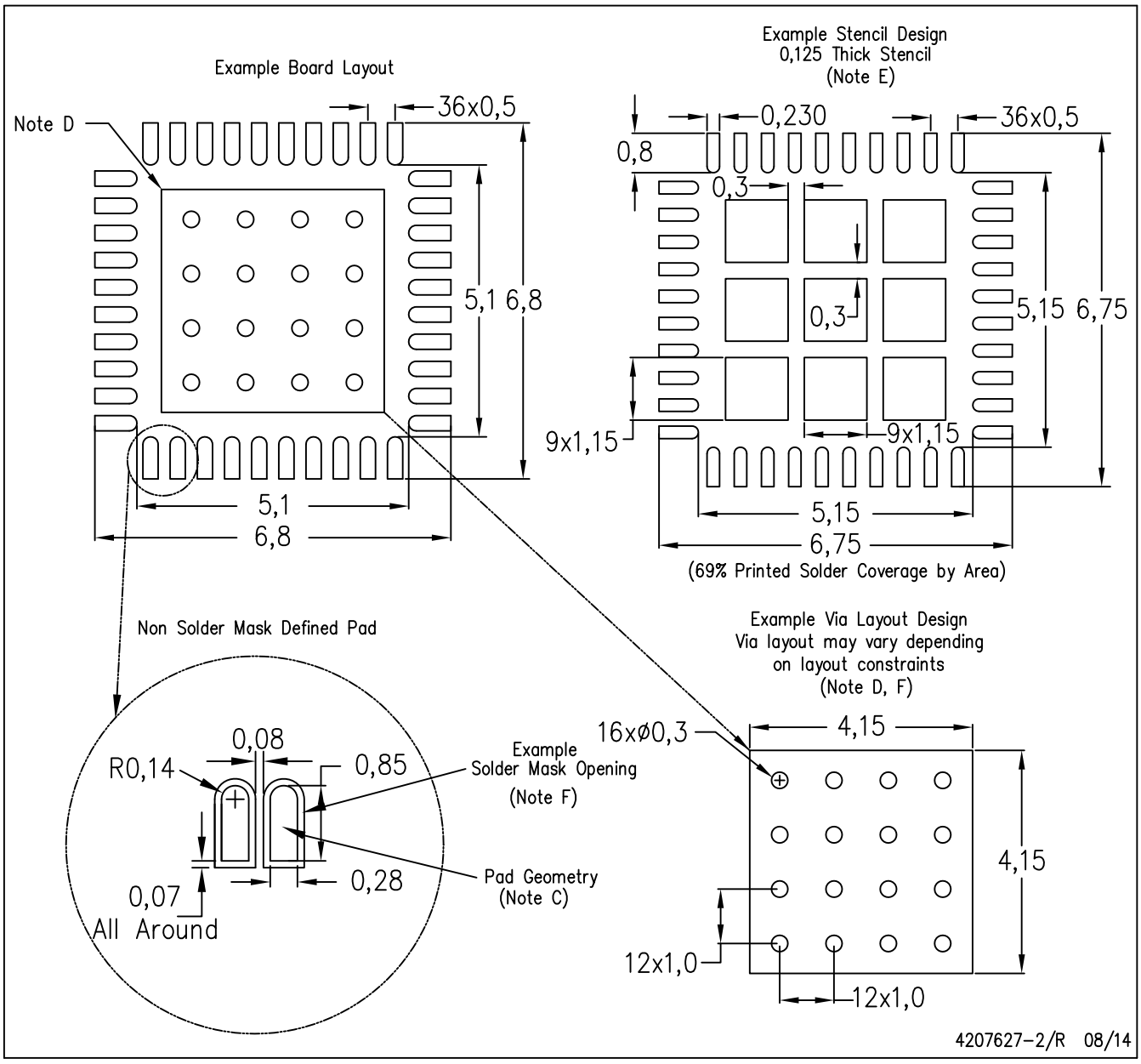
Exposed Thermal Pad Dimensions

4206355–2/X 08/14

NOTES: A. All linear dimensions are in millimeters

B. The Pin 1 Identification mark is an optional feature that may be present on some devices In addition, this Pin 1 feature if present is electrically connected to the center thermal pad and therefore should be considered when routing the board layout.

