



# THE DATASHEET OF MSP430F6458IPZR



# MSP430F665x, MSP430F645x, MSP430F565x, MSP430F535x Mixed-Signal Microcontrollers

## 1 Device Overview

### 1.1 Features

- Low Supply Voltage Range:  
3.6 V Down to 1.8 V
- Ultra-Low-Power Consumption
  - Active Mode (AM):  
All System Clocks Active:  
295  $\mu$ A/MHz at 8 MHz, 3.0 V, Flash Program Execution (Typical)
  - Standby Mode (LPM3):  
Watchdog With Crystal, and Supply Supervisor Operational, Full RAM Retention, Fast Wakeup:  
2.0  $\mu$ A at 2.2 V, 2.2  $\mu$ A at 3.0 V (Typical)
  - Shutdown, Real-Time Clock (RTC) Mode (LPM3.5):  
Shutdown Mode, Active RTC With Crystal:  
1.1  $\mu$ A at 3.0 V (Typical)
  - Shutdown Mode (LPM4.5):  
0.45  $\mu$ A at 3.0 V (Typical)
- Wake up From Standby Mode in 3  $\mu$ s (Typical)
- 16-Bit RISC Architecture, Extended Memory, up to 20-MHz System Clock
- Flexible Power-Management System
  - Fully Integrated LDO With Programmable Regulated Core Supply Voltage
  - Supply Voltage Supervision, Monitoring, and Brownout
- Unified Clock System
  - FLL Control Loop for Frequency Stabilization
  - Low-Power Low-Frequency Internal Clock Source (VLO)
  - Low-Frequency Trimmed Internal Reference Source (REFO)
  - 32-kHz Crystals (XT1)
  - High-Frequency Crystals up to 32 MHz (XT2)
- Four 16-Bit Timers With 3, 5, or 7 Capture/Compare Registers
- Three Universal Serial Communication Interfaces (USCIs)
  - USCI\_A0, USCI\_A1, and USCI\_A2 Each Support:
    - Enhanced UART With Automatic Baud-Rate Detection
    - IrDA Encoder and Decoder
    - Synchronous SPI
  - USCI\_B0, USCI\_B1, and USCI\_B2 Each Support:
    - I<sup>2</sup>C
    - Synchronous SPI
- Full-Speed Universal Serial Bus (USB)
  - Integrated USB-PHY
  - Integrated 3.3-V and 1.8-V USB Power System
  - Integrated USB-PLL
  - Eight Input and Eight Output Endpoints
- 12-Bit Analog-to-Digital Converter (ADC) With Internal Shared Reference, Sample-and-Hold, and Autoscan Feature
- Two 12-Bit Digital-to-Analog Converters (DACs) With Synchronization
- Voltage Comparator
- Integrated LCD Driver With Contrast Control for up to 160 Segments
- Hardware Multiplier Supports 32-Bit Operations
- Serial Onboard Programming, No External Programming Voltage Needed
- Six-Channel Internal DMA
- RTC Module With Supply Voltage Backup Switch
- [Device Comparison](#) Summarizes the Available Family Members

### 1.2 Applications

- Analog and Digital Sensor Systems
- Digital Motor Controls
- Remote Controls
- Thermostats
- Digital Timers
- Hand-Held Meters



## 1.3 Description

The TI MSP family of ultra-low-power microcontrollers consists of several devices that feature different sets of peripherals targeted for various applications. The architecture, combined with five low-power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows the device to wake up from low-power modes to active mode in 3  $\mu$ s (typical).

The MSP430F665x and MSP430F565x series are microcontroller configurations with four 16-bit timers, a high-performance 12-bit ADC, three USCIs, a hardware multiplier, DMA, an RTC module with alarm capabilities, a comparator, USB 2.0, and up to 74 I/O pins.

The MSP430F645x and MSP430F535x series are microcontroller configurations with an integrated 3.3-V LDO, four 16-bit timers, a high-performance 12-bit ADC, three USCIs, a hardware multiplier, DMA, an RTC module with alarm capabilities, a comparator, and up to 74 I/O pins.

For complete module descriptions, see the [MSP430F5xx and MSP430F6xx Family User's Guide](#).

### Device Information<sup>(1)</sup>

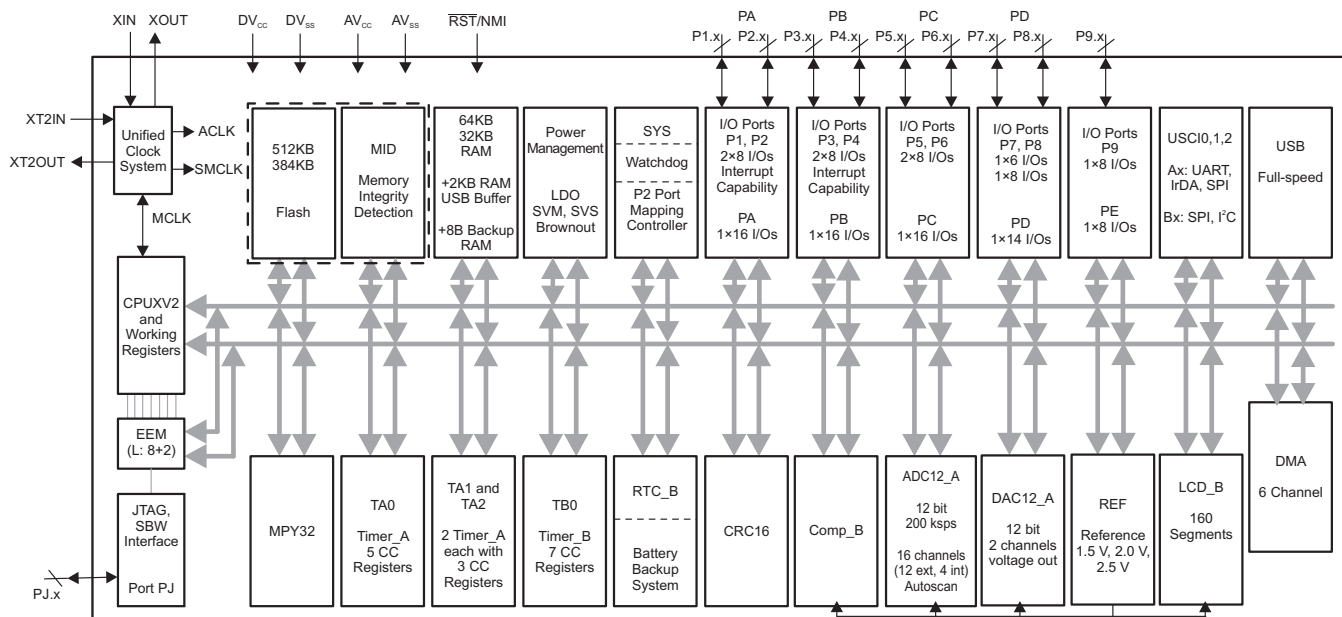
| PART NUMBER     | PACKAGE                     | BODY SIZE <sup>(2)</sup> |
|-----------------|-----------------------------|--------------------------|
| MSP430F6659IZQW | MicroStar Junior™ BGA (113) | 7 mm × 7 mm              |
| MSP430F6659IPZ  | LQFP (100)                  | 14 mm × 14 mm            |

(1) For the most current device, package, and ordering information, see the *Package Option Addendum* in [Section 8](#), or see the TI website at [www.ti.com](http://www.ti.com).

(2) The sizes shown here are approximations. For the package dimensions with tolerances, see the *Mechanical Data* in [Section 8](#).

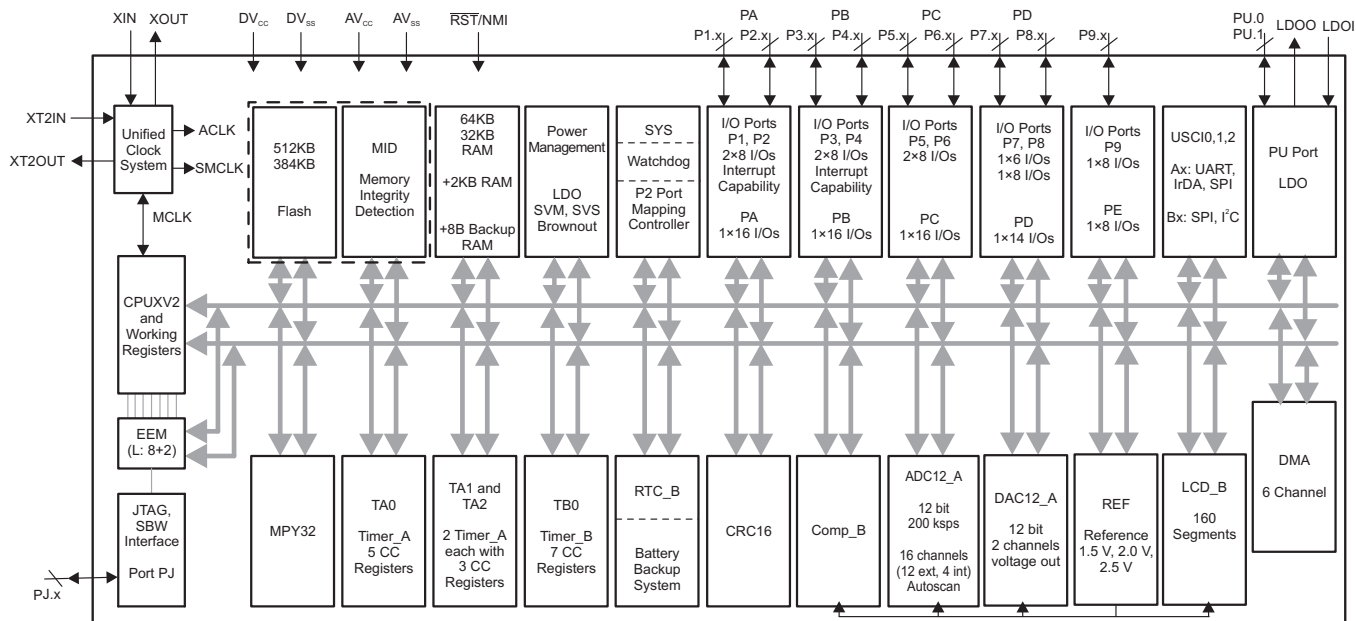
## 1.4 Functional Block Diagrams

Figure 1-1 through Figure 1-4 show the functional block diagrams.



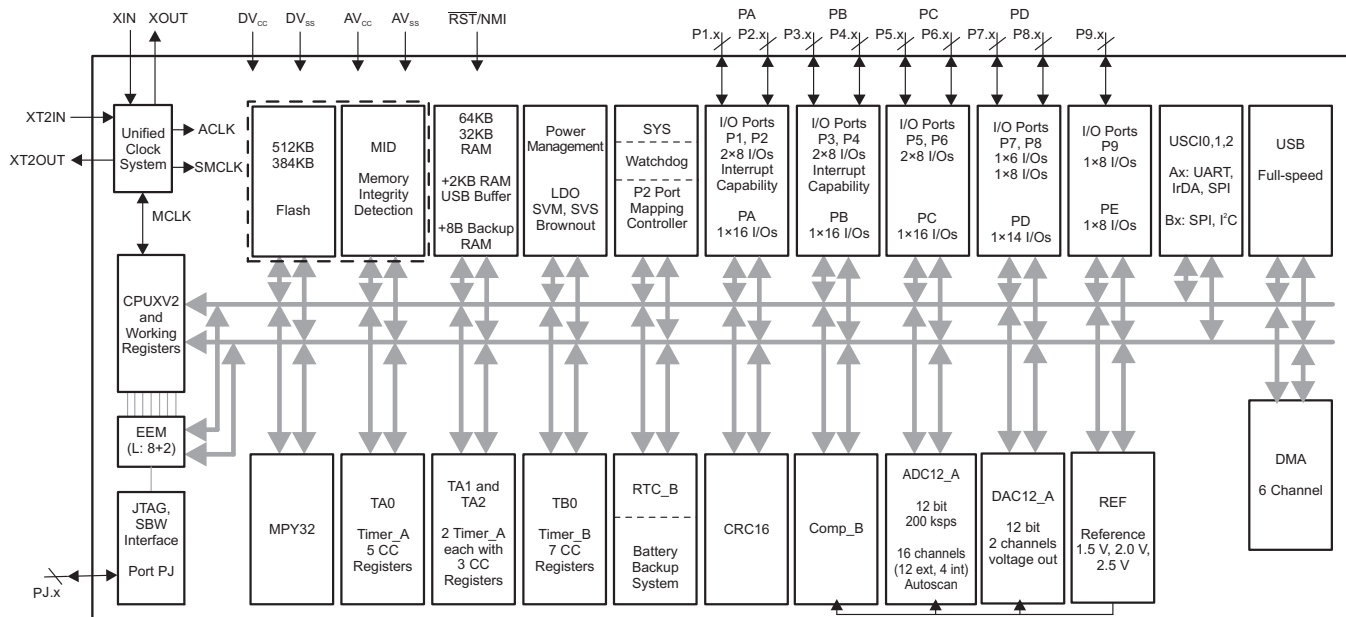
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**Figure 1-1. Functional Block Diagram – MSP430F6659, MSP430F6658**



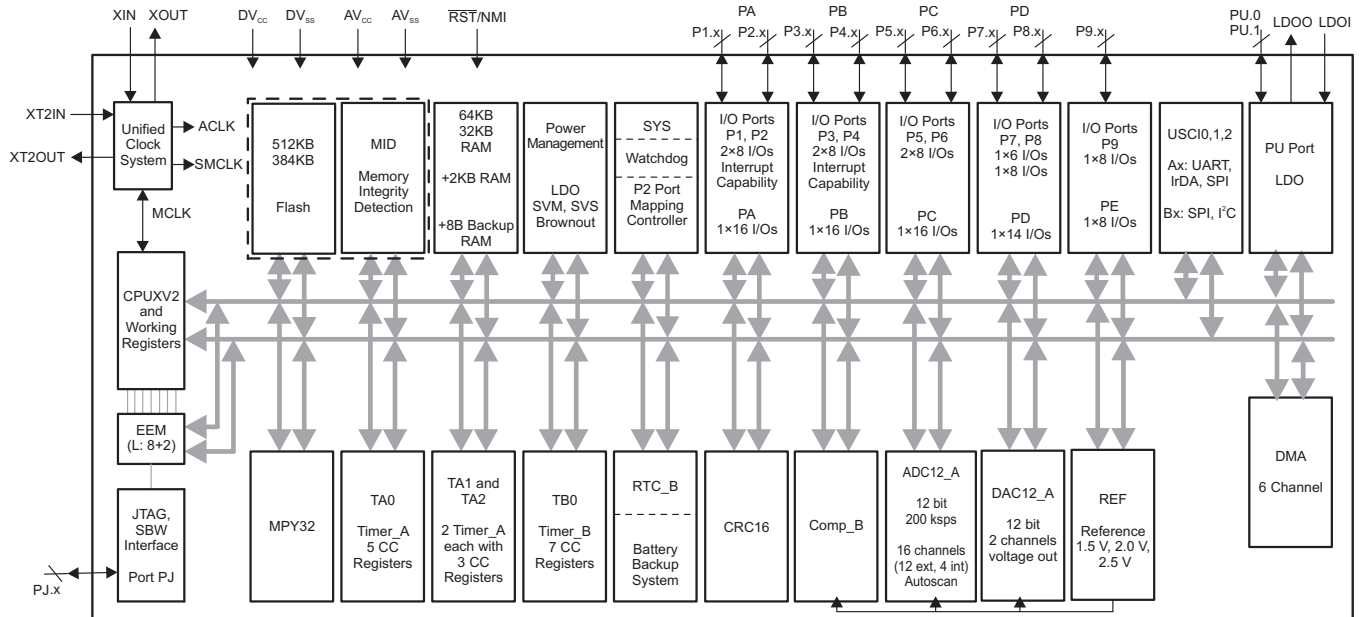
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**Figure 1-2. Functional Block Diagram – MSP430F6459, MSP430F6458**



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**Figure 1-3. Functional Block Diagram – MSP430F5659, MSP430F5658**



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**Figure 1-4. Functional Block Diagram – MSP430F5359, MSP430F5358**

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## 2 Revision History

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

| Changes from October 21, 2013 to September 26, 2018                                                                                                                                                                                                              | Page                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| • Format and organization changes throughout document, including addition of section numbering .....                                                                                                                                                             | <a href="#">1</a>   |
| • Added <i>Device Information</i> table .....                                                                                                                                                                                                                    | <a href="#">2</a>   |
| • Added <a href="#">Section 1.4</a> and moved all functional block diagrams to it.....                                                                                                                                                                           | <a href="#">2</a>   |
| • Added <a href="#">Section 3.1</a> , <i>Related Products</i> .....                                                                                                                                                                                              | <a href="#">8</a>   |
| • Added "Port U is supplied the LDOO rail" to the description of PU.0 and PU.1 in <a href="#">Table 4-1</a> , <i>Signal Descriptions</i> ...                                                                                                                     | <a href="#">19</a>  |
| • Added <a href="#">Section 5</a> and moved all electrical specifications to it .....                                                                                                                                                                            | <a href="#">21</a>  |
| • Added typical conditions statements at the beginning of <a href="#">Section 5</a> , <i>Specifications</i> .....                                                                                                                                                | <a href="#">21</a>  |
| • Added <a href="#">Section 5.2</a> , <i>ESD Ratings</i> .....                                                                                                                                                                                                   | <a href="#">21</a>  |
| • Moved <a href="#">Section 5.7</a> , <i>Thermal Resistance Characteristics</i> .....                                                                                                                                                                            | <a href="#">25</a>  |
| • Changed the TYP value of the $C_{L,eff}$ parameter with Test Conditions of "XTS = 0, XCAPx = 0" from 2 pF to 1 pF in <a href="#">Section 5.16</a> , <i>Crystal Oscillator, XT1, Low-Frequency Mode</i> .....                                                   | <a href="#">30</a>  |
| • Changed the MIN value of the $V_{(DVCC\_BOR\_hys)}$ parameter from 60 mV to 50 mV in <a href="#">Section 5.21</a> , <i>PMM, Brownout Reset (BOR)</i> .....                                                                                                     | <a href="#">34</a>  |
| • Updated notes (1) and (2) and added note (3) in <a href="#">Section 5.27</a> , <i>Wake-up Times From Low-Power Modes and Reset</i> .....                                                                                                                       | <a href="#">36</a>  |
| • Corrected typo in the description of the $V_{BAT3}$ parameter: changed " $V_{BAT3} \neq V_{BAT}/3$ " to " $V_{BAT3} \approx V_{BAT}/3$ " in <a href="#">Section 5.30</a> , <i>Battery Backup</i> .....                                                         | <a href="#">37</a>  |
| • Removed ADC12DIV from the formula for the TYP value in the second row of the $t_{CONVERT}$ parameter in <a href="#">Section 5.38</a> , <i>12-Bit ADC, Timing Parameters</i> , because ADC12CLK is after division .....                                         | <a href="#">45</a>  |
| • Added the $TC_{SENSOR}$ parameter in <a href="#">Section 5.42</a> , <i>12-Bit ADC, Temperature Sensor and Built-In <math>V_{MID}</math></i> .....                                                                                                              | <a href="#">46</a>  |
| • Changed the note that starts "The temperature sensor offset ..." from "...offset can be as much as $\pm 20^{\circ}\text{C}$ " to "...offset can be significant" .....                                                                                          | <a href="#">46</a>  |
| • Changed DAC12xDAT to DAC12_xDAT in $I_{L(DAC12)}$ Test Conditions in <a href="#">Section 5.47</a> , <i>12-Bit DAC, Output Specifications</i> .....                                                                                                             | <a href="#">51</a>  |
| • Removed note from " $R_{i(VREF+)}$ , $R_{i(VREF-)}$ " parameter in <a href="#">Section 5.48</a> , <i>12-Bit DAC, Reference Input Specifications</i> ...                                                                                                        | <a href="#">52</a>  |
| • Changed from $f_{DAC12\_OUT}$ to $f_{DAC12\_1OUT}$ in the first row of the Test Conditions for the "Channel-to-channel crosstalk" parameter in <a href="#">Section 5.50</a> , <i>12-Bit DAC, Dynamic Specifications (Continued)</i> .....                      | <a href="#">53</a>  |
| • Changed the value of DAC12_xDAT from 7F7h to F7Fh and changed the x-axis label from $f_{Toggle}$ to $1/f_{Toggle}$ in <a href="#">Figure 5-22</a> , <i>Crosstalk Test Conditions</i> .....                                                                     | <a href="#">53</a>  |
| • <a href="#">Section 5.51</a> , <i>Comparator_B</i> : Added second row for the $t_{EN\_CMP}$ parameter with Test Conditions of "CBPWRMD = 10" and MAX value of 100 $\mu\text{s}$ ; Removed "CBPWRMD = 10" option in first row of Test Conditions.....           | <a href="#">54</a>  |
| • Added note on $R_{PUR}$ in <a href="#">Section 5.55</a> , <i>USB-PWR (USB Power System)</i> .....                                                                                                                                                              | <a href="#">55</a>  |
| • Removed RTC_B from LPM4.5 wake-up options in <a href="#">Section 6.3</a> , <i>Operating Modes</i> .....                                                                                                                                                        | <a href="#">59</a>  |
| • Throughout document, changed "bootstrap loader" to "bootloader" .....                                                                                                                                                                                          | <a href="#">63</a>  |
| • Added the paragraph that begins "Using the MSP430 RTC_B Module With Battery Backup Supply describes how to..." .....                                                                                                                                           | <a href="#">68</a>  |
| • Corrected spelling of NMIFG in <a href="#">Table 6-12</a> , <i>System Module Interrupt Vector Registers</i> .....                                                                                                                                              | <a href="#">69</a>  |
| • Corrected register names (added "USB" prefix as required) in <a href="#">Table 6-53</a> , <i>USB Control Registers</i> .....                                                                                                                                   | <a href="#">89</a>  |
| • Added P7SEL.2 and XT2BYPASS inputs with AND and OR gates in <a href="#">Figure 6-10</a> , <i>Port P7 (P7.3) Diagram</i> .....                                                                                                                                  | <a href="#">104</a> |
| • Changed P7SEL.3 column from X to 0 for "P7.3 (I/O)" rows in <a href="#">Table 6-63</a> , <i>Port P7 (P7.2 and P7.3) Pin Functions</i> .....                                                                                                                    | <a href="#">104</a> |
| • Updated <a href="#">Table 6-67</a> , <i>Port PU.0, PU.1 Functions</i> .....                                                                                                                                                                                    | <a href="#">112</a> |
| • Added <a href="#">Section 6.13.14</a> , <i>Port PU.0, PU.1 Ports (F645x, F535x)</i> .....                                                                                                                                                                      | <a href="#">113</a> |
| • Added <a href="#">Section 7</a> , <i>Device and Documentation Support</i> , and moved <i>Development Tools Support</i> , <i>Device and Development Tool Nomenclature</i> , <i>Trademarks</i> , and <i>Electrostatic Discharge Caution</i> sections to it ..... | <a href="#">117</a> |
| • Replaced former section <i>Development Tools Support</i> with <a href="#">Section 7.3</a> , <i>Tools and Software</i> .....                                                                                                                                    | <a href="#">119</a> |
| • Added <a href="#">Section 8</a> , <i>Mechanical, Packaging, and Orderable Information</i> .....                                                                                                                                                                | <a href="#">123</a> |

### 3 Device Comparison

Table 3-1 summarizes the available family members.

Table 3-1. Device Comparison<sup>(1)(2)</sup>

| DEVICE      | FLASH<br>(KB) | SRAM<br>(KB) <sup>(3)</sup> | Timer_A <sup>(4)</sup> | Timer_B <sup>(5)</sup> | USCI                                |                                        | ADC12_A<br>(Ch) | DAC12_A<br>(Ch) | Comp_B<br>(Ch) | I/O | USB | LCD | PACKAGE            |
|-------------|---------------|-----------------------------|------------------------|------------------------|-------------------------------------|----------------------------------------|-----------------|-----------------|----------------|-----|-----|-----|--------------------|
|             |               |                             |                        |                        | CHANNEL<br>A:<br>UART, IrDA,<br>SPI | CHANNEL<br>B:<br>SPI, I <sup>2</sup> C |                 |                 |                |     |     |     |                    |
| MSP430F6659 | 512           | 64 + 2                      | 5, 3, 3                | 7                      | 3                                   | 3                                      | 12 ext, 4 int   | 2               | 12             | 74  | Yes | Yes | 100 PZ,<br>113 ZQW |
| MSP430F6658 | 384           | 32 + 2                      | 5, 3, 3                | 7                      | 3                                   | 3                                      | 12 ext, 4 int   | 2               | 12             | 74  | Yes | Yes | 100 PZ,<br>113 ZQW |
| MSP430F6459 | 512           | 66                          | 5, 3, 3                | 7                      | 3                                   | 3                                      | 12 ext, 4 int   | 2               | 12             | 74  | No  | Yes | 100 PZ,<br>113 ZQW |
| MSP430F6458 | 384           | 34                          | 5, 3, 3                | 7                      | 3                                   | 3                                      | 12 ext, 4 int   | 2               | 12             | 74  | No  | Yes | 100 PZ,<br>113 ZQW |
| MSP430F5659 | 512           | 64 + 2                      | 5, 3, 3                | 7                      | 3                                   | 3                                      | 12 ext, 4 int   | 2               | 12             | 74  | Yes | No  | 100 PZ,<br>113 ZQW |
| MSP430F5658 | 384           | 32 + 2                      | 5, 3, 3                | 7                      | 3                                   | 3                                      | 12 ext, 4 int   | 2               | 12             | 74  | Yes | No  | 100 PZ,<br>113 ZQW |
| MSP430F5359 | 512           | 66                          | 5, 3, 3                | 7                      | 3                                   | 3                                      | 12 ext, 4 int   | 2               | 12             | 74  | No  | No  | 100 PZ,<br>113 ZQW |
| MSP430F5358 | 384           | 34                          | 5, 3, 3                | 7                      | 3                                   | 3                                      | 12 ext, 4 int   | 2               | 12             | 74  | No  | No  | 100 PZ,<br>113 ZQW |

(1) For the most current device, package, and ordering information, see the *Package Option Addendum* in Section 8, or see the TI website at [www.ti.com](http://www.ti.com).

(2) Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at [www.ti.com/packaging](http://www.ti.com/packaging).

(3) The additional 2KB of USB SRAM that is listed can be used as general-purpose SRAM when USB is not in use.

(4) 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 and the second instantiation having 5 capture compare registers and PWM output generators, respectively.

(5) 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 and the second instantiation having 5 capture compare registers and PWM output generators, respectively.

### 3.1 Related Products

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

**Products for TI Microcontrollers** TI's low-power and high-performance MCUs, with wired and wireless connectivity options, are optimized for a broad range of applications.

**Products for MSP430 Ultra-Low-Power Microcontrollers** One platform. One ecosystem. Endless possibilities. Enabling the connected world with innovations in ultra-low-power microcontrollers with advanced peripherals for precise sensing and measurement.

**Companion Products for MSP430F6659** Review products that are frequently purchased or used with this product.

**TI Reference Designs** Find reference designs that leverage the best in TI technology to solve your system-level challenges.

## 4 Terminal Configuration and Functions

### 4.1 Pin Diagrams

Figure 4-1 shows the pinout of the 100-pin PZ package for the MSP430F6659 and MSP430F6658 devices.

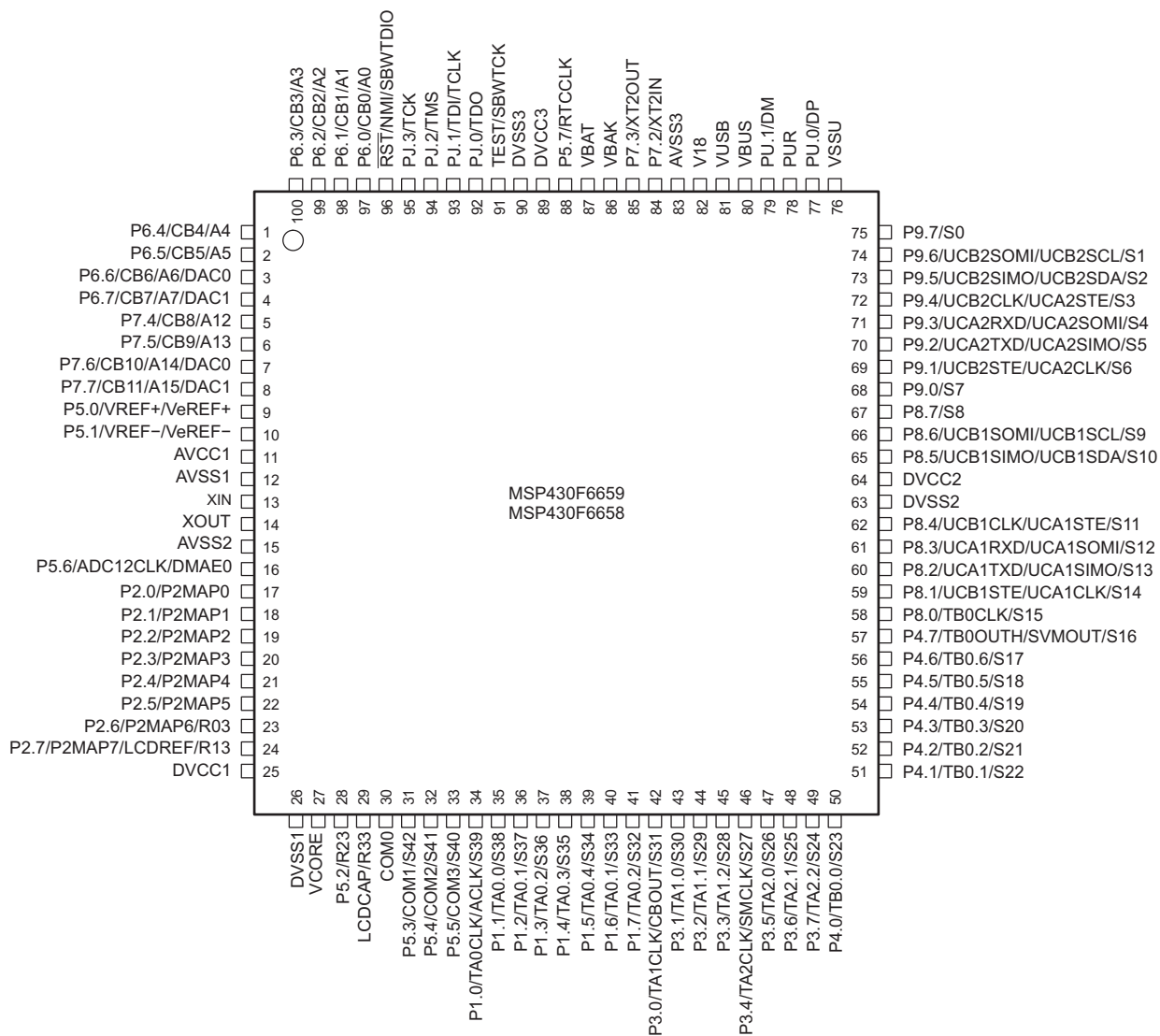


**Figure 4-1. 100-Pin PZ Package (Top View) – MSP430F6659IPZ, MSP430F6658IPZ**

Figure 4-1 shows the pinout of the 100-pin PZ package for the MSP430F6459 and MSP430F6458 devices.

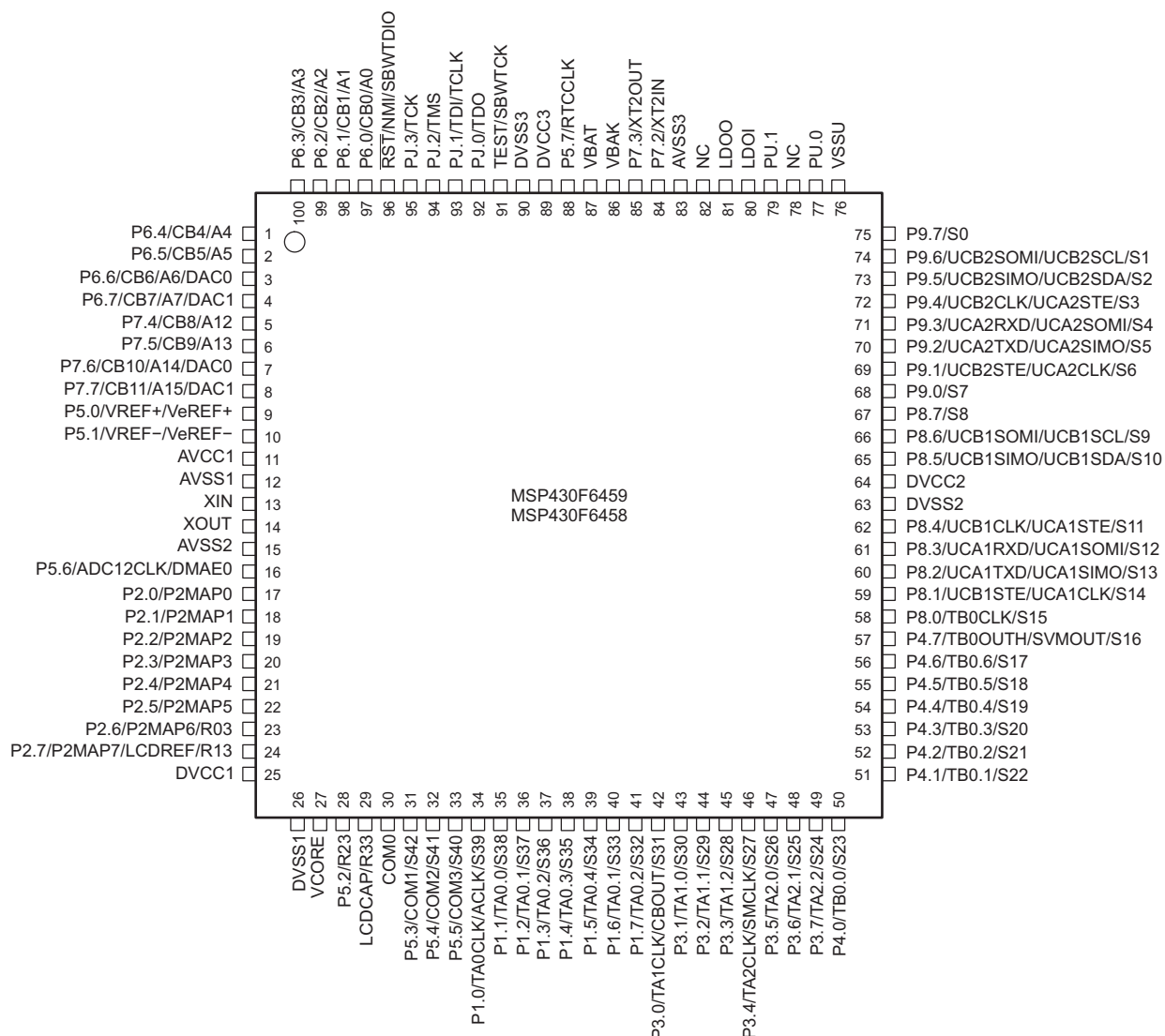


Figure 4-2. 100-Pin PZ Package (Top View) – MSP430F6459IPZ, MSP430F6458IPZ

Figure 4-3 shows the pinout of the 100-pin PZ package for the MSP430F5659 and MSP430F5658 devices.

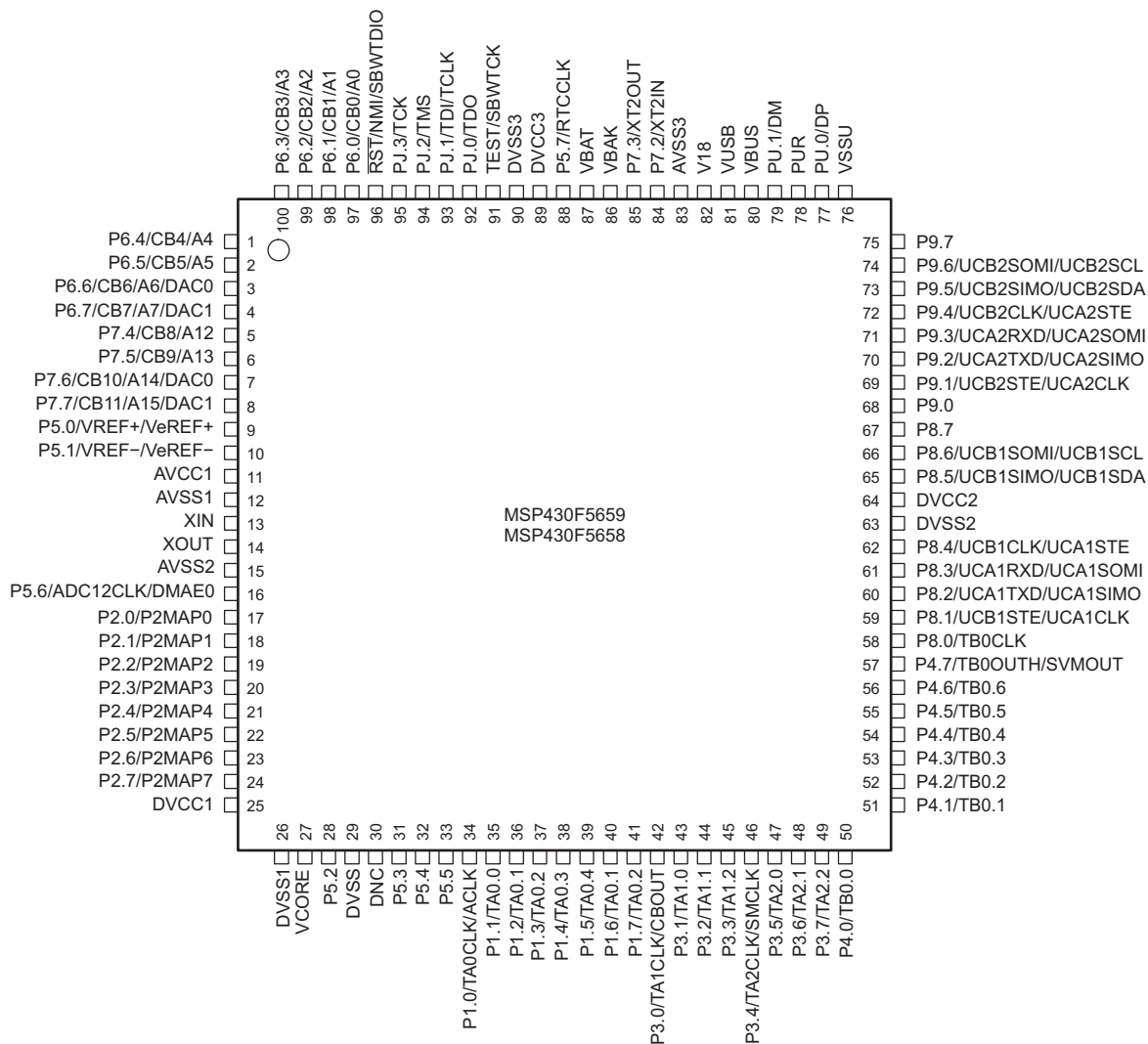


**Figure 4-3. 100-Pin PZ Package (Top View) – MSP430F5659IPZ, MSP430F5658IPZ**

Figure 4-4 shows the pinout of the 100-pin PZ package for the MSP430F5359 and MSP430F5358 devices.

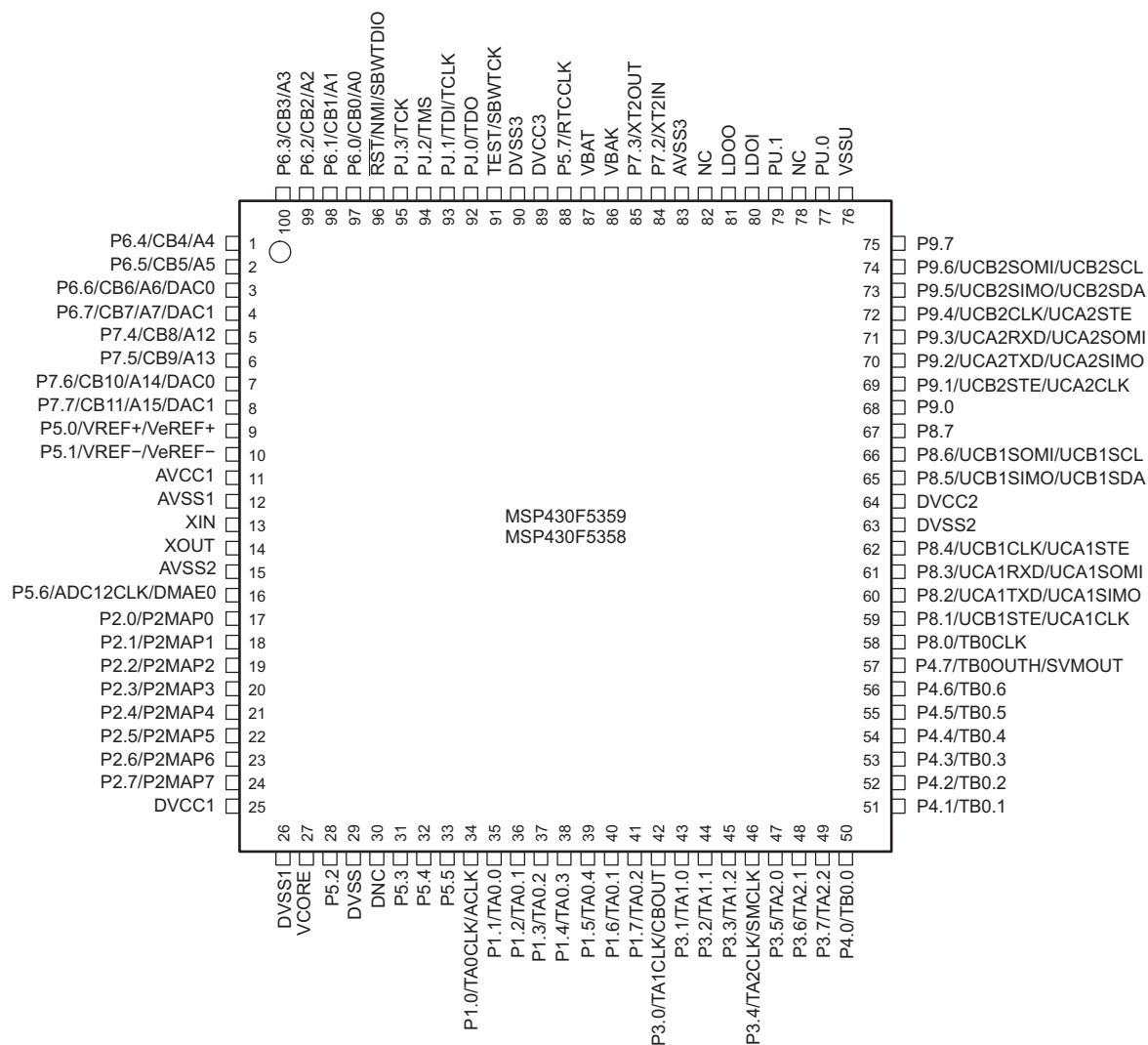


Figure 4-4. 100-Pin PZ Package (Top View) – MSP430F5359IPZ, MSP430F5358IPZ

Figure 4-4 shows the pinout of the 113-pin ZQW package. See Section 4.2 for the pin assignments.

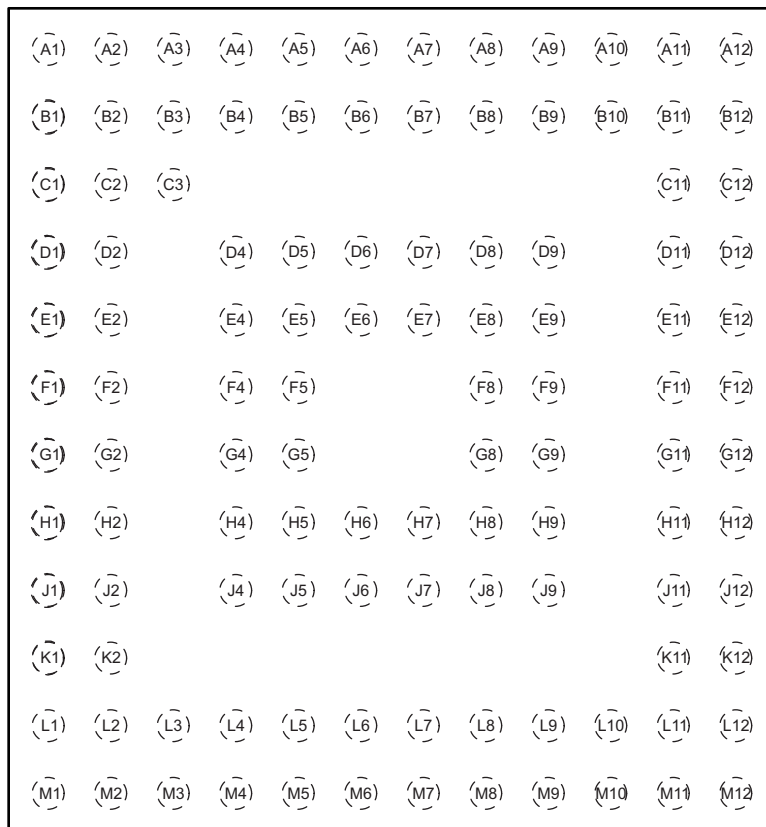


**Figure 4-5. 113-Pin ZQW Package (Top View) – MSP430F6659IZQW, MSP430F6658IZQW, MSP430F6459IZQW, MSP430F6458IZQW, MSP430F5659IZQW, MSP430F5658IZQW, MSP430F5359IZQW, MSP430F5358IZQW**

## 4.2 Signal Descriptions

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

**Table 4-1. Signal Descriptions**

| TERMINAL           |    | NO.       | I/O <sup>(1)</sup> | DESCRIPTION                                                                                                                                                                 |
|--------------------|----|-----------|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NAME               |    |           |                    |                                                                                                                                                                             |
|                    | PZ | ZQW       |                    |                                                                                                                                                                             |
| P6.4/CB4/A4        | 1  | A1        | I/O                | General-purpose digital I/O<br>Comparator_B input CB4<br>Analog input A4 for ADC                                                                                            |
| P6.5/CB5/A5        | 2  | B2        | I/O                | General-purpose digital I/O<br>Comparator_B input CB5<br>Analog input A5 for ADC                                                                                            |
| P6.6/CB6/A6/DAC0   | 3  | B1        | I/O                | General-purpose digital I/O<br>Comparator_B input CB6<br>Analog input A6 for ADC<br>DAC12.0 output                                                                          |
| P6.7/CB7/A7/DAC1   | 4  | C2        | I/O                | General-purpose digital I/O<br>Comparator_B input CB7<br>Analog input A7 for ADC<br>DAC12.1 output                                                                          |
| P7.4/CB8/A12       | 5  | C1        | I/O                | General-purpose digital I/O<br>Comparator_B input CB8<br>Analog input A12 –ADC                                                                                              |
| P7.5/CB9/A13       | 6  | C3        | I/O                | General-purpose digital I/O<br>Comparator_B input CB9<br>Analog input A13 for ADC                                                                                           |
| P7.6/CB10/A14/DAC0 | 7  | D2        | I/O                | General-purpose digital I/O<br>Comparator_B input CB10<br>Analog input A14 for ADC<br>DAC12.0 output                                                                        |
| P7.7/CB11/A15/DAC1 | 8  | D1        | I/O                | General-purpose digital I/O<br>Comparator_B input CB11<br>Analog input A15 for ADC<br>DAC12.1 output                                                                        |
| P5.0/VREF+/VeREF+  | 9  | D4        | I/O                | General-purpose digital I/O<br>Output of reference voltage to the ADC<br>Input for an external reference voltage to the ADC                                                 |
| P5.1/VREF-/VeREF-  | 10 | E4        | I/O                | General-purpose digital I/O<br>Negative terminal for the ADC's reference voltage for both sources, the internal reference voltage, or an external applied reference voltage |
| AVCC1              | 11 | E1,<br>E2 |                    | Analog power supply                                                                                                                                                         |
| AVSS1              | 12 | F2        |                    | Analog ground supply                                                                                                                                                        |
| XIN                | 13 | F1        | I                  | Input terminal for crystal oscillator XT1                                                                                                                                   |
| XOUT               | 14 | G1        | O                  | Output terminal of crystal oscillator XT1                                                                                                                                   |

(1) I = input, O = output, N/A = not available on this package offering

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

| TERMINAL               |     |     | I/O <sup>(1)</sup> | DESCRIPTION                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------|-----|-----|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NAME                   | NO. |     |                    |                                                                                                                                                                                                                                                                                                                                                                               |
|                        | PZ  | ZQW |                    |                                                                                                                                                                                                                                                                                                                                                                               |
| AVSS2                  | 15  | G2  |                    | Analog ground supply                                                                                                                                                                                                                                                                                                                                                          |
| P5.6/ADC12CLK/DMAE0    | 16  | H1  | I/O                | General-purpose digital I/O                                                                                                                                                                                                                                                                                                                                                   |
|                        |     |     |                    | Conversion clock output ADC                                                                                                                                                                                                                                                                                                                                                   |
|                        |     |     |                    | DMA external trigger input                                                                                                                                                                                                                                                                                                                                                    |
| P2.0/P2MAP0            | 17  | G4  | I/O                | General-purpose digital I/O with port interrupt and mappable secondary function<br>Default mapping: USCI_B0 SPI slave transmit enable; USCI_A0 clock input/output                                                                                                                                                                                                             |
| P2.1/P2MAP1            | 18  | H2  | I/O                | General-purpose digital I/O with port interrupt and mappable secondary function<br>Default mapping: USCI_B0 SPI slave in, master out; USCI_B0 I2C data                                                                                                                                                                                                                        |
| P2.2/P2MAP2            | 19  | J1  | I/O                | General-purpose digital I/O with port interrupt and mappable secondary function<br>Default mapping: USCI_B0 SPI slave out, master in; USCI_B0 I2C clock                                                                                                                                                                                                                       |
| P2.3/P2MAP3            | 20  | H4  | I/O                | General-purpose digital I/O with port interrupt and mappable secondary function<br>Default mapping: USCI_B0 clock input/output; USCI_A0 SPI slave transmit enable                                                                                                                                                                                                             |
| P2.4/P2MAP4            | 21  | J2  | I/O                | General-purpose digital I/O with port interrupt and mappable secondary function<br>Default mapping: USCI_A0 UART transmit data; USCI_A0 SPI slave in, master out                                                                                                                                                                                                              |
| P2.5/P2MAP5            | 22  | K1  | I/O                | General-purpose digital I/O with port interrupt and mappable secondary function<br>Default mapping: USCI_A0 UART receive data; USCI_A0 slave out, master in                                                                                                                                                                                                                   |
| P2.6/P2MAP6/R03        | 23  | K2  | I/O                | General-purpose digital I/O with port interrupt and mappable secondary function<br>Default mapping: no secondary function<br>Input/output port of lowest analog LCD voltage (V5) (not available on F5659, F5658, F5359, F5358 devices)                                                                                                                                        |
| P2.7/P2MAP7/LCDREF/R13 | 24  | L2  | I/O                | General-purpose digital I/O with port interrupt and mappable secondary function<br>Default mapping: no secondary function<br>External reference voltage input for regulated LCD voltage (not available on F5659, F5658, F5359, F5358 devices)<br>Input/output port of third most positive analog LCD voltage (V3 or V4) (not available on F5659, F5658, F5359, F5358 devices) |
| DVCC1                  | 25  | L1  |                    | Digital power supply                                                                                                                                                                                                                                                                                                                                                          |
| DVSS1                  | 26  | M1  |                    | Digital ground supply                                                                                                                                                                                                                                                                                                                                                         |
| VCORE <sup>(2)</sup>   | 27  | M2  |                    | Regulated core power supply (internal use only, no external current loading)                                                                                                                                                                                                                                                                                                  |
| P5.2/R23               | 28  | L3  | I/O                | General-purpose digital I/O<br>Input/output port of second most positive analog LCD voltage (V2) (not available on F5659, F5658, F5359, F5358 devices)                                                                                                                                                                                                                        |
| LDCAP/R33              | 29  | M3  | I/O                | LCD capacitor connection (not available on F5659, F5658, F5359, F5358 devices)<br>Input/output port of most positive analog LCD voltage (V1) (not available on F5659, F5658, F5359, F5358 devices)                                                                                                                                                                            |
| DVSS                   | 29  | M3  |                    | Digital ground supply (not available on F6659, F6658, F6459, and F6458 devices)                                                                                                                                                                                                                                                                                               |
| COM0                   | 30  | J4  | O                  | LCD common output COM0 for LCD backplane (not available on F5659, F5658, F5359, F5358 devices)                                                                                                                                                                                                                                                                                |
| DNC                    | 30  | J4  |                    | Do not connect. TI strongly recommends leaving this terminal open (not available on F6659, F6658, F6459, and F6458 devices)                                                                                                                                                                                                                                                   |
| P5.3/COM1/S42          | 31  | L4  | I/O                | General-purpose digital I/O<br>LCD common output COM1 for LCD backplane (not available on F5659, F5658, F5359, F5358 devices)<br>LCD segment output S42 (not available on F5659, F5658, F5359, F5358 devices)                                                                                                                                                                 |

(2) VCORE is for internal use only. No external current loading is possible. VCORE should only be connected to the recommended capacitor value, C<sub>VCORE</sub>.

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

| TERMINAL              |     | I/O <sup>(1)</sup> | DESCRIPTION                                                                                                                                                                                                                    |
|-----------------------|-----|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NAME                  | NO. |                    |                                                                                                                                                                                                                                |
|                       | PZ  | ZQW                |                                                                                                                                                                                                                                |
| P5.4/COM2/S41         | 32  | M4                 | I/O<br>General-purpose digital I/O<br>LCD common output COM2 for LCD backplane (not available on F5659, F5658, F5359, F5358 devices)<br>LCD segment output S41 (not available on F5659, F5658, F5359, F5358 devices)           |
| P5.5/COM3/S40         | 33  | J5                 | I/O<br>General-purpose digital I/O<br>LCD common output COM3 for LCD backplane (not available on F5659, F5658, F5359, F5358 devices)<br>LCD segment output S40 (not available on F5659, F5658, F5359, F5358 devices)           |
| P1.0/TA0CLK/ACLK/S39  | 34  | L5                 | I/O<br>General-purpose digital I/O with port interrupt<br>Timer TA0 clock signal TACLK input<br>ACLK output (divided by 1, 2, 4, 8, 16, or 32)<br>LCD segment output S39 (not available on F5659, F5658, F5359, F5358 devices) |
| P1.1/TA0.0/S38        | 35  | M5                 | I/O<br>General-purpose digital I/O with port interrupt<br>Timer TA0 CCR0 capture: CCI0A input, compare: Out0 output<br>BSL transmit output<br>LCD segment output S38 (not available on F5659, F5658, F5359, F5358 devices)     |
| P1.2/TA0.1/S37        | 36  | J6                 | I/O<br>General-purpose digital I/O with port interrupt<br>Timer TA0 CCR1 capture: CCI1A input, compare: Out1 output<br>BSL receive input<br>LCD segment output S37 (not available on F5659, F5658, F5359, F5358 devices)       |
| P1.3/TA0.2/S36        | 37  | H6                 | I/O<br>General-purpose digital I/O with port interrupt<br>Timer TA0 CCR2 capture: CCI2A input, compare: Out2 output<br>LCD segment output S36 (not available on F5659, F5658, F5359, F5358 devices)                            |
| P1.4/TA0.3/S35        | 38  | M6                 | I/O<br>General-purpose digital I/O with port interrupt<br>Timer TA0 CCR3 capture: CCI3A input compare: Out3 output<br>LCD segment output S35 (not available on F5659, F5658, F5359, F5358 devices)                             |
| P1.5/TA0.4/S34        | 39  | L6                 | I/O<br>General-purpose digital I/O with port interrupt<br>Timer TA0 CCR4 capture: CCI4A input, compare: Out4 output<br>LCD segment output S34 (not available on F5659, F5658, F5359, F5358 devices)                            |
| P1.6/TA0.1/S33        | 40  | J7                 | I/O<br>General-purpose digital I/O with port interrupt<br>Timer TA0 CCR1 capture: CCI1B input, compare: Out1 output<br>LCD segment output S33 (not available on F5659, F5658, F5359, F5358 devices)                            |
| P1.7/TA0.2/S32        | 41  | M7                 | I/O<br>General-purpose digital I/O with port interrupt<br>Timer TA0 CCR2 capture: CCI2B input, compare: Out2 output<br>LCD segment output S32 (not available on F5659, F5658, F5359, F5358 devices)                            |
| P3.0/TA1CLK/CBOUT/S31 | 42  | L7                 | I/O<br>General-purpose digital I/O with port interrupt<br>Timer TA1 clock input<br>Comparator_B output<br>LCD segment output S31 (not available on F5659, F5658, F5359, F5358 devices)                                         |
| P3.1/TA1.0/S30        | 43  | H7                 | I/O<br>General-purpose digital I/O with port interrupt<br>Timer TA1 capture CCR0: CCI0A/CCI0B input, compare: Out0 output<br>LCD segment output S30 (not available on F5659, F5658, F5359, F5358 devices)                      |

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

| TERMINAL              |     |     | I/O <sup>(1)</sup> | DESCRIPTION                                                                                                                                                                                        |
|-----------------------|-----|-----|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NAME                  | NO. |     |                    |                                                                                                                                                                                                    |
|                       | PZ  | ZQW |                    |                                                                                                                                                                                                    |
| P3.2/TA1.1/S29        | 44  | M8  | I/O                | General-purpose digital I/O with port interrupt<br>Timer TA1 capture CCR1: CCI1A/CCI1B input, compare: Out1 output<br>LCD segment output S29 (not available on F5659, F5658, F5359, F5358 devices) |
| P3.3/TA1.2/S28        | 45  | L8  | I/O                | General-purpose digital I/O with port interrupt<br>Timer TA1 capture CCR2: CCI2A/CCI2B input, compare: Out2 output<br>LCD segment output S28 (not available on F5659, F5658, F5359, F5358 devices) |
| P3.4/TA2CLK/SMCLK/S27 | 46  | J8  | I/O                | General-purpose digital I/O with port interrupt<br>Timer TA2 clock input<br>SMCLK output<br>LCD segment output S27 (not available on F5659, F5658, F5359, F5358 devices)                           |
| P3.5/TA2.0/S26        | 47  | M9  | I/O                | General-purpose digital I/O with port interrupt<br>Timer TA2 capture CCR0: CCI0A/CCI0B input, compare: Out0 output<br>LCD segment output S26 (not available on F5659, F5658, F5359, F5358 devices) |
| P3.6/TA2.1/S25        | 48  | L9  | I/O                | General-purpose digital I/O with port interrupt<br>Timer TA2 capture CCR1: CCI1A/CCI1B input, compare: Out1 output<br>LCD segment output S25 (not available on F5659, F5658, F5359, F5358 devices) |
| P3.7/TA2.2/S24        | 49  | M10 | I/O                | General-purpose digital I/O with port interrupt<br>Timer TA2 capture CCR2: CCI2A/CCI2B input, compare: Out2 output<br>LCD segment output S24 (not available on F5659, F5658, F5359, F5358 devices) |
| P4.0/TB0.0/S23        | 50  | J9  | I/O                | General-purpose digital I/O with port interrupt<br>Timer TB0 capture CCR0: CCI0A/CCI0B input, compare: Out0 output<br>LCD segment output S23 (not available on F5659, F5658, F5359, F5358 devices) |
| P4.1/TB0.1/S22        | 51  | M11 | I/O                | General-purpose digital I/O with port interrupt<br>Timer TB0 capture CCR1: CCI1A/CCI1B input, compare: Out1 output<br>LCD segment output S22 (not available on F5659, F5658, F5359, F5358 devices) |
| P4.2/TB0.2/S21        | 52  | L10 | I/O                | General-purpose digital I/O with port interrupt<br>Timer TB0 capture CCR2: CCI2A/CCI2B input, compare: Out2 output<br>LCD segment output S21 (not available on F5659, F5658, F5359, F5358 devices) |
| P4.3/TB0.3/S20        | 53  | M12 | I/O                | General-purpose digital I/O with port interrupt<br>Timer TB0 capture CCR3: CCI3A/CCI3B input, compare: Out3 output<br>LCD segment output S20 (not available on F5659, F5658, F5359, F5358 devices) |
| P4.4/TB0.4/S19        | 54  | L12 | I/O                | General-purpose digital I/O with port interrupt<br>Timer TB0 capture CCR4: CCI4A/CCI4B input, compare: Out4 output<br>LCD segment output S19 (not available on F5659, F5658, F5359, F5358 devices) |
| P4.5/TB0.5/S18        | 55  | L11 | I/O                | General-purpose digital I/O with port interrupt<br>Timer TB0 capture CCR5: CCI5A/CCI5B input, compare: Out5 output<br>LCD segment output S18 (not available on F5659, F5658, F5359, F5358 devices) |
| P4.6/TB0.6/S17        | 56  | K11 | I/O                | General-purpose digital I/O with port interrupt<br>Timer TB0 capture CCR6: CCI6A/CCI6B input, compare: Out6 output<br>LCD segment output S17 (not available on F5659, F5658, F5359, F5358 devices) |

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

| TERMINAL                  |     |     | I/O <sup>(1)</sup> | DESCRIPTION                                                                                                                                                                                       |
|---------------------------|-----|-----|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NAME                      | NO. |     |                    |                                                                                                                                                                                                   |
|                           | PZ  | ZQW |                    |                                                                                                                                                                                                   |
| P4.7/TB0OUTH/SVMOUT/S16   | 57  | K12 | I/O                | General-purpose digital I/O with port interrupt<br>Timer TB0: Switch all PWM outputs high impedance<br>SVM output<br>LCD segment output S16 (not available on F5659, F5658, F5359, F5358 devices) |
| P8.0/TB0CLK/S15           | 58  | J11 | I/O                | General-purpose digital I/O<br>Timer TB0 clock input<br>LCD segment output S15 (not available on F5659, F5658, F5359, F5358 devices)                                                              |
| P8.1/UCB1STE/UCA1CLK/S14  | 59  | J12 | I/O                | General-purpose digital I/O<br>USCI_B1 SPI slave transmit enable<br>USCI_A1 clock input/output<br>LCD segment output S14 (not available on F5659, F5658, F5359, F5358 devices)                    |
| P8.2/UCA1TXD/UCA1SIMO/S13 | 60  | H11 | I/O                | General-purpose digital I/O<br>USCI_A1 UART transmit data<br>USCI_A1 SPI slave in, master out<br>LCD segment output S13 (not available on F5659, F5658, F5359, F5358 devices)                     |
| P8.3/UCA1RXD/UCA1SOMI/S12 | 61  | H12 | I/O                | General-purpose digital I/O<br>USCI_A1 UART receive data<br>USCI_A1 SPI slave out, master in<br>LCD segment output S12 (not available on F5659, F5658, F5359, F5358 devices)                      |
| P8.4/UCB1CLK/UCA1STE/S11  | 62  | G11 | I/O                | General-purpose digital I/O<br>USCI_B1 clock input/output<br>USCI_A1 SPI slave transmit enable<br>LCD segment output S11 (not available on F5659, F5658, F5359, F5358 devices)                    |
| DVSS2                     | 63  | G12 |                    | Digital ground supply                                                                                                                                                                             |
| DVCC2                     | 64  | F12 |                    | Digital power supply                                                                                                                                                                              |
| P8.5/UCB1SIMO/UCB1SDA/S10 | 65  | F11 | I/O                | General-purpose digital I/O<br>USCI_B1 SPI slave in, master out<br>USCI_B1 I2C data<br>LCD segment output S10 (not available on F5659, F5658, F5359, F5358 devices)                               |
| P8.6/UCB1SOMI/UCB1SCL/S9  | 66  | G9  | I/O                | General-purpose digital I/O<br>USCI_B1 SPI slave out, master in<br>USCI_B1 I2C clock<br>LCD segment output S9 (not available on F5659, F5658, F5359, F5358 devices)                               |
| P8.7/S8                   | 67  | E12 | I/O                | General-purpose digital I/O<br>LCD segment output S8 (not available on F5659, F5658, F5359, F5358 devices)                                                                                        |
| P9.0/S7                   | 68  | E11 | I/O                | General-purpose digital I/O<br>LCD segment output S7 (not available on F5659, F5658, F5359, F5358 devices)                                                                                        |
| P9.1/UCB2STE/UCA2CLK/S6   | 69  | F9  | I/O                | General-purpose digital I/O<br>USCI_B2 SPI slave transmit enable<br>USCI_A2 clock input/output<br>LCD segment output S6 (not available on F5659, F5658, F5359, F5358 devices)                     |

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

| TERMINAL                 |     | I/O <sup>(1)</sup> | DESCRIPTION |                                                                                                                                                                                         |
|--------------------------|-----|--------------------|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NAME                     | NO. |                    |             |                                                                                                                                                                                         |
|                          | PZ  |                    |             | ZQW                                                                                                                                                                                     |
| P9.2/UCA2TXD/UCA2SIMO/S5 | 70  | D12                | I/O         | General-purpose digital I/O<br>USCI_A2 UART transmit data<br>USCI_A2 SPI slave in, master out<br>LCD segment output S5 (not available on F5659, F5658, F5359, F5358 devices)            |
| P9.3/UCA2RXD/UCA2SOMI/S4 | 71  | D11                | I/O         | General-purpose digital I/O<br>USCI_A2 UART receive data<br>USCI_A2 SPI slave out, master in<br>LCD segment output S4 (not available on F5659, F5658, F5359, F5358 devices)             |
| P9.4/UCB2CLK/UCA2STE/S3  | 72  | E9                 | I/O         | General-purpose digital I/O<br>USCI_B2 clock input/output<br>USCI_A2 SPI slave transmit enable<br>LCD segment output S3 (not available on F5659, F5658, F5359, F5358 devices)           |
| P9.5/UCB2SIMO/UCB2SDA/S2 | 73  | C12                | I/O         | General-purpose digital I/O<br>USCI_B2 SPI slave in, master out<br>USCI_B2 I2C data<br>LCD segment output S2 (not available on F5659, F5658, F5359, F5358 devices)                      |
| P9.6/UCB2SOMI/UCB2SCL/S1 | 74  | C11                | I/O         | General-purpose digital I/O<br>USCI_B2 SPI slave out, master in<br>USCI_B2 I2C clock<br>LCD segment output S1 (not available on F5659, F5658, F5359, F5358 devices)                     |
| P9.7/S0                  | 75  | D9                 | I/O         | General-purpose digital I/O<br>LCD segment output S0 (not available on F5659, F5658, F5359, F5358 devices)                                                                              |
| VSSU                     | 76  | B11,<br>B12        |             | USB PHY or PU ground supply                                                                                                                                                             |
| PU.0/DP                  | 77  | A12                | I/O         | General-purpose digital I/O – controlled by USB or PU control register (Port U is supplied the LDOO rail)<br>USB data terminal DP (not available on F6459, F6458, F5359, F5358 devices) |
| PUR                      | 78  | B10                | I/O         | USB pullup resistor pin (open drain) (not available on F6459, F6458, F5359, F5358 devices)                                                                                              |
| NC                       | 78  | B10                |             | Not connected (not available on F6659, F6658, F5659, F5658 devices)                                                                                                                     |
| PU.1/DM                  | 79  | A11                | I/O         | General-purpose digital I/O – controlled by USB or PU control register (Port U is supplied the LDOO rail)<br>USB data terminal DM (not available on F6459, F6458, F5359, F5358 devices) |
| VBUS                     | 80  | A10                |             | USB LDO input (connect to USB power source) (not available on F6459, F6458, F5359, F5358 devices)                                                                                       |
| LDOI                     | 80  | A10                |             | LDO input (not available on F6659, F6658, F5659, F5658 devices)                                                                                                                         |
| VUSB                     | 81  | A9                 |             | USB LDO output (not available on F6459, F6458, F5359, F5358 devices)                                                                                                                    |
| LDOO                     | 81  | A9                 |             | LDO output (not available on F6659, F6658, F5659, F5658 devices)                                                                                                                        |
| V18                      | 82  | B9                 |             | USB regulated power (internal use only, no external current loading) (not available on F6459, F6458, F5359, F5358 devices)                                                              |
| NC                       | 82  | B9                 |             | Not connected (not available on F6659, F6658, F5659, F5658 devices)                                                                                                                     |
| AVSS3                    | 83  | A8                 |             | Analog ground supply                                                                                                                                                                    |
| P7.2/XT2IN               | 84  | B8                 | I/O         | General-purpose digital I/O<br>Input terminal for crystal oscillator XT2                                                                                                                |

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

| TERMINAL                             |     |                                                                          | I/O <sup>(1)</sup> | DESCRIPTION                                                                                                                                  |
|--------------------------------------|-----|--------------------------------------------------------------------------|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| NAME                                 | NO. |                                                                          |                    |                                                                                                                                              |
|                                      | PZ  | ZQW                                                                      |                    |                                                                                                                                              |
| P7.3/XT2OUT                          | 85  | B7                                                                       | I/O                | General-purpose digital I/O<br>Output terminal of crystal oscillator XT2                                                                     |
| VBAK                                 | 86  | A7                                                                       |                    | Capacitor for backup subsystem. Do not load this pin externally. For capacitor values, see C <sub>BAK</sub> in <a href="#">Section 5.3</a> . |
| VBAT                                 | 87  | D8                                                                       |                    | Backup supply voltage. If backup voltage is not supplied, connect to DVCC externally.                                                        |
| P5.7/RTCCLK                          | 88  | D7                                                                       | I/O                | General-purpose digital I/O<br>RTCCLK output                                                                                                 |
| DVCC3                                | 89  | A6                                                                       |                    | Digital power supply                                                                                                                         |
| DVSS3                                | 90  | A5                                                                       |                    | Digital ground supply                                                                                                                        |
| TEST/SBWTK                           | 91  | B6                                                                       | I                  | Test mode pin – select digital I/O on JTAG pins<br>Spy-Bi-Wire input clock                                                                   |
| PJ.0/TDO                             | 92  | B5                                                                       | I/O                | General-purpose digital I/O<br>Test data output port                                                                                         |
| PJ.1/TDI/TCLK                        | 93  | A4                                                                       | I/O                | General-purpose digital I/O<br>Test data input or test clock input                                                                           |
| PJ.2/TMS                             | 94  | E7                                                                       | I/O                | General-purpose digital I/O<br>Test mode select                                                                                              |
| PJ.3/TCK                             | 95  | D6                                                                       | I/O                | General-purpose digital I/O<br>Test clock                                                                                                    |
| $\overline{\text{RST}}$ /NMI/SBWTDIO | 96  | A3                                                                       | I/O                | Reset input active low <sup>(3)</sup><br>Nonmaskable interrupt input<br>Spy-Bi-Wire data input/output                                        |
| P6.0/CB0/A0                          | 97  | B4                                                                       | I/O                | General-purpose digital I/O<br>Comparator_B input CB0<br>Analog input A0 for ADC                                                             |
| P6.1/CB1/A1                          | 98  | B3                                                                       | I/O                | General-purpose digital I/O<br>Comparator_B input CB1<br>Analog input A1 for ADC                                                             |
| P6.2/CB2/A2                          | 99  | A2                                                                       | I/O                | General-purpose digital I/O<br>Comparator_B input CB2<br>Analog input A2 for ADC                                                             |
| P6.3/CB3/A3                          | 100 | D5                                                                       | I/O                | General-purpose digital I/O<br>Comparator_B input CB3<br>Analog input A3 for ADC                                                             |
| Reserved                             | N/A | E5,<br>E6,<br>E8,<br>F4,<br>F5,<br>F8,<br>G5,<br>G8,<br>H5,<br>H8,<br>H9 |                    | Reserved BGA package balls. TI recommends connecting to ground (DVSS, AVSS).                                                                 |

(3) When this pin is configured as reset, the internal pullup resistor is enabled by default.

## 5 Specifications

All graphs in this section are for typical conditions, unless otherwise noted.

Typical (TYP) values are specified at  $V_{CC} = 3.3\text{ V}$  and  $T_A = 25^\circ\text{C}$ , unless otherwise noted.

### 5.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

|                                                                                                  | MIN  | MAX            | UNIT |
|--------------------------------------------------------------------------------------------------|------|----------------|------|
| Voltage applied at $V_{CC}$ to $V_{SS}$                                                          | −0.3 | 4.1            | V    |
| Voltage applied to any pin (excluding V <sub>CORE</sub> , V <sub>BUS</sub> , V18) <sup>(2)</sup> | −0.3 | $V_{CC} + 0.3$ | V    |
| Diode current at any device pin                                                                  |      | ±2             | mA   |
| Storage temperature, $T_{stg}$ <sup>(3)</sup>                                                    | −55  | 150            | °C   |
| Maximum junction temperature, $T_J$                                                              |      | 95             | °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) All voltages referenced to  $V_{SS}$ . V<sub>CORE</sub> is for internal device use only. No external DC loading or voltage should be applied.
- (3) 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 <sup>(1)</sup>              | ±1000 | V    |
|                                     | Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup> | ±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

|               |                                                                                                                                        | MIN                                             | NOM  | MAX | UNIT  |
|---------------|----------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|------|-----|-------|
| $V_{CC}$      | Supply voltage during program execution and flash programming ( $AVCC1 = DVCC1 = DVCC2 = DVCC3 = DV_{CC} = V_{CC}$ ) <sup>(1)(2)</sup> | PMMCOREVx = 0                                   | 1.8  | 3.6 | V     |
|               |                                                                                                                                        | PMMCOREVx = 0, 1                                | 2.0  | 3.6 |       |
|               |                                                                                                                                        | PMMCOREVx = 0, 1, 2                             | 2.2  | 3.6 |       |
|               |                                                                                                                                        | PMMCOREVx = 0, 1, 2, 3                          | 2.4  | 3.6 |       |
| $V_{CC,USB}$  | Supply voltage during USB operation, USB PLL disabled, USB_EN = 1, UPLLEN = 0                                                          | PMMCOREVx = 0                                   | 1.8  | 3.6 | V     |
|               |                                                                                                                                        | PMMCOREVx = 0, 1                                | 2.0  | 3.6 |       |
|               |                                                                                                                                        | PMMCOREVx = 0, 1, 2                             | 2.2  | 3.6 |       |
|               |                                                                                                                                        | PMMCOREVx = 0, 1, 2, 3                          | 2.4  | 3.6 |       |
|               | Supply voltage during USB operation, USB PLL enabled <sup>(3)</sup> , USB_EN = 1, UPLLEN = 1                                           | PMMCOREVx = 2                                   | 2.2  | 3.6 |       |
|               |                                                                                                                                        | PMMCOREVx = 2, 3                                | 2.4  | 3.6 |       |
| $V_{SS}$      | Supply voltage ( $AVSS1 = AVSS2 = AVSS3 = DVSS1 = DVSS2 = DVSS3 = V_{SS}$ )                                                            |                                                 | 0    |     | V     |
| $V_{BAT,RTC}$ | Backup-supply voltage with RTC operational                                                                                             | $T_A = 0^\circ\text{C}$ to $85^\circ\text{C}$   | 1.55 | 3.6 | V     |
|               |                                                                                                                                        | $T_A = -40^\circ\text{C}$ to $85^\circ\text{C}$ | 1.70 | 3.6 |       |
| $V_{BAT,MEM}$ | Backup-supply voltage with backup memory retained.                                                                                     | $T_A = -40^\circ\text{C}$ to $85^\circ\text{C}$ | 1.20 | 3.6 | V     |
| $T_A$         | Operating free-air temperature                                                                                                         | I version                                       | −40  | 85  | °C    |
| $T_J$         | Operating junction temperature                                                                                                         | I version                                       | −40  | 85  | °C    |
| $C_{BAK}$     | Capacitance at pin VBAK                                                                                                                |                                                 | 1    | 4.7 | 10 nF |

- (1) TI recommends powering AVCC and DVCC from the same source. A maximum difference of 0.3 V between AVCC and DVCC can be tolerated during power up and operation.
- (2) The minimum supply voltage is defined by the supervisor SVS levels when it is enabled. See the [Section 5.23](#) threshold parameters for the exact values and further details.
- (3) USB operation with USB PLL enabled requires PMMCOREVx ≥ 2 for proper operation.

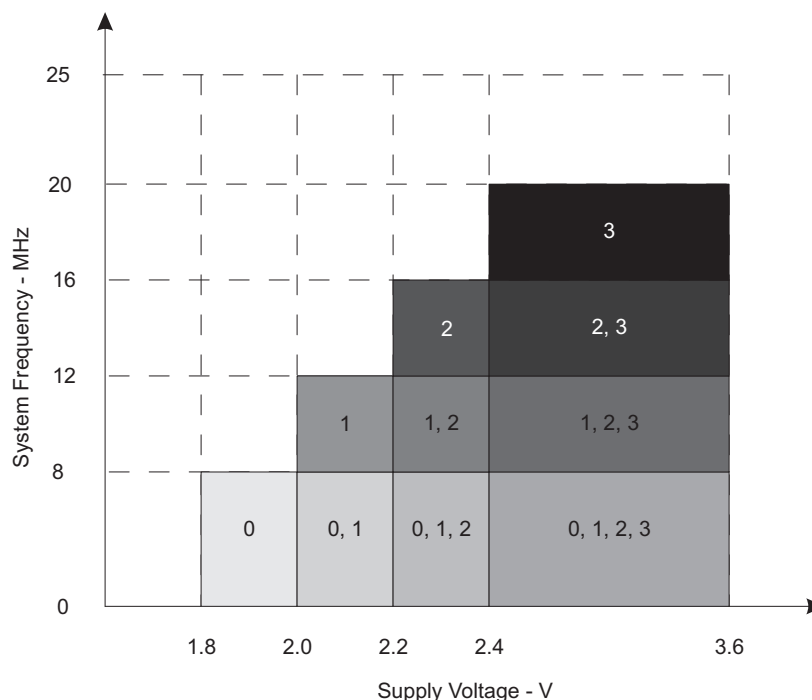
## Recommended Operating Conditions (continued)

|                                           |                                                                                                     |                                                                          | MIN | NOM | MAX  | UNIT   |
|-------------------------------------------|-----------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|-----|-----|------|--------|
| C <sub>VCORE</sub>                        | Capacitor at VCORE <sup>(4)</sup>                                                                   |                                                                          | 470 |     |      | nF     |
| C <sub>DVCC</sub> /<br>C <sub>VCORE</sub> | Capacitor ratio of DVCC to VCORE                                                                    |                                                                          | 10  |     |      |        |
| f <sub>SYSTEM</sub>                       | Processor frequency (maximum MCLK frequency) <sup>(5)(6)</sup><br>(see <a href="#">Figure 5-1</a> ) | PMMCOREVx = 0,<br>1.8 V ≤ V <sub>CC</sub> ≤ 3.6 V<br>(default condition) | 0   |     | 8.0  | MHz    |
|                                           |                                                                                                     | PMMCOREVx = 1,<br>2 V ≤ V <sub>CC</sub> ≤ 3.6 V                          | 0   |     | 12.0 |        |
|                                           |                                                                                                     | PMMCOREVx = 2,<br>2.2 V ≤ V <sub>CC</sub> ≤ 3.6 V                        | 0   |     | 16.0 |        |
|                                           |                                                                                                     | PMMCOREVx = 3,<br>2.4 V ≤ V <sub>CC</sub> ≤ 3.6 V                        | 0   |     | 20.0 |        |
| f <sub>SYSTEM_USB</sub>                   | Minimum processor frequency for USB operation                                                       |                                                                          | 1.5 |     |      | MHz    |
| USB_wait                                  | Wait state cycles during USB operation                                                              |                                                                          | 16  |     |      | cycles |

(4) A capacitor tolerance of ±20% or better is required.