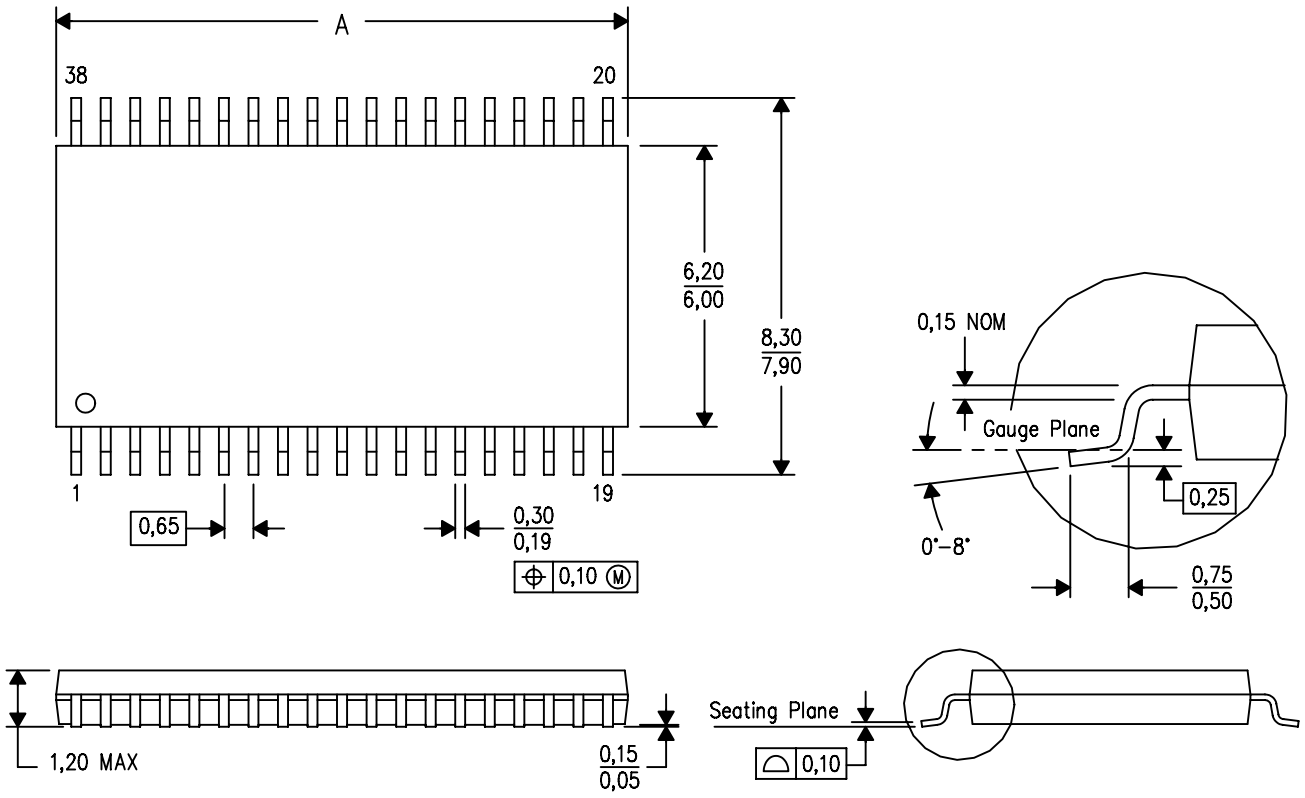
RHA (S–PVQFN–N40) PLASTIC QUAD FLATPACK NO–LEAD




NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate designs.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat–Pack Packages, Texas Instruments Literature No. SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <http://www.ti.com>.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
F. Customers should contact their board fabrication site for recommended solder mask tolerances and via tenting recommendations for vias placed in the thermal pad.