(5) The MSP430 CPU is clocked directly with MCLK. Both the high and low phase of MCLK must not exceed the pulse duration of the specified maximum frequency.

(6) Modules may have a different maximum input clock specification. See the specification of the respective module in this data sheet.



NOTE: The numbers within the fields denote the supported PMMCOREVx settings.

**Figure 5-1. Frequency vs Supply Voltage**

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

over recommended operating free-air temperature (unless otherwise noted)<sup>(1) (2) (3)</sup>

| PARAMETER              | EXECUTION MEMORY | V <sub>CC</sub> | PMMCOREVx | FREQUENCY (f <sub>DCO</sub> = f <sub>MCLK</sub> = f <sub>SMCLK</sub> ) |      |       |     |        |     |        |     | UNIT |
|------------------------|------------------|-----------------|-----------|------------------------------------------------------------------------|------|-------|-----|--------|-----|--------|-----|------|
|                        |                  |                 |           | 1 MHz                                                                  |      | 8 MHz |     | 12 MHz |     | 20 MHz |     |      |
|                        |                  |                 |           | TYP                                                                    | MAX  | TYP   | MAX | TYP    | MAX | TYP    | MAX |      |
| I <sub>AM, Flash</sub> | Flash            | 3 V             | 0         | 0.36                                                                   | 0.45 | 2.4   | 2.7 |        |     |        |     | mA   |
|                        |                  |                 | 1         | 0.41                                                                   |      | 2.7   |     | 4.0    | 4.4 |        |     |      |
|                        |                  |                 | 2         | 0.46                                                                   |      | 2.9   |     | 4.3    |     |        |     |      |
|                        |                  |                 | 3         | 0.51                                                                   |      | 3.1   |     | 4.5    |     | 7.4    |     |      |
| I <sub>AM, RAM</sub>   | RAM              | 3 V             | 0         | 0.18                                                                   | 0.23 | 1.0   | 1.3 |        |     |        |     | mA   |
|                        |                  |                 | 1         | 0.20                                                                   |      | 1.2   |     | 1.7    | 1.9 |        |     |      |
|                        |                  |                 | 2         | 0.22                                                                   |      | 1.3   |     | 2.0    |     |        |     |      |
|                        |                  |                 | 3         | 0.23                                                                   |      | 1.4   |     | 2.2    |     | 3.6    |     |      |

(1) All inputs are tied to 0 V or to  $V_{CC}$ . Outputs do not source or sink any current.

(2) The currents are 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.

(3) Characterized with program executing typical data processing. USB disabled ( $V_{USBEN} = 0$ ,  $SLDOEN = 0$ ).

 $f_{ACLK} = 32786 \text{ Hz}$ ,  $f_{DCO} = f_{MCLK} = f_{SMCLK}$  at specified frequency.

 $XTS = CPUOFF = SCG0 = SCG1 = OSCOFF = SMCLKOFF = 0$ .

## 5.5 Low-Power Mode Supply Currents (Into $V_{CC}$ ) Excluding External Current

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)<sup>(1) (2)</sup>

| PARAMETER         |                                                   | $V_{CC}$ | PMMCOREVx | -40°C |     | 25°C |     | 60°C |     | 85°C |     | UNIT    |
|-------------------|---------------------------------------------------|----------|-----------|-------|-----|------|-----|------|-----|------|-----|---------|
|                   |                                                   |          |           | TYP   | MAX | TYP  | MAX | TYP  | MAX | TYP  | MAX |         |
| $I_{LPM0, 1MHz}$  | Low-power mode 0 <sup>(3) (4)</sup>               | 2.2 V    | 0         | 69    |     | 73   | 95  | 79   |     | 85   | 125 | $\mu A$ |
|                   |                                                   | 3 V      | 3         | 79    |     | 83   | 120 | 87   |     | 96   | 155 |         |
| $I_{LPM2}$        | Low-power mode 2 <sup>(5) (4)</sup>               | 2.2 V    | 0         | 6.1   |     | 6.7  | 9.0 | 8.0  |     | 13   | 32  | $\mu A$ |
|                   |                                                   | 3 V      | 3         | 6.5   |     | 7.1  | 9.5 | 8.5  |     | 14   | 34  |         |
| $I_{LPM3, XT1LF}$ | Low-power mode 3, crystal mode <sup>(6) (4)</sup> | 2.2 V    | 0         | 1.5   |     | 2.0  | 3.3 | 3.3  |     | 8.2  | 27  | $\mu A$ |
|                   |                                                   |          | 1         | 1.7   |     | 2.2  |     | 3.6  |     | 8.7  |     |         |
|                   |                                                   |          | 2         | 1.9   |     | 2.4  |     | 3.8  |     | 8.9  |     |         |
|                   |                                                   | 3 V      | 0         | 1.8   |     | 2.2  | 3.5 | 3.6  |     | 8.6  | 28  |         |
|                   |                                                   |          | 1         | 1.9   |     | 2.4  |     | 3.8  |     | 9.0  |     |         |
|                   |                                                   |          | 2         | 2.1   |     | 2.6  |     | 4.0  |     | 9.1  |     |         |
|                   |                                                   |          | 3         | 2.1   |     | 2.6  | 4.2 | 4.0  |     | 9.1  | 29  |         |

(1) All inputs are tied to 0 V or to  $V_{CC}$ . Outputs do not source or sink any current.

(2) The currents are characterized with a Micro Crystal CC4V-T1A SMD crystal with a load capacitance of 9 pF. The internal and external load capacitance are chosen to closely match the required 9 pF.

(3) Current for watchdog timer clocked by SMCLK included.  $ACLK$  = low frequency crystal operation ( $XTS = 0$ ,  $XT1DRIVEx = 0$ ).

 $CPUOFF = 1$ ,  $SCG0 = 0$ ,  $SCG1 = 0$ ,  $OSCOFF = 0$  (LPM0),  $f_{ACLK} = 32768 \text{ Hz}$ ,  $f_{MCLK} = 0 \text{ MHz}$ ,  $f_{SMCLK} = f_{DCO} = 1 \text{ MHz}$ 

USB disabled ( $V_{USBEN} = 0$ ,  $SLDOEN = 0$ ).

(4) Current for brownout included. Low-side supervisor and monitors disabled ( $SVSL$ ,  $SVM_L$ ). High-side supervisor and monitor disabled ( $SVSH$ ,  $SVM_H$ ). RAM retention enabled.

(5) Current for watchdog timer clocked by  $ACLK$  and RTC clocked by LFXT1 (32768 Hz) included.  $ACLK$  = low frequency crystal operation ( $XTS = 0$ ,  $XT1DRIVEx = 0$ ).

 $CPUOFF = 1$ ,  $SCG0 = 0$ ,  $SCG1 = 1$ ,  $OSCOFF = 0$  (LPM2),  $f_{ACLK} = 32768 \text{ Hz}$ ,  $f_{MCLK} = 0 \text{ MHz}$ ,  $f_{SMCLK} = f_{DCO} = 0 \text{ MHz}$ , DCO setting = 1-MHz operation, DCO bias generator enabled.

USB disabled ( $V_{USBEN} = 0$ ,  $SLDOEN = 0$ )

(6) Current for watchdog timer clocked by  $ACLK$  and RTC clocked by LFXT1 (32768 Hz) included.  $ACLK$  = low frequency crystal operation ( $XTS = 0$ ,  $XT1DRIVEx = 0$ ).

 $CPUOFF = 1$ ,  $SCG0 = 1$ ,  $SCG1 = 1$ ,  $OSCOFF = 0$  (LPM3),  $f_{ACLK} = 32768 \text{ Hz}$ ,  $f_{MCLK} = f_{SMCLK} = f_{DCO} = 0 \text{ MHz}$ 

USB disabled ( $V_{USBEN} = 0$ ,  $SLDOEN = 0$ )

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

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)<sup>(1) (2)</sup>

| PARAMETER                                                                                                                         | $V_{CC}$ | PMMCOREVx | -40°C |     | 25°C |     | 60°C |     | 85°C |     | UNIT    |
|-----------------------------------------------------------------------------------------------------------------------------------|----------|-----------|-------|-----|------|-----|------|-----|------|-----|---------|
|                                                                                                                                   |          |           | TYP   | MAX | TYP  | MAX | TYP  | MAX | TYP  | MAX |         |
| $I_{LPM3,VLO, WDT}$ Low-power mode 3, VLO mode, Watchdog enabled <sup>(7) (4)</sup>                                               | 3 V      | 0         | 1.0   |     | 1.3  | 2.7 | 2.7  |     | 7.4  | 26  | $\mu A$ |
|                                                                                                                                   |          | 1         | 1.1   |     | 1.5  |     | 2.8  |     | 7.7  |     |         |
|                                                                                                                                   |          | 2         | 1.1   |     | 1.6  |     | 2.9  |     | 7.8  |     |         |
|                                                                                                                                   |          | 3         | 1.1   |     | 1.6  | 3.2 | 2.9  |     | 7.8  | 30  |         |
| $I_{LPM4}$ Low-power mode 4 <sup>(8) (4)</sup>                                                                                    | 3 V      | 0         | 0.9   |     | 1.3  | 2.5 | 2.5  |     | 6.8  | 26  | $\mu A$ |
|                                                                                                                                   |          | 1         | 1.0   |     | 1.3  |     | 2.6  |     | 7.0  |     |         |
|                                                                                                                                   |          | 2         | 1.0   |     | 1.4  |     | 2.7  |     | 7.2  |     |         |
|                                                                                                                                   |          | 3         | 1.0   |     | 1.4  | 3.1 | 2.7  |     | 7.2  | 27  |         |
| $I_{LPM3.5,RTC, VCC}$ Low-power mode 3.5 (LPM3.5) current with active RTC into primary supply pin DV <sub>CC</sub> <sup>(9)</sup> | 3 V      |           |       |     | 0.5  |     |      |     | 0.75 | 1.8 | $\mu A$ |
| $I_{LPM3.5,RTC, VBAT}$ Low-power mode 3.5 (LPM3.5) current with active RTC into backup supply pin VBAT <sup>(10)</sup>            | 3 V      |           |       |     | 0.6  |     |      |     | 0.75 | 1.0 | $\mu A$ |
| $I_{LPM3.5,RTC, TOT}$ Total Low-power mode 3.5 (LPM3.5) current with active RTC <sup>(11)</sup>                                   | 3 V      |           | 1.0   |     | 1.1  |     | 1.2  |     | 1.5  | 2.8 | $\mu A$ |
| $I_{LPM4.5}$ Low-power mode 4.5 <sup>(12)</sup>                                                                                   | 3 V      |           | 0.4   |     | 0.45 | 0.6 | 0.5  |     | 0.76 | 1.8 | $\mu A$ |

(7) Current for watchdog timer clocked by VLO included.

CPUOFF = 1, SCG0 = 1, SCG1 = 1, OSCOFF = 0 (LPM3),  $f_{ACLK} = f_{MCLK} = f_{SMCLK} = f_{DCO} = 0$  MHz  
USB disabled (VUSBEN = 0, SLDOEN = 0)

(8) CPUOFF = 1, SCG0 = 1, SCG1 = 1, OSCOFF = 1 (LPM4),  $f_{DCO} = f_{ACLK} = f_{MCLK} = f_{SMCLK} = 0$  MHz  
USB disabled (VUSBEN = 0, SLDOEN = 0)

(9)  $V_{VBAT} = V_{CC} - 0.2$  V,  $f_{DCO} = f_{MCLK} = f_{SMCLK} = 0$  MHz,  $f_{ACLK} = 32768$  Hz, PMMREGOFF = 1, RTC in backup domain active

(10)  $V_{VBAT} = V_{CC} - 0.2$  V,  $f_{DCO} = f_{MCLK} = f_{SMCLK} = 0$  MHz,  $f_{ACLK} = 32768$  Hz, PMMREGOFF = 1, RTC in backup domain active, no current drawn on VBAK

(11)  $f_{DCO} = f_{MCLK} = f_{SMCLK} = 0$  MHz,  $f_{ACLK} = 32768$  Hz, PMMREGOFF = 1, RTC in backup domain active, no current drawn on VBAK

(12) Internal regulator disabled. No data retention.

CPUOFF = 1, SCG0 = 1, SCG1 = 1, OSCOFF = 1, PMMREGOFF = 1 (LPM4.5),  $f_{DCO} = f_{ACLK} = f_{MCLK} = f_{SMCLK} = 0$  MHz

## 5.6 Low-Power Mode With LCD Supply Currents (Into $V_{CC}$ ) Excluding External Current

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)<sup>(1) (2)</sup>

| PARAMETER                            | V <sub>CC</sub> | PMMCOREVx | TEMPERATURE (T <sub>A</sub> ) |     |      |     |      |     |      |     | UNIT |
|--------------------------------------|-----------------|-----------|-------------------------------|-----|------|-----|------|-----|------|-----|------|
|                                      |                 |           | –40°C                         |     | 25°C |     | 60°C |     | 85°C |     |      |
|                                      |                 |           | TYP                           | MAX | TYP  | MAX | TYP  | MAX | TYP  | MAX |      |
| I <sub>LPM3 LCD</sub> ,<br>int. bias | 3 V             | 0         | 2.7                           |     | 3.3  | 4.8 | 4.7  |     | 9.5  | 28  | μA   |
|                                      |                 | 1         | 2.9                           |     | 3.5  |     | 5.0  |     | 9.9  |     |      |
|                                      |                 | 2         | 3.0                           |     | 3.7  |     | 5.2  |     | 10.2 |     |      |
|                                      |                 | 3         | 3.1                           |     | 3.7  | 5.3 | 5.2  |     | 10.2 | 30  |      |
| I <sub>LPM3 LCD,CP</sub>             | 2.2 V           | 0         |                               |     | 3.6  |     |      |     |      |     | μA   |
|                                      |                 | 1         |                               |     | 3.7  |     |      |     |      |     |      |
|                                      |                 | 2         |                               |     | 4.0  |     |      |     |      |     |      |
|                                      | 3 V             | 0         |                               |     | 3.5  |     |      |     |      |     |      |
|                                      |                 | 1         |                               |     | 3.7  |     |      |     |      |     |      |
|                                      |                 | 2         |                               |     | 3.8  |     |      |     |      |     |      |
|                                      |                 | 3         |                               |     | 3.9  |     |      |     |      |     |      |

(1) All inputs are tied to 0 V or to  $V_{CC}$ . Outputs do not source or sink any current.

(2) The currents are characterized with a Micro Crystal CC4V-T1A SMD crystal with a load capacitance of 9 pF. The internal and external load capacitance are chosen to closely match the required 9 pF.

(3) Current for watchdog timer clocked by ACLK and RTC clocked by LFXT1 (32768 Hz) included. ACLK = low frequency crystal operation (XTS = 0, XT1DRIVEx = 0).

CPUOFF = 1, SCG0 = 1, SCG1 = 1, OSCOFF = 0 (LPM3),  $f_{ACLK}$  = 32768 Hz,  $f_{MCLK}$  =  $f_{SMCLK}$  =  $f_{DCO}$  = 0 MHz

Current for brownout included. Low-side supervisor (SVSL) and low-side monitor (SVM<sub>L</sub>) disabled. High-side supervisor (SVSH) and high-side monitor (SVM<sub>H</sub>) disabled. RAM retention enabled.

(4) LCDMx = 11 (4-mux mode), LCDREXT = 0, LCDEXTBIAS = 0 (internal biasing), LCD2B = 0 (1/3 bias), LCDCPEN = 0 (charge pump disabled), LCDSSEL = 0, LCDPREx = 101, LCDDIVx = 00011 ( $f_{LCD}$  = 32768 Hz / 32 / 4 = 256 Hz)  
Even segments S0, S2,... = 0, odd segments S1, S3,... = 1. No LCD panel load.

(5) LCDMx = 11 (4-mux mode), LCDREXT = 0, LCDEXTBIAS = 0 (internal biasing), LCD2B = 0 (1/3 bias), LCDCPEN = 1 (charge pump enabled), VLCDx = 1000 ( $V_{LCD}$  = 3 V, typical), LCDSSEL = 0, LCDPREx = 101, LCDDIVx = 00011 ( $f_{LCD}$  = 32768 Hz / 32 / 4 = 256 Hz)  
Even segments S0, S2,... = 0, odd segments S1, S3,... = 1. No LCD panel load.

## 5.7 Thermal Resistance Characteristics

| THERMAL METRIC     |                                                                  | PACKAGE   | VALUE | UNIT |
|--------------------|------------------------------------------------------------------|-----------|-------|------|
| $\theta_{JA}$      | Junction-to-ambient thermal resistance, still air <sup>(1)</sup> | QFP (PZ)  | 122   | °C/W |
|                    |                                                                  | BGA (ZQW) | 108   |      |
| $\theta_{JC(TOP)}$ | Junction-to-case (top) thermal resistance <sup>(2)</sup>         | QFP (PZ)  | 83    | °C/W |
|                    |                                                                  | BGA (ZQW) | 72    |      |
| $\theta_{JB}$      | Junction-to-board thermal resistance <sup>(3)</sup>              | QFP (PZ)  | 98    | °C/W |
|                    |                                                                  | BGA (ZQW) | 76    |      |

(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.

## 5.8 Schmitt-Trigger Inputs – General-Purpose I/O<sup>(1)</sup>

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

| PARAMETER                                                                        | TEST CONDITIONS                                                                                  | V <sub>CC</sub> | MIN  | TYP | MAX  | UNIT |
|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|-----------------|------|-----|------|------|
| V <sub>IT+</sub> Positive-going input threshold voltage                          |                                                                                                  | 1.8 V           | 0.80 |     | 1.40 | V    |
|                                                                                  |                                                                                                  | 3 V             | 1.50 |     | 2.10 |      |
| V <sub>IT–</sub> Negative-going input threshold voltage                          |                                                                                                  | 1.8 V           | 0.45 |     | 1.00 | V    |
|                                                                                  |                                                                                                  | 3 V             | 0.75 |     | 1.65 |      |
| V <sub>hys</sub> Input voltage hysteresis (V <sub>IT+</sub> – V <sub>IT–</sub> ) |                                                                                                  | 1.8 V           | 0.3  |     | 0.8  | V    |
|                                                                                  |                                                                                                  | 3 V             | 0.4  |     | 1.0  |      |
| R <sub>Pull</sub> Pullup or pulldown resistor <sup>(2)</sup>                     | For pullup: V <sub>IN</sub> = V <sub>SS</sub><br>For pulldown: V <sub>IN</sub> = V <sub>CC</sub> |                 | 20   | 35  | 50   | kΩ   |
| C <sub>I</sub> Input capacitance                                                 | V <sub>IN</sub> = V <sub>SS</sub> or V <sub>CC</sub>                                             |                 |      | 5   |      | pF   |

(1) The same parametrics apply to the clock input pin when the crystal bypass mode is used on XT1 (XIN) or XT2 (XT2IN).

(2) Also applies to  $\overline{\text{RST}}$  pin when pullup or pulldown resistor is enabled.

## 5.9 Inputs – Ports P1, P2, P3, and P4<sup>(1)</sup>

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

| PARAMETER                                                   | TEST CONDITIONS                                                                             | V <sub>CC</sub> | MIN | MAX | UNIT |
|-------------------------------------------------------------|---------------------------------------------------------------------------------------------|-----------------|-----|-----|------|
| t <sub>(int)</sub> External interrupt timing <sup>(2)</sup> | Port P1, P2, P3, P4: P1.x to P4.x,<br>External trigger pulse duration to set interrupt flag | 2.2 V, 3 V      | 20  |     | ns   |

(1) Some devices may contain additional ports with interrupts. See the block diagram and terminal function descriptions.

(2) An external signal sets the interrupt flag every time the minimum interrupt pulse duration t<sub>(int)</sub> is met. It may be set by trigger signals shorter than t<sub>(int)</sub>.

## 5.10 Leakage Current – General-Purpose I/O

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

| PARAMETER                                             | TEST CONDITIONS       | V <sub>CC</sub> | MIN | MAX | UNIT |
|-------------------------------------------------------|-----------------------|-----------------|-----|-----|------|
| I <sub>lkg(Px.y)</sub> High-impedance leakage current | See <sup>(1)(2)</sup> | 1.8 V, 3 V      |     | ±50 | nA   |

(1) The leakage current is measured with V<sub>SS</sub> or V<sub>CC</sub> applied to the corresponding pin(s), unless otherwise noted.

(2) The leakage of the digital port pins is measured individually. The port pin is selected for input, and the pullup or pulldown resistor is disabled.

## 5.11 Outputs – General-Purpose I/O (Full Drive Strength)

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

| PARAMETER                                 | TEST CONDITIONS                              | V <sub>CC</sub> | MIN                    | MAX                    | UNIT |
|-------------------------------------------|----------------------------------------------|-----------------|------------------------|------------------------|------|
| V <sub>OH</sub> High-level output voltage | I <sub>(OHmax)</sub> = –3 mA <sup>(1)</sup>  | 1.8 V           | V <sub>CC</sub> – 0.25 | V <sub>CC</sub>        | V    |
|                                           | I <sub>(OHmax)</sub> = –10 mA <sup>(2)</sup> |                 | V <sub>CC</sub> – 0.60 | V <sub>CC</sub>        |      |
|                                           | I <sub>(OHmax)</sub> = –5 mA <sup>(1)</sup>  | 3 V             | V <sub>CC</sub> – 0.25 | V <sub>CC</sub>        |      |
|                                           | I <sub>(OHmax)</sub> = –15 mA <sup>(2)</sup> |                 | V <sub>CC</sub> – 0.60 | V <sub>CC</sub>        |      |
| V <sub>OL</sub> Low-level output voltage  | I <sub>(OLmax)</sub> = 3 mA <sup>(1)</sup>   | 1.8 V           | V <sub>SS</sub>        | V <sub>SS</sub> + 0.25 | V    |
|                                           | I <sub>(OLmax)</sub> = 10 mA <sup>(2)</sup>  |                 | V <sub>SS</sub>        | V <sub>SS</sub> + 0.60 |      |
|                                           | I <sub>(OLmax)</sub> = 5 mA <sup>(1)</sup>   | 3 V             | V <sub>SS</sub>        | V <sub>SS</sub> + 0.25 |      |
|                                           | I <sub>(OLmax)</sub> = 15 mA <sup>(2)</sup>  |                 | V <sub>SS</sub>        | V <sub>SS</sub> + 0.60 |      |

(1) The maximum total current, I<sub>(OHmax)</sub> and I<sub>(OLmax)</sub>, for all outputs combined should not exceed ±48 mA to hold the maximum voltage drop specified.

(2) The maximum total current, I<sub>(OHmax)</sub> and I<sub>(OLmax)</sub>, for all outputs combined should not exceed ±100 mA to hold the maximum voltage drop specified.

## 5.12 Outputs – General-Purpose I/O (Reduced Drive Strength)

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

| PARAMETER                                 | TEST CONDITIONS                             | V <sub>CC</sub> | MIN                    | MAX                    | UNIT |
|-------------------------------------------|---------------------------------------------|-----------------|------------------------|------------------------|------|
| V <sub>OH</sub> High-level output voltage | I <sub>(OHmax)</sub> = –1 mA <sup>(2)</sup> | 1.8 V           | V <sub>CC</sub> – 0.25 | V <sub>CC</sub>        | V    |
|                                           | I <sub>(OHmax)</sub> = –3 mA <sup>(3)</sup> |                 | V <sub>CC</sub> – 0.60 | V <sub>CC</sub>        |      |
|                                           | I <sub>(OHmax)</sub> = –2 mA <sup>(2)</sup> | 3 V             | V <sub>CC</sub> – 0.25 | V <sub>CC</sub>        |      |
|                                           | I <sub>(OHmax)</sub> = –6 mA <sup>(3)</sup> |                 | V <sub>CC</sub> – 0.60 | V <sub>CC</sub>        |      |
| V <sub>OL</sub> Low-level output voltage  | I <sub>(OLmax)</sub> = 1 mA <sup>(2)</sup>  | 1.8 V           | V <sub>SS</sub>        | V <sub>SS</sub> + 0.25 | V    |
|                                           | I <sub>(OLmax)</sub> = 3 mA <sup>(3)</sup>  |                 | V <sub>SS</sub>        | V <sub>SS</sub> + 0.60 |      |
|                                           | I <sub>(OLmax)</sub> = 2 mA <sup>(2)</sup>  | 3 V             | V <sub>SS</sub>        | V <sub>SS</sub> + 0.25 |      |
|                                           | I <sub>(OLmax)</sub> = 6 mA <sup>(3)</sup>  |                 | V <sub>SS</sub>        | V <sub>SS</sub> + 0.60 |      |

(1) Selecting reduced drive strength may reduce EMI.

(2) The maximum total current, I<sub>(OHmax)</sub> and I<sub>(OLmax)</sub>, for all outputs combined, should not exceed ±48 mA to hold the maximum voltage drop specified.

(3) The maximum total current, I<sub>(OHmax)</sub> and I<sub>(OLmax)</sub>, for all outputs combined, should not exceed ±100 mA to hold the maximum voltage drop specified.

## 5.13 Output Frequency – Ports P1, P2, and P3

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

| PARAMETER                                           | TEST CONDITIONS                                                                                                             | MIN                                       | MAX | UNIT |
|-----------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-----|------|
| f <sub>Px,y</sub> Port output frequency (with load) | P3.4/TA2CLK/SMCLK/S27,<br>C <sub>L</sub> = 20 pF, R <sub>L</sub> = 1 kΩ <sup>(1)</sup> or 3.2 kΩ <sup>(2)</sup> (3)         | V <sub>CC</sub> = 1.8 V,<br>PMMCOREVx = 0 | 8   | MHz  |
|                                                     |                                                                                                                             | V <sub>CC</sub> = 3 V,<br>PMMCOREVx = 3   | 20  |      |
| f <sub>Port_CLK</sub> Clock output frequency        | P1.0/TA0CLK/ACLK/S39,<br>P3.4/TA2CLK/SMCLK/S27,<br>P2.0/P2MAP0 (P2MAP0 = PM_MCLK),<br>C <sub>L</sub> = 20 pF <sup>(3)</sup> | V <sub>CC</sub> = 1.8 V,<br>PMMCOREVx = 0 | 8   | MHz  |
|                                                     |                                                                                                                             | V <sub>CC</sub> = 3 V,<br>PMMCOREVx = 3   | 20  |      |

(1) Full drive strength of port: A resistive divider with 2 × 0.5 kΩ between V<sub>CC</sub> and V<sub>SS</sub> is used as load. The output is connected to the center tap of the divider.

(2) Reduced drive strength of port: A resistive divider with 2 × 1.6 kΩ between V<sub>CC</sub> and V<sub>SS</sub> is used as load. The output is connected to the center tap of the divider.

(3) The output voltage reaches at least 10% and 90% V<sub>CC</sub> at the specified toggle frequency.

## 5.14 Typical Characteristics – Outputs, Reduced Drive Strength (PxDS.y = 0)

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

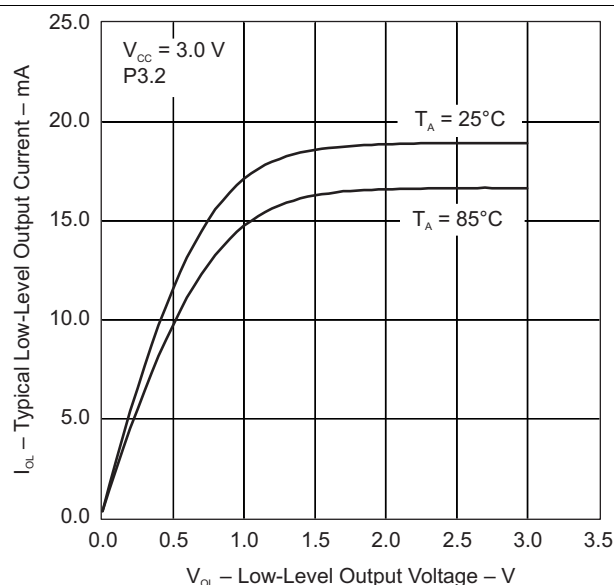


Figure 5-2. Typical Low-Level Output Current vs Low-Level Output Voltage

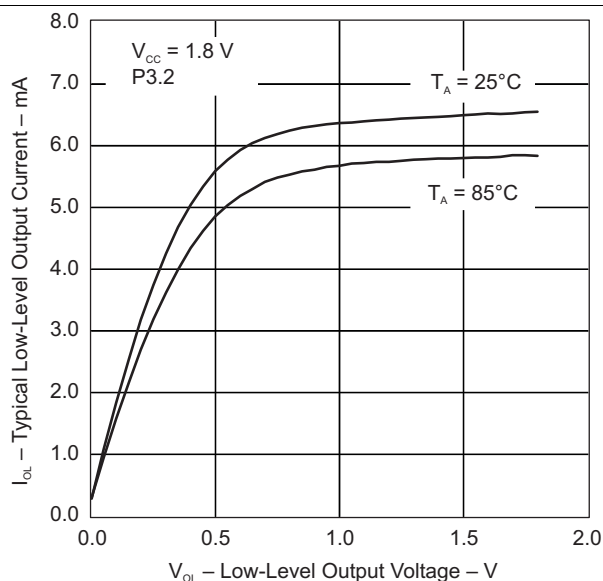


Figure 5-3. Typical Low-Level Output Current vs Low-Level Output Voltage

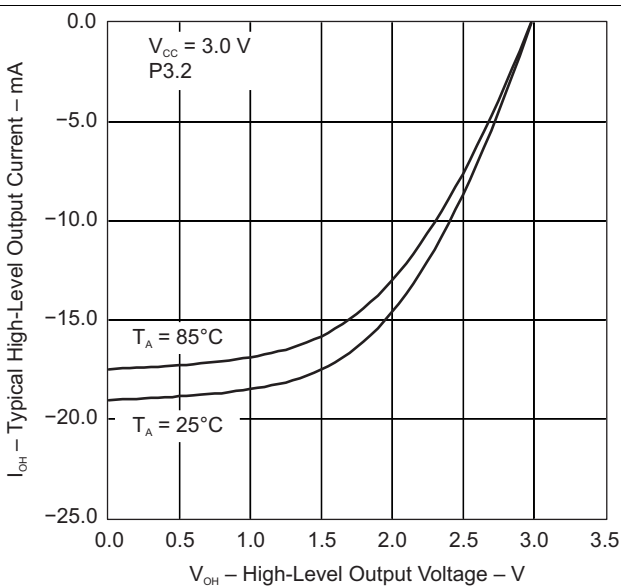


Figure 5-4. Typical High-Level Output Current vs High-Level Output Voltage

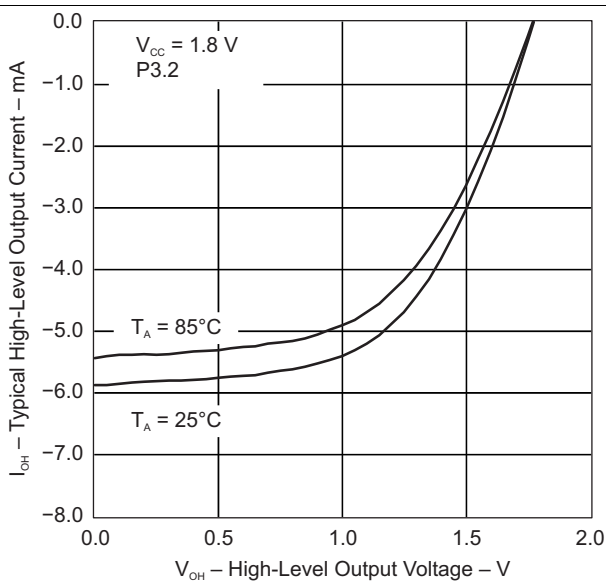


Figure 5-5. Typical High-Level Output Current vs High-Level Output Voltage

## 5.15 Typical Characteristics – Outputs, Full Drive Strength (PxDS.y = 1)

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

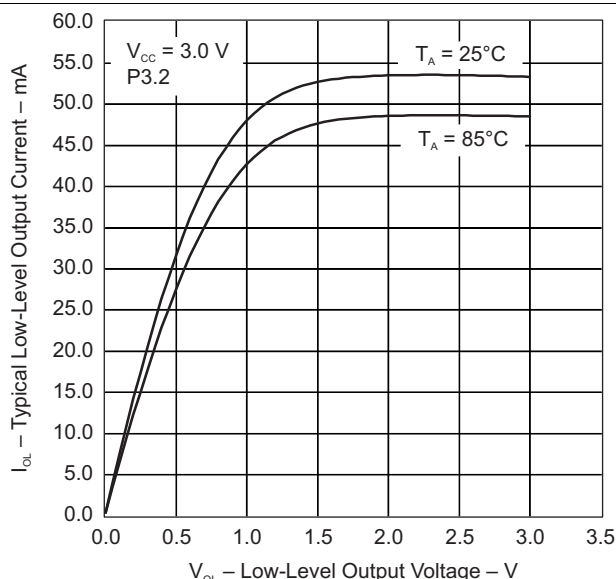


Figure 5-6. Typical Low-Level Output Current vs Low-Level Output Voltage

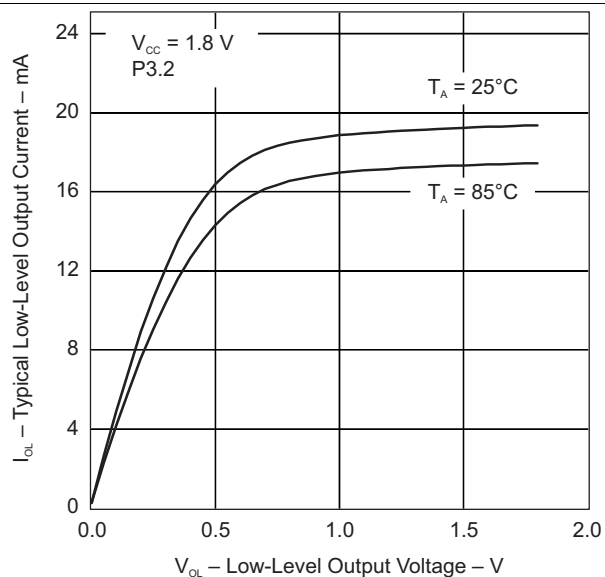


Figure 5-7. Typical Low-Level Output Current vs Low-Level Output Voltage

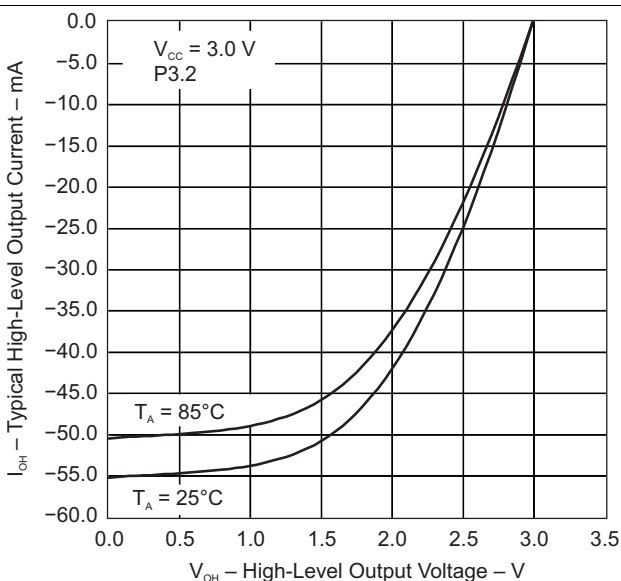


Figure 5-8. Typical High-Level Output Current vs High-Level Output Voltage

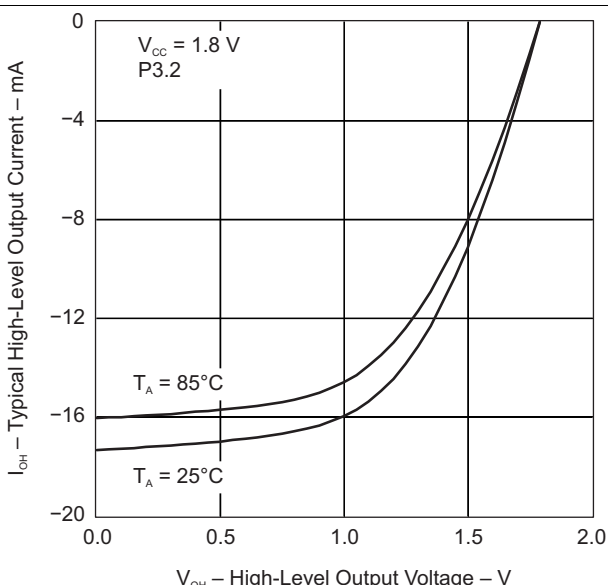


Figure 5-9. Typical High-Level Output Current vs High-Level Output Voltage

## 5.16 Crystal Oscillator, XT1, Low-Frequency Mode<sup>(1)</sup>

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

| PARAMETER              |                                                                                            | TEST CONDITIONS                                                                                                                      | V <sub>CC</sub> | MIN   | TYP    | MAX   | UNIT |
|------------------------|--------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|-----------------|-------|--------|-------|------|
| ΔI <sub>DVCC,LF</sub>  | Differential XT1 oscillator crystal current consumption from lowest drive setting, LF mode | f <sub>OSC</sub> = 32768 Hz, XTS = 0, XT1BYPASS = 0, XT1DRIVE <sub>x</sub> = 1, T <sub>A</sub> = 25°C                                | 3 V             | 0.075 |        |       | μA   |
|                        |                                                                                            | f <sub>OSC</sub> = 32768 Hz, XTS = 0, XT1BYPASS = 0, XT1DRIVE <sub>x</sub> = 2, T <sub>A</sub> = 25°C                                |                 | 0.170 |        |       |      |
|                        |                                                                                            | f <sub>OSC</sub> = 32768 Hz, XTS = 0, XT1BYPASS = 0, XT1DRIVE <sub>x</sub> = 3, T <sub>A</sub> = 25°C                                |                 | 0.290 |        |       |      |
| f <sub>XT1,LF0</sub>   | XT1 oscillator crystal frequency, LF mode                                                  | XTS = 0, XT1BYPASS = 0                                                                                                               |                 | 32768 |        |       | Hz   |
| f <sub>XT1,LF,SW</sub> | XT1 oscillator logic-level square-wave input frequency, LF mode                            | XTS = 0, XT1BYPASS = 1 <sup>(2)</sup> <sup>(3)</sup>                                                                                 |                 | 10    | 32.768 | 50    | kHz  |
| OA <sub>LF</sub>       | Oscillation allowance for LF crystals <sup>(4)</sup>                                       | XTS = 0, XT1BYPASS = 0, XT1DRIVE <sub>x</sub> = 0, f <sub>XT1,LF</sub> = 32768 Hz, C <sub>L,eff</sub> = 6 pF, T <sub>A</sub> = 25°C  | 3 V             | 210   |        |       | kΩ   |
|                        |                                                                                            | XTS = 0, XT1BYPASS = 0, XT1DRIVE <sub>x</sub> = 1, f <sub>XT1,LF</sub> = 32768 Hz, C <sub>L,eff</sub> = 12 pF, T <sub>A</sub> = 25°C |                 | 300   |        |       |      |
| C <sub>L,eff</sub>     | Integrated effective load capacitance, LF mode <sup>(5)</sup>                              | XTS = 0, XCAP <sub>x</sub> = 0 <sup>(6)</sup>                                                                                        |                 | 1     |        |       | pF   |
|                        |                                                                                            | XTS = 0, XCAP <sub>x</sub> = 1                                                                                                       |                 | 5.5   |        |       |      |
|                        |                                                                                            | XTS = 0, XCAP <sub>x</sub> = 2                                                                                                       |                 | 8.5   |        |       |      |
|                        |                                                                                            | XTS = 0, XCAP <sub>x</sub> = 3                                                                                                       |                 | 12.0  |        |       |      |
|                        | Duty cycle, LF mode                                                                        | XTS = 0, Measured at ACLK, f <sub>XT1,LF</sub> = 32768 Hz                                                                            |                 | 30%   |        | 70%   |      |
| f <sub>Fault,LF</sub>  | Oscillator fault frequency, LF mode <sup>(7)</sup>                                         | XTS = 0 <sup>(8)</sup>                                                                                                               |                 | 10    |        | 10000 | Hz   |
| t <sub>START,LF</sub>  | Start-up time, LF mode                                                                     | f <sub>OSC</sub> = 32768 Hz, XTS = 0, XT1BYPASS = 0, XT1DRIVE <sub>x</sub> = 0, T <sub>A</sub> = 25°C, C <sub>L,eff</sub> = 6 pF     | 3 V             | 1000  |        |       | ms   |
|                        |                                                                                            | f <sub>OSC</sub> = 32768 Hz, XTS = 0, XT1BYPASS = 0, XT1DRIVE <sub>x</sub> = 3, T <sub>A</sub> = 25°C, C <sub>L,eff</sub> = 12 pF    |                 | 500   |        |       |      |

- (1) To improve EMI on the XT1 oscillator, the following guidelines should be observed.
  - 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 XIN and XOUT.
  - Avoid running PCB traces underneath or adjacent to the XIN and XOUT pins.
  - Use assembly materials and processes that avoid any parasitic load on the oscillator XIN and XOUT pins.
  - If conformal coating is used, make sure that it does not induce capacitive or resistive leakage between the oscillator pins.
- (2) When XT1BYPASS is set, XT1 circuit is automatically powered down. Input signal is a digital square wave with parametrics defined in the Schmitt-trigger Inputs section of this data sheet.
- (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 XT1DRIVE<sub>x</sub> 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 XT1DRIVE<sub>x</sub> = 0, C<sub>L,eff</sub> ≤ 6 pF.
  - For XT1DRIVE<sub>x</sub> = 1, 6 pF ≤ C<sub>L,eff</sub> ≤ 9 pF.
  - For XT1DRIVE<sub>x</sub> = 2, 6 pF ≤ C<sub>L,eff</sub> ≤ 10 pF.
  - For XT1DRIVE<sub>x</sub> = 3, C<sub>L,eff</sub> ≥ 6 pF.
- (5) Includes parasitic bond and package capacitance (approximately 2 pF per pin). Because the PCB adds additional capacitance, verify the correct load by measuring the ACLK frequency. For a correct setup, the effective load capacitance should always match the specification of the used crystal.
- (6) Requires external capacitors at both terminals. Values are specified by crystal manufacturers.
- (7) Frequencies below the MIN specification set the fault flag. Frequencies above the MAX specification do not set the fault flag. Frequencies between the MIN and MAX specifications might set the flag.
- (8) Measured with logic-level input frequency but also applies to operation with crystals.

## 5.17 Crystal Oscillator, XT2

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)<sup>(1) (2)</sup>

| PARAMETER                                                                            | TEST CONDITIONS                                                                                                            | V <sub>CC</sub> | MIN | TYP | MAX | UNIT |
|--------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|-----------------|-----|-----|-----|------|
| I <sub>DVCC,XT2</sub> XT2 oscillator crystal current consumption                     | f <sub>OSC</sub> = 4 MHz, XT2OFF = 0, XT2BYPASS = 0, XT2DRIVE <sub>x</sub> = 0, T <sub>A</sub> = 25°C                      | 3 V             |     | 200 |     | μA   |
|                                                                                      | f <sub>OSC</sub> = 12 MHz, XT2OFF = 0, XT2BYPASS = 0, XT2DRIVE <sub>x</sub> = 1, T <sub>A</sub> = 25°C                     |                 |     | 260 |     |      |
|                                                                                      | f <sub>OSC</sub> = 20 MHz, XT2OFF = 0, XT2BYPASS = 0, XT2DRIVE <sub>x</sub> = 2, T <sub>A</sub> = 25°C                     |                 |     | 325 |     |      |
|                                                                                      | f <sub>OSC</sub> = 32 MHz, XT2OFF = 0, XT2BYPASS = 0, XT2DRIVE <sub>x</sub> = 3, T <sub>A</sub> = 25°C                     |                 |     | 450 |     |      |
| f <sub>XT2,HF0</sub> XT2 oscillator crystal frequency, mode 0                        | XT2DRIVE <sub>x</sub> = 0, XT2BYPASS = 0 <sup>(3)</sup>                                                                    |                 | 4   |     | 8   | MHz  |
| f <sub>XT2,HF1</sub> XT2 oscillator crystal frequency, mode 1                        | XT2DRIVE <sub>x</sub> = 1, XT2BYPASS = 0 <sup>(3)</sup>                                                                    |                 | 8   |     | 16  | MHz  |
| f <sub>XT2,HF2</sub> XT2 oscillator crystal frequency, mode 2                        | XT2DRIVE <sub>x</sub> = 2, XT2BYPASS = 0 <sup>(3)</sup>                                                                    |                 | 16  |     | 24  | MHz  |
| f <sub>XT2,HF3</sub> XT2 oscillator crystal frequency, mode 3                        | XT2DRIVE <sub>x</sub> = 3, XT2BYPASS = 0 <sup>(3)</sup>                                                                    |                 | 24  |     | 32  | MHz  |
| f <sub>XT2,HF,SW</sub> XT2 oscillator logic-level square-wave input frequency        | XT2BYPASS = 1 <sup>(4) (3)</sup>                                                                                           |                 | 0.7 |     | 32  | MHz  |
| O <sub>AHF</sub> Oscillation allowance for HF crystals <sup>(5)</sup>                | XT2DRIVE <sub>x</sub> = 0, XT2BYPASS = 0, f <sub>XT2,HF0</sub> = 6 MHz, C <sub>L,eff</sub> = 15 pF, T <sub>A</sub> = 25°C  | 3 V             |     | 450 |     | Ω    |
|                                                                                      | XT2DRIVE <sub>x</sub> = 1, XT2BYPASS = 0, f <sub>XT2,HF1</sub> = 12 MHz, C <sub>L,eff</sub> = 15 pF, T <sub>A</sub> = 25°C |                 |     | 320 |     |      |
|                                                                                      | XT2DRIVE <sub>x</sub> = 2, XT2BYPASS = 0, f <sub>XT2,HF2</sub> = 20 MHz, C <sub>L,eff</sub> = 15 pF, T <sub>A</sub> = 25°C |                 |     | 200 |     |      |
|                                                                                      | XT2DRIVE <sub>x</sub> = 3, XT2BYPASS = 0, f <sub>XT2,HF3</sub> = 32 MHz, C <sub>L,eff</sub> = 15 pF, T <sub>A</sub> = 25°C |                 |     | 200 |     |      |
| t <sub>START,HF</sub> Start-up time                                                  | f <sub>OSC</sub> = 6 MHz, XT2BYPASS = 0, XT2DRIVE <sub>x</sub> = 0, T <sub>A</sub> = 25°C, C <sub>L,eff</sub> = 15 pF      | 3 V             |     | 0.5 |     | ms   |
|                                                                                      | f <sub>OSC</sub> = 20 MHz, XT2BYPASS = 0, XT2DRIVE <sub>x</sub> = 3, T <sub>A</sub> = 25°C, C <sub>L,eff</sub> = 15 pF     |                 |     | 0.3 |     |      |
| C <sub>L,eff</sub> Integrated effective load capacitance, HF mode <sup>(6) (1)</sup> |                                                                                                                            |                 |     | 1   |     | pF   |
| Duty cycle                                                                           | Measured at ACLK, f <sub>XT2,HF2</sub> = 20 MHz                                                                            |                 | 40% | 50% | 60% |      |
| f <sub>Fault,HF</sub> Oscillator fault frequency <sup>(7)</sup>                      | XT2BYPASS = 1 <sup>(8)</sup>                                                                                               |                 | 30  |     | 300 | kHz  |

(1) Requires external capacitors at both terminals. Values are specified by crystal manufacturers.

(2) To improve EMI on the XT2 oscillator the following guidelines should be observed.

- 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 XT2IN and XT2OUT.
- Avoid running PCB traces underneath or adjacent to the XT2IN and XT2OUT pins.
- Use assembly materials and processes that avoid any parasitic load on the oscillator XT2IN and XT2OUT pins.
- If conformal coating is used, make sure that it does not induce capacitive or resistive leakage between the oscillator pins.

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

(4) When XT2BYPASS is set, the XT2 circuit is automatically powered down.

(5) Oscillation allowance is based on a safety factor of 5 for recommended crystals.

(6) Includes parasitic bond and package capacitance (approximately 2 pF per pin).

Because the PCB adds additional capacitance, verify the correct load by measuring the ACLK frequency. For a correct setup, the effective load capacitance should always match the specification of the used crystal.

(7) Frequencies below the MIN specification set the fault flag. Frequencies above the MAX specification do not set the fault flag. Frequencies between the MIN and MAX specifications might set the flag.

(8) Measured with logic-level input frequency but also applies to operation with crystals.

## 5.18 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                 | V <sub>CC</sub> | MIN | TYP | MAX | UNIT |
|------------------------------------------------------------------------|---------------------------------|-----------------|-----|-----|-----|------|
| f <sub>VLO</sub> VLO frequency                                         | Measured at ACLK                | 1.8 V to 3.6 V  | 6   | 9.4 | 14  | kHz  |
| df <sub>VLO</sub> /dT VLO frequency temperature drift                  | Measured at ACLK <sup>(1)</sup> | 1.8 V to 3.6 V  |     | 0.5 |     | %/°C |
| df <sub>VLO</sub> /dV <sub>CC</sub> VLO frequency supply voltage drift | Measured at ACLK <sup>(2)</sup> | 1.8 V to 3.6 V  |     | 4   |     | %/V  |
| Duty cycle                                                             | Measured at ACLK                | 1.8 V to 3.6 V  | 40% | 50% | 60% |      |

(1) 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))

(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)

## 5.19 Internal Reference, Low-Frequency Oscillator (REFO)

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

| PARAMETER                                                                | TEST CONDITIONS                    | V <sub>CC</sub> | MIN | TYP   | MAX   | UNIT |
|--------------------------------------------------------------------------|------------------------------------|-----------------|-----|-------|-------|------|
| I <sub>REFO</sub> REFO oscillator current consumption                    | T <sub>A</sub> = 25°C              | 1.8 V to 3.6 V  |     | 3     |       | μA   |
| f <sub>REFO</sub>                                                        | REFO frequency calibrated          | 1.8 V to 3.6 V  |     | 32768 |       | Hz   |
|                                                                          | REFO absolute tolerance calibrated | 1.8 V to 3.6 V  |     |       | ±3.5% |      |
|                                                                          | T <sub>A</sub> = 25°C              | 3 V             |     |       | ±1.5% |      |
| df <sub>REFO</sub> /dT REFO frequency temperature drift                  | Measured at ACLK <sup>(1)</sup>    | 1.8 V to 3.6 V  |     | 0.01  |       | %/°C |
| df <sub>REFO</sub> /dV <sub>CC</sub> REFO frequency supply voltage drift | Measured at ACLK <sup>(2)</sup>    | 1.8 V to 3.6 V  |     | 1.0   |       | %/V  |
| Duty cycle                                                               | Measured at ACLK                   | 1.8 V to 3.6 V  | 40% | 50%   | 60%   |      |
| t <sub>START</sub> REFO start-up time                                    | 40%/60% duty cycle                 | 1.8 V to 3.6 V  |     | 25    |       | μs   |

(1) 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))

(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)

## 5.20 DCO Frequency

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

| PARAMETER                                                          | TEST CONDITIONS                                            | MIN  | TYP | MAX  | UNIT  |
|--------------------------------------------------------------------|------------------------------------------------------------|------|-----|------|-------|
| $f_{DCO(0,0)}$ DCO frequency (0, 0) <sup>(1)</sup>                 | DCORSELx = 0, DCOx = 0, MODx = 0                           | 0.07 |     | 0.20 | MHz   |
| $f_{DCO(0,31)}$ DCO frequency (0, 31) <sup>(1)</sup>               | DCORSELx = 0, DCOx = 31, MODx = 0                          | 0.70 |     | 1.70 | MHz   |
| $f_{DCO(1,0)}$ DCO frequency (1, 0) <sup>(1)</sup>                 | DCORSELx = 1, DCOx = 0, MODx = 0                           | 0.15 |     | 0.36 | MHz   |
| $f_{DCO(1,31)}$ DCO frequency (1, 31) <sup>(1)</sup>               | DCORSELx = 1, DCOx = 31, MODx = 0                          | 1.47 |     | 3.45 | MHz   |
| $f_{DCO(2,0)}$ DCO frequency (2, 0) <sup>(1)</sup>                 | DCORSELx = 2, DCOx = 0, MODx = 0                           | 0.32 |     | 0.75 | MHz   |
| $f_{DCO(2,31)}$ DCO frequency (2, 31) <sup>(1)</sup>               | DCORSELx = 2, DCOx = 31, MODx = 0                          | 3.17 |     | 7.38 | MHz   |
| $f_{DCO(3,0)}$ DCO frequency (3, 0) <sup>(1)</sup>                 | DCORSELx = 3, DCOx = 0, MODx = 0                           | 0.64 |     | 1.51 | MHz   |
| $f_{DCO(3,31)}$ DCO frequency (3, 31) <sup>(1)</sup>               | DCORSELx = 3, DCOx = 31, MODx = 0                          | 6.07 |     | 14.0 | MHz   |
| $f_{DCO(4,0)}$ DCO frequency (4, 0) <sup>(1)</sup>                 | DCORSELx = 4, DCOx = 0, MODx = 0                           | 1.3  |     | 3.2  | MHz   |
| $f_{DCO(4,31)}$ DCO frequency (4, 31) <sup>(1)</sup>               | DCORSELx = 4, DCOx = 31, MODx = 0                          | 12.3 |     | 28.2 | MHz   |
| $f_{DCO(5,0)}$ DCO frequency (5, 0) <sup>(1)</sup>                 | DCORSELx = 5, DCOx = 0, MODx = 0                           | 2.5  |     | 6.0  | MHz   |
| $f_{DCO(5,31)}$ DCO frequency (5, 31) <sup>(1)</sup>               | DCORSELx = 5, DCOx = 31, MODx = 0                          | 23.7 |     | 54.1 | MHz   |
| $f_{DCO(6,0)}$ DCO frequency (6, 0) <sup>(1)</sup>                 | DCORSELx = 6, DCOx = 0, MODx = 0                           | 4.6  |     | 10.7 | MHz   |
| $f_{DCO(6,31)}$ DCO frequency (6, 31) <sup>(1)</sup>               | DCORSELx = 6, DCOx = 31, MODx = 0                          | 39.0 |     | 88.0 | MHz   |
| $f_{DCO(7,0)}$ DCO frequency (7, 0) <sup>(1)</sup>                 | DCORSELx = 7, DCOx = 0, MODx = 0                           | 8.5  |     | 19.6 | MHz   |
| $f_{DCO(7,31)}$ DCO frequency (7, 31) <sup>(1)</sup>               | DCORSELx = 7, DCOx = 31, MODx = 0                          | 60   |     | 135  | MHz   |
| $S_{DCORSEL}$ Frequency step between range DCORSEL and DCORSEL + 1 | $S_{RSEL} = f_{DCO(DCORSEL+1,DCO)} / f_{DCO(DCORSEL,DCO)}$ | 1.2  |     | 2.3  | ratio |
| $S_{DCO}$ Frequency step between tap DCO and DCO + 1               | $S_{DCO} = f_{DCO(DCORSEL,DCO+1)} / f_{DCO(DCORSEL,DCO)}$  | 1.02 |     | 1.12 | ratio |
| Duty cycle                                                         | Measured at SMCLK                                          | 40%  | 50% | 60%  |       |
| $df_{DCO}/dT$ DCO frequency temperature drift                      | $f_{DCO} = 1 \text{ MHz}$                                  |      | 0.1 |      | %/°C  |
| $df_{DCO}/dV_{CC}$ DCO frequency voltage drift                     | $f_{DCO} = 1 \text{ MHz}$                                  |      | 1.9 |      | %/V   |

- (1) When selecting the proper DCO frequency range (DCORSELx), the target DCO frequency,  $f_{DCO}$ , should be set to reside within the range of  $f_{DCO(n,0),MAX} \leq f_{DCO} \leq f_{DCO(n,31),MIN}$ , where  $f_{DCO(n,0),MAX}$  represents the maximum frequency specified for the DCO frequency, range n, tap 0 (DCOx = 0) and  $f_{DCO(n,31),MIN}$  represents the minimum frequency specified for the DCO frequency, range n, tap 31 (DCOx = 31). This ensures that the target DCO frequency resides within the range selected. If the actual  $f_{DCO}$  frequency for the selected range causes the FLL or the application to select tap 0 or 31, the DCO fault flag is set to report that the selected range is at its minimum or maximum tap setting.

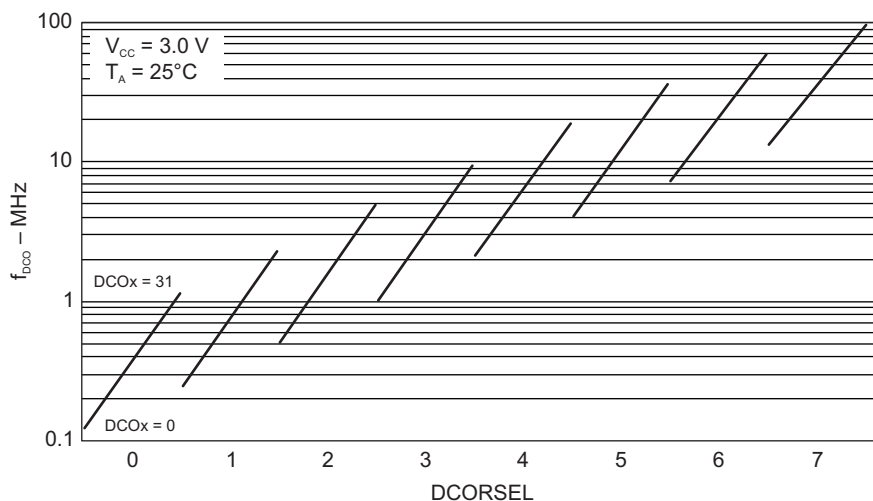


Figure 5-10. Typical DCO Frequency

## 5.21 PMM, Brownout Reset (BOR)

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

| PARAMETER              |                                                                       | TEST CONDITIONS                 | MIN  | TYP  | MAX  | UNIT |
|------------------------|-----------------------------------------------------------------------|---------------------------------|------|------|------|------|
| $V_{(DVCC\_BOR\_IT-)}$ | BOR <sub>H</sub> on voltage, DV <sub>CC</sub> falling level           | $ dDV_{CC}/dt  < 3 \text{ V/s}$ |      |      | 1.45 | V    |
| $V_{(DVCC\_BOR\_IT+)}$ | BOR <sub>H</sub> off voltage, DV <sub>CC</sub> rising level           | $ dDV_{CC}/dt  < 3 \text{ V/s}$ | 0.80 | 1.30 | 1.50 | V    |
| $V_{(DVCC\_BOR\_hys)}$ | BOR <sub>H</sub> hysteresis                                           |                                 | 50   |      | 250  | mV   |
| $t_{RESET}$            | Pulse duration required at $\overline{RST}/NMI$ pin to accept a reset |                                 | 2    |      |      | μs   |

## 5.22 PMM, Core Voltage

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

| PARAMETER        |                                              | TEST CONDITIONS                                                                                   | MIN | TYP  | MAX | UNIT |
|------------------|----------------------------------------------|---------------------------------------------------------------------------------------------------|-----|------|-----|------|
| $V_{CORE3(AM)}$  | Core voltage, active mode, PMMCOREV = 3      | $2.4 \text{ V} \leq DV_{CC} \leq 3.6 \text{ V}, 0 \text{ mA} \leq I(V_{CORE}) \leq 21 \text{ mA}$ |     | 1.90 |     | V    |
| $V_{CORE2(AM)}$  | Core voltage, active mode, PMMCOREV = 2      | $2.2 \text{ V} \leq DV_{CC} \leq 3.6 \text{ V}, 0 \text{ mA} \leq I(V_{CORE}) \leq 21 \text{ mA}$ |     | 1.80 |     | V    |
| $V_{CORE1(AM)}$  | Core voltage, active mode, PMMCOREV = 1      | $2 \text{ V} \leq DV_{CC} \leq 3.6 \text{ V}, 0 \text{ mA} \leq I(V_{CORE}) \leq 17 \text{ mA}$   |     | 1.60 |     | V    |
| $V_{CORE0(AM)}$  | Core voltage, active mode, PMMCOREV = 0      | $1.8 \text{ V} \leq DV_{CC} \leq 3.6 \text{ V}, 0 \text{ mA} \leq I(V_{CORE}) \leq 13 \text{ mA}$ |     | 1.40 |     | V    |
| $V_{CORE3(LPM)}$ | Core voltage, low-current mode, PMMCOREV = 3 | $2.4 \text{ V} \leq DV_{CC} \leq 3.6 \text{ V}, 0 \text{ μA} \leq I(V_{CORE}) \leq 30 \text{ μA}$ |     | 1.94 |     | V    |
| $V_{CORE2(LPM)}$ | Core voltage, low-current mode, PMMCOREV = 2 | $2.2 \text{ V} \leq DV_{CC} \leq 3.6 \text{ V}, 0 \text{ μA} \leq I(V_{CORE}) \leq 30 \text{ μA}$ |     | 1.84 |     | V    |
| $V_{CORE1(LPM)}$ | Core voltage, low-current mode, PMMCOREV = 1 | $2 \text{ V} \leq DV_{CC} \leq 3.6 \text{ V}, 0 \text{ μA} \leq I(V_{CORE}) \leq 30 \text{ μA}$   |     | 1.64 |     | V    |
| $V_{CORE0(LPM)}$ | Core voltage, low-current mode, PMMCOREV = 0 | $1.8 \text{ V} \leq DV_{CC} \leq 3.6 \text{ V}, 0 \text{ μA} \leq I(V_{CORE}) \leq 30 \text{ μA}$ |     | 1.44 |     | V    |

## 5.23 PMM, SVS High Side

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

| PARAMETER                                                           | TEST CONDITIONS                                          | MIN  | TYP  | MAX  | UNIT |
|---------------------------------------------------------------------|----------------------------------------------------------|------|------|------|------|
| $I_{(SVSH)}$ SVS current consumption                                | SVSHE = 0, DV <sub>CC</sub> = 3.6 V                      |      | 0    |      | nA   |
|                                                                     | SVSHE = 1, DV <sub>CC</sub> = 3.6 V, SVSHFP = 0          |      | 200  |      |      |
|                                                                     | SVSHE = 1, DV <sub>CC</sub> = 3.6 V, SVSHFP = 1          |      | 2.0  |      | μA   |
| $V_{(SVSH\_IT-)}$ SVS <sub>H</sub> on voltage level <sup>(1)</sup>  | SVSHE = 1, SVSHRVL = 0                                   | 1.59 | 1.64 | 1.69 | V    |
|                                                                     | SVSHE = 1, SVSHRVL = 1                                   | 1.79 | 1.84 | 1.91 |      |
|                                                                     | SVSHE = 1, SVSHRVL = 2                                   | 1.98 | 2.04 | 2.11 |      |
|                                                                     | SVSHE = 1, SVSHRVL = 3                                   | 2.10 | 2.16 | 2.23 |      |
| $V_{(SVSH\_IT+)}$ SVS <sub>H</sub> off voltage level <sup>(1)</sup> | SVSHE = 1, SVSMHRRRL = 0                                 | 1.62 | 1.74 | 1.81 | V    |
|                                                                     | SVSHE = 1, SVSMHRRRL = 1                                 | 1.88 | 1.94 | 2.01 |      |
|                                                                     | SVSHE = 1, SVSMHRRRL = 2                                 | 2.07 | 2.14 | 2.21 |      |
|                                                                     | SVSHE = 1, SVSMHRRRL = 3                                 | 2.20 | 2.26 | 2.33 |      |
|                                                                     | SVSHE = 1, SVSMHRRRL = 4                                 | 2.32 | 2.40 | 2.48 |      |
|                                                                     | SVSHE = 1, SVSMHRRRL = 5                                 | 2.56 | 2.70 | 2.84 |      |
|                                                                     | SVSHE = 1, SVSMHRRRL = 6                                 | 2.85 | 3.00 | 3.15 |      |
|                                                                     | SVSHE = 1, SVSMHRRRL = 7                                 | 2.85 | 3.00 | 3.15 |      |
| $t_{pd(SVSH)}$ SVS <sub>H</sub> propagation delay                   | SVSHE = 1, dV <sub>DVCC</sub> /dt = 10 mV/μs, SVSHFP = 1 |      | 2.5  |      | μs   |
|                                                                     | SVSHE = 1, dV <sub>DVCC</sub> /dt = 1 mV/μs, SVSHFP = 0  |      | 20   |      |      |
| $t_{(SVSH)}$ SVS <sub>H</sub> on or off delay time                  | SVSHE = 0→1, SVSHFP = 1                                  |      | 12.5 |      | μs   |
|                                                                     | SVSHE = 0→1, SVSHFP = 0                                  |      | 100  |      |      |
| dV <sub>DVCC</sub> /dt DV <sub>CC</sub> rise time                   |                                                          | 0    |      | 1000 | V/s  |

(1) The SVS<sub>H</sub> settings available depend on the VCORE (PMMCOREVx) setting. See the *Power Management Module and Supply Voltage Supervisor* chapter in the [MSP430x5xx and MSP430x6xx Family User's Guide](#) on recommended settings and usage.

## 5.24 PMM, SVM High Side

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

| PARAMETER                                                            | TEST CONDITIONS                                          | MIN  | TYP  | MAX  | UNIT |
|----------------------------------------------------------------------|----------------------------------------------------------|------|------|------|------|
| $I_{(SVMH)}$ SVM <sub>H</sub> current consumption                    | SVMHE = 0, DV <sub>CC</sub> = 3.6 V                      |      | 0    |      | nA   |
|                                                                      | SVMHE = 1, DV <sub>CC</sub> = 3.6 V, SVMHFP = 0          |      | 200  |      |      |
|                                                                      | SVMHE = 1, DV <sub>CC</sub> = 3.6 V, SVMHFP = 1          |      | 2.0  |      | μA   |
| $V_{(SVMH)}$ SVM <sub>H</sub> on or off voltage level <sup>(1)</sup> | SVMHE = 1, SVSMHRRRL = 0                                 | 1.65 | 1.74 | 1.86 | V    |
|                                                                      | SVMHE = 1, SVSMHRRRL = 1                                 | 1.85 | 1.94 | 2.02 |      |
|                                                                      | SVMHE = 1, SVSMHRRRL = 2                                 | 2.02 | 2.14 | 2.22 |      |
|                                                                      | SVMHE = 1, SVSMHRRRL = 3                                 | 2.18 | 2.26 | 2.35 |      |
|                                                                      | SVMHE = 1, SVSMHRRRL = 4                                 | 2.32 | 2.40 | 2.48 |      |
|                                                                      | SVMHE = 1, SVSMHRRRL = 5                                 | 2.56 | 2.70 | 2.84 |      |
|                                                                      | SVMHE = 1, SVSMHRRRL = 6                                 | 2.85 | 3.00 | 3.15 |      |
|                                                                      | SVMHE = 1, SVSMHRRRL = 7                                 | 2.85 | 3.00 | 3.15 |      |
|                                                                      | SVMHE = 1, SVMHOVPE = 1                                  |      | 3.75 |      |      |
| $t_{pd(SVMH)}$ SVM <sub>H</sub> propagation delay                    | SVMHE = 1, dV <sub>DVCC</sub> /dt = 10 mV/μs, SVMHFP = 1 |      | 2.5  |      | μs   |
|                                                                      | SVMHE = 1, dV <sub>DVCC</sub> /dt = 1 mV/μs, SVMHFP = 0  |      | 20   |      |      |
| $t_{(SVMH)}$ SVM <sub>H</sub> on or off delay time                   | SVMHE = 0→1, SVMHFP = 1                                  |      | 12.5 |      | μs   |
|                                                                      | SVMHE = 0→1, SVMHFP = 0                                  |      | 100  |      |      |

(1) The SVM<sub>H</sub> settings available depend on the VCORE (PMMCOREVx) setting. See the *Power Management Module and Supply Voltage Supervisor* chapter in the [MSP430x5xx and MSP430x6xx Family User's Guide](#) on recommended settings and usage.

## 5.25 PMM, SVS Low Side

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

| PARAMETER                                          | TEST CONDITIONS                                                    | MIN | TYP  | MAX | UNIT |
|----------------------------------------------------|--------------------------------------------------------------------|-----|------|-----|------|
| $I_{(SVSL)}$ SVS <sub>L</sub> current consumption  | SVSLE = 0, PMMCOREV = 2                                            |     | 0    |     | nA   |
|                                                    | SVSLE = 1, PMMCOREV = 2, SVSLFP = 0                                |     | 200  |     |      |
|                                                    | SVSLE = 1, PMMCOREV = 2, SVSLFP = 1                                |     | 2.0  |     | μA   |
| $t_{pd(SVSL)}$ SVS <sub>L</sub> propagation delay  | SVSLE = 1, $dV_{CORE}/dt = 10 \text{ mV}/\mu\text{s}$ , SVSLFP = 1 |     | 2.5  |     | μs   |
|                                                    | SVSLE = 1, $dV_{CORE}/dt = 1 \text{ mV}/\mu\text{s}$ , SVSLFP = 0  |     | 20   |     |      |
| $t_{(SVSL)}$ SVS <sub>L</sub> on or off delay time | SVSLE = 0→1, SVSLFP = 1                                            |     | 12.5 |     | μs   |
|                                                    | SVSLE = 0→1, SVSLFP = 0                                            |     | 100  |     |      |

## 5.26 PMM, SVM Low Side

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

| PARAMETER                                          | TEST CONDITIONS                                                    | MIN | TYP  | MAX | UNIT |
|----------------------------------------------------|--------------------------------------------------------------------|-----|------|-----|------|
| $I_{(SVML)}$ SVM <sub>L</sub> current consumption  | SVMLE = 0, PMMCOREV = 2                                            |     | 0    |     | nA   |
|                                                    | SVMLE = 1, PMMCOREV = 2, SVMLFP = 0                                |     | 200  |     |      |
|                                                    | SVMLE = 1, PMMCOREV = 2, SVMLFP = 1                                |     | 2.0  |     | μA   |
| $t_{pd(SVML)}$ SVM <sub>L</sub> propagation delay  | SVMLE = 1, $dV_{CORE}/dt = 10 \text{ mV}/\mu\text{s}$ , SVMLFP = 1 |     | 2.5  |     | μs   |
|                                                    | SVMLE = 1, $dV_{CORE}/dt = 1 \text{ mV}/\mu\text{s}$ , SVMLFP = 0  |     | 20   |     |      |
| $t_{(SVML)}$ SVM <sub>L</sub> on or off delay time | SVMLE = 0→1, SVMLFP = 1                                            |     | 12.5 |     | μs   |
|                                                    | SVMLE = 0→1, SVMLFP = 0                                            |     | 100  |     |      |

## 5.27 Wake-up Times From Low-Power Modes

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

| PARAMETER                                                                                        | TEST CONDITIONS                                                                                                    | MIN | TYP | MAX | UNIT |
|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|-----|-----|-----|------|
| $t_{\text{WAKE-UP-FAST}}$ Wake-up time from LPM2, LPM3, or LPM4 to active mode <sup>(1)</sup>    | PMMCOREV = SVSMLRRL = n (where n = 0, 1, 2, or 3), SVSLFP = 1, $f_{\text{MCLK}} \geq 4.0 \text{ MHz}$              |     | 3   | 6.5 | μs   |
|                                                                                                  | PMMCOREV = SVSMLRRL = n (where n = 0, 1, 2, or 3), SVSLFP = 1, $1 \text{ MHz} < f_{\text{MCLK}} < 4.0 \text{ MHz}$ |     | 4   | 8.0 |      |
| $t_{\text{WAKE-UP-SLOW}}$ Wake-up time from LPM2, LPM3, or LPM4 to active mode <sup>(2)(3)</sup> | PMMCOREV = SVSMLRRL = n (where n = 0, 1, 2, or 3), SVSLFP = 0                                                      |     | 150 | 165 |      |
| $t_{\text{WAKE-UP LPM5}}$ Wake-up time from LPM3.5 or LPM4.5 to active mode <sup>(4)</sup>       |                                                                                                                    |     | 2   | 3   | ms   |
| $t_{\text{WAKE-UP-RESET}}$ Wake-up time from RST or BOR event to active mode <sup>(4)</sup>      |                                                                                                                    |     | 2   | 3   | ms   |

- (1) This value represents the time from the wake-up event to the first active edge of MCLK. The wake-up time depends on the performance mode of the low-side supervisor (SVS<sub>L</sub>) and low-side monitor (SVM<sub>L</sub>).  $t_{\text{WAKE-UP-FAST}}$  is possible with SVS<sub>L</sub> and SVM<sub>L</sub> in full performance mode or disabled. For specific register settings, see the *Low-Side SVS and SVM Control and Performance Mode Selection* section in the *Power Management Module and Supply Voltage Supervisor* chapter of the [MSP430x5xx and MSP430x6xx Family User's Guide](#).
- (2) This value represents the time from the wake-up event to the first active edge of MCLK. The wake-up time depends on the performance mode of the low-side supervisor (SVS<sub>L</sub>) and low-side monitor (SVM<sub>L</sub>).  $t_{\text{WAKE-UP-SLOW}}$  is set with SVS<sub>L</sub> and SVM<sub>L</sub> in normal mode (low current mode). For specific register settings, see the *Low-Side SVS and SVM Control and Performance Mode Selection* section in the *Power Management Module and Supply Voltage Supervisor* chapter of the [MSP430x5xx and MSP430x6xx Family User's Guide](#).
- (3) The wake-up times from LPM0 and LPM1 to AM are not specified. They are proportional to MCLK cycle time but are not affected by the performance mode settings as for LPM2, LPM3, and LPM4.
- (4) This value represents the time from the wake-up event to the reset vector execution.

## 5.28 Timer\_A – Timers TA0, TA1, and TA2

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

| PARAMETER                                     | TEST CONDITIONS                                                       | V <sub>CC</sub> | MIN | MAX | UNIT |
|-----------------------------------------------|-----------------------------------------------------------------------|-----------------|-----|-----|------|
| f <sub>TA</sub> Timer_A input clock frequency | Internal: SMCLK or ACLK,<br>External: TACLK,<br>Duty cycle = 50% ±10% | 1.8 V, 3 V      |     | 20  | MHz  |
| t <sub>TA,cap</sub> Timer_A capture timing    | All capture inputs, Minimum pulse duration required for capture       | 1.8 V, 3 V      | 20  |     | ns   |

## 5.29 Timer\_B – Timer TB0

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

| PARAMETER                                     | TEST CONDITIONS                                                       | V <sub>CC</sub> | MIN | MAX | UNIT |
|-----------------------------------------------|-----------------------------------------------------------------------|-----------------|-----|-----|------|
| f <sub>TB</sub> Timer_B input clock frequency | Internal: SMCLK or ACLK,<br>External: TBCLK,<br>Duty cycle = 50% ±10% | 1.8 V, 3 V      |     | 20  | MHz  |
| t <sub>TB,cap</sub> Timer_B capture timing    | All capture inputs, Minimum pulse duration required for capture       | 1.8 V, 3 V      | 20  |     | ns   |

## 5.30 Battery Backup

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

| PARAMETER                  |                                                                                                    | TEST CONDITIONS                                     |                        | V <sub>CC</sub> | MIN                    | TYP  | MAX  | UNIT |
|----------------------------|----------------------------------------------------------------------------------------------------|-----------------------------------------------------|------------------------|-----------------|------------------------|------|------|------|
| I <sub>VBAT</sub>          | Current into VBAT terminal if no primary battery is connected                                      | VBAT = 1.7 V,<br>DVCC not connected,<br>RTC running | T <sub>A</sub> = −40°C |                 |                        | 0.43 |      | μA   |
|                            |                                                                                                    |                                                     | T <sub>A</sub> = 25°C  |                 |                        | 0.52 |      |      |
|                            |                                                                                                    |                                                     | T <sub>A</sub> = 60°C  |                 |                        | 0.58 |      |      |
|                            |                                                                                                    |                                                     | T <sub>A</sub> = 85°C  |                 |                        | 0.66 |      |      |
|                            |                                                                                                    | VBAT = 2.2 V,<br>DVCC not connected,<br>RTC running | T <sub>A</sub> = −40°C |                 |                        | 0.50 |      |      |
|                            |                                                                                                    |                                                     | T <sub>A</sub> = 25°C  |                 |                        | 0.59 |      |      |
|                            |                                                                                                    |                                                     | T <sub>A</sub> = 60°C  |                 |                        | 0.64 |      |      |
|                            |                                                                                                    |                                                     | T <sub>A</sub> = 85°C  |                 |                        | 0.72 |      |      |
|                            |                                                                                                    | VBAT = 3 V,<br>DVCC not connected,<br>RTC running   | T <sub>A</sub> = −40°C |                 |                        | 0.68 |      |      |
|                            |                                                                                                    |                                                     | T <sub>A</sub> = 25°C  |                 |                        | 0.75 |      |      |
|                            |                                                                                                    |                                                     | T <sub>A</sub> = 60°C  |                 |                        | 0.79 |      |      |
|                            |                                                                                                    |                                                     | T <sub>A</sub> = 85°C  |                 |                        | 0.87 |      |      |
| V <sub>SWITCH</sub>        | Switch-over level (V <sub>CC</sub> to VBAT)                                                        | C <sub>VCC</sub> = 4.7 μF                           | General                |                 | V <sub>SVSH_IT</sub> - |      | V    |      |
|                            |                                                                                                    |                                                     | SVSHRL = 0             |                 | 1.59                   | 1.69 |      |      |
|                            |                                                                                                    |                                                     | SVSHRL = 1             |                 | 1.79                   | 1.91 |      |      |
|                            |                                                                                                    |                                                     | SVSHRL = 2             |                 | 1.98                   | 2.11 |      |      |
|                            |                                                                                                    |                                                     | SVSHRL = 3             |                 | 2.10                   | 2.23 |      |      |
| R <sub>ON_VBAT</sub>       | On-resistance of switch between VBAT and VBAK                                                      | V <sub>BAT</sub> = 1.8 V                            |                        | 0 V             |                        | 0.35 | 1    | kΩ   |
| V <sub>BAT3</sub>          | VBAT to ADC input channel 12:<br>V <sub>BAT</sub> divided, V <sub>BAT3</sub> ≈ V <sub>BAT</sub> /3 |                                                     | 1.8 V                  |                 | 0.6                    | ±5%  | V    |      |
|                            |                                                                                                    |                                                     | 3 V                    |                 | 1.0                    | ±5%  |      |      |
|                            |                                                                                                    |                                                     | 3.6 V                  |                 | 1.2                    | ±5%  |      |      |
| t <sub>Sample, VBAT3</sub> | VBAT to ADC: Sampling time required if VBAT3 selected                                              | ADC12ON = 1,<br>Error of conversion result ≤ 2 LSB  |                        |                 | 1000                   |      | ns   |      |
| V <sub>CHVx</sub>          | Charger end voltage                                                                                | CHVx = 2                                            |                        |                 | 2.65                   | 2.7  | 2.9  | V    |
| R <sub>CHARGE</sub>        | Charge limiting resistor                                                                           | CHCx = 1                                            |                        |                 |                        |      | 5.2  | kΩ   |
|                            |                                                                                                    | CHCx = 2                                            |                        |                 |                        |      | 10.2 |      |
|                            |                                                                                                    | CHCx = 3                                            |                        |                 |                        |      | 20   |      |

### 5.31 USCI (UART Mode)

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

| PARAMETER                                                                 | TEST CONDITIONS                                                     | V <sub>CC</sub> | MIN                 | MAX | UNIT |
|---------------------------------------------------------------------------|---------------------------------------------------------------------|-----------------|---------------------|-----|------|
| f <sub>USCI</sub> USCI input clock frequency                              | Internal: SMCLK or ACLK,<br>External: UCLK<br>Duty cycle = 50% ±10% |                 | f <sub>SYSTEM</sub> |     | MHz  |
| f <sub>BITCLK</sub> BITCLK clock frequency<br>(equals baud rate in MBaud) |                                                                     |                 | 1                   |     | MHz  |
| t <sub>r</sub> UART receive deglitch time <sup>(1)</sup>                  |                                                                     | 2.2 V           | 50                  | 600 | ns   |
|                                                                           |                                                                     | 3 V             | 50                  | 600 |      |

- (1) Pulses on the UART receive input (UCxRX) shorter than the UART receive deglitch time are suppressed. To make sure that pulses are correctly recognized, their duration should exceed the maximum specification of the deglitch time.