DA (R–PDSO–G**) PLASTIC SMALL–OUTLINE PACKAGE

38 PIN SHOWN




| DIM \ PINS ** | 30 | 32 | 38 |
|---|---|---|---|
| A MAX | 11,10 | 11,10 | 12,60 |
| A MIN | 10,90 | 10,90 | 12,40 |
| △D MO–153 Variation | DB–1 | DC | DD–1 |

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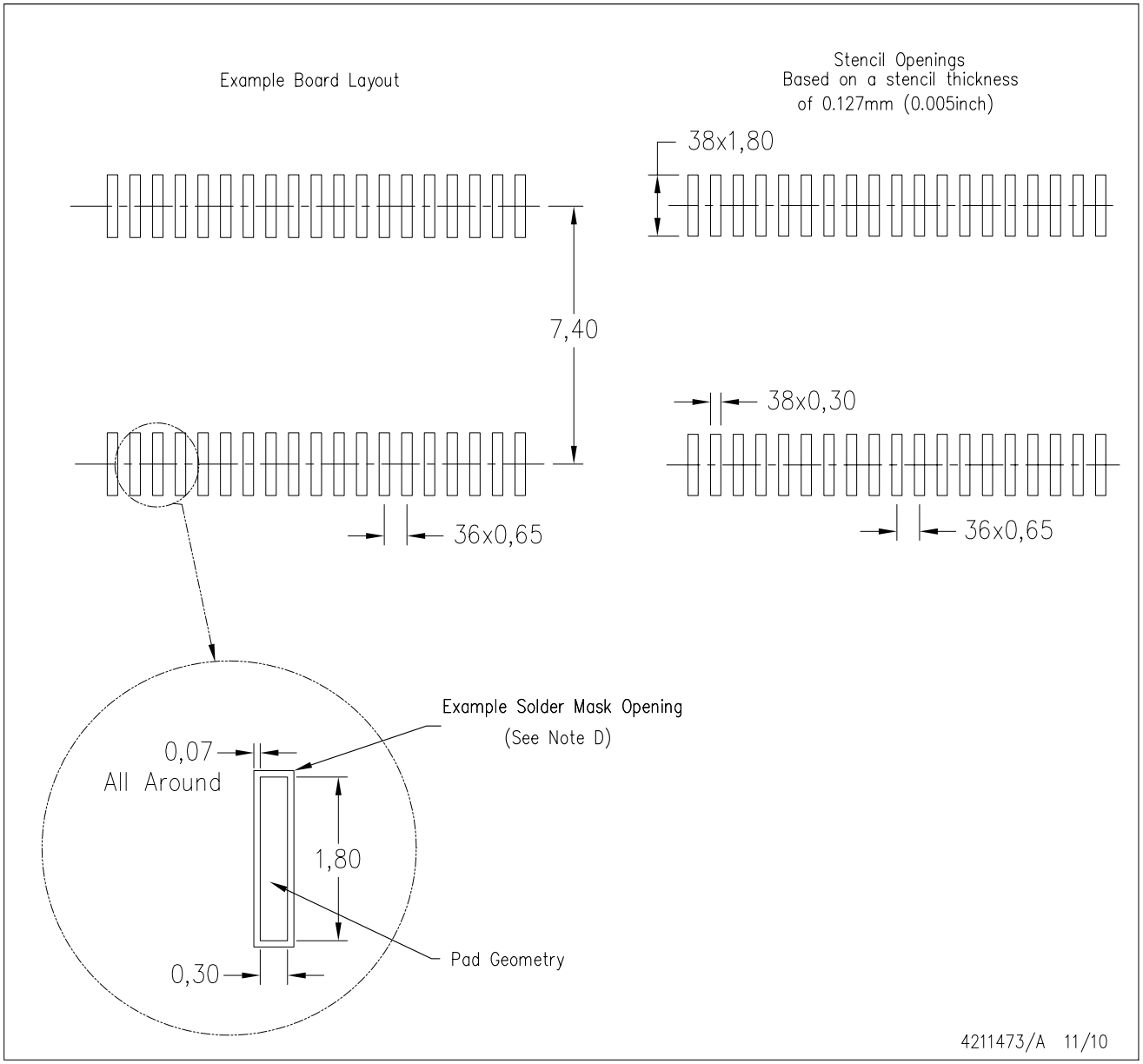
NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
△D Falls within JEDEC MO–153, except 30 pin body length.

DA (R–PDSO–G38) PLASTIC SMALL OUTLINE




NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC–7525 for other stencil recommendations.
D. Contact the board fabrication site for recommended soldermask tolerances.