### 5.32 USCI (SPI Master Mode)

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

(see [Figure 5-11](#) and )

| PARAMETER                                                        | TEST CONDITIONS                                                  | V <sub>CC</sub> | MIN                 | MAX | UNIT |
|------------------------------------------------------------------|------------------------------------------------------------------|-----------------|---------------------|-----|------|
| f <sub>USCI</sub> USCI input clock frequency                     | SMCLK or ACLK,<br>Duty cycle = 50% ±10%                          |                 | f <sub>SYSTEM</sub> |     | MHz  |
| t <sub>SU,MI</sub> SOMI input data setup time                    | PMMCOREV = 0                                                     | 1.8 V           | 55                  |     | ns   |
|                                                                  |                                                                  | 3 V             | 38                  |     |      |
|                                                                  | PMMCOREV = 3                                                     | 2.4 V           | 30                  |     |      |
|                                                                  |                                                                  | 3 V             | 25                  |     |      |
| t <sub>HD,MI</sub> SOMI input data hold time                     | PMMCOREV = 0                                                     | 1.8 V           | 0                   |     | ns   |
|                                                                  |                                                                  | 3 V             | 0                   |     |      |
|                                                                  | PMMCOREV = 3                                                     | 2.4 V           | 0                   |     |      |
|                                                                  |                                                                  | 3 V             | 0                   |     |      |
| t <sub>VALID,MO</sub> SIMO output data valid time <sup>(2)</sup> | UCLK edge to SIMO valid,<br>C <sub>L</sub> = 20 pF, PMMCOREV = 0 | 1.8 V           |                     | 20  | ns   |
|                                                                  |                                                                  | 3 V             |                     | 18  |      |
|                                                                  | UCLK edge to SIMO valid,<br>C <sub>L</sub> = 20 pF, PMMCOREV = 3 | 2.4 V           |                     | 16  |      |
|                                                                  |                                                                  | 3 V             |                     | 15  |      |
| t <sub>HD,MO</sub> SIMO output data hold time <sup>(3)</sup>     | C <sub>L</sub> = 20 pF, PMMCOREV = 0                             | 1.8 V           | –10                 |     | ns   |
|                                                                  |                                                                  | 3 V             | –8                  |     |      |
|                                                                  | C <sub>L</sub> = 20 pF, PMMCOREV = 3                             | 2.4 V           | –10                 |     |      |
|                                                                  |                                                                  | 3 V             | –8                  |     |      |

- (1)  $f_{UCXCLK} = 1/2t_{LO/Hi}$  with  $t_{LO/Hi} \geq \max(t_{VALID,MO(USCI)} + t_{SU,SI(Slave)}, t_{SU,MI(USCI)} + t_{VALID,SO(Slave)})$   
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 5-11](#) and [Figure 5-12](#).
- (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 5-11](#) and [Figure 5-12](#).

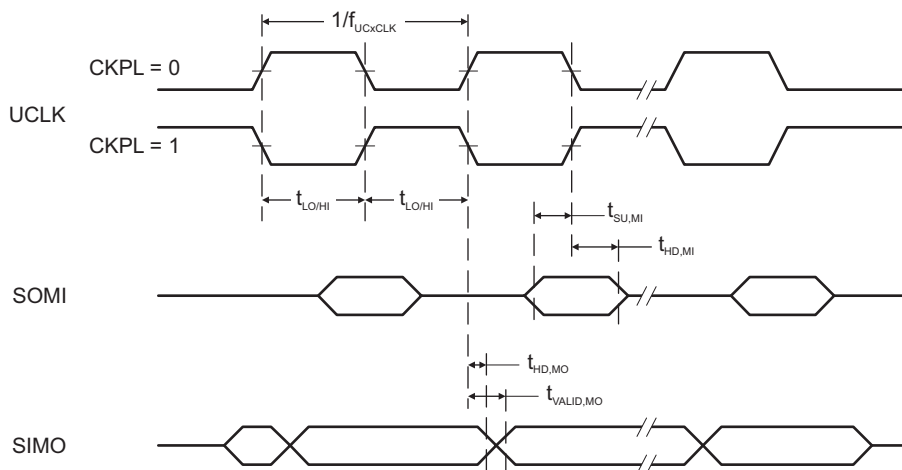


**Figure 5-11. SPI Master Mode, CKPH = 0**

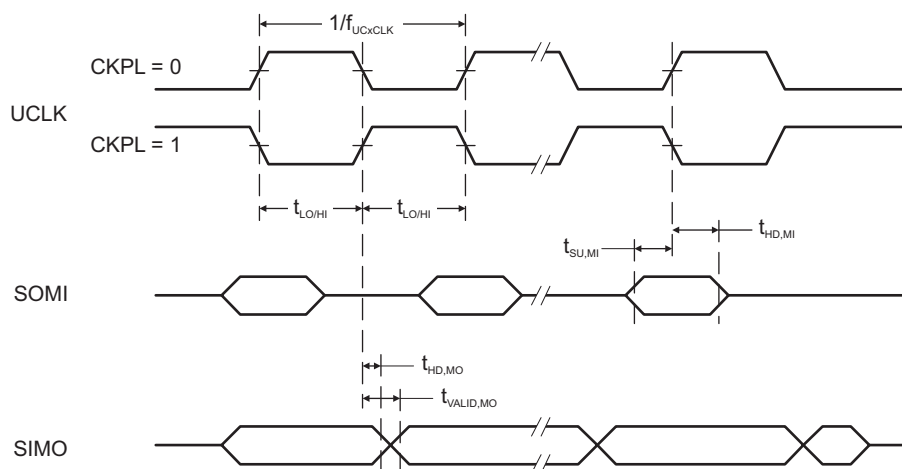


**Figure 5-12. SPI Master Mode, CKPH = 1**

### 5.33 USCI (SPI Slave Mode)

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)<sup>(1)</sup>  
(see [Figure 5-13](#) and [Figure 5-14](#))

| PARAMETER                                                       | TEST CONDITIONS                                                  | V <sub>CC</sub> | MIN | MAX | UNIT |
|-----------------------------------------------------------------|------------------------------------------------------------------|-----------------|-----|-----|------|
| $t_{STE,LEAD}$ STE lead time, STE low to clock                  | PMMCOREV = 0                                                     | 1.8 V           | 11  |     | ns   |
|                                                                 |                                                                  | 3 V             | 8   |     |      |
|                                                                 | PMMCOREV = 3                                                     | 2.4 V           | 7   |     |      |
|                                                                 |                                                                  | 3 V             | 6   |     |      |
| $t_{STE,LAG}$ STE lag time, last clock to STE high              | PMMCOREV = 0                                                     | 1.8 V           | 1   |     | ns   |
|                                                                 |                                                                  | 3 V             | 1   |     |      |
|                                                                 | PMMCOREV = 3                                                     | 2.4 V           | 1   |     |      |
|                                                                 |                                                                  | 3 V             | 1   |     |      |
| $t_{STE,ACC}$ STE access time, STE low to SOMI data out         | PMMCOREV = 0                                                     | 1.8 V           |     | 66  | ns   |
|                                                                 |                                                                  | 3 V             |     | 50  |      |
|                                                                 | PMMCOREV = 3                                                     | 2.4 V           |     | 36  |      |
|                                                                 |                                                                  | 3 V             |     | 30  |      |
| $t_{STE,DIS}$ STE disable time, STE high to SOMI high impedance | PMMCOREV = 0                                                     | 1.8 V           |     | 30  | ns   |
|                                                                 |                                                                  | 3 V             |     | 30  |      |
|                                                                 | PMMCOREV = 3                                                     | 2.4 V           |     | 30  |      |
|                                                                 |                                                                  | 3 V             |     | 30  |      |
| $t_{SU,SI}$ SIMO input data setup time                          | PMMCOREV = 0                                                     | 1.8 V           | 5   |     | ns   |
|                                                                 |                                                                  | 3 V             | 5   |     |      |
|                                                                 | PMMCOREV = 3                                                     | 2.4 V           | 2   |     |      |
|                                                                 |                                                                  | 3 V             | 2   |     |      |
| $t_{HD,SI}$ SIMO input data hold time                           | PMMCOREV = 0                                                     | 1.8 V           | 5   |     | ns   |
|                                                                 |                                                                  | 3 V             | 5   |     |      |
|                                                                 | PMMCOREV = 3                                                     | 2.4 V           | 5   |     |      |
|                                                                 |                                                                  | 3 V             | 5   |     |      |
| $t_{VALID,SO}$ SOMI output data valid time <sup>(2)</sup>       | UCLK edge to SOMI valid,<br>C <sub>L</sub> = 20 pF, PMMCOREV = 0 | 1.8 V           |     | 76  | ns   |
|                                                                 |                                                                  | 3 V             |     | 60  |      |
|                                                                 | UCLK edge to SOMI valid,<br>C <sub>L</sub> = 20 pF, PMMCOREV = 3 | 2.4 V           |     | 44  |      |
|                                                                 |                                                                  | 3 V             |     | 40  |      |
| $t_{HD,SO}$ SOMI output data hold time <sup>(3)</sup>           | C <sub>L</sub> = 20 pF, PMMCOREV = 0                             | 1.8 V           | 12  |     | ns   |
|                                                                 |                                                                  | 3 V             | 12  |     |      |
|                                                                 | C <sub>L</sub> = 20 pF, PMMCOREV = 3                             | 2.4 V           | 12  |     |      |
|                                                                 |                                                                  | 3 V             | 12  |     |      |

- (1)  $f_{UCXCLK} = 1/2t_{LO/HI}$  with  $t_{LO/HI} \geq \max(t_{VALID,MO(Master)} + t_{SU,SI(USCI)}, t_{SU,MI(Master)} + t_{VALID,SO(USCI)})$   
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 5-13](#) and [Figure 5-14](#).
- (3) Specifies how long data on the SOMI output is valid after the output changing UCLK clock edge. See the timing diagrams in [Figure 5-13](#) and [Figure 5-14](#).

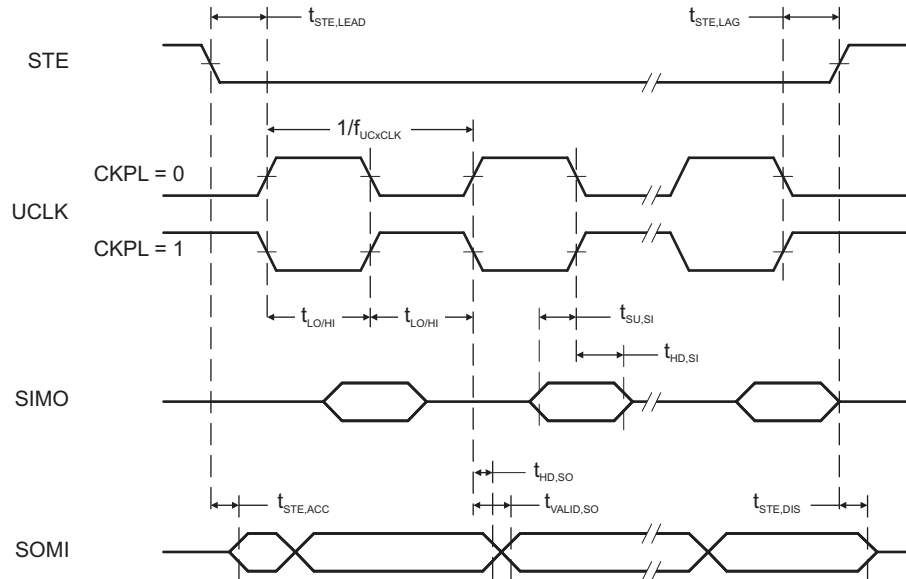


**Figure 5-13. SPI Slave Mode, CKPH = 0**

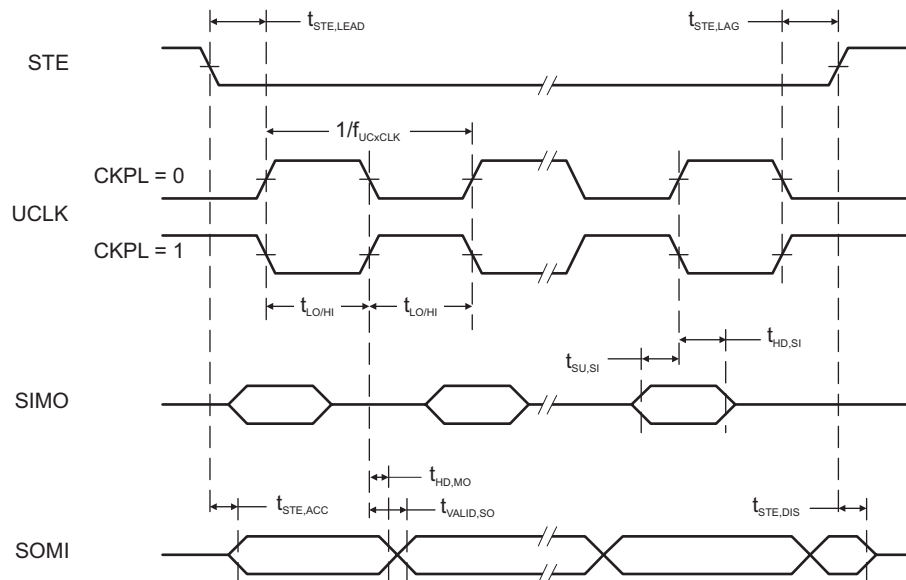


**Figure 5-14. SPI Slave Mode, CKPH = 1**

### 5.34 USCI (I<sup>2</sup>C Mode)

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see [Figure 5-15](#))

| PARAMETER           |                                                     | TEST CONDITIONS                                                     | V <sub>CC</sub> | MIN                 | MAX | UNIT |
|---------------------|-----------------------------------------------------|---------------------------------------------------------------------|-----------------|---------------------|-----|------|
| f <sub>USCI</sub>   | USCI input clock frequency                          | Internal: SMCLK or ACLK,<br>External: UCLK<br>Duty cycle = 50% ±10% |                 | f <sub>SYSTEM</sub> |     | MHz  |
| f <sub>SCL</sub>    | SCL clock frequency                                 |                                                                     | 2.2 V, 3 V      | 0                   | 400 | kHz  |
| t <sub>HD,STA</sub> | Hold time (repeated) START                          | f <sub>SCL</sub> ≤ 100 kHz                                          | 2.2 V, 3 V      | 4.0                 |     | μs   |
|                     |                                                     | f <sub>SCL</sub> > 100 kHz                                          |                 | 0.6                 |     |      |
| t <sub>SU,STA</sub> | Setup time for a repeated START                     | f <sub>SCL</sub> ≤ 100 kHz                                          | 2.2 V, 3 V      | 4.7                 |     | μs   |
|                     |                                                     | f <sub>SCL</sub> > 100 kHz                                          |                 | 0.6                 |     |      |
| t <sub>HD,DAT</sub> | Data hold time                                      |                                                                     | 2.2 V, 3 V      | 0                   |     | ns   |
| t <sub>SU,DAT</sub> | Data setup time                                     |                                                                     | 2.2 V, 3 V      | 250                 |     | ns   |
| t <sub>SU,STO</sub> | Setup time for STOP                                 | f <sub>SCL</sub> ≤ 100 kHz                                          | 2.2 V, 3 V      | 4.0                 |     | μs   |
|                     |                                                     | f <sub>SCL</sub> > 100 kHz                                          |                 | 0.6                 |     |      |
| t <sub>SP</sub>     | Pulse duration of spikes suppressed by input filter |                                                                     | 2.2 V           | 50                  | 600 | ns   |
|                     |                                                     |                                                                     | 3 V             | 50                  | 600 |      |

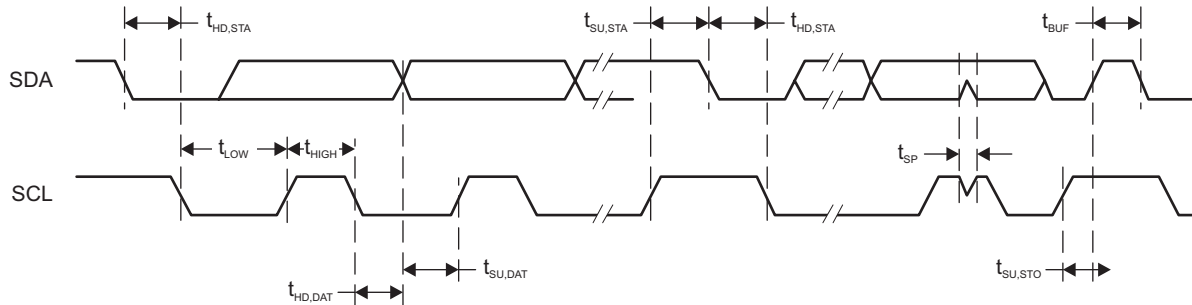


**Figure 5-15. I<sup>2</sup>C Mode Timing**

### 5.35 LCD\_B Operating Characteristics

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

| PARAMETER                  | CONDITIONS                                                                                     | MIN                                                        | TYP      | MAX            | UNIT          |
|----------------------------|------------------------------------------------------------------------------------------------|------------------------------------------------------------|----------|----------------|---------------|
| $V_{CC,LCD\_B,CP\ en,3.6}$ | Supply voltage range, charge pump enabled, $V_{LCD} \leq 3.6\text{ V}$                         | 2.2                                                        |          | 3.6            | V             |
| $V_{CC,LCD\_B,CP\ en,3.3}$ | Supply voltage range, charge pump enabled, $V_{LCD} \leq 3.3\text{ V}$                         | 2.0                                                        |          | 3.6            | V             |
| $V_{CC,LCD\_B,int.\ bias}$ | Supply voltage range, internal biasing, charge pump disabled                                   | 2.4                                                        |          | 3.6            | V             |
| $V_{CC,LCD\_B,ext.\ bias}$ | Supply voltage range, external biasing, charge pump disabled                                   | 2.4                                                        |          | 3.6            | V             |
| $V_{CC,LCD\_B,VLCDEXT}$    | Supply voltage range, external LCD voltage, internal or external biasing, charge pump disabled | 2.0                                                        |          | 3.6            | V             |
| $V_{LCDCAP/R33}$           | External LCD voltage at LCDCAP/R33, internal or external biasing, charge pump disabled         | 2.4                                                        |          | 3.6            | V             |
| $C_{LCDCAP}$               | Capacitor on LCDCAP when charge pump enabled                                                   |                                                            | 4.7      | 10             | $\mu\text{F}$ |
| $f_{Frame}$                | LCD frame frequency range                                                                      | 0                                                          |          | 100            | Hz            |
| $f_{ACLK,in}$              | ACLK input frequency range                                                                     | 30                                                         | 32       | 40             | kHz           |
| $C_{Panel}$                | Panel capacitance                                                                              |                                                            |          | 10000          | pF            |
| $V_{R33}$                  | Analog input voltage at R33                                                                    | 2.4                                                        |          | $V_{CC} + 0.2$ | V             |
| $V_{R23,1/3bias}$          | Analog input voltage at R23                                                                    | $V_{R13} \times \frac{V_{R03} + 2/3}{(V_{R33} - V_{R03})}$ |          | $V_{R33}$      | V             |
| $V_{R13,1/3bias}$          | Analog input voltage at R13 with 1/3 biasing                                                   | $V_{R03} \times \frac{V_{R03} + 1/3}{(V_{R33} - V_{R03})}$ |          | $V_{R23}$      | V             |
| $V_{R13,1/2bias}$          | Analog input voltage at R13 with 1/2 biasing                                                   | $V_{R03} \times \frac{V_{R03} + 1/2}{(V_{R33} - V_{R03})}$ |          | $V_{R33}$      | V             |
| $V_{R03}$                  | Analog input voltage at R03                                                                    | $R0EXT = 1$                                                | $V_{SS}$ |                | V             |
| $V_{LCD}-V_{R03}$          | Voltage difference between $V_{LCD}$ and R03                                                   | 2.4                                                        |          | $V_{CC} + 0.2$ | V             |
| $V_{LCDREF/R13}$           | External LCD reference voltage applied at LCDREF/R13                                           | 0.8                                                        | 1.2      | 1.5            | V             |

## 5.36 LCD\_B Electrical Characteristics

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

| PARAMETER               |                                                    | TEST CONDITIONS                                        | V <sub>CC</sub> | MIN             | TYP | MAX | UNIT |
|-------------------------|----------------------------------------------------|--------------------------------------------------------|-----------------|-----------------|-----|-----|------|
| V <sub>LCD</sub>        | LCD voltage                                        | VLCDx = 0000, VLCDxEXT = 0                             | 2.4 V to 3.6 V  | V <sub>CC</sub> |     |     | V    |
|                         |                                                    | LCDCPEN = 1, VLCDx = 0001                              | 2 V to 3.6 V    | 2.59            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 0010                              | 2 V to 3.6 V    | 2.66            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 0011                              | 2 V to 3.6 V    | 2.72            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 0100                              | 2 V to 3.6 V    | 2.79            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 0101                              | 2 V to 3.6 V    | 2.85            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 0110                              | 2 V to 3.6 V    | 2.92            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 0111                              | 2 V to 3.6 V    | 2.98            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 1000                              | 2 V to 3.6 V    | 3.05            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 1001                              | 2 V to 3.6 V    | 3.10            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 1010                              | 2 V to 3.6 V    | 3.17            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 1011                              | 2 V to 3.6 V    | 3.24            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 1100                              | 2 V to 3.6 V    | 3.30            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 1101                              | 2.2 V to 3.6 V  | 3.36            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 1110                              | 2.2 V to 3.6 V  | 3.42            |     |     |      |
|                         |                                                    | LCDCPEN = 1, VLCDx = 1111                              | 2.2 V to 3.6 V  | 3.48            |     | 3.6 |      |
| I <sub>CC,Peak,CP</sub> | Peak supply currents due to charge pump activities | LCDCPEN = 1, VLCDx = 1111                              | 2.2 V           | 400             |     |     | μA   |
| t <sub>LCD,CP,on</sub>  | Time to charge C <sub>LCD</sub> when discharged    | C <sub>LCD</sub> = 4.7 μF, LCDCPEN = 0→1, VLCDx = 1111 | 2.2 V           | 100             |     | 500 | ms   |
| I <sub>CP,Load</sub>    | Maximum charge pump load current                   | LCDCPEN = 1, VLCDx = 1111                              | 2.2 V           | 50              |     |     | μA   |
| R <sub>LCD,Seg</sub>    | LCD driver output impedance, segment lines         | LCDCPEN = 1, VLCDx = 1000, I <sub>LOAD</sub> = ±10 μA  | 2.2 V           |                 |     | 10  | kΩ   |
| R <sub>LCD,COM</sub>    | LCD driver output impedance, common lines          | LCDCPEN = 1, VLCDx = 1000, I <sub>LOAD</sub> = ±10 μA  | 2.2 V           |                 |     | 10  | kΩ   |

## 5.37 12-Bit ADC, Power Supply and Input Range Conditions

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

| PARAMETER                                                                       | TEST CONDITIONS                                                                                     | V <sub>CC</sub> | MIN | TYP | MAX              | UNIT |
|---------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-----------------|-----|-----|------------------|------|
| AV <sub>CC</sub> Analog supply voltage                                          | AVCC and DVCC are connected together, AVSS and DVSS are connected together, V(AVSS) = V(DVSS) = 0 V |                 | 2.2 |     | 3.6              | V    |
| V <sub>(Ax)</sub> Analog input voltage range <sup>(2)</sup>                     | All ADC12 analog input pins Ax                                                                      |                 | 0   |     | AV <sub>CC</sub> | V    |
| I <sub>ADC12_A</sub> Operating supply current into AVCC terminal <sup>(3)</sup> | f <sub>ADC12CLK</sub> = 5.0 MHz <sup>(4)</sup>                                                      | 2.2 V           |     | 150 | 200              | μA   |
|                                                                                 |                                                                                                     | 3 V             |     | 150 | 250              |      |
| C <sub>I</sub> Input capacitance                                                | Only one terminal Ax can be selected at one time                                                    | 2.2 V           |     | 20  | 25               | pF   |
| R <sub>I</sub> Input MUX ON resistance                                          | 0 V ≤ VIN ≤ V(AVCC)                                                                                 |                 | 10  | 200 | 1900             | Ω    |

(1) The leakage current is specified by the digital I/O input leakage.

(2) The analog input voltage range must be within the selected reference voltage range V<sub>R+</sub> to V<sub>R-</sub> for valid conversion results. If the reference voltage is supplied by an external source or if the internal voltage is used and REFOUT = 1, then decoupling capacitors are required. See [Section 5.43](#) and [Section 5.44](#).

(3) The internal reference supply current is not included in current consumption parameter I<sub>ADC12</sub>.

(4) ADC12ON = 1, REFON = 0, SHT0 = 0, SHT1 = 0, ADC12DIV = 0

### 5.38 12-Bit ADC, Timing Parameters

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

| PARAMETER                                                      | TEST CONDITIONS                                                                                                                                | V <sub>CC</sub> | MIN  | TYP                               | MAX | UNIT |
|----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|------|-----------------------------------|-----|------|
| f <sub>ADC12CLK</sub> ADC conversion clock                     | For specified performance of ADC12 linearity parameters using an external reference voltage or AV <sub>CC</sub> as reference <sup>(1)</sup>    | 2.2 V, 3 V      | 0.45 | 4.8                               | 5.0 | MHz  |
|                                                                | For specified performance of ADC12 linearity parameters using the internal reference <sup>(2)</sup>                                            |                 | 0.45 | 2.4                               | 4.0 |      |
|                                                                | For specified performance of ADC12 linearity parameters using the internal reference <sup>(3)</sup>                                            |                 | 0.45 | 2.4                               | 2.7 |      |
| f <sub>ADC12OSC</sub> Internal ADC12 oscillator <sup>(4)</sup> | ADC12DIV = 0, f <sub>ADC12CLK</sub> = f <sub>ADC12OSC</sub>                                                                                    | 2.2 V, 3 V      | 4.2  | 4.8                               | 5.4 | MHz  |
| t <sub>CONVERT</sub> Conversion time                           | REFON = 0, Internal oscillator, ADC12OSC used for ADC conversion clock                                                                         | 2.2 V, 3 V      | 2.4  |                                   | 3.1 | μs   |
|                                                                | External f <sub>ADC12CLK</sub> from ACLK, MCLK or SMCLK, ADC12SSEL ≠ 0                                                                         |                 |      | 13 ×<br>1 / f <sub>ADC12CLK</sub> |     |      |
| t <sub>Sample</sub> Sampling time                              | R <sub>S</sub> = 400 Ω, R <sub>I</sub> = 200 Ω, C <sub>I</sub> = 20 pF, τ = [R <sub>S</sub> + R <sub>I</sub> ] × C <sub>I</sub> <sup>(5)</sup> | 2.2 V, 3 V      | 1000 |                                   |     | ns   |

(1) REFOUT = 0, external reference voltage: SREF2 = 0, SREF1 = 1, SREF0 = 0. AV<sub>CC</sub> as reference voltage: SREF2 = 0, SREF1 = 0, SREF0 = 0. The specified performance of the ADC12 linearity is ensured when using the ADC12OSC. For other clock sources, the specified performance of the ADC12 linearity is ensured with f<sub>ADC12CLK</sub> maximum of 5.0 MHz.

(2) SREF2 = 0, SREF1 = 1, SREF0 = 0, ADC12SR = 0, REFOUT = 1

(3) SREF2 = 0, SREF1 = 1, SREF0 = 0, ADC12SR = 0, REFOUT = 0. The specified performance of the ADC12 linearity is ensured when using the ADC12OSC divided by 2.

(4) The ADC12OSC is sourced directly from MODOSC inside the UCS.

(5) Approximately 10 Tau (τ) are needed to get an error of less than ±0.5 LSB:

t<sub>Sample</sub> = ln(2<sup>n+1</sup>) × (R<sub>S</sub> + R<sub>I</sub>) × C<sub>I</sub> + 800 ns, where n = ADC resolution = 12, R<sub>S</sub> = external source resistance

### 5.39 12-Bit ADC, Linearity Parameters Using an External Reference Voltage

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

| PARAMETER                                                  | TEST CONDITIONS                      | V <sub>CC</sub> | MIN | TYP  | MAX  | UNIT |
|------------------------------------------------------------|--------------------------------------|-----------------|-----|------|------|------|
| E <sub>I</sub> Integral linearity error <sup>(1)</sup>     | 1.4 V ≤ dVREF ≤ 1.6 V <sup>(2)</sup> | 2.2 V, 3 V      |     |      | ±2   | LSB  |
|                                                            | 1.6 V < dVREF <sup>(2)</sup>         |                 |     |      | ±1.7 |      |
| E <sub>D</sub> Differential linearity error <sup>(1)</sup> | See <sup>(2)</sup>                   | 2.2 V, 3 V      |     |      | ±1   | LSB  |
| E <sub>O</sub> Offset error <sup>(3)</sup>                 | dVREF ≤ 2.2 V <sup>(2)</sup>         | 2.2 V, 3 V      |     | ±3   | ±5.6 | LSB  |
|                                                            | dVREF > 2.2 V <sup>(2)</sup>         | 2.2 V, 3 V      |     | ±1.5 | ±3.5 |      |
| E <sub>G</sub> Gain error <sup>(3)</sup>                   | See <sup>(2)</sup>                   | 2.2 V, 3 V      |     | ±1   | ±2.5 | LSB  |
| E <sub>T</sub> Total unadjusted error                      | dVREF ≤ 2.2 V <sup>(2)</sup>         | 2.2 V, 3 V      |     | ±3.5 | ±7.1 | LSB  |
|                                                            | dVREF > 2.2 V <sup>(2)</sup>         | 2.2 V, 3 V      |     | ±2   | ±5   |      |

(1) Parameters are derived using the histogram method.

(2) The external reference voltage is selected by: SREF2 = 0 or 1, SREF1 = 1, SREF0 = 0. dVREF = V<sub>R+</sub> – V<sub>R-</sub>. V<sub>R+</sub> < AV<sub>CC</sub>. V<sub>R-</sub> > AV<sub>SS</sub>. Unless otherwise mentioned dVREF > 1.5 V. Impedance of the external reference voltage R < 100 Ω and two decoupling capacitors, 10 μF and 100 nF, should be connected to VREF to decouple the dynamic current. Also see the [MSP430F5xx and MSP430F6xx Family User's Guide](#).

(3) Parameters are derived using a best fit curve.

## 5.40 12-Bit ADC, Linearity Parameters Using $V_{CC}$ as Reference Voltage

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

| PARAMETER                                         | TEST CONDITIONS    | $V_{CC}$   | MIN | TYP | MAX  | UNIT |
|---------------------------------------------------|--------------------|------------|-----|-----|------|------|
| $E_I$ Integral linearity error <sup>(1)</sup>     | See <sup>(2)</sup> | 2.2 V, 3 V |     |     | ±2.0 | LSB  |
| $E_D$ Differential linearity error <sup>(1)</sup> | See <sup>(2)</sup> | 2.2 V, 3 V |     |     | ±1   | LSB  |
| $E_O$ Offset error <sup>(3)</sup>                 | See <sup>(2)</sup> | 2.2 V, 3 V |     | ±1  | ±2   | LSB  |
| $E_G$ Gain error <sup>(3)</sup>                   | See <sup>(2)</sup> | 2.2 V, 3 V |     | ±2  | ±4   | LSB  |
| $E_T$ Total unadjusted error                      | See <sup>(2)</sup> | 2.2 V, 3 V |     | ±2  | ±5   | LSB  |

(1) Parameters are derived using the histogram method.

(2)  $V_{CC}$  as reference voltage is selected by: SREF2 = 0, SREF1 = 0, SREF0 = 0.

(3) Parameters are derived using a best fit curve.

## 5.41 12-Bit ADC, Linearity Parameters Using the Internal Reference Voltage

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

| PARAMETER                                         | TEST CONDITIONS <sup>(1)</sup>                         | $V_{CC}$   | MIN | TYP | MAX                | UNIT |
|---------------------------------------------------|--------------------------------------------------------|------------|-----|-----|--------------------|------|
| $E_I$ Integral linearity error <sup>(2)</sup>     | ADC12SR = 0, REFOUT = 1<br>$f_{ADC12CLK} \leq 4.0$ MHz | 2.2 V, 3 V |     |     | ±2.0               | LSB  |
|                                                   | ADC12SR = 0, REFOUT = 0<br>$f_{ADC12CLK} \leq 2.7$ MHz |            |     |     | ±2.5               |      |
| $E_D$ Differential linearity error <sup>(2)</sup> | ADC12SR = 0, REFOUT = 1<br>$f_{ADC12CLK} \leq 4.0$ MHz | 2.2 V, 3 V | -1  |     | +1.5               | LSB  |
|                                                   | ADC12SR = 0, REFOUT = 1<br>$f_{ADC12CLK} \leq 2.7$ MHz |            |     |     | ±1                 |      |
|                                                   | ADC12SR = 0, REFOUT = 0<br>$f_{ADC12CLK} \leq 2.7$ MHz |            | -1  |     | +2.5               |      |
| $E_O$ Offset error <sup>(3)</sup>                 | ADC12SR = 0, REFOUT = 1<br>$f_{ADC12CLK} \leq 4.0$ MHz | 2.2 V, 3 V |     | ±2  | ±4                 | LSB  |
|                                                   | ADC12SR = 0, REFOUT = 0<br>$f_{ADC12CLK} \leq 2.7$ MHz |            |     | ±2  | ±4                 |      |
| $E_G$ Gain error <sup>(3)</sup>                   | ADC12SR = 0, REFOUT = 1<br>$f_{ADC12CLK} \leq 4.0$ MHz | 2.2 V, 3 V |     | ±1  | ±2.5               | LSB  |
|                                                   | ADC12SR = 0, REFOUT = 0<br>$f_{ADC12CLK} \leq 2.7$ MHz |            |     |     | ±1% <sup>(4)</sup> | VREF |
| $E_T$ Total unadjusted error                      | ADC12SR = 0, REFOUT = 1<br>$f_{ADC12CLK} \leq 4.0$ MHz | 2.2 V, 3 V |     | ±2  | ±5                 | LSB  |
|                                                   | ADC12SR = 0, REFOUT = 0<br>$f_{ADC12CLK} \leq 2.7$ MHz |            |     |     | ±1% <sup>(4)</sup> | VREF |

(1) The external reference voltage is selected by: SREF2 = 0, SREF1 = 0, SREF0 = 1.  $dV_{REF} = V_{R+} - V_{R-}$ .

(2) Parameters are derived using the histogram method.

(3) Parameters are derived using a best fit curve.

(4) The gain error and the total unadjusted error are dominated by the accuracy of the integrated reference module absolute accuracy. In this mode, the reference voltage used by the ADC12\_A is not available on a pin.

## 5.42 12-Bit ADC, Temperature Sensor and Built-In $V_{MID}$ <sup>(1)</sup>

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

| PARAMETER                                                                          | TEST CONDITIONS                                                     | $V_{CC}$   | MIN  | TYP                 | MAX  | UNIT          |
|------------------------------------------------------------------------------------|---------------------------------------------------------------------|------------|------|---------------------|------|---------------|
| $V_{SENSOR}$ Temperature sensor voltage <sup>(2)</sup><br>(see Figure 5-16)        | ADC12ON = 1, INCH = 0Ah, $T_A = 0^\circ\text{C}$                    | 2.2 V      |      | 680                 |      | mV            |
|                                                                                    |                                                                     | 3 V        |      | 680                 |      |               |
| $TC_{SENSOR}$ Temperature coefficient of sensor                                    | ADC12ON = 1, INCH = 0Ah                                             | 2.2 V, 3V  |      | 2.25 <sup>(2)</sup> |      | mV/°C         |
| $t_{SENSOR(sample)}$ Sample time required if channel 10 is selected <sup>(3)</sup> | ADC12ON = 1, INCH = 0Ah,<br>Error of conversion result $\leq 1$ LSB | 2.2 V      |      | 30                  |      | $\mu\text{s}$ |
|                                                                                    |                                                                     | 3 V        |      | 30                  |      |               |
| $V_{MID}$ $AV_{CC}$ divider at channel 11                                          | ADC12ON = 1, INCH = 0Bh,<br>$V_{MID} \approx 0.5 \times V_{AVCC}$   | 2.2 V      | 1.06 | 1.1                 | 1.14 | V             |
|                                                                                    |                                                                     | 3 V        | 1.46 | 1.5                 | 1.54 |               |
| $t_{VMID(sample)}$ Sample time required if channel 11 is selected <sup>(4)</sup>   | ADC12ON = 1, INCH = 0Bh,<br>Error of conversion result $\leq 1$ LSB | 2.2 V, 3 V |      | 1000                |      | ns            |

(1) The temperature sensor is provided by the REF module. See the REF module parametric,  $I_{REF+}$ , regarding the current consumption of the temperature sensor.

(2) The temperature sensor offset can be significant. TI recommends a single-point calibration to minimize the offset error of the built-in temperature sensor. The TLV structure contains calibration values for  $30^\circ\text{C} \pm 3^\circ\text{C}$  and  $85^\circ\text{C} \pm 3^\circ\text{C}$  for each of the available reference voltage levels. The sensor voltage can be computed as  $V_{SENSE} = TC_{SENSOR} \times (\text{Temperature}, ^\circ\text{C}) + V_{SENSOR}$ , where  $TC_{SENSOR}$  and  $V_{SENSOR}$  can be computed from the calibration values for higher accuracy. Also see the [MSP430F5xx and MSP430F6xx Family User's Guide](#).

(3) The typical equivalent impedance of the sensor is 51 k $\Omega$ . The sample time required includes the sensor-on time  $t_{SENSOR(on)}$ .

(4) The on-time  $t_{VMID(on)}$  is included in the sampling time  $t_{VMID(sample)}$ ; no additional on time is needed.

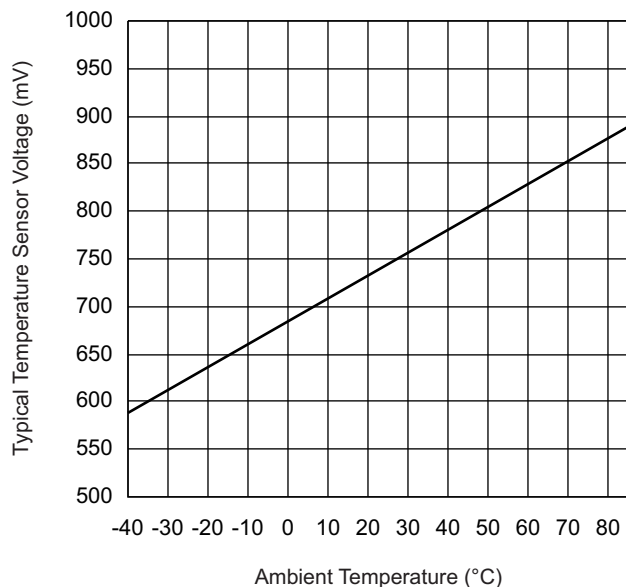


**Figure 5-16. Typical Temperature Sensor Voltage**

### 5.43 REF, External Reference

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

| PARAMETER                                                     |                                                       | TEST CONDITIONS                                                                                                                                           | V <sub>CC</sub> | MIN  | MAX              | UNIT |
|---------------------------------------------------------------|-------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|------|------------------|------|
| V <sub>eREF+</sub>                                            | Positive external reference voltage input             | V <sub>eREF+</sub> > V <sub>REF-</sub> /V <sub>eREF-</sub> <sup>(2)</sup>                                                                                 |                 | 1.4  | AV <sub>CC</sub> | V    |
| V <sub>REF-</sub> /V <sub>eREF-</sub>                         | Negative external reference voltage input             | V <sub>eREF+</sub> > V <sub>REF-</sub> /V <sub>eREF-</sub> <sup>(3)</sup>                                                                                 |                 | 0    | 1.2              | V    |
| (V <sub>eREF+</sub> – V <sub>REF-</sub> /V <sub>eREF-</sub> ) | Differential external reference voltage input         | V <sub>eREF+</sub> > V <sub>REF-</sub> /V <sub>eREF-</sub> <sup>(4)</sup>                                                                                 |                 | 1.4  | AV <sub>CC</sub> | V    |
| I <sub>VeREF+</sub> ,<br>I <sub>VREF-/VeREF-</sub>            | Static input current                                  | 1.4 V ≤ V <sub>eREF+</sub> ≤ V <sub>AVCC</sub> , V <sub>eREF-</sub> = 0 V,<br>f <sub>ADC12CLK</sub> = 5 MHz, ADC12SHTx = 1h,<br>Conversion rate 200 ksp/s | 2.2 V, 3 V      | –26  | 26               | μA   |
|                                                               |                                                       | 1.4 V ≤ V <sub>eREF+</sub> ≤ V <sub>AVCC</sub> , V <sub>eREF-</sub> = 0 V,<br>f <sub>ADC12CLK</sub> = 5 MHz, ADC12SHTx = 8h,<br>Conversion rate 20 ksp/s  | 2.2 V, 3 V      | –1.2 | +1.2             |      |
| C <sub>VREF+/-</sub>                                          | Capacitance at VREF+ or VREF- terminal <sup>(5)</sup> |                                                                                                                                                           |                 | 10   |                  | μF   |

- (1) The external reference is used during ADC conversion to charge and discharge the capacitance array. The input capacitance, C<sub>i</sub>, 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) The accuracy limits the minimum positive external reference voltage. Lower reference voltage levels may be applied with reduced accuracy requirements.
- (3) The accuracy limits the maximum negative external reference voltage. Higher reference voltage levels may be applied with reduced accuracy requirements.
- (4) The accuracy limits minimum external differential reference voltage. Lower differential reference voltage levels may be applied with reduced accuracy requirements.
- (5) Two decoupling capacitors, 10 μF and 100 nF, should be connected to VREF to decouple the dynamic current required for an external reference source if it is used for the ADC12\_A. Also see the [MSP430F5xx and MSP430F6xx Family User's Guide](#).

## 5.44 REF, Built-In Reference

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

| PARAMETER                                                                           | TEST CONDITIONS                                                                                                                                                          | V <sub>CC</sub> | MIN        | TYP  | MAX  | UNIT   |
|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|------------|------|------|--------|
| V <sub>REF+</sub><br>Positive built-in reference voltage output                     | REFVSEL = {2} for 2.5 V, REFON = REFOUT = 1, I <sub>VREF+</sub> = 0 A                                                                                                    | 3 V             |            | 2.5  | ±1%  | V      |
|                                                                                     | REFVSEL = {1} for 2 V, REFON = REFOUT = 1, I <sub>VREF+</sub> = 0 A                                                                                                      | 3 V             |            | 2.0  | ±1%  |        |
|                                                                                     | REFVSEL = {0} for 1.5 V, REFON = REFOUT = 1, I <sub>VREF+</sub> = 0 A                                                                                                    | 2.2 V, 3 V      |            | 1.5  | ±1%  |        |
| AV <sub>CC(min)</sub><br>AVCC minimum voltage, Positive built-in reference active   | REFVSEL = {0} for 1.5 V                                                                                                                                                  |                 | 2.2        |      |      | V      |
|                                                                                     | REFVSEL = {1} for 2 V                                                                                                                                                    |                 | 2.3        |      |      |        |
|                                                                                     | REFVSEL = {2} for 2.5 V                                                                                                                                                  |                 | 2.8        |      |      |        |
| I <sub>REF+</sub><br>Operating supply current into AVCC terminal <sup>(2) (3)</sup> | ADC12SR = 1 <sup>(4)</sup> , REFON = 1, REFOUT = 0, REFBURST = 0                                                                                                         | 3 V             |            | 70   | 100  | μA     |
|                                                                                     | ADC12SR = 1 <sup>(4)</sup> , REFON = 1, REFOUT = 1, REFBURST = 0                                                                                                         |                 |            | 0.45 | 0.75 | mA     |
|                                                                                     | ADC12SR = 0 <sup>(4)</sup> , REFON = 1, REFOUT = 0, REFBURST = 0                                                                                                         |                 |            | 210  | 310  | μA     |
|                                                                                     | ADC12SR = 0 <sup>(4)</sup> , REFON = 1, REFOUT = 1, REFBURST = 0                                                                                                         |                 |            | 0.95 | 1.7  | mA     |
| I <sub>L(VREF+)</sub><br>Load-current regulation, VREF+ terminal <sup>(5)</sup>     | REFVSEL = {0, 1, 2}, I <sub>VREF+</sub> = +10 μA or –1000 μA, AV <sub>CC</sub> = AV <sub>CC(min)</sub> for each reference level, REFVSEL = {0, 1, 2}, REFON = REFOUT = 1 |                 |            | 1500 | 2500 | μV/mA  |
| C <sub>VREF+</sub><br>Capacitance at VREF+ terminal                                 | REFON = REFOUT = 1 <sup>(6)</sup> , 0 mA ≤ I <sub>VREF+</sub> ≤ I <sub>VREF+(max)</sub>                                                                                  | 2.2 V, 3 V      | 20         |      | 100  | pF     |
| TC <sub>REF+</sub><br>Temperature coefficient of built-in reference <sup>(7)</sup>  | I <sub>VREF+</sub> is a constant in the range of 0 mA ≤ I <sub>VREF+</sub> ≤ –1 mA                                                                                       | REFOUT = 0      | 2.2 V, 3 V | 20   |      | ppm/°C |
| TC <sub>REF+</sub><br>Temperature coefficient of built-in reference <sup>(7)</sup>  | I <sub>VREF+</sub> is a constant in the range of 0 mA ≤ I <sub>VREF+</sub> ≤ –1 mA                                                                                       | REFOUT = 1      | 2.2 V, 3 V | 20   | 50   | ppm/°C |
| PSRR <sub>DC</sub><br>Power supply rejection ratio (DC)                             | AV <sub>CC</sub> = AV <sub>CC(min)</sub> to AV <sub>CC(max)</sub> , T <sub>A</sub> = 25°C, REFVSEL = {0, 1, 2}, REFON = 1, REFOUT = 0 or 1                               |                 |            | 120  | 300  | μV/V   |
| PSRR <sub>AC</sub><br>Power supply rejection ratio (AC)                             | AV <sub>CC</sub> = AV <sub>CC(min)</sub> to AV <sub>CC(max)</sub> , T <sub>A</sub> = 25°C, REFVSEL = {0, 1, 2}, REFON = 1, REFOUT = 0 or 1                               |                 |            | 1    |      | mV/V   |
| t <sub>SETTLE</sub><br>Settling time of reference voltage <sup>(8)</sup>            | AV <sub>CC</sub> = AV <sub>CC(min)</sub> to AV <sub>CC(max)</sub> , REFVSEL = {0, 1, 2}, REFOUT = 0, REFON = 0 → 1                                                       |                 |            | 75   |      | μs     |
|                                                                                     | AV <sub>CC</sub> = AV <sub>CC(min)</sub> to AV <sub>CC(max)</sub> , C <sub>VREF</sub> = C <sub>VREF(max)</sub> , REFVSEL = {0, 1, 2}, REFOUT = 1, REFON = 0 → 1          |                 |            | 75   |      |        |

- (1) The reference is supplied to the ADC by the REF module and is buffered locally inside the ADC. The ADC uses two internal buffers, one smaller and one larger for driving the VREF+ terminal. When REFOUT = 1, the reference is available at the VREF+ terminal and is used as the reference for the conversion and uses the larger buffer. When REFOUT = 0, the reference is only used as the reference for the conversion and uses the smaller buffer.
- (2) The internal reference current is supplied from the AVCC terminal. Consumption is independent of the ADC12ON control bit, unless a conversion is active. REFOUT = 0 represents the current contribution of the smaller buffer. REFOUT = 1 represents the current contribution of the larger buffer without external load.
- (3) The temperature sensor is provided by the REF module. Its current is supplied from the AVCC terminal and is equivalent to I<sub>REF+</sub> with REFON = 1 and REFOUT = 0.
- (4) For devices without the ADC12, the parametric with ADC12SR = 0 are applicable.
- (5) Contribution only due to the reference and buffer including package. This does not include resistance due to PCB trace or other causes.
- (6) Two decoupling capacitors, 10 μF and 100 nF, should be connected to VREF to decouple the dynamic current required for an external reference source if it is used for the ADC12. Also see the [MSP430F5xx and MSP430F6xx Family User's Guide](#).
- (7) 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)).
- (8) The condition is that the error in a conversion started after t<sub>REFON</sub> is less than ±0.5 LSB. The settling time depends on the external capacitive load when REFOUT = 1.

## 5.45 12-Bit DAC, Supply Specifications

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

| PARAMETER        |                                                      | TEST CONDITIONS                                                                                                 | V <sub>CC</sub> | MIN  | TYP | MAX  | UNIT |
|------------------|------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------|------|-----|------|------|
| AV <sub>CC</sub> | Analog supply voltage                                | AV <sub>CC</sub> = DV <sub>CC</sub> , AV <sub>SS</sub> = DV <sub>SS</sub> = 0 V                                 |                 | 2.20 |     | 3.60 | V    |
| I <sub>DD</sub>  | Supply current, single DAC channel <sup>(1)(2)</sup> | DAC12AMPx = 2, DAC12IR = 0, DAC12IOG = 1<br>DAC12_xDAT = 0800h<br>V <sub>REF+</sub> = V <sub>REF+</sub> = 1.5 V | 3 V             |      | 65  | 110  | μA   |
|                  |                                                      | DAC12AMPx = 2, DAC12IR = 1,<br>DAC12_xDAT = 0800h,<br>V <sub>REF+</sub> = V <sub>REF+</sub> = AV <sub>CC</sub>  | 2.2 V, 3 V      |      | 65  | 110  |      |
|                  |                                                      | DAC12AMPx = 5, DAC12IR = 1,<br>DAC12_xDAT = 0800h,<br>V <sub>REF+</sub> = V <sub>REF+</sub> = AV <sub>CC</sub>  |                 |      | 250 | 300  |      |
|                  |                                                      | DAC12AMPx = 7, DAC12IR = 1,<br>DAC12_xDAT = 0800h,<br>V <sub>REF+</sub> = V <sub>REF+</sub> = AV <sub>CC</sub>  |                 |      | 750 | 1000 |      |
| PSRR             | Power supply rejection ratio <sup>(3)(4)</sup>       | DAC12_xDAT = 800h, V <sub>REF+</sub> = 1.5 V,<br>ΔAV <sub>CC</sub> = 100 mV                                     | 2.2 V           |      | 70  |      | dB   |
|                  |                                                      | DAC12_xDAT = 800h, V <sub>REF+</sub> = 1.5 V or 2.5 V,<br>ΔAV <sub>CC</sub> = 100 mV                            | 3 V             |      | 70  |      |      |

(1) No load at the output pin, DAC12\_0 or DAC12\_1, assuming that the control bits for the shared pins are set properly.

(2) Current into reference terminals not included. If DAC12IR = 1 current flows through the input divider; see Reference Input specifications.

(3) PSRR = 20 log (ΔAV<sub>CC</sub> / ΔV<sub>DAC12\_xOUT</sub>)

(4) The internal reference is not used.

## 5.46 12-Bit DAC, Linearity Specifications

See [Figure 5-17](#), over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER                         |                                                     | TEST CONDITIONS                                       | V <sub>CC</sub>                                       | MIN | TYP  | MAX  | UNIT          |
|-----------------------------------|-----------------------------------------------------|-------------------------------------------------------|-------------------------------------------------------|-----|------|------|---------------|
| Resolution                        |                                                     | 12-bit monotonic                                      |                                                       | 12  |      |      | bits          |
| INL                               | Integral nonlinearity <sup>(1)</sup>                | V <sub>REF+</sub> = 1.5 V, DAC12AMPx = 7, DAC12IR = 1 | 2.2 V                                                 |     | ±2   | ±4   | LSB           |
|                                   |                                                     | V <sub>REF+</sub> = 2.5 V, DAC12AMPx = 7, DAC12IR = 1 | 3 V                                                   |     | ±2   | ±4   |               |
| DNL                               | Differential nonlinearity <sup>(1)</sup>            | V <sub>REF+</sub> = 1.5 V, DAC12AMPx = 7, DAC12IR = 1 | 2.2 V                                                 |     | ±0.4 | ±1   | LSB           |
|                                   |                                                     | V <sub>REF+</sub> = 2.5 V, DAC12AMPx = 7, DAC12IR = 1 | 3 V                                                   |     | ±0.4 | ±1   |               |
| E <sub>O</sub>                    | Offset voltage                                      | Without calibration <sup>(1) (2)</sup>                | V <sub>REF+</sub> = 1.5 V, DAC12AMPx = 7, DAC12IR = 1 |     |      | ±21  | mV            |
|                                   |                                                     |                                                       | V <sub>REF+</sub> = 2.5 V, DAC12AMPx = 7, DAC12IR = 1 |     |      | ±21  |               |
|                                   |                                                     | With calibration <sup>(1) (2)</sup>                   | V <sub>REF+</sub> = 1.5 V, DAC12AMPx = 7, DAC12IR = 1 |     |      | ±1.5 |               |
|                                   |                                                     |                                                       | V <sub>REF+</sub> = 2.5 V, DAC12AMPx = 7, DAC12IR = 1 |     |      | ±1.5 |               |
| d <sub>E(O)</sub> /d <sub>T</sub> | Offset error temperature coefficient <sup>(1)</sup> | With calibration                                      | 2.2 V, 3 V                                            |     | ±10  |      | μV/°C         |
| E <sub>G</sub>                    | Gain error                                          | V <sub>REF+</sub> = 1.5 V                             | 2.2 V                                                 |     |      | ±2.5 | %FSR          |
|                                   |                                                     | V <sub>REF+</sub> = 2.5 V                             | 3 V                                                   |     |      | ±2.5 |               |
| d <sub>E(G)</sub> /d <sub>T</sub> | Gain temperature coefficient <sup>(1)</sup>         |                                                       | 2.2 V, 3 V                                            |     | 10   |      | ppm of FSR/°C |
| t <sub>Offset_Cal</sub>           | Time for offset calibration <sup>(3)</sup>          | DAC12AMPx = 2                                         | 2.2 V, 3 V                                            |     |      | 165  | ms            |
|                                   |                                                     | DAC12AMPx = 3, 5                                      |                                                       |     |      | 66   |               |
|                                   |                                                     | DAC12AMPx = 4, 6, 7                                   |                                                       |     |      | 16.5 |               |

- (1) Parameters calculated from the best-fit curve from 0x0F to 0xFF. The best-fit curve method is used to deliver coefficients “a” and “b” of the first-order equation:  $y = a + bx$ .  $V_{DAC12\_XOUT} = E_O + (1 + E_G) \times (V_{REF+}/4095) \times DAC12\_xDAT$ , DAC12IR = 1.
- (2) The offset calibration works on the output operational amplifier. Offset Calibration is triggered setting bit DAC12CALON
- (3) The offset calibration can be done if DAC12AMPx = {2, 3, 4, 5, 6, 7}. The output operational amplifier is switched off with DAC12AMPx = {0, 1}. TI recommends configuring the DAC12 module before initiating calibration. Port activity during calibration may affect accuracy and is not recommended.

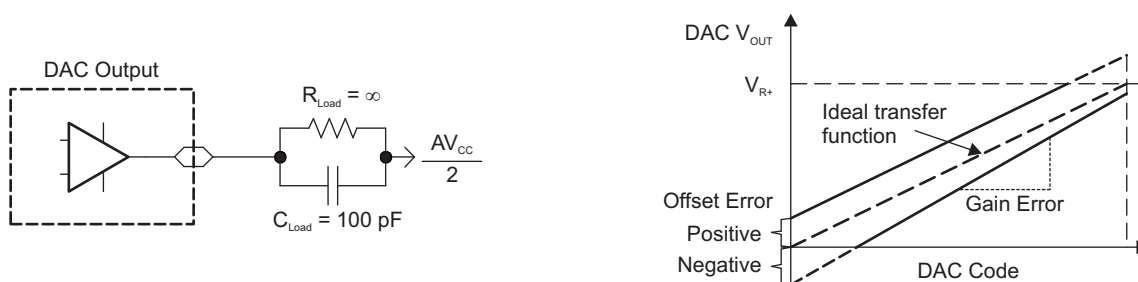


**Figure 5-17. Linearity Test Load Conditions and Gain/Offset Definition**

## 5.47 12-Bit DAC, Output Specifications

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

| PARAMETER                                                            | TEST CONDITIONS                                                                                                 | V <sub>CC</sub> | MIN                     | TYP | MAX              | UNIT |
|----------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------|-------------------------|-----|------------------|------|
| V <sub>O</sub> Output voltage range <sup>(1)</sup> (see Figure 5-18) | No load, V <sub>REF+</sub> = AV <sub>CC</sub> , DAC12_xDAT = 0h, DAC12IR = 1, DAC12AMPx = 7                     | 2.2 V, 3 V      | 0                       |     | 0.005            | V    |
|                                                                      | No load, V <sub>REF+</sub> = AV <sub>CC</sub> , DAC12_xDAT = 0FFFh, DAC12IR = 1, DAC12AMPx = 7                  |                 | AV <sub>CC</sub> – 0.05 |     | AV <sub>CC</sub> |      |
|                                                                      | R <sub>Load</sub> = 3 kΩ, V <sub>REF+</sub> = AV <sub>CC</sub> , DAC12_xDAT = 0h, DAC12IR = 1, DAC12AMPx = 7    |                 | 0                       |     | 0.1              |      |
|                                                                      | R <sub>Load</sub> = 3 kΩ, V <sub>REF+</sub> = AV <sub>CC</sub> , DAC12_xDAT = 0FFFh, DAC12IR = 1, DAC12AMPx = 7 |                 | AV <sub>CC</sub> – 0.13 |     | AV <sub>CC</sub> |      |
| C <sub>L(DAC12)</sub> Maximum DAC12 load capacitance                 |                                                                                                                 | 2.2 V, 3 V      |                         |     | 100              | pF   |
| I <sub>L(DAC12)</sub> Maximum DAC12 load current                     | DAC12AMPx = 2, DAC12_xDAT = 0FFFh, V <sub>O/P(DAC12)</sub> > AV <sub>CC</sub> – 0.3                             | 2.2 V, 3 V      | –1                      |     |                  | mA   |
|                                                                      | DAC12AMPx = 2, DAC12_xDAT = 0h, V <sub>O/P(DAC12)</sub> < 0.3 V                                                 |                 |                         |     | 1                |      |
| R <sub>O/P(DAC12)</sub> Output resistance (see Figure 5-18)          | R <sub>Load</sub> = 3 kΩ, V <sub>O/P(DAC12)</sub> < 0.3 V, DAC12AMPx = 2, DAC12_xDAT = 0h                       | 2.2 V, 3 V      |                         | 150 | 250              | Ω    |
|                                                                      | R <sub>Load</sub> = 3 kΩ, V <sub>O/P(DAC12)</sub> > AV <sub>CC</sub> – 0.3 V, DAC12_xDAT = 0FFFh                |                 |                         | 150 | 250              |      |
|                                                                      | R <sub>Load</sub> = 3 kΩ, 0.3 V ≤ V <sub>O/P(DAC12)</sub> ≤ AV <sub>CC</sub> – 0.3 V                            |                 |                         |     | 6                |      |

(1) Data is valid after the offset calibration of the output amplifier.

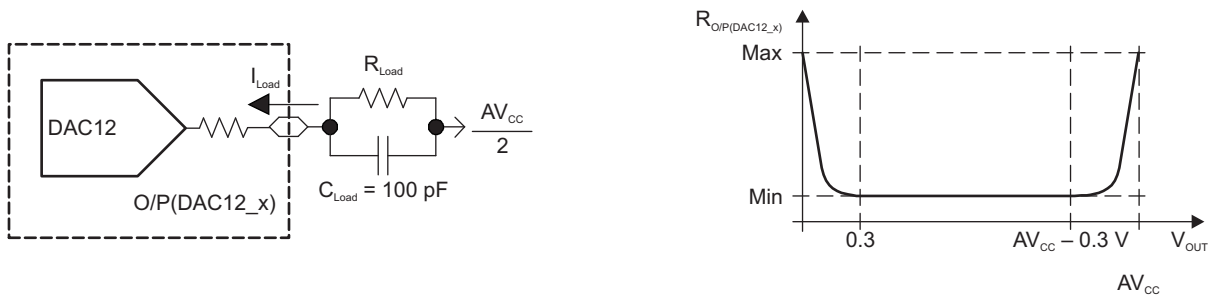


Figure 5-18. DAC12\_x Output Resistance Tests

## 5.48 12-Bit DAC, Reference Input Specifications

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

| PARAMETER                                         |                               | TEST CONDITIONS                                                           | V <sub>CC</sub> | MIN                 | TYP | MAX                    | UNIT |
|---------------------------------------------------|-------------------------------|---------------------------------------------------------------------------|-----------------|---------------------|-----|------------------------|------|
| V <sub>REF+</sub>                                 | Reference input voltage range | DAC12IR = 0 <sup>(1)</sup> (2)                                            | 2.2 V, 3 V      | AV <sub>CC</sub> /3 |     | AV <sub>CC</sub> + 0.2 | V    |
|                                                   |                               | DAC12IR = 1 <sup>(3)</sup> (4)                                            |                 | AV <sub>CC</sub>    |     | AV <sub>CC</sub> + 0.2 |      |
| R <sub>i(VREF+)</sub> ,<br>R <sub>i(VeREF+)</sub> | Reference input resistance    | DAC12_0 IR = DAC12_1 IR = 0                                               | 2.2 V, 3 V      | 20                  |     |                        | MΩ   |
|                                                   |                               | DAC12_0 IR = 1, DAC12_1 IR = 0                                            |                 | 52                  |     | kΩ                     |      |
|                                                   |                               | DAC12_0 IR = 0, DAC12_1 IR = 1                                            |                 | 52                  |     |                        |      |
|                                                   |                               | DAC12_0 IR = DAC12_1 IR = 1, DAC12_0 SREFx = DAC12_1 SREFx <sup>(5)</sup> |                 | 26                  |     |                        |      |

(1) For a full-scale output, the reference input voltage can be as high as 1/3 of the maximum output voltage swing (AV<sub>CC</sub>).

(2) The maximum voltage applied at reference input voltage terminal V<sub>REF+</sub> = [AV<sub>CC</sub> - V<sub>E(O)</sub>] / [3 × (1 + E<sub>G</sub>)].

(3) For a full-scale output, the reference input voltage can be as high as the maximum output voltage swing (AV<sub>CC</sub>).

(4) The maximum voltage applied at reference input voltage terminal V<sub>REF+</sub> = [AV<sub>CC</sub> - V<sub>E(O)</sub>] / (1 + E<sub>G</sub>).

(5) When DAC12IR = 1 and DAC12SREFx = 0 or 1 for both channels, the reference input resistive dividers for each DAC are in parallel reducing the reference input resistance.

## 5.49 12-Bit DAC, Dynamic Specifications

V<sub>REF</sub> = V<sub>CC</sub>, DAC12IR = 1 (see Figure 5-19 and Figure 5-20), over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER           |                             | TEST CONDITIONS                                                                                       |                           | V <sub>CC</sub> | MIN  | TYP  | MAX | UNIT |
|---------------------|-----------------------------|-------------------------------------------------------------------------------------------------------|---------------------------|-----------------|------|------|-----|------|
| t <sub>ON</sub>     | DAC12 on time               | DAC12_xDAT = 800h, Error <sub>V(O)</sub> < ±0.5 LSB <sup>(1)</sup> (see <a href="#">Figure 5-19</a> ) | DAC12AMPx = 0 → {2, 3, 4} | 2.2 V, 3 V      |      | 60   | 120 | μs   |
|                     |                             |                                                                                                       | DAC12AMPx = 0 → {5, 6}    |                 |      | 15   | 30  |      |
|                     |                             |                                                                                                       | DAC12AMPx = 0 → 7         |                 |      | 6    | 12  |      |
| t <sub>S(FS)</sub>  | Settling time, full scale   | DAC12_xDAT = 80h → F7Fh → 80h                                                                         | DAC12AMPx = 2             | 2.2 V, 3 V      |      | 100  | 200 | μs   |
|                     |                             |                                                                                                       | DAC12AMPx = 3, 5          |                 |      | 40   | 80  |      |
|                     |                             |                                                                                                       | DAC12AMPx = 4, 6, 7       |                 |      | 15   | 30  |      |
| t <sub>S(C-C)</sub> | Settling time, code to code | DAC12_xDAT = 3F8h → 408h → 3F8h, BF8h → C08h → BF8h                                                   | DAC12AMPx = 2             | 2.2 V, 3 V      |      | 5    |     | μs   |
|                     |                             |                                                                                                       | DAC12AMPx = 3, 5          |                 |      | 2    |     |      |
|                     |                             |                                                                                                       | DAC12AMPx = 4, 6, 7       |                 |      | 1    |     |      |
| SR                  | Slew rate                   | DAC12_xDAT = 80h → F7Fh → 80h <sup>(2)</sup>                                                          | DAC12AMPx = 2             | 2.2 V, 3 V      | 0.05 | 0.35 |     | V/μs |
|                     |                             |                                                                                                       | DAC12AMPx = 3, 5          |                 | 0.35 | 1.10 |     |      |
|                     |                             |                                                                                                       | DAC12AMPx = 4, 6, 7       |                 | 1.50 | 5.20 |     |      |
|                     | Glitch energy               | DAC12_xDAT = 800h → 7FFh → 800h                                                                       | DAC12AMPx = 7             | 2.2 V, 3 V      |      | 35   |     | nV-s |

(1) R<sub>Load</sub> and C<sub>Load</sub> connected to AV<sub>SS</sub> (not AV<sub>CC</sub>/2) in Figure 5-19.

(2) Slew rate applies to output voltage steps ≥ 200 mV.

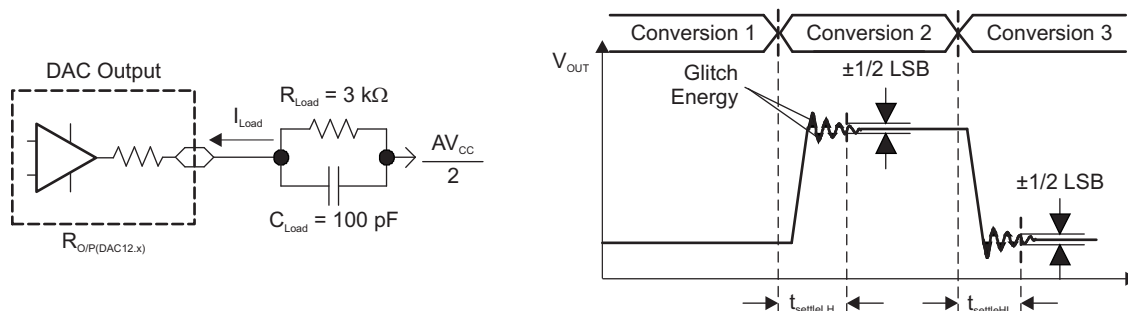


Figure 5-19. Settling Time and Glitch Energy Testing

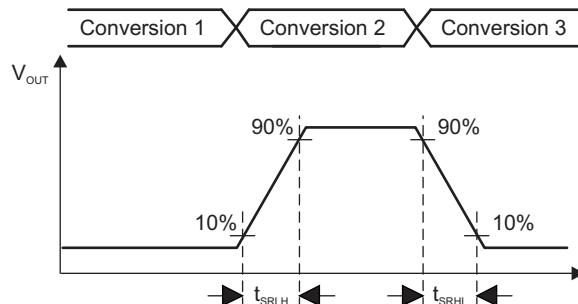


**Figure 5-20. Slew Rate Testing**

## 5.50 12-Bit DAC, Dynamic Specifications (Continued)

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

| PARAMETER                                                                                                                       | TEST CONDITIONS                                                                                                                                                     | V <sub>CC</sub> | MIN | TYP | MAX | UNIT |
|---------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-----|-----|-----|------|
| BW <sub>-3dB</sub><br>3-dB bandwidth,<br>V <sub>DC</sub> = 1.5 V,<br>V <sub>AC</sub> = 0.1 V <sub>PP</sub> (see<br>Figure 5-21) | DAC12AMPx = {2, 3, 4}, DAC12SREFx = 2,<br>DAC12IR = 1, DAC12_xDAT = 800h<br>T <sub>A</sub> = 25°C                                                                   | 2.2 V, 3 V      | 40  |     |     | kHz  |
|                                                                                                                                 | DAC12AMPx = {5, 6}, DAC12SREFx = 2,<br>DAC12IR = 1, DAC12_xDAT = 800h<br>T <sub>A</sub> = 25°C                                                                      |                 | 180 |     |     |      |
|                                                                                                                                 | DAC12AMPx = 7, DAC12SREFx = 2,<br>DAC12IR = 1, DAC12_xDAT = 800h<br>T <sub>A</sub> = 25°C                                                                           |                 | 550 |     |     |      |
| Channel-to-channel<br>crosstalk <sup>(1)</sup> (see Figure 5-22)                                                                | DAC12_0DAT = 800h, No load,<br>DAC12_1DAT = 80h ↔ F7Fh, R <sub>Load</sub> = 3 kΩ,<br>f <sub>DAC12_1OUT</sub> = 10 kHz at 50/50 duty cycle,<br>T <sub>A</sub> = 25°C | 2.2 V, 3 V      |     | -80 |     | dB   |
|                                                                                                                                 | DAC12_0DAT = 80h ↔ F7Fh, R <sub>Load</sub> = 3 kΩ,<br>DAC12_1DAT = 800h, No load,<br>f <sub>DAC12_0OUT</sub> = 10 kHz at 50/50 duty cycle,<br>T <sub>A</sub> = 25°C |                 |     | -80 |     |      |

(1) R<sub>Load</sub> = 3 kΩ, C<sub>Load</sub> = 100 pF

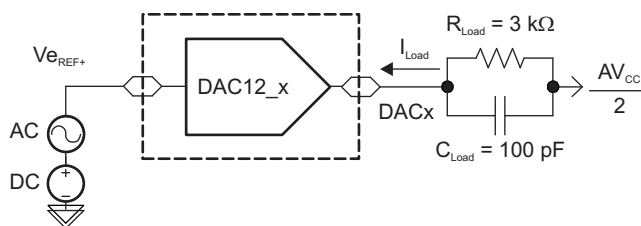


**Figure 5-21. Test Conditions for 3-dB Bandwidth Specification**

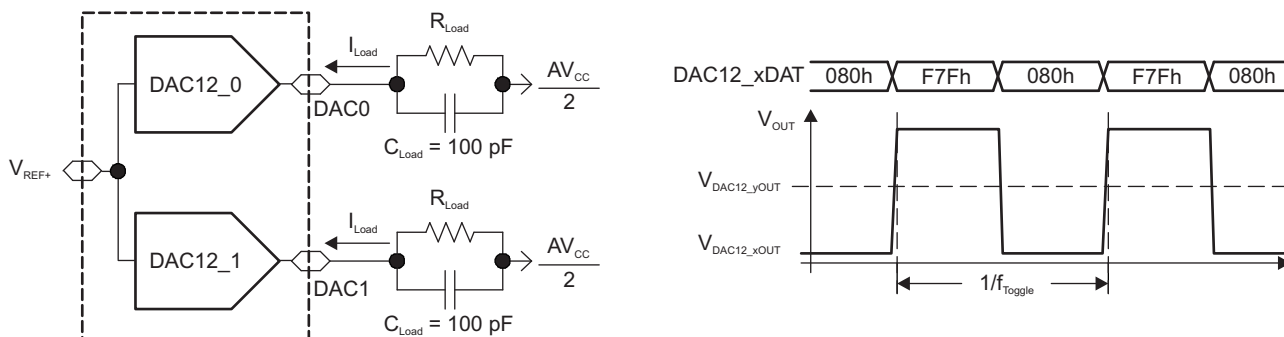


**Figure 5-22. Crosstalk Test Conditions**

## 5.51 Comparator\_B

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

| PARAMETER              |                                                                                            | TEST CONDITIONS                                                | V <sub>CC</sub> | MIN                            | TYP                          | MAX                            | UNIT |
|------------------------|--------------------------------------------------------------------------------------------|----------------------------------------------------------------|-----------------|--------------------------------|------------------------------|--------------------------------|------|
| V <sub>CC</sub>        | Supply voltage                                                                             |                                                                |                 | 1.8                            |                              | 3.6                            | V    |
| I <sub>AVCC_COMP</sub> | Comparator operating supply current into AVCC terminal, Excludes reference resistor ladder | CBPWRMD = 00                                                   | 1.8 V           |                                |                              | 40                             | μA   |
|                        |                                                                                            |                                                                | 2.2 V           |                                | 30                           | 50                             |      |
|                        |                                                                                            |                                                                | 3 V             |                                | 40                           | 65                             |      |
|                        |                                                                                            | CBPWRMD = 01                                                   | 2.2 V, 3 V      |                                | 10                           | 30                             |      |
|                        |                                                                                            | CBPWRMD = 10                                                   | 2.2 V, 3 V      |                                | 0.1                          | 0.5                            |      |
| I <sub>AVCC_REF</sub>  | Quiescent current of local reference voltage amplifier into AVCC terminal                  | CBREFACC = 1, CBREFLx = 01                                     |                 |                                |                              | 22                             | μA   |
| V <sub>IC</sub>        | Common mode input range                                                                    |                                                                |                 | 0                              |                              | V <sub>CC</sub> – 1            | V    |
| V <sub>OFFSET</sub>    | Input offset voltage                                                                       | CBPWRMD = 00                                                   |                 |                                |                              | ±20                            | mV   |
|                        |                                                                                            | CBPWRMD = 01 or 10                                             |                 |                                |                              | ±10                            |      |
| C <sub>IN</sub>        | Input capacitance                                                                          |                                                                |                 |                                | 5                            |                                | pF   |
| R <sub>SIN</sub>       | Series input resistance                                                                    | On (switch closed)                                             |                 |                                | 3                            | 4                              | kΩ   |
|                        |                                                                                            | Off (switch open)                                              |                 | 50                             |                              |                                | MΩ   |
| t <sub>PD</sub>        | Propagation delay, response time                                                           | CBPWRMD = 00, CBF = 0                                          |                 |                                |                              | 450                            | ns   |
|                        |                                                                                            | CBPWRMD = 01, CBF = 0                                          |                 |                                |                              | 600                            |      |
|                        |                                                                                            | CBPWRMD = 10, CBF = 0                                          |                 |                                |                              | 50                             | μs   |
| t <sub>PD,filter</sub> | Propagation delay with filter active                                                       | CBPWRMD = 00, CBON = 1, CBF = 1, CBF <sub>DLY</sub> = 00       |                 | 0.35                           | 0.6                          | 1.0                            | μs   |
|                        |                                                                                            | CBPWRMD = 00, CBON = 1, CBF = 1, CBF <sub>DLY</sub> = 01       |                 | 0.6                            | 1.0                          | 1.8                            |      |
|                        |                                                                                            | CBPWRMD = 00, CBON = 1, CBF = 1, CBF <sub>DLY</sub> = 10       |                 | 1.0                            | 1.8                          | 3.4                            |      |
|                        |                                                                                            | CBPWRMD = 00, CBON = 1, CBF = 1, CBF <sub>DLY</sub> = 11       |                 | 1.8                            | 3.4                          | 6.5                            |      |
| t <sub>EN_CMP</sub>    | Comparator enable time                                                                     | CBON = 0 to CBON = 1<br>CBPWRMD = 00 or 01                     |                 |                                | 1                            | 2                              | μs   |
|                        |                                                                                            | CBON = 0 to CBON = 1<br>CBPWRMD = 10                           |                 |                                |                              | 100                            |      |
| t <sub>EN_REF</sub>    | Resistor reference enable time                                                             | CBON = 0 to CBON = 1                                           |                 |                                | 0.3                          | 1.5                            | μs   |
| V <sub>CB_REF</sub>    | Reference voltage for a given tap                                                          | V <sub>IN</sub> = reference into resistor ladder (n = 0 to 31) |                 | $V_{IN} \times (n + 0.5) / 32$ | $V_{IN} \times (n + 1) / 32$ | $V_{IN} \times (n + 1.5) / 32$ | V    |

## 5.52 Ports PU.0 and PU.1

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

| PARAMETER       |                           | TEST CONDITIONS                                         | MIN | MAX | UNIT |
|-----------------|---------------------------|---------------------------------------------------------|-----|-----|------|
| V <sub>OH</sub> | High-level output voltage | V <sub>USB</sub> = 3.3 V ±10%, I <sub>OH</sub> = –25 mA | 2.4 |     | V    |
| V <sub>OL</sub> | Low-level output voltage  | V <sub>USB</sub> = 3.3 V ±10%, I <sub>OL</sub> = 25 mA  |     | 0.4 | V    |
| V <sub>IH</sub> | High-level input voltage  | V <sub>USB</sub> = 3.3 V ±10%                           | 2.0 |     | V    |
| V <sub>IL</sub> | Low-level input voltage   | V <sub>USB</sub> = 3.3 V ±10%                           |     | 0.8 | V    |

## 5.53 USB Output Ports DP and DM

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

| PARAMETER          |                     | TEST CONDITIONS                                                                  | MIN | MAX | UNIT |
|--------------------|---------------------|----------------------------------------------------------------------------------|-----|-----|------|
| V <sub>OH</sub>    | D+, D- single ended | USB 2.0 load conditions                                                          | 2.8 | 3.6 | V    |
| V <sub>OL</sub>    | D+, D- single ended | USB 2.0 load conditions                                                          | 0   | 0.3 | V    |
| Z <sub>(DRV)</sub> | D+, D- impedance    | Including external series resistor of 27 Ω                                       | 28  | 44  | Ω    |
| t <sub>RISE</sub>  | Rise time           | Full speed, differential, C <sub>L</sub> = 50 pF, 10%/90%, R <sub>pu</sub> on D+ | 4   | 20  | ns   |
| t <sub>FALL</sub>  | Fall time           | Full speed, differential, C <sub>L</sub> = 50 pF, 10%/90%, R <sub>pu</sub> on D+ | 4   | 20  | ns   |

## 5.54 USB Input Ports DP and DM

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

| PARAMETER         |                                      | TEST CONDITIONS | MIN | MAX | UNIT |
|-------------------|--------------------------------------|-----------------|-----|-----|------|
| V <sub>(CM)</sub> | Differential input common mode range |                 | 0.8 | 2.5 | V    |
| Z <sub>(IN)</sub> | Input impedance                      |                 | 300 |     | kΩ   |
| V <sub>CRS</sub>  | Crossover voltage                    |                 | 1.3 | 2.0 | V    |
| V <sub>IL</sub>   | Static SE input logic low level      |                 |     | 0.8 | V    |
| V <sub>IH</sub>   | Static SE input logic high level     |                 | 2.0 |     | V    |
| V <sub>DI</sub>   | Differential input voltage           |                 |     | 0.2 | V    |

## 5.55 USB-PWR (USB Power System)

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

| PARAMETER            |                                                             | TEST CONDITIONS                     | MIN  | TYP | MAX  | UNIT |
|----------------------|-------------------------------------------------------------|-------------------------------------|------|-----|------|------|
| V <sub>LAUNCH</sub>  | V <sub>BUS</sub> detection threshold                        |                                     |      |     | 3.75 | V    |
| V <sub>BUS</sub>     | USB bus voltage                                             | Normal operation                    | 3.76 |     | 5.5  | V    |
| V <sub>USB</sub>     | USB LDO output voltage                                      |                                     |      | 3.3 | ±9%  | V    |
| V <sub>18</sub>      | Internal USB voltage <sup>(1)</sup>                         |                                     |      | 1.8 |      | V    |
| I <sub>USB_EXT</sub> | Maximum external current from VUSB terminal <sup>(2)</sup>  | USB LDO is on                       |      |     | 12   | mA   |
| I <sub>DET</sub>     | USB LDO current overload detection <sup>(3)</sup>           |                                     | 60   |     | 100  | mA   |
| I <sub>SUSPEND</sub> | Operating supply current into VBUS terminal. <sup>(4)</sup> | USB LDO is on, USB PLL disabled     |      |     | 250  | μA   |
| C <sub>BUS</sub>     | VBUS terminal recommended capacitance                       |                                     |      | 4.7 |      | μF   |
| C <sub>USB</sub>     | VUSB terminal recommended capacitance                       |                                     |      | 220 |      | nF   |
| C <sub>18</sub>      | V18 terminal recommended capacitance                        |                                     |      | 220 |      | nF   |
| t <sub>ENABLE</sub>  | Settling time V <sub>USB</sub> and V <sub>18</sub>          | Within 2%, recommended capacitances |      |     | 2    | ms   |
| R <sub>PUR</sub>     | Pullup resistance of PUR terminal <sup>(5)</sup>            |                                     | 70   | 110 | 150  | Ω    |

(1) This voltage is for internal use only. No external DC loading should be applied.