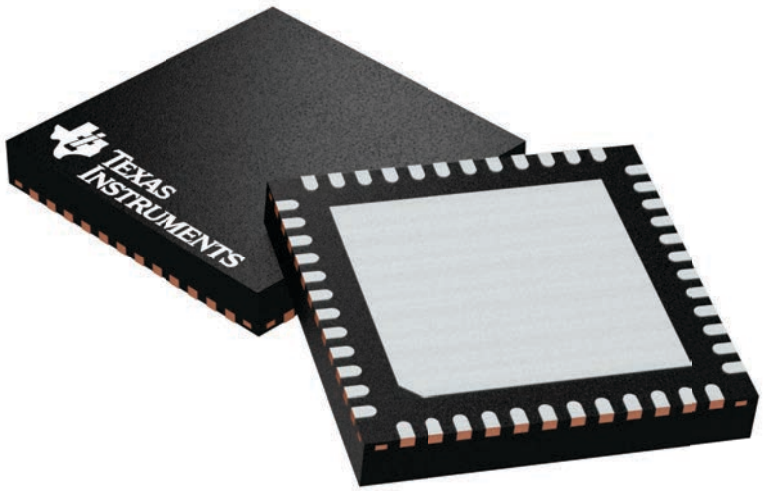
# GENERIC PACKAGE VIEW

## RGZ 48

## VQFN - 1 mm max height

**7 x 7, 0.5 mm pitch**

PLASTIC QUADFLAT PACK- NO LEAD




Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

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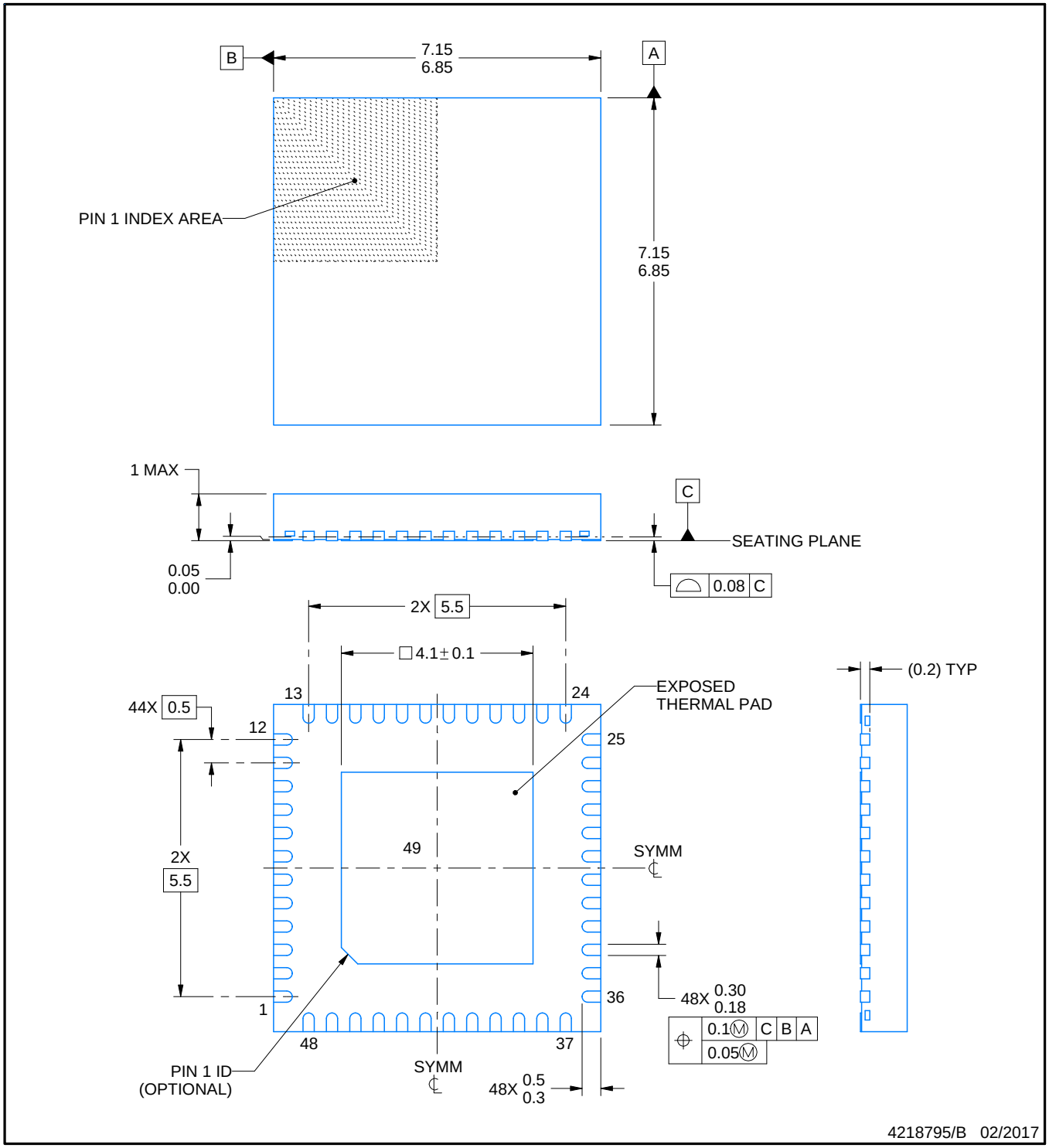
# RGZ0048B