(2) This represents additional current that can be supplied to the application from the VUSB terminal beyond the needs of the USB operation.

(3) A current overload will be detected when the total current supplied from the USB LDO, including I<sub>USB\_EXT</sub>, exceeds this value.

(4) Does not include current contribution of R<sub>pu</sub> and R<sub>pd</sub> as outlined in the USB specification.

(5) This value, in series with an external resistor between PUR and D+, produces the R<sub>pu</sub> as outlined in the USB specification.

## 5.56 USB-PLL (USB Phase Locked Loop)

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

| PARAMETER    |                          | MIN | TYP  | MAX | UNIT |
|--------------|--------------------------|-----|------|-----|------|
| $I_{PLL}$    | Operating supply current |     |      | 7   | mA   |
| $f_{PLL}$    | PLL frequency            |     | 48   |     | MHz  |
| $f_{UPD}$    | PLL reference frequency  | 1.5 |      | 3   | MHz  |
| $t_{LOCK}$   | PLL lock time            |     |      | 2   | ms   |
| $t_{Jitter}$ | PLL jitter               |     | 1000 |     | ps   |

## 5.57 Flash Memory

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

| PARAMETER              |                                                                                                  | $T_J$ | MIN    | TYP    | MAX | UNIT   |
|------------------------|--------------------------------------------------------------------------------------------------|-------|--------|--------|-----|--------|
| $DV_{CC(PGM/ERASE)}$   | Program and erase supply voltage                                                                 |       | 1.8    |        | 3.6 | V      |
| $I_{PGM}$              | Average supply current from DVCC during program                                                  |       |        | 3      | 5   | mA     |
| $I_{ERASE}$            | Average supply current from DVCC during erase                                                    |       |        | 6      | 15  | mA     |
| $I_{MERASE}, I_{BANK}$ | Average supply current from DVCC during mass erase or bank erase                                 |       |        | 6      | 15  | mA     |
| $t_{CPT}$              | Cumulative program time <sup>(1)</sup>                                                           |       |        |        | 16  | ms     |
|                        | Program and erase endurance                                                                      |       | $10^4$ | $10^5$ |     | cycles |
| $t_{Retention}$        | Data retention duration                                                                          | 25°C  | 100    |        |     | years  |
| $t_{Word}$             | Word or byte program time <sup>(2)</sup>                                                         |       | 64     |        | 85  | μs     |
| $t_{Block, 0}$         | Block program time for first byte or word <sup>(2)</sup>                                         |       | 49     |        | 65  | μs     |
| $t_{Block, 1-(N-1)}$   | Block program time for each additional byte or word, except for last byte or word <sup>(2)</sup> |       | 37     |        | 49  | μs     |
| $t_{Block, N}$         | Block program time for last byte or word <sup>(2)</sup>                                          |       | 55     |        | 73  | μs     |
| $t_{Seg Erase}$        | Erase time for segment, mass erase, and bank erase when available <sup>(2)</sup>                 |       | 23     |        | 32  | ms     |
| $f_{MCLK, MGR}$        | MCLK frequency in marginal read mode (FCTL4.MGR0 = 1 or FCTL4.MGR1 = 1)                          |       | 0      |        | 1   | MHz    |

(1) The cumulative program time must not be exceeded when writing to a 128-byte flash block. This parameter applies to all programming methods: individual word write, individual byte write, and block write modes.

(2) These values are hardwired into the state machine of the flash controller.

## 5.58 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 |
|----------------|--------------------------------------------------------------------------------------|-----------------|-------|-----|-----|------|
| $f_{SBW}$      | Spy-Bi-Wire input frequency                                                          | 2.2 V, 3 V      | 0     |     | 20  | MHz  |
| $t_{SBW, Low}$ | Spy-Bi-Wire low clock pulse duration                                                 | 2.2 V, 3 V      | 0.025 |     | 15  | μs   |
| $t_{SBW, En}$  | Spy-Bi-Wire enable time (TEST high to acceptance of first clock edge) <sup>(1)</sup> | 2.2 V, 3 V      |       |     | 1   | μs   |
| $t_{SBW, Rst}$ | Spy-Bi-Wire return to normal operation time                                          |                 | 15    |     | 100 | μs   |
| $f_{TCK}$      | TCK input frequency for 4-wire JTAG <sup>(2)</sup>                                   | 2.2 V           | 0     |     | 5   | MHz  |
|                |                                                                                      | 3 V             | 0     |     | 10  |      |
| $R_{internal}$ | Internal pulldown resistance on TEST                                                 | 2.2 V, 3 V      | 45    | 60  | 80  | kΩ   |

(1) Tools that access the Spy-Bi-Wire interface must wait for the  $t_{SBW, En}$  time after pulling the TEST/SBW\_TCK pin high before applying the first SBW\_TCK clock edge.

(2)  $f_{TCK}$  may be restricted to meet the timing requirements of the module selected.

## 6 Detailed Description

### 6.1 CPU ([Link to User's Guide](#))

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 (see [Figure 6-1](#)).

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

|                          |           |
|--------------------------|-----------|
| Program Counter          | PC/R0     |
| Stack Pointer            | SP/R1     |
| Status Register          | SR/CG1/R2 |
| Constant Generator       | CG2/R3    |
| General-Purpose Register | R4        |
| General-Purpose Register | R5        |
| General-Purpose Register | R6        |
| General-Purpose Register | R7        |
| General-Purpose Register | R8        |
| General-Purpose Register | R9        |
| General-Purpose Register | R10       |
| General-Purpose Register | R11       |
| General-Purpose Register | R12       |
| General-Purpose Register | R13       |
| General-Purpose Register | R14       |
| General-Purpose Register | R15       |

**Figure 6-1. Integrated CPU Registers**

## 6.2 Instruction Set

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. [Table 6-1](#) lists examples of the three types of instruction formats. [Table 6-2](#) lists the address modes.

**Table 6-1. Instruction Word Formats**

| INSTRUCTION WORD FORMAT                     | EXAMPLE   | OPERATION                                 |
|---------------------------------------------|-----------|-------------------------------------------|
| Dual operands, source-destination           | ADD R4,R5 | $R4 + R5 \rightarrow R5$                  |
| Single operands, destination only           | CALL R8   | $PC \rightarrow (TOS), R8 \rightarrow PC$ |
| Relative jump, unconditional or conditional | JNE       | Jump-on-equal bit = 0                     |

**Table 6-2. Address Mode Descriptions**

| ADDRESS MODE            | S <sup>(1)</sup> | D <sup>(1)</sup> | SYNTAX           | EXAMPLE          | OPERATION                                             |
|-------------------------|------------------|------------------|------------------|------------------|-------------------------------------------------------|
| Register                | +                | +                | MOV Rs,Rd        | MOV R10,R11      | $R10 \rightarrow R11$                                 |
| Indexed                 | +                | +                | MOV X(Rn),Y(Rm)  | MOV 2(R5),6(R6)  | $M(2+R5) \rightarrow M(6+R6)$                         |
| Symbolic (PC relative)  | +                | +                | MOV EDE,TONI     |                  | $M(EDE) \rightarrow M(TONI)$                          |
| Absolute                | +                | +                | MOV &MEM, &TCDAT |                  | $M(MEM) \rightarrow M(TCDAT)$                         |
| Indirect                | +                |                  | MOV @Rn,Y(Rm)    | MOV @R10,Tab(R6) | $M(R10) \rightarrow M(Tab+R6)$                        |
| Indirect auto-increment | +                |                  | MOV @Rn+,Rm      | MOV @R10+,R11    | $M(R10) \rightarrow R11$<br>$R10 + 2 \rightarrow R10$ |
| Immediate               | +                |                  | MOV #X,TONI      | MOV #45,TONI     | $\#45 \rightarrow M(TONI)$                            |

(1) S = source, D = destination

## 6.3 Operating Modes

The MCUs have one active mode and seven software-selectable low-power modes of operation. An interrupt event can wake up the device from any of the low-power modes, service the request, and restore back to the low-power mode on return from the interrupt program.

Software can configure the following operating modes:

- Active mode (AM)
  - All clocks are active
- Low-power mode 0 (LPM0)
  - CPU is disabled
  - ACLK and SMCLK remain active, MCLK is disabled
  - FLL loop control remains active
- Low-power mode 1 (LPM1)
  - CPU is disabled
  - FLL loop control is disabled
  - ACLK and SMCLK remain active, MCLK is disabled
- Low-power mode 2 (LPM2)
  - CPU is disabled
  - MCLK, FLL loop control, and DCOCLK are disabled
  - DC generator of the DCO remains enabled
  - ACLK remains active
- Low-power mode 3 (LPM3)
  - CPU is disabled
  - MCLK, FLL loop control, and DCOCLK are disabled
  - DC generator of the DCO is disabled
  - ACLK remains active
- Low-power mode 4 (LPM4)
  - CPU is disabled
  - ACLK is disabled
  - MCLK, FLL loop control, and DCOCLK are disabled
  - DC generator of the DCO is disabled
  - Crystal oscillator is stopped
  - Complete data retention
- Low-power mode 3.5 (LPM3.5)
  - Internal regulator disabled
  - No data retention
  - RTC enabled and clocked by low-frequency oscillator
  - Wake-up input from  $\overline{\text{RST}}/\text{NMI}$ , RTC\_B, P1, P2, P3, and P4
- Low-power mode 4.5 (LPM4.5)
  - Internal regulator disabled
  - No data retention
  - Wake-up input from  $\overline{\text{RST}}/\text{NMI}$ , P1, P2, P3, and P4

## 6.4 Interrupt Vector Addresses

The interrupt vectors and the power-up start address are in the address range 0FFFFh to 0FF80h (see [Table 6-3](#)). The vector contains the 16-bit address of the appropriate interrupt-handler instruction sequence.

**Table 6-3. Interrupt Sources, Flags, and Vectors**

| INTERRUPT SOURCE                                                                                                  | INTERRUPT FLAG                                                                                                          | SYSTEM INTERRUPT | WORD ADDRESS | PRIORITY    |
|-------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|------------------|--------------|-------------|
| <b>System Reset</b><br>Power up, External Reset<br>Watchdog time-out, key violation<br>Flash memory key violation | WDTIFG, KEYV (SYSRSTIV) <sup>(1) (2)</sup>                                                                              | Reset            | 0FFFEh       | 63, highest |
| <b>System NMI</b><br>PMM<br>Vacant memory access<br>JTAG mailbox                                                  | SVMLIFG, SVMHIFG, DLYLIFG, DLYHIFG,<br>SVMLVLRIFG, SVMHVLRFIFG, VMAIFG,<br>JMBINIFG, JMBOUTIFG (SYSSNIV) <sup>(1)</sup> | (Non)maskable    | 0FFFCh       | 62          |
| <b>User NMI</b><br>NMI<br>Oscillator fault<br>Flash memory access violation                                       | NMIIFG, OFIFG, ACCVIFG, BUSIFG<br>(SYSUNIV) <sup>(1) (2)</sup>                                                          | (Non)maskable    | 0FFFAh       | 61          |
| Comp_B                                                                                                            | Comparator B interrupt flags (CBIV) <sup>(1) (3)</sup>                                                                  | Maskable         | 0FFF8h       | 60          |
| Timer TB0                                                                                                         | TB0CCR0 CCIFG0 <sup>(3)</sup>                                                                                           | Maskable         | 0FFF6h       | 59          |
| Timer TB0                                                                                                         | TB0CCR1 CCIFG1 to TB0CCR6 CCIFG6,<br>TB0IFG (TB0IV) <sup>(1) (3)</sup>                                                  | Maskable         | 0FFF4h       | 58          |
| Watchdog interval timer mode                                                                                      | WDTIFG                                                                                                                  | Maskable         | 0FFF2h       | 57          |
| USCI_A0 receive or transmit                                                                                       | UCA0RXIFG, UCA0TXIFG (UCA0IV) <sup>(1) (3)</sup>                                                                        | Maskable         | 0FFF0h       | 56          |
| USCI_B0 receive or transmit                                                                                       | UCB0RXIFG, UCB0TXIFG (UCB0IV) <sup>(1) (3)</sup>                                                                        | Maskable         | 0FFFEh       | 55          |
| ADC12_A                                                                                                           | ADC12IFG0 to ADC12IFG15 (ADC12IV) <sup>(1) (3)</sup>                                                                    | Maskable         | 0FFECCh      | 54          |
| Timer TA0                                                                                                         | TA0CCR0 CCIFG0 <sup>(3)</sup>                                                                                           | Maskable         | 0FFEAh       | 53          |
| Timer TA0                                                                                                         | TA0CCR1 CCIFG1 to TA0CCR4 CCIFG4,<br>TA0IFG (TA0IV) <sup>(1) (3)</sup>                                                  | Maskable         | 0FFE8h       | 52          |
| USB_UBM <sup>(4)</sup>                                                                                            | USB interrupts (USBIV) <sup>(1) (3)</sup>                                                                               | Maskable         | 0FFE6h       | 51          |
| LDO-PWR <sup>(5)</sup>                                                                                            | LDOOFFIFG, LDOONIFG, LDOOVLIFG                                                                                          |                  |              |             |
| DMA                                                                                                               | DMA0IFG, DMA1IFG, DMA2IFG, DMA3IFG,<br>DMA4IFG, DMA5IFG (DMAIV) <sup>(1) (3)</sup>                                      | Maskable         | 0FFE4h       | 50          |
| Timer TA1                                                                                                         | TA1CCR0 CCIFG0 <sup>(3)</sup>                                                                                           | Maskable         | 0FFE2h       | 49          |
| Timer TA1                                                                                                         | TA1CCR1 CCIFG1 to TA1CCR2 CCIFG2,<br>TA1IFG (TA1IV) <sup>(1) (3)</sup>                                                  | Maskable         | 0FFE0h       | 48          |
| I/O Port P1                                                                                                       | P1IFG.0 to P1IFG.7 (P1IV) <sup>(1)(3)</sup>                                                                             | Maskable         | 0FFDEh       | 47          |
| USCI_A1 receive or transmit                                                                                       | UCA1RXIFG, UCA1TXIFG (UCA1IV) <sup>(1) (3)</sup>                                                                        | Maskable         | 0FFDCh       | 46          |
| USCI_B1 receive or transmit                                                                                       | UCB1RXIFG, UCB1TXIFG (UCB1IV) <sup>(1) (3)</sup>                                                                        | Maskable         | 0FFDAh       | 45          |
| I/O port P2                                                                                                       | P2IFG.0 to P2IFG.7 (P2IV) <sup>(1) (3)</sup>                                                                            | Maskable         | 0FFD8h       | 44          |
| LCD_B <sup>(6)</sup>                                                                                              | LCD_B Interrupt Flags (LCDBIV) <sup>(1)</sup>                                                                           | Maskable         | 0FFD6h       | 43          |
| RTC_B                                                                                                             | RTCRDYIFG, RTCTEVIFG, RTCAIFG,<br>RT0PSIFG, RT1PSIFG, RTCOFIFG (RTCIV) <sup>(1) (3)</sup>                               | Maskable         | 0FFD4h       | 42          |
| DAC12_A                                                                                                           | DAC12_0IFG, DAC12_1IFG <sup>(1) (3)</sup>                                                                               | Maskable         | 0FFD2h       | 41          |
| Timer TA2                                                                                                         | TA2CCR0 CCIFG0 <sup>(3)</sup>                                                                                           | Maskable         | 0FFD0h       | 40          |
| Timer TA2                                                                                                         | TA2CCR1 CCIFG1 to TA2CCR2 CCIFG2,<br>TA2IFG (TA2IV) <sup>(1) (3)</sup>                                                  | Maskable         | 0FFCEh       | 39          |

(1) Multiple source flags

(2) A reset is generated if the CPU tries to fetch instructions from within peripheral space or vacant memory space.

(Non)maskable: the individual interrupt enable bit can disable an interrupt event, but the general interrupt enable bit cannot disable it.

(3) Interrupt flags are in the module.

(4) Only on devices with peripheral module USB (MSP430F665x and MSP430F565x)

(5) Only on devices with peripheral module LDO-PWR (MSP430F535x and MSP430F645x)

(6) Only on devices with peripheral module LCD\_B (MSP430F665x and MSP430F645x), otherwise reserved (MSP430F535x and MSP430F565x)

**Table 6-3. Interrupt Sources, Flags, and Vectors (continued)**

| INTERRUPT SOURCE            | INTERRUPT FLAG                                   | SYSTEM INTERRUPT | WORD ADDRESS | PRIORITY  |
|-----------------------------|--------------------------------------------------|------------------|--------------|-----------|
| I/O port P3                 | P3IFG.0 to P3IFG.7 (P3IV) <sup>(1) (3)</sup>     | Maskable         | 0FFCCh       | 38        |
| I/O Port P4                 | P4IFG.0 to P4IFG.7 (P4IV) <sup>(1) (3)</sup>     | Maskable         | 0FFCAh       | 37        |
| USCI_A2 receive or transmit | UCA2RXIFG, UCA2TXIFG (UCA2IV) <sup>(1) (3)</sup> |                  | 0FFC8h       | 36        |
| USCI_B2 receive or transmit | UCB2RXIFG, UCB2TXIFG (UCB2IV) <sup>(1) (3)</sup> |                  | 0FFC6h       | 35        |
| Reserved                    | Reserved <sup>(7)</sup>                          |                  | 0FFC4h       | 34        |
|                             |                                                  |                  | ⋮            | ⋮         |
|                             |                                                  |                  | 0FF80h       | 0, lowest |

(7) Reserved interrupt vectors at addresses are not used in this device and can be used for regular program code if necessary. To maintain compatibility with other devices, TI recommends reserving these locations.

## 6.5 Memory Organization

Table 6-4 summarizes the memory map of all device variants.

**Table 6-4. Memory Organization<sup>(1)</sup>**

|                                 |            | <b>MSP430F6458<br/>MSP430F5358</b>                                               | <b>MSP430F6459<br/>MSP430F5359</b>                                               | <b>MSP430F6658<br/>MSP430F5658</b>                                               | <b>MSP430F6659<br/>MSP430F5659</b>                                               |
|---------------------------------|------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Memory (flash)                  | Total Size | 384KB                                                                            | 512KB                                                                            | 384KB                                                                            | 512KB                                                                            |
| Main: interrupt vector          |            | 00FFFFh to 00FF80h                                                               | 00FFFFh to 00FF80h                                                               | 00FFFFh to 00FF80h                                                               | 00FFFFh to 00FF80h                                                               |
| Main: code memory               | Bank 3     | N/A                                                                              | 128KB<br>087FFFh to 068000h                                                      | N/A                                                                              | 128KB<br>087FFFh to 068000h                                                      |
|                                 | Bank 2     | 128KB<br>067FFFh to 048000h                                                      | 128KB<br>067FFFh-48000h                                                          | 128KB<br>067FFFh to 048000h                                                      | 128KB<br>067FFFh-48000h                                                          |
|                                 | Bank 1     | 128KB<br>047FFFh to 028000h                                                      | 128KB<br>047FFFh to 028000h                                                      | 128KB<br>047FFFh to 028000h                                                      | 128KB<br>047FFFh to 028000h                                                      |
|                                 | Bank 0     | 128KB<br>027FFFh to 008000h                                                      | 128KB<br>027FFFh to 008000h                                                      | 128KB<br>027FFFh to 008000h                                                      | 128KB<br>027FFFh to 008000h                                                      |
| MID support software (ROM)      | Total Size | 1KB<br>006FFFh to 006C00h                                                        | 1KB<br>006FFFh to 006C00h                                                        | 1KB<br>006FFFh to 006C00h                                                        | 1KB<br>006FFFh to 006C00h                                                        |
| RAM                             | Sector 3   | 16KB<br>0FBFFFh to 0F8000h                                                       | 16KB<br>0FBFFFh to 0F8000h                                                       | 16KB<br>0FBFFFh to 0F8000h                                                       | 16KB<br>0FBFFFh to 0F8000h                                                       |
|                                 | Sector 2   | N/A                                                                              | 16KB<br>0F7FFFh to 0F4000h                                                       | N/A                                                                              | 16KB<br>0F7FFFh to 0F4000h                                                       |
|                                 | Sector 1   | N/A                                                                              | 16KB<br>0F3FFFh to 0F0000h                                                       | N/A                                                                              | 16KB<br>0F3FFFh to 0F0000h                                                       |
|                                 | Sector 0   | 16KB<br>0063FFFh to 002400h<br>(mirrored at address range<br>0FFFFFh to 0FC000h) | 16KB<br>0063FFFh to 002400h<br>(mirrored at address range<br>0FFFFFh to 0FC000h) | 16KB<br>0063FFFh to 002400h<br>(mirrored at address range<br>0FFFFFh to 0FC000h) | 16KB<br>0063FFFh to 002400h<br>(mirrored at address range<br>0FFFFFh to 0FC000h) |
| RAM <sup>(2)</sup>              | Sector 7   | 2KB<br>0023FFFh to 001C00h                                                       | 2KB<br>0023FFFh to 001C00h                                                       | N/A                                                                              | N/A                                                                              |
| USB RAM <sup>(3)</sup>          | Sector 7   | N/A                                                                              | N/A                                                                              | 2KB<br>0023FFFh to 001C00h                                                       | 2KB<br>0023FFFh to 001C00h                                                       |
| Information memory (flash)      | Info A     | 128 B<br>0019FFFh to 001980h                                                     | 128 B<br>0019FFFh to 001980h                                                     | 128 B<br>0019FFFh to 001980h                                                     | 128 B<br>0019FFFh to 001980h                                                     |
|                                 | Info B     | 128 B<br>00197Fh to 001900h                                                      | 128 B<br>00197Fh to 001900h                                                      | 128 B<br>00197Fh to 001900h                                                      | 128 B<br>00197Fh to 001900h                                                      |
|                                 | Info C     | 128 B<br>0018FFFh to 001880h                                                     | 128 B<br>0018FFFh to 001880h                                                     | 128 B<br>0018FFFh to 001880h                                                     | 128 B<br>0018FFFh to 001880h                                                     |
|                                 | Info D     | 128 B<br>00187Fh to 001800h                                                      | 128 B<br>00187Fh to 001800h                                                      | 128 B<br>00187Fh to 001800h                                                      | 128 B<br>00187Fh to 001800h                                                      |
| Bootloader (BSL) memory (flash) | BSL 3      | 512 B<br>0017FFFh to 001600h                                                     | 512 B<br>0017FFFh to 001600h                                                     | 512 B<br>0017FFFh to 001600h                                                     | 512 B<br>0017FFFh to 001600h                                                     |
|                                 | BSL 2      | 512 B<br>0015FFFh to 001400h                                                     | 512 B<br>0015FFFh to 001400h                                                     | 512 B<br>0015FFFh to 001400h                                                     | 512 B<br>0015FFFh to 001400h                                                     |
|                                 | BSL 1      | 512 B<br>0013FFFh to 001200h                                                     | 512 B<br>0013FFFh to 001200h                                                     | 512 B<br>0013FFFh to 001200h                                                     | 512 B<br>0013FFFh to 001200h                                                     |
|                                 | BSL 0      | 512 B<br>0011FFFh to 001000h                                                     | 512 B<br>0011FFFh to 001000h                                                     | 512 B<br>0011FFFh to 001000h                                                     | 512 B<br>0011FFFh to 001000h                                                     |
| Peripherals                     | Size       | 4KB<br>000FFFh to 000000h                                                        | 4KB<br>000FFFh to 000000h                                                        | 4KB<br>000FFFh to 000000h                                                        | 4KB<br>000FFFh to 000000h                                                        |

(1) N/A = Not available

(2) Only available on F6459, F6458, F5359, F5358 devices.

(3) Only available on F6659, F6658, F5659, F5658 devices. USB RAM can be used as general-purpose RAM when not used for USB operation.

## 6.6 Bootloader (BSL)

The BSL enables users to program the flash memory or RAM using various serial interfaces. Access to the device memory by the BSL is protected by an user-defined password. For complete description of the features of the BSL and its implementation, see the [MSP430 Flash Device Bootloader \(BSL\) User's Guide](#).

### 6.6.1 USB BSL

The devices MSP430F565x and MSP430F665x come preprogrammed with the USB BSL. Use of the USB BSL requires external access to six pins (see [Table 6-5](#)). In addition to these pins, the application must support external components necessary for normal USB operation; for example, the proper crystal on XT2IN and XT2OUT or proper decoupling.

**Table 6-5. USB BSL Pin Requirements and Functions**

| DEVICE SIGNAL                                     | BSL FUNCTION                 |
|---------------------------------------------------|------------------------------|
| $\overline{\text{RST}}/\text{NMI}/\text{SBWTDIO}$ | Entry sequence signal        |
| PU.0/DP                                           | USB data terminal DP         |
| PU.1/DM                                           | USB data terminal DM         |
| PUR                                               | USB pullup resistor terminal |
| VBUS                                              | USB bus power supply         |
| VSSU                                              | USB ground supply            |

#### NOTE

The default USB BSL evaluates the logic level of the PUR pin after a BOR reset. If it is pulled high externally, then the BSL is invoked. Therefore, unless the application is invoking the BSL, it is important to keep PUR pulled low after a BOR reset, even if BSL or USB is never used. TI recommends applying a 1-M $\Omega$  resistor to ground.

### 6.6.2 UART BSL

All devices without a USB module (MSP430F535x and MSP430F645x) come preprogrammed with the UART BSL. A UART BSL is also available for devices with USB module that can be programmed by the user into the BSL memory by replacing the preprogrammed, factory supplied, USB BSL. Use of the UART BSL requires external access to six pins (see [Table 6-6](#)).

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

| DEVICE SIGNAL                                     | BSL FUNCTION          |
|---------------------------------------------------|-----------------------|
| $\overline{\text{RST}}/\text{NMI}/\text{SBWTDIO}$ | Entry sequence signal |
| TEST/SBWTK                                        | Entry sequence signal |
| P1.1                                              | Data transmit         |
| P1.2                                              | Data receive          |
| VCC                                               | Power supply          |
| VSS                                               | Ground supply         |

## 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  $\overline{\text{RST}}/\text{NMI}/\text{SBWTDIO}$  is required to interface with MSP430 development tools and device programmers. [Table 6-7](#) 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 BSL and its implementation, see [MSP430 Programming With the JTAG Interface](#).

**Table 6-7. 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            |
| $\overline{\text{RST}}/\text{NMI}/\text{SBWTDIO}$ | 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 two wire Spy-Bi-Wire interface. Spy-Bi-Wire can be used to interface with MSP430 development tools and device programmers. [Table 6-8](#) 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 6-8. Spy-Bi-Wire Pin Requirements and Functions**

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

## 6.8 Flash Memory ([Link to User's Guide](#))

The flash memory can be programmed through the JTAG port, Spy-Bi-Wire (SBW), the BSL, or in-system by the CPU. The CPU can perform single-byte, single-word, and long-word writes to the flash memory. Features of the flash memory include:

- Flash memory has n segments of main memory and four segments of information memory (A to D) of 128 bytes each. Each segment in main memory is 512 bytes in size.
- Segments 0 to n may be erased in one step, or each segment may be individually erased.
- Segments A to D can be erased individually, or as a group with segments 0 to n. Segments A to D are also called *information memory*.
- Segment A can be locked separately.

## 6.9 Memory Integrity Detection (MID) [\(Link to User's Guide\)](#)

The MID is an add-on to the flash memory controller. MID provides additional functionality over the regular flash operation methods. The main purpose of the MID function is to gain higher reliability of flash content and overall system integrity in harsh environments and in application areas that require such features. The on-chip MID ROM contains the factory-programmed MID support software. This software package provides several software functions that allow an application to use all of the features of the MID.

The MID functionality can be enabled for different flash memory ranges. These memory ranges are selectable by the cw0 parameter of the MID function MidEnable() (see [Table 6-9](#)).

**Table 6-9. Address Range Coverage of cw0 Parameter of MidEnable() Function**

| BITS OF cw0 PARAMETER | MSP430F6659<br>MSP430F6459<br>MSP430F5659<br>MSP430F5359 | MSP430F6658<br>MSP430F6458<br>MSP430F5658<br>MSP430F5358 |
|-----------------------|----------------------------------------------------------|----------------------------------------------------------|
| cw0.15                | 087FFFh to 080000h                                       | N/A                                                      |
| cw0.14                | 07FFFFh to 078000h                                       | N/A                                                      |
| cw0.13                | 077FFFh to 070000h                                       | N/A                                                      |
| cw0.12                | 06FFFFh to 068000h                                       | N/A                                                      |
| cw0.11                | 067FFFh to 060000h                                       | 067FFFh to 060000h                                       |
| cw0.10                | 05FFFFh to 058000h                                       | 05FFFFh to 058000h                                       |
| cw0.9                 | 057FFFh to 050000h                                       | 057FFFh to 050000h                                       |
| cw0.8                 | 04FFFFh to 048000h                                       | 04FFFFh to 048000h                                       |
| cw0.7                 | 047FFFh to 040000h                                       | 047FFFh to 040000h                                       |
| cw0.6                 | 03FFFFh to 038000h                                       | 03FFFFh to 038000h                                       |
| cw0.5                 | 037FFFh to 030000h                                       | 037FFFh to 030000h                                       |
| cw0.4                 | 02FFFFh to 028000h                                       | 02FFFFh to 028000h                                       |
| cw0.3                 | 027FFFh to 020000h                                       | 027FFFh to 020000h                                       |
| cw0.2                 | 01FFFFh to 018000h                                       | 01FFFFh to 018000h                                       |
| cw0.1                 | 017FFFh to 010000h                                       | 017FFFh to 010000h                                       |
| cw0.0                 | 00FFFFh to 008000h                                       | 00FFFFh to 008000h                                       |

## 6.10 RAM [\(Link to User's Guide\)](#)

The RAM is made up of n sectors. Each sector can be completely powered down to save leakage; however, all data are lost. Features of the RAM include:

- RAM has n sectors. The size of a sector can be found in [Section 6.5](#).
- Each sector 0 to n can be complete disabled; however, data retention is lost.
- Each sector 0 to n automatically enters low-power retention mode when possible.
- For devices that contain USB memory, the USB memory can be used as normal RAM if USB is not required.

## 6.11 Backup RAM [\(Link to User's Guide\)](#)

The backup RAM provides a limited number of bytes of RAM that are retained during LPMx.5 and during operation from a backup supply if the battery backup system module is implemented.

There are 8 bytes of backup RAM available. It can be word-wise accessed by the control registers BAKMEM0, BAKMEM1, BAKMEM2, and BAKMEM3.

## 6.12 Peripherals

Peripherals are connected to the CPU through data, address, and control buses. Peripherals can be managed using all instructions. For complete module descriptions, see the [MSP430F5xx and MSP430F6xx Family User's Guide](#).

### 6.12.1 Digital I/O ([Link to User's Guide](#))

Nine 8-bit I/O ports are implemented: P1 through P9 are complete, and port PJ contains four individual I/O ports.

- 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.
- Programmable drive strength on all ports.
- Edge-selectable interrupt input capability for all the eight bits of ports P1, P2, P3, and P4.
- Read and write access to port-control registers is supported by all instructions.
- Ports can be accessed byte-wise (P1 through P9) or word-wise in pairs (PA through PD).

### 6.12.2 Port Mapping Controller ([Link to User's Guide](#))

The port mapping controller allows the flexible and reconfigurable mapping of digital functions to port P2. [Table 6-10](#) lists the available mappings, and [Table 6-11](#) lists the default settings.

**Table 6-10. Port Mapping Mnemonics and Functions**

| VALUE | PxMAPy MNEMONIC | INPUT PIN FUNCTION                                                       | OUTPUT PIN FUNCTION                  |
|-------|-----------------|--------------------------------------------------------------------------|--------------------------------------|
| 0     | PM_NONE         | None                                                                     | DVSS                                 |
| 1     | PM_CBOUT        | –                                                                        | Comparator_B output                  |
|       | PM_TB0CLK       | Timer TB0 clock input                                                    | –                                    |
| 2     | PM_ADC12CLK     | –                                                                        | ADC12CLK                             |
|       | PM_DMAE0        | DMAE0 Input                                                              | –                                    |
| 3     | PM_SVMOUT       | –                                                                        | SVM output                           |
|       | PM_TB0OUTH      | Timer TB0 high impedance input<br>TB0OUTH                                | –                                    |
| 4     | PM_TB0CCR0B     | Timer TB0 CCR0 capture input CCI0B                                       | Timer TB0: TB0.0 compare output Out0 |
| 5     | PM_TB0CCR1B     | Timer TB0 CCR1 capture input CCI1B                                       | Timer TB0: TB0.1 compare output Out1 |
| 6     | PM_TB0CCR2B     | Timer TB0 CCR2 capture input CCI2B                                       | Timer TB0: TB0.2 compare output Out2 |
| 7     | PM_TB0CCR3B     | Timer TB0 CCR3 capture input CCI3B                                       | Timer TB0: TB0.3 compare output Out3 |
| 8     | PM_TB0CCR4B     | Timer TB0 CCR4 capture input CCI4B                                       | Timer TB0: TB0.4 compare output Out4 |
| 9     | PM_TB0CCR5B     | Timer TB0 CCR5 capture input CCI5B                                       | Timer TB0: TB0.5 compare output Out5 |
| 10    | PM_TB0CCR6B     | Timer TB0 CCR6 capture input CCI6B                                       | Timer TB0: TB0.6 compare output Out6 |
| 11    | PM_UCA0RXD      | USCI_A0 UART RXD (Direction controlled by USCI – input)                  |                                      |
|       | PM_UCA0SOMI     | USCI_A0 SPI slave out master in (direction controlled by USCI)           |                                      |
| 12    | PM_UCA0TXD      | USCI_A0 UART TXD (Direction controlled by USCI – output)                 |                                      |
|       | PM_UCA0SIMO     | USCI_A0 SPI slave in master out (direction controlled by USCI)           |                                      |
| 13    | PM_UCA0CLK      | USCI_A0 clock input/output (direction controlled by USCI)                |                                      |
|       | PM_UCB0STE      | USCI_B0 SPI slave transmit enable (direction controlled by USCI – input) |                                      |
| 14    | PM_UCB0SOMI     | USCI_B0 SPI slave out master in (direction controlled by USCI)           |                                      |
|       | PM_UCB0SCL      | USCI_B0 I2C clock (open drain and direction controlled by USCI)          |                                      |
| 15    | PM_UCB0SIMO     | USCI_B0 SPI slave in master out (direction controlled by USCI)           |                                      |
|       | PM_UCB0SDA      | USCI_B0 I2C data (open drain and direction controlled by USCI)           |                                      |
| 16    | PM_UCB0CLK      | USCI_B0 clock input/output (direction controlled by USCI)                |                                      |
|       | PM_UCA0STE      | USCI_A0 SPI slave transmit enable (direction controlled by USCI – input) |                                      |

**Table 6-10. Port Mapping Mnemonics and Functions (continued)**

| VALUE                    | PxMAPy MNEMONIC | INPUT PIN FUNCTION                                                                                                         | OUTPUT PIN FUNCTION |
|--------------------------|-----------------|----------------------------------------------------------------------------------------------------------------------------|---------------------|
| 17                       | PM_MCLK         | –                                                                                                                          | MCLK                |
| 18                       | Reserved        | Reserved for test purposes. Do not use this setting.                                                                       |                     |
| 19                       | Reserved        | Reserved for test purposes. Do not use this setting.                                                                       |                     |
| 20-30                    | Reserved        | None                                                                                                                       | DVSS                |
| 31 (0FFh) <sup>(1)</sup> | PM_ANALOG       | Disables the output driver and the input Schmitt-trigger to prevent parasitic cross currents when applying analog signals. |                     |

(1) The value of the PM\_ANALOG mnemonic is set to 0FFh. The port mapping registers are only 5 bits wide, and the upper bits are ignored, which results in a read value of 31.

**Table 6-11. Default Mapping**

| PIN                    | PxMAPy MNEMONIC            | INPUT PIN FUNCTION                                                                                                                     | OUTPUT PIN FUNCTION |
|------------------------|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| P2.0/P2MAP0            | PM_UCB0STE,<br>PM_UCA0CLK  | USCI_B0 SPI slave transmit enable (direction controlled by USCI – input),<br>USCI_A0 clock input/output (direction controlled by USCI) |                     |
| P2.1/P2MAP1            | PM_UCB0SIMO,<br>PM_UCB0SDA | USCI_B0 SPI slave in master out (direction controlled by USCI),<br>USCI_B0 I2C data (open drain and direction controlled by USCI)      |                     |
| P2.2/P2MAP2            | PM_UCB0SOMI,<br>PM_UCB0SCL | USCI_B0 SPI slave out master in (direction controlled by USCI),<br>USCI_B0 I2C clock (open drain and direction controlled by USCI)     |                     |
| P2.3/P2MAP3            | PM_UCB0CLK,<br>PM_UCA0STE  | USCI_B0 clock input/output (direction controlled by USCI),<br>USCI_A0 SPI slave transmit enable (direction controlled by USCI – input) |                     |
| P2.4/P2MAP4            | PM_UCA0TXD,<br>PM_UCA0SIMO | USCI_A0 UART TXD (direction controlled by USCI – output),<br>USCI_A0 SPI slave in master out (direction controlled by USCI)            |                     |
| P2.5/P2MAP5            | PM_UCA0RXD,<br>PM_UCA0SOMI | USCI_A0 UART RXD (direction controlled by USCI – input),<br>USCI_A0 SPI slave out master in (direction controlled by USCI)             |                     |
| P2.6/P2MAP6/ R03       | PM_NONE                    | –                                                                                                                                      | DVSS                |
| P2.7/P2MAP7/LCDREF/R13 | PM_NONE                    | –                                                                                                                                      | DVSS                |

### 6.12.3 Oscillator and System Clock ([Link to User's Guide](#))

The clock system is supported by the Unified Clock System (UCS) module that includes support for a 32-kHz watch crystal oscillator (in XT1 LF mode; XT1 HF mode is not supported), an internal very-low-power low-frequency oscillator (VLO), an internal trimmed low-frequency oscillator (REFO), an integrated internal digitally controlled oscillator (DCO), and a high-frequency crystal oscillator (XT2). The UCS module is designed to meet the requirements of both low system cost and low power consumption. The UCS module features digital frequency locked loop (FLL) hardware that, in conjunction with a digital modulator, stabilizes the DCO frequency to a programmable multiple of the watch crystal frequency. The internal DCO provides a fast turnon clock source and stabilizes in 3  $\mu$ s (typical). The UCS module provides the following clock signals:

- Auxiliary clock (ACLK), sourced from a 32-kHz watch crystal (XT1), a high-frequency crystal (XT2), the internal low-frequency oscillator (VLO), the trimmed low-frequency oscillator (REFO), or the internal digitally-controlled oscillator DCO.
- Main clock (MCLK), the system clock used by the CPU. MCLK can be sourced by same sources available to ACLK.
- Sub-Main clock (SMCLK), the subsystem clock used by the peripheral modules. SMCLK can be sourced by same sources available to ACLK.
- ACLK/n, the buffered output of ACLK, ACLK/2, ACLK/4, ACLK/8, ACLK/16, ACLK/32.