# PACKAGE OUTLINE

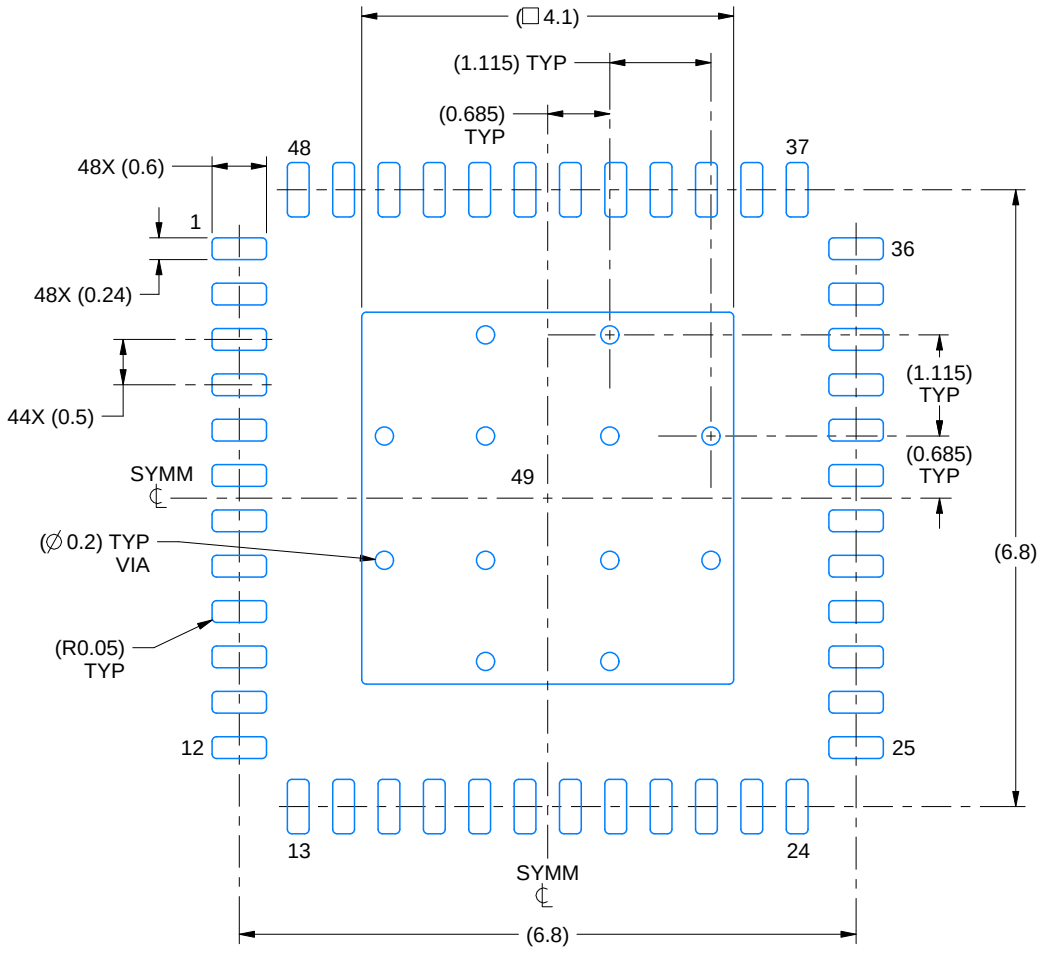
## VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD

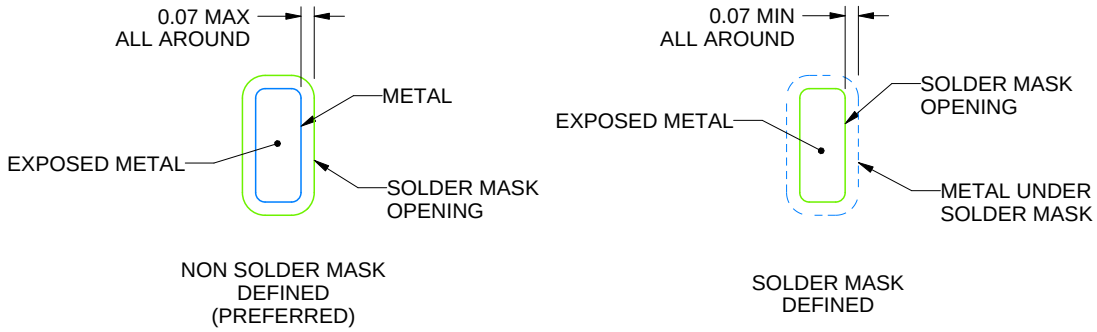



NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.




LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:12X

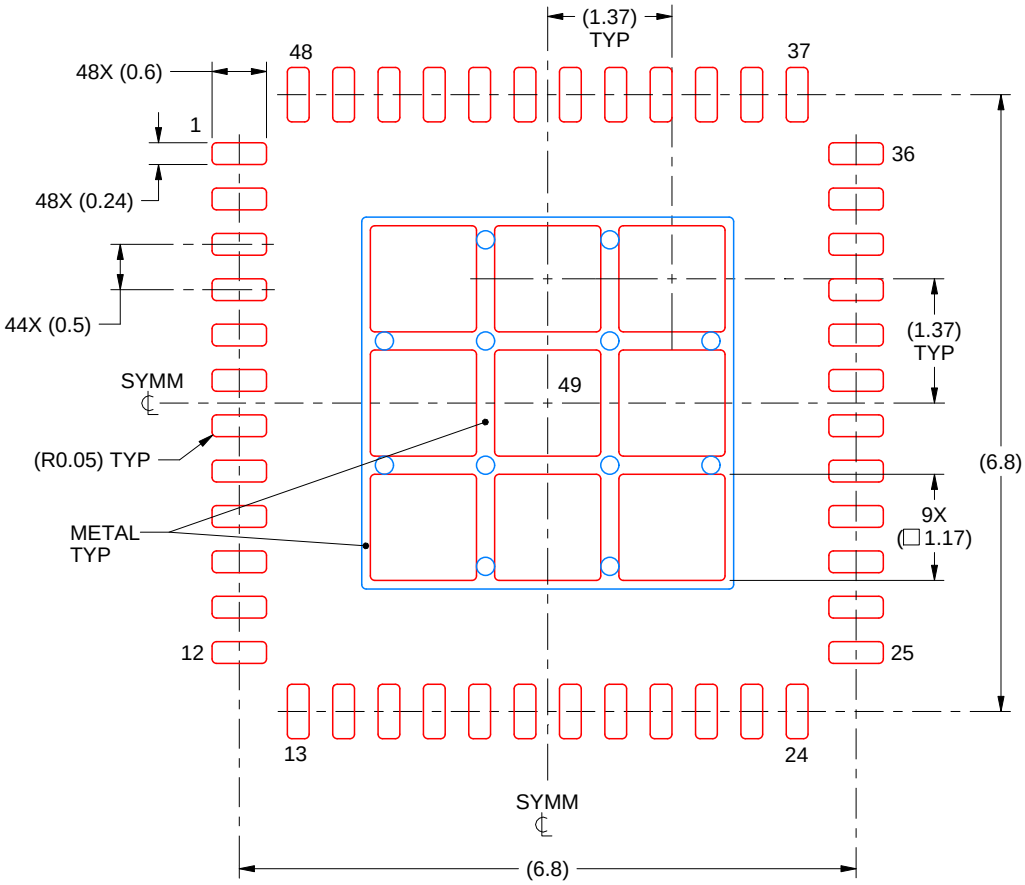



SOLDER MASK DETAILS

4218795/B 02/2017

NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.




SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 49
73% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
SCALE:12X

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NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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