#### 6.12.4 Power-Management Module (PMM) ([Link to User's Guide](#))

The PMM includes an integrated voltage regulator that supplies the core voltage to the device and contains programmable output levels to provide for power optimization. The PMM also includes supply voltage supervisor (SVS) and supply voltage monitoring (SVM) circuitry, as well as brownout protection. The brownout circuit is implemented to provide the proper internal reset signal to the device during power-on and power-off. The SVS and SVM circuitry detects if the supply voltage drops below a user-selectable level and supports both supply voltage supervision (the device is automatically reset) and supply voltage monitoring (the device is not automatically reset). SVS and SVM circuitry is available on the primary supply and core supply.

#### 6.12.5 Hardware Multiplier (MPY) ([Link to User's Guide](#))

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 and unsigned multiplication as well as signed and unsigned multiply-and-accumulate operations.

#### 6.12.6 Real-Time Clock (RTC\_B) ([Link to User's Guide](#))

The RTC\_B module can be configured for real-time clock (RTC) or calendar mode providing seconds, minutes, hours, day of week, day of month, month, and year. Calendar mode integrates an internal calendar which 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. The implementation on this device supports operation in LPM3.5 mode and operation from a backup supply.

[Using the MSP430 RTC\\_B Module With Battery Backup Supply](#) describes how to use the RTC\_B with battery backup supply functionality to retain the time and keep the RTC counting through loss of main power supply, as well as how to handle correct reinitialization when the main power supply is restored.

#### 6.12.7 Watchdog Timer (WDT\_A) ([Link to User's Guide](#))

The primary function of the WDT\_A module is to perform a controlled system restart after 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.

#### 6.12.8 System Module (SYS) ([Link to User's Guide](#))

The SYS module handles many of the system functions within the device. These include power-on reset and power-up clear handling, NMI source selection and management, reset interrupt vector generators, bootloader entry mechanisms, and configuration management (device descriptors). SYS also includes a data exchange mechanism using JTAG called a JTAG mailbox that can be used in the application. [Table 6-12](#) lists the SYS module interrupt vector registers.

**Table 6-12. System Module Interrupt Vector Registers**

| INTERRUPT VECTOR REGISTER | INTERRUPT EVENT                | WORD ADDRESS | OFFSET     | PRIORITY |
|---------------------------|--------------------------------|--------------|------------|----------|
| SYSRSTIV, System Reset    | No interrupt pending           | 019Eh        | 00h        | Highest  |
|                           | Brownout (BOR)                 |              | 02h        |          |
|                           | RST/NMI (BOR)                  |              | 04h        |          |
|                           | PMMSWBOR (BOR)                 |              | 06h        |          |
|                           | LPM3.5 or LPM4.5 wakeup (BOR)  |              | 08h        |          |
|                           | Security violation (BOR)       |              | 0Ah        |          |
|                           | SVSL (POR)                     |              | 0Ch        |          |
|                           | SVSH (POR)                     |              | 0Eh        |          |
|                           | SVML_OVP (POR)                 |              | 10h        |          |
|                           | SVMH_OVP (POR)                 |              | 12h        |          |
|                           | PMMSWPOR (POR)                 |              | 14h        |          |
|                           | WDT time-out (PUC)             |              | 16h        |          |
|                           | WDT key violation (PUC)        |              | 18h        |          |
|                           | KEYV flash key violation (PUC) |              | 1Ah        |          |
|                           | Reserved                       |              | 1Ch        |          |
|                           | Peripheral area fetch (PUC)    |              | 1Eh        |          |
|                           | PMM key violation (PUC)        |              | 20h        |          |
|                           | Reserved                       |              | 22h to 3Eh | Lowest   |
| SYSSNIV, System NMI       | No interrupt pending           | 019Ch        | 00h        | Highest  |
|                           | SVMLIFG                        |              | 02h        |          |
|                           | SVMHIFG                        |              | 04h        |          |
|                           | DLYLIFG                        |              | 06h        |          |
|                           | DLYHIFG                        |              | 08h        |          |
|                           | VMAIFG                         |              | 0Ah        |          |
|                           | JMBINIFG                       |              | 0Ch        |          |
|                           | JMBOUTIFG                      |              | 0Eh        |          |
|                           | SVMLVLRIFG                     |              | 10h        |          |
|                           | SVMHVLRIFG                     |              | 12h        |          |
|                           | Reserved                       |              | 14h to 1Eh | Lowest   |
| SYSUNIV, User NMI         | No interrupt pending           | 019Ah        | 00h        | Highest  |
|                           | NMIIFG                         |              | 02h        |          |
|                           | OFIFG                          |              | 04h        |          |
|                           | ACCVIFG                        |              | 06h        |          |
|                           | BUSIFG                         |              | 08h        |          |
|                           | Reserved                       |              | 0Ah to 1Eh | Lowest   |
| SYSBERRIV, Bus Error      | No interrupt pending           | 0198h        | 00h        | Highest  |
|                           | USB wait state time-out        |              | 02h        |          |
|                           | Reserved                       |              | 04h        |          |
|                           | MID error                      |              | 06h        |          |
|                           | Reserved                       |              | 08h to 1Eh | Lowest   |

### 6.12.9 DMA Controller ([Link to User's Guide](#))

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\_A 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 awaken to move data to or from a peripheral.

The USB timestamp generator also uses the channel 0, 1, and 2 DMA trigger assignments described in [Table 6-13](#). The USB timestamp generator is available only on devices with the USB module (MSP430F565x and MSP430F665x).

**Table 6-13. DMA Trigger Assignments<sup>(1)</sup>**

| TRIGGER | CHANNEL                  |         |         |         |         |         |
|---------|--------------------------|---------|---------|---------|---------|---------|
|         | 0                        | 1       | 2       | 3       | 4       | 5       |
| 0       | DMAREQ                   |         |         |         |         |         |
| 1       | TA0CCR0 CCIFG            |         |         |         |         |         |
| 2       | TA0CCR2 CCIFG            |         |         |         |         |         |
| 3       | TA1CCR0 CCIFG            |         |         |         |         |         |
| 4       | TA1CCR2 CCIFG            |         |         |         |         |         |
| 5       | TA2CCR0 CCIFG            |         |         |         |         |         |
| 6       | TA2CCR2 CCIFG            |         |         |         |         |         |
| 7       | TBCCR0 CCIFG             |         |         |         |         |         |
| 8       | TBCCR2 CCIFG             |         |         |         |         |         |
| 9       | Reserved                 |         |         |         |         |         |
| 10      | Reserved                 |         |         |         |         |         |
| 11      | Reserved                 |         |         |         |         |         |
| 12      | UCA2RXIFG                |         |         |         |         |         |
| 13      | UCA2TXIFG                |         |         |         |         |         |
| 14      | UCB2RXIFG                |         |         |         |         |         |
| 15      | UCB2TXIFG                |         |         |         |         |         |
| 16      | UCA0RXIFG                |         |         |         |         |         |
| 17      | UCA0TXIFG                |         |         |         |         |         |
| 18      | UCB0RXIFG                |         |         |         |         |         |
| 19      | UCB0TXIFG                |         |         |         |         |         |
| 20      | UCA1RXIFG                |         |         |         |         |         |
| 21      | UCA1TXIFG                |         |         |         |         |         |
| 22      | UCB1RXIFG                |         |         |         |         |         |
| 23      | UCB1TXIFG                |         |         |         |         |         |
| 24      | ADC12IFGx                |         |         |         |         |         |
| 25      | DAC12_0IFG               |         |         |         |         |         |
| 26      | DAC12_1IFG               |         |         |         |         |         |
| 27      | USB FNRXD <sup>(2)</sup> |         |         |         |         |         |
| 28      | USB ready <sup>(2)</sup> |         |         |         |         |         |
| 29      | MPY ready                |         |         |         |         |         |
| 30      | DMA5IFG                  | DMA0IFG | DMA1IFG | DMA2IFG | DMA3IFG | DMA4IFG |
| 31      | DMAE0                    |         |         |         |         |         |

- (1) Reserved DMA triggers may be used by other devices in the family. Reserved DMA triggers do not cause any DMA trigger event when selected.
- (2) Only on devices with peripheral module USB (MSP430F565x and MSP430F665x), otherwise reserved (MSP430F535x and MSP430F645x).

### 6.12.10 Universal Serial Communication Interface (USCI) (Links to User's Guide: [UART Mode](#), [SPI Mode](#), [I<sup>2</sup>C Mode](#))

The USCI modules are used for serial data communication. The USCI module supports synchronous communication protocols such as SPI (3- or 4-pin) and I<sup>2</sup>C, and asynchronous communication protocols such as UART, enhanced UART with automatic baudrate detection, and IrDA. Each USCI module contains two portions, A and B.

The USCI\_An module provides support for SPI (3- or 4-pin), UART, enhanced UART, or IrDA.

The USCI\_Bn module provides support for SPI (3- or 4-pin) or I<sup>2</sup>C.

The MSP430F665x, MSP430F645x, MSP430F565x, MSP430F535x MCUs include three complete USCI modules (n = 0 to 2).

### 6.12.11 Timer TA0 (Link to User's Guide)

Timer TA0 is a 16-bit timer/counter (Timer\_A type) with five capture/compare registers. TA0 supports multiple capture/compares, PWM outputs, and interval timing (see [Table 6-14](#)). TA0 also has extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each of the capture/compare registers.

**Table 6-14. Timer TA0 Signal Connections**

| INPUT PIN NUMBER |         | DEVICE INPUT SIGNAL | MODULE INPUT SIGNAL       | MODULE BLOCK | MODULE OUTPUT SIGNAL | DEVICE OUTPUT SIGNAL | OUTPUT PIN NUMBER                     |         |
|------------------|---------|---------------------|---------------------------|--------------|----------------------|----------------------|---------------------------------------|---------|
| PZ               | ZQW     |                     |                           |              |                      |                      | PZ                                    | ZQW     |
| 34-P1.0          | L5-P1.0 | TA0CLK              | TACLK                     | Timer        | NA                   | NA                   |                                       |         |
|                  |         | ACLK                | ACLK                      |              |                      |                      |                                       |         |
|                  |         | SMCLK               | SMCLK                     |              |                      |                      |                                       |         |
| 34-P1.0          | L5-P1.0 | TA0CLK              | $\overline{\text{TACLK}}$ | CCR0         | TA0                  | TA0.0                |                                       |         |
| 35-P1.1          | M5-P1.1 | TA0.0               | CCI0A                     |              |                      |                      | 35-P1.1                               | M5-P1.1 |
|                  |         | DV <sub>SS</sub>    | CCI0B                     |              |                      |                      |                                       |         |
|                  |         | DV <sub>SS</sub>    | GND                       |              |                      |                      |                                       |         |
|                  |         | DV <sub>CC</sub>    | V <sub>CC</sub>           | CCR1         | TA1                  | TA0.1                |                                       |         |
| 36-P1.2          | J6-P1.2 | TA0.1               | CCI1A                     |              |                      |                      | 36-P1.2                               | J6-P1.2 |
| 40-P1.6          | J7-P1.6 | TA0.1               | CCI1B                     |              |                      |                      | 40-P1.6                               | J7-P1.6 |
|                  |         | DV <sub>SS</sub>    | GND                       |              |                      |                      | ADC12_A (internal)<br>ADC12SHSx = {1} |         |
|                  |         | DV <sub>CC</sub>    | V <sub>CC</sub>           | CCR2         | TA2                  | TA0.2                |                                       |         |
| 37-P1.3          | H6-P1.3 | TA0.2               | CCI2A                     |              |                      |                      | 37-P1.3                               | H6-P1.3 |
| 41-P1.7          | M7-P1.7 | TA0.2               | CCI2B                     |              |                      |                      | 41-P1.7                               | M7-P1.7 |
|                  |         | DV <sub>SS</sub>    | GND                       |              |                      |                      |                                       |         |
|                  |         | DV <sub>CC</sub>    | V <sub>CC</sub>           | CCR3         | TA3                  | TA0.3                |                                       |         |
| 38-P1.4          | M6-P1.4 | TA0.3               | CCI3A                     |              |                      |                      | 38-P1.4                               | M6-P1.4 |
|                  |         | DV <sub>SS</sub>    | CCI3B                     |              |                      |                      |                                       |         |
|                  |         | DV <sub>SS</sub>    | GND                       |              |                      |                      |                                       |         |
|                  |         | DV <sub>CC</sub>    | V <sub>CC</sub>           | CCR4         | TA4                  | TA0.4                |                                       |         |
| 39-P1.5          | L6-P1.5 | TA0.4               | CCI4A                     |              |                      |                      | 39-P1.5                               | L6-P1.5 |
|                  |         | DV <sub>SS</sub>    | CCI4B                     |              |                      |                      |                                       |         |
|                  |         | DV <sub>SS</sub>    | GND                       |              |                      |                      |                                       |         |
|                  |         | DV <sub>CC</sub>    | V <sub>CC</sub>           |              |                      |                      |                                       |         |

### 6.12.12 Timer TA1 ([Link to User's Guide](#))

Timer TA1 is a 16-bit timer/counter (Timer\_A type) with three capture/compare registers. TA1 supports multiple capture/compares, PWM outputs, and interval timing (see [Table 6-15](#)). TA1 also has extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each of the capture/compare registers.

**Table 6-15. Timer TA1 Signal Connections**

| INPUT PIN NUMBER |         | DEVICE<br>INPUT<br>SIGNAL | MODULE<br>INPUT<br>SIGNAL | MODULE<br>BLOCK | MODULE<br>OUTPUT<br>SIGNAL | DEVICE<br>OUTPUT<br>SIGNAL | OUTPUT PIN NUMBER                         |         |
|------------------|---------|---------------------------|---------------------------|-----------------|----------------------------|----------------------------|-------------------------------------------|---------|
| PZ               | ZQW     |                           |                           |                 |                            |                            | PZ                                        | ZQW     |
| 42-P3.0          | L7-P3.0 | TA1CLK                    | TACLK                     | Timer           | NA                         | NA                         |                                           |         |
|                  |         | ACLK                      | ACLK                      |                 |                            |                            |                                           |         |
|                  |         | SMCLK                     | SMCLK                     |                 |                            |                            |                                           |         |
| 42-P3.0          | L7-P3.0 | TA1CLK                    | TACLK                     | CCR0            | TA0                        | TA1.0                      | 43-P3.1                                   | H7-P3.1 |
| 43-P3.1          | H7-P3.1 | TA1.0                     | CCI0A                     |                 |                            |                            |                                           |         |
|                  |         | DV <sub>SS</sub>          | CCI0B                     |                 |                            |                            |                                           |         |
|                  |         | DV <sub>SS</sub>          | GND                       |                 |                            |                            |                                           |         |
|                  |         | DV <sub>CC</sub>          | V <sub>CC</sub>           | CCR1            | TA1                        | TA1.1                      | 44-P3.2                                   | M8-P3.2 |
| 44-P3.2          | M8-P3.2 | TA1.1                     | CCI1A                     |                 |                            |                            | DAC12_A<br>DAC12_0, DAC12_1<br>(internal) |         |
|                  |         | CBOUT<br>(internal)       | CCI1B                     |                 |                            |                            |                                           |         |
|                  |         | DV <sub>SS</sub>          | GND                       |                 |                            |                            |                                           |         |
|                  |         | DV <sub>CC</sub>          | V <sub>CC</sub>           | CCR2            | TA2                        | TA1.2                      | 45-P3.3                                   | L8-P3.3 |
| 45-P3.3          | L8-P3.3 | TA1.2                     | CCI2A                     |                 |                            |                            |                                           |         |
|                  |         | ACLK<br>(internal)        | CCI2B                     |                 |                            |                            |                                           |         |
|                  |         | DV <sub>SS</sub>          | GND                       |                 |                            |                            |                                           |         |
|                  |         | DV <sub>CC</sub>          | V <sub>CC</sub>           |                 |                            |                            |                                           |         |

### 6.12.13 Timer TA2 ([Link to User's Guide](#))

Timer TA2 is a 16-bit timer/counter (Timer\_A type) with three capture/compare registers. TA2 supports multiple capture/compares, PWM outputs, and interval timing (see [Table 6-16](#)). TA2 also has extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each of the capture/compare registers.

**Table 6-16. Timer TA2 Signal Connections**

| INPUT PIN NUMBER |          | DEVICE<br>INPUT<br>SIGNAL | MODULE<br>INPUT<br>SIGNAL | MODULE<br>BLOCK | MODULE<br>OUTPUT<br>SIGNAL | DEVICE<br>OUTPUT<br>SIGNAL | OUTPUT PIN NUMBER |          |
|------------------|----------|---------------------------|---------------------------|-----------------|----------------------------|----------------------------|-------------------|----------|
| PZ               | ZQW      |                           |                           |                 |                            |                            | PZ                | ZQW      |
| 46-P3.4          | J8-P3.4  | TA2CLK                    | TACLK                     | Timer           | NA                         | NA                         |                   |          |
|                  |          | ACLK                      | ACLK                      |                 |                            |                            |                   |          |
|                  |          | SMCLK                     | SMCLK                     |                 |                            |                            |                   |          |
| 46-P3.4          | J8-P3.4  | TA2CLK                    | TACLK                     | CCR0            | TA0                        | TA2.0                      | 47-P3.5           | M9-P3.5  |
| 47-P3.5          | M9-P3.5  | TA2.0                     | CCI0A                     |                 |                            |                            |                   |          |
|                  |          | DV <sub>SS</sub>          | CCI0B                     |                 |                            |                            |                   |          |
|                  |          | DV <sub>SS</sub>          | GND                       |                 |                            |                            |                   |          |
|                  |          | DV <sub>CC</sub>          | V <sub>CC</sub>           | CCR1            | TA1                        | TA2.1                      | 48-P3.6           | L9-P3.6  |
| 48-P3.6          | L9-P3.6  | TA2.1                     | CCI1A                     |                 |                            |                            |                   |          |
|                  |          | CBOUT<br>(internal)       | CCI1B                     |                 |                            |                            |                   |          |
|                  |          | DV <sub>SS</sub>          | GND                       |                 |                            |                            |                   |          |
|                  |          | DV <sub>CC</sub>          | V <sub>CC</sub>           | CCR2            | TA2                        | TA2.2                      | 49-P3.7           | M10-P3.7 |
| 49-P3.7          | M10-P3.7 | TA2.2                     | CCI2A                     |                 |                            |                            |                   |          |
|                  |          | ACLK<br>(internal)        | CCI2B                     |                 |                            |                            |                   |          |
|                  |          | DV <sub>SS</sub>          | GND                       |                 |                            |                            |                   |          |
|                  |          | DV <sub>CC</sub>          | V <sub>CC</sub>           |                 |                            |                            |                   |          |

### 6.12.14 Timer TB0 ([Link to User's Guide](#))

Timer TB0 is a 16-bit timer/counter (Timer\_B type) with seven capture/compare registers. TB0 supports multiple capture/compares, PWM outputs, and interval timing (see [Table 6-17](#)). TB0 also 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. Timer TB0 Signal Connections**

| INPUT PIN NUMBER                             |                                               | DEVICE<br>INPUT<br>SIGNAL | MODULE<br>INPUT<br>SIGNAL  | MODULE<br>BLOCK | MODULE<br>OUTPUT<br>SIGNAL | DEVICE<br>OUTPUT<br>SIGNAL | OUTPUT PIN NUMBER                               |                                   |
|----------------------------------------------|-----------------------------------------------|---------------------------|----------------------------|-----------------|----------------------------|----------------------------|-------------------------------------------------|-----------------------------------|
| PZ                                           | ZQW                                           |                           |                            |                 |                            |                            | PZ                                              | ZQW                               |
| 58-P8.0<br>P2MAP <sub>x</sub> <sup>(1)</sup> | J11-P8.0<br>P2MAP <sub>x</sub> <sup>(1)</sup> | TB0CLK                    | TB0CLK                     | Timer           | NA                         | NA                         |                                                 |                                   |
|                                              |                                               | ACLK                      | ACLK                       |                 |                            |                            |                                                 |                                   |
|                                              |                                               | SMCLK                     | SMCLK                      |                 |                            |                            |                                                 |                                   |
| 58-P8.0<br>P2MAP <sub>x</sub> <sup>(1)</sup> | J11-P8.0<br>P2MAP <sub>x</sub> <sup>(1)</sup> | TB0CLK                    | $\overline{\text{TB0CLK}}$ |                 |                            |                            |                                                 |                                   |
| 50-P4.0                                      | J9-P4.0                                       | TB0.0                     | CCI0A                      | CCR0            | TB0                        | TB0.0                      | 50-P4.0                                         | J9-P4.0                           |
| P2MAP <sub>x</sub> <sup>(1)</sup>            | P2MAP <sub>x</sub> <sup>(1)</sup>             | TB0.0                     | CCI0B                      |                 |                            |                            | P2MAP <sub>x</sub> <sup>(1)</sup>               | P2MAP <sub>x</sub> <sup>(1)</sup> |
|                                              |                                               | DV <sub>SS</sub>          | GND                        |                 |                            |                            | ADC12 (internal)<br>ADC12SHS <sub>x</sub> = {2} |                                   |
|                                              |                                               | DV <sub>CC</sub>          | V <sub>CC</sub>            |                 |                            |                            |                                                 |                                   |
| 51-P4.1                                      | M11-P4.1                                      | TB0.1                     | CCI1A                      | CCR1            | TB1                        | TB0.1                      | 51-P4.1                                         | M11-P4.1                          |
| P2MAP <sub>x</sub> <sup>(1)</sup>            | P2MAP <sub>x</sub> <sup>(1)</sup>             | TB0.1                     | CCI1B                      |                 |                            |                            | P2MAP <sub>x</sub> <sup>(1)</sup>               | P2MAP <sub>x</sub> <sup>(1)</sup> |
|                                              |                                               | DV <sub>SS</sub>          | GND                        |                 |                            |                            | ADC12 (internal)<br>ADC12SHS <sub>x</sub> = {3} |                                   |
|                                              |                                               | DV <sub>CC</sub>          | V <sub>CC</sub>            |                 |                            |                            |                                                 |                                   |
| 52-P4.2                                      | L10-P4.2                                      | TB0.2                     | CCI2A                      | CCR2            | TB2                        | TB0.2                      | 52-P4.2                                         | L10-P4.2                          |
| P2MAP <sub>x</sub> <sup>(1)</sup>            | P2MAP <sub>x</sub> <sup>(1)</sup>             | TB0.2                     | CCI2B                      |                 |                            |                            | P2MAP <sub>x</sub> <sup>(1)</sup>               | P2MAP <sub>x</sub> <sup>(1)</sup> |
|                                              |                                               | DV <sub>SS</sub>          | GND                        |                 |                            |                            | DAC12_A<br>DAC12_0, DAC12_1<br>(internal)       |                                   |
|                                              |                                               | DV <sub>CC</sub>          | V <sub>CC</sub>            |                 |                            |                            |                                                 |                                   |
| 53-P4.3                                      | M12-P4.3                                      | TB0.3                     | CCI3A                      | CCR3            | TB3                        | TB0.3                      | 53-P4.3                                         | M12-P4.3                          |
| P2MAP <sub>x</sub> <sup>(1)</sup>            | P2MAP <sub>x</sub> <sup>(1)</sup>             | TB0.3                     | CCI3B                      |                 |                            |                            | P2MAP <sub>x</sub> <sup>(1)</sup>               | P2MAP <sub>x</sub> <sup>(1)</sup> |
|                                              |                                               | DV <sub>SS</sub>          | GND                        |                 |                            |                            |                                                 |                                   |
|                                              |                                               | DV <sub>CC</sub>          | V <sub>CC</sub>            |                 |                            |                            |                                                 |                                   |
| 54-P4.4                                      | L12-P4.4                                      | TB0.4                     | CCI4A                      | CCR4            | TB4                        | TB0.4                      | 54-P4.4                                         | L12-P4.4                          |
| P2MAP <sub>x</sub> <sup>(1)</sup>            | P2MAP <sub>x</sub> <sup>(1)</sup>             | TB0.4                     | CCI4B                      |                 |                            |                            | P2MAP <sub>x</sub> <sup>(1)</sup>               | P2MAP <sub>x</sub> <sup>(1)</sup> |
|                                              |                                               | DV <sub>SS</sub>          | GND                        |                 |                            |                            |                                                 |                                   |
|                                              |                                               | DV <sub>CC</sub>          | V <sub>CC</sub>            |                 |                            |                            |                                                 |                                   |
| 55-P4.5                                      | L11-P4.5                                      | TB0.5                     | CCI5A                      | CCR5            | TB5                        | TB0.5                      | 55-P4.5                                         | L11-P4.5                          |
| P2MAP <sub>x</sub> <sup>(1)</sup>            | P2MAP <sub>x</sub> <sup>(1)</sup>             | TB0.5                     | CCI5B                      |                 |                            |                            | P2MAP <sub>x</sub> <sup>(1)</sup>               | P2MAP <sub>x</sub> <sup>(1)</sup> |
|                                              |                                               | DV <sub>SS</sub>          | GND                        |                 |                            |                            |                                                 |                                   |
|                                              |                                               | DV <sub>CC</sub>          | V <sub>CC</sub>            |                 |                            |                            |                                                 |                                   |
| 56-P4.6                                      | K11-P4.6                                      | TB0.6                     | CCI6A                      | CCR6            | TB6                        | TB0.6                      | 56-P4.6                                         | K11-P4.6                          |
| P2MAP <sub>x</sub> <sup>(1)</sup>            | P2MAP <sub>x</sub> <sup>(1)</sup>             | TB0.6                     | CCI6B                      |                 |                            |                            | P2MAP <sub>x</sub> <sup>(1)</sup>               | P2MAP <sub>x</sub> <sup>(1)</sup> |
|                                              |                                               | DV <sub>SS</sub>          | GND                        |                 |                            |                            |                                                 |                                   |
|                                              |                                               | DV <sub>CC</sub>          | V <sub>CC</sub>            |                 |                            |                            |                                                 |                                   |

(1) Timer functions are selectable through the port mapping controller.

### 6.12.15 **Comparator\_B** ([Link to User's Guide](#))

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

### 6.12.16 **ADC12\_A** ([Link to User's Guide](#))

The ADC12\_A module supports fast 12-bit analog-to-digital conversions. The module implements a 12-bit SAR core, sample select control, reference generator, and a 16 word conversion-and-control buffer. The conversion-and-control buffer allows up to 16 independent ADC samples to be converted and stored without any CPU intervention.

### 6.12.17 **DAC12\_A** ([Link to User's Guide](#))

The DAC12\_A module is a 12-bit R-ladder voltage-output DAC. The DAC12\_A may be used in 8-bit or 12-bit mode, and may be used in conjunction with the DMA controller. When multiple DAC12\_A modules are present, they may be grouped together for synchronous operation.

### 6.12.18 **CRC16** ([Link to User's Guide](#))

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

### 6.12.19 **Voltage Reference (REF) Module** ([Link to User's Guide](#))

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

### 6.12.20 **LCD\_B** ([Link to User's Guide](#))

The LCD\_B driver generates the segment and common signals that are required to drive a liquid crystal display (LCD). The LCD\_B controller has dedicated data memories to hold segment drive information. Common and segment signals are generated as defined by the mode. Static, 2-mux, 3-mux, and 4-mux LCDs are supported. The module can provide a LCD voltage independent of the supply voltage with its integrated charge pump. It is possible to control the level of the LCD voltage, and thus contrast, by software. The module also provides an automatic blinking capability for individual segments.

The LCD\_B module is available only on the MSP430F665x and MSP430F645x devices.

### 6.12.21 **USB Universal Serial Bus** ([Link to User's Guide](#))

The USB module is a fully integrated USB interface that is compliant with the USB 2.0 specification. The module supports full-speed operation of control, interrupt, and bulk transfers. The module includes an integrated LDO, PHY, and PLL. The PLL is highly flexible and supports a wide range of input clock frequencies. When USB RAM is not used for USB communication, it can be used by the system.

The USB module is available only on the MSP430F665x and MSP430F565x devices.

### 6.12.22 **LDO and PU Port**

The integrated 3.3-V power system incorporates an integrated 3.3-V LDO regulator that allows the entire MSP430 microcontroller to be powered from nominal 5-V LDO when it is made available for the system. Alternatively, the power system can supply power only to other components within the system, or it can be unused altogether.

The Port U Pins (PU.0 and PU.1) function as general-purpose high-current I/O pins. These pins can only be configured together as either both inputs or both outputs. Port U is supplied by the LDO rail. If the 3.3-V LDO is not being used in the system (disabled), the LDO pin can be supplied externally.

The LDO-PWR module (LDO and PU Port) is available on only the MSP430F645x and MSP430F535x devices.

### 6.12.23 Embedded Emulation Module (EEM) (L Version) ([Link to User's Guide](#))

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

- Eight hardware triggers or breakpoints on memory access
- Two hardware triggers or breakpoints on CPU register write access
- Up to 10 hardware triggers can be combined to form complex triggers or breakpoints
- Two cycle counters
- Sequencer
- State storage
- Clock control on module level

### 6.12.24 Peripheral File Map

[Table 6-18](#) lists the base register address for each available peripheral.

**Table 6-18. Peripherals**

| MODULE NAME                                                  | BASE ADDRESS | OFFSET ADDRESS RANGE <sup>(1)</sup> |
|--------------------------------------------------------------|--------------|-------------------------------------|
| Special Functions (see <a href="#">Table 6-19</a> )          | 0100h        | 000h to 01Fh                        |
| PMM (see <a href="#">Table 6-20</a> )                        | 0120h        | 000h to 010h                        |
| Flash Control (see <a href="#">Table 6-21</a> )              | 0140h        | 000h to 00Fh                        |
| CRC16 (see <a href="#">Table 6-22</a> )                      | 0150h        | 000h to 007h                        |
| RAM Control (see <a href="#">Table 6-23</a> )                | 0158h        | 000h to 001h                        |
| Watchdog (see <a href="#">Table 6-24</a> )                   | 015Ch        | 000h to 001h                        |
| UCS (see <a href="#">Table 6-25</a> )                        | 0160h        | 000h to 01Fh                        |
| SYS (see <a href="#">Table 6-26</a> )                        | 0180h        | 000h to 01Fh                        |
| Shared Reference (see <a href="#">Table 6-27</a> )           | 01B0h        | 000h to 001h                        |
| Port Mapping Control (see <a href="#">Table 6-28</a> )       | 01C0h        | 000h to 003h                        |
| Port Mapping Port P2 (see <a href="#">Table 6-28</a> )       | 01D0h        | 000h to 007h                        |
| Port P1, P2 (see <a href="#">Table 6-29</a> )                | 0200h        | 000h to 01Fh                        |
| Port P3, P4 (see <a href="#">Table 6-30</a> )                | 0220h        | 000h to 01Fh                        |
| Port P5, P6 (see <a href="#">Table 6-31</a> )                | 0240h        | 000h to 00Bh                        |
| Port P7, P8 (see <a href="#">Table 6-32</a> )                | 0260h        | 000h to 00Bh                        |
| Port P9 (see <a href="#">Table 6-33</a> )                    | 0280h        | 000h to 00Bh                        |
| Port PJ (see <a href="#">Table 6-34</a> )                    | 0320h        | 000h to 01Fh                        |
| Timer TA0 (see <a href="#">Table 6-35</a> )                  | 0340h        | 000h to 02Eh                        |
| Timer TA1 (see <a href="#">Table 6-36</a> )                  | 0380h        | 000h to 02Eh                        |
| Timer TB0 (see <a href="#">Table 6-37</a> )                  | 03C0h        | 000h to 02Eh                        |
| Timer TA2 (see <a href="#">Table 6-38</a> )                  | 0400h        | 000h to 02Eh                        |
| Battery Backup (see <a href="#">Table 6-39</a> )             | 0480h        | 000h to 01Fh                        |
| RTC_B (see <a href="#">Table 6-40</a> )                      | 04A0h        | 000h to 01Fh                        |
| 32-Bit Hardware Multiplier (see <a href="#">Table 6-41</a> ) | 04C0h        | 000h to 02Fh                        |
| DMA General Control (see <a href="#">Table 6-42</a> )        | 0500h        | 000h to 00Fh                        |
| DMA Channel 0 (see <a href="#">Table 6-42</a> )              | 0510h        | 000h to 00Ah                        |
| DMA Channel 1 (see <a href="#">Table 6-42</a> )              | 0520h        | 000h to 00Ah                        |
| DMA Channel 2 (see <a href="#">Table 6-42</a> )              | 0530h        | 000h to 00Ah                        |
| DMA Channel 3 (see <a href="#">Table 6-42</a> )              | 0540h        | 000h to 00Ah                        |
| DMA Channel 4 (see <a href="#">Table 6-42</a> )              | 0550h        | 000h to 00Ah                        |
| DMA Channel 5 (see <a href="#">Table 6-42</a> )              | 0560h        | 000h to 00Ah                        |
| USCI_A0 (see <a href="#">Table 6-43</a> )                    | 05C0h        | 000h to 01Fh                        |

(1) For a detailed description of the individual control register offset addresses, see the [MSP430F5xx and MSP430F6xx Family User's Guide](#).

**Table 6-18. Peripherals (continued)**

| MODULE NAME                                                                            | BASE ADDRESS | OFFSET ADDRESS RANGE <sup>(1)</sup> |
|----------------------------------------------------------------------------------------|--------------|-------------------------------------|
| USCI_B0 (see <a href="#">Table 6-44</a> )                                              | 05E0h        | 000h to 01Fh                        |
| USCI_A1 (see <a href="#">Table 6-45</a> )                                              | 0600h        | 000h to 01Fh                        |
| USCI_B1 (see <a href="#">Table 6-46</a> )                                              | 0620h        | 000h to 01Fh                        |
| USCI_A2 (see <a href="#">Table 6-47</a> )                                              | 0640h        | 000h to 01Fh                        |
| USCI_B2 (see <a href="#">Table 6-48</a> )                                              | 0660h        | 000h to 01Fh                        |
| ADC12_A (see <a href="#">Table 6-49</a> )                                              | 0700h        | 000h to 03Fh                        |
| DAC12_A (see <a href="#">Table 6-50</a> )                                              | 0780h        | 000h to 01Fh                        |
| Comparator_B (see <a href="#">Table 6-51</a> )                                         | 08C0h        | 000h to 00Fh                        |
| USB configuration (see <a href="#">Table 6-52</a> ) <sup>(2)</sup>                     | 0900h        | 000h to 014h                        |
| USB control (see <a href="#">Table 6-53</a> ) <sup>(2)</sup>                           | 0920h        | 000h to 01Fh                        |
| LDO-PWR; LDO and Port U configuration (see <a href="#">Table 6-54</a> ) <sup>(3)</sup> | 0900h        | 000h to 014h                        |
| LCD_B control (see <a href="#">Table 6-55</a> ) <sup>(4)</sup>                         | 0A00h        | 000h to 05Fh                        |

(2) Only on devices with peripheral module USB.

(3) Only on devices with peripheral module LDO-PWR.

(4) Only on devices with peripheral module LCD\_B.

**Table 6-19. 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 6-20. PMM Registers (Base Address: 0120h)**

| REGISTER DESCRIPTION     | REGISTER | OFFSET |
|--------------------------|----------|--------|
| PMM control 0            | PMMCTL0  | 00h    |
| PMM control 1            | PMMCTL1  | 02h    |
| SVS high-side control    | SVSMHCTL | 04h    |
| SVS low-side control     | SVSMLCTL | 06h    |
| PMM interrupt flags      | PMMIFG   | 0Ch    |
| PMM interrupt enable     | PMMIE    | 0Eh    |
| PMM power mode 5 control | PM5CTL0  | 10h    |

**Table 6-21. Flash Control Registers (Base Address: 0140h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|----------------------|----------|--------|
| Flash control 1      | FCTL1    | 00h    |
| Flash control 3      | FCTL3    | 04h    |
| Flash control 4      | FCTL4    | 06h    |

**Table 6-22. CRC16 Registers (Base Address: 0150h)**

| REGISTER DESCRIPTION | REGISTER   | OFFSET |
|----------------------|------------|--------|
| CRC data input       | CRC16DI    | 00h    |
| CRC result           | CRC16INRES | 04h    |

**Table 6-23. RAM Control Registers (Base Address: 0158h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|----------------------|----------|--------|
| RAM control 0        | RCCTL0   | 00h    |

**Table 6-24. Watchdog Registers (Base Address: 015Ch)**

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

**Table 6-25. UCS Registers (Base Address: 0160h)**

| REGISTER DESCRIPTION | REGISTER | OFFSET |
|----------------------|----------|--------|
| UCS control 0        | UCSCTL0  | 00h    |
| UCS control 1        | UCSCTL1  | 02h    |
| UCS control 2        | UCSCTL2  | 04h    |
| UCS control 3        | UCSCTL3  | 06h    |
| UCS control 4        | UCSCTL4  | 08h    |
| UCS control 5        | UCSCTL5  | 0Ah    |
| UCS control 6        | UCSCTL6  | 0Ch    |
| UCS control 7        | UCSCTL7  | 0Eh    |
| UCS control 8        | UCSCTL8  | 10h    |

**Table 6-26. SYS Registers (Base Address: 0180h)**

| REGISTER DESCRIPTION          | REGISTER  | OFFSET |
|-------------------------------|-----------|--------|
| System control                | SYSCTL    | 00h    |
| Bootloader configuration area | SYSBSLC   | 02h    |
| 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    |
| Bus error vector generator    | SYSBERRIV | 18h    |
| User NMI vector generator     | SYSUNIV   | 1Ah    |
| System NMI vector generator   | SYSSNIV   | 1Ch    |
| Reset vector generator        | SYSRSTIV  | 1Eh    |

**Table 6-27. Shared Reference Registers (Base Address: 01B0h)**

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

**Table 6-28. Port Mapping Registers  
(Base Address of Port Mapping Control: 01C0h, Port P4: 01D0h)**

| REGISTER DESCRIPTION  | REGISTER | OFFSET |
|-----------------------|----------|--------|
| Port mapping password | PMAPPWD  | 00h    |
| Port mapping control  | PMAPCTL  | 02h    |
| Port P2.0 mapping     | P2MAP0   | 00h    |
| Port P2.1 mapping     | P2MAP1   | 01h    |
| Port P2.2 mapping     | P2MAP2   | 02h    |
| Port P2.3 mapping     | P2MAP3   | 03h    |
| Port P2.4 mapping     | P2MAP4   | 04h    |
| Port P2.5 mapping     | P2MAP5   | 05h    |
| Port P2.6 mapping     | P2MAP6   | 06h    |
| Port P2.7 mapping     | P2MAP7   | 07h    |

**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 drive strength        | P1DS     | 08h    |
| Port P1 selection             | P1SEL    | 0Ah    |
| Port P1 interrupt vector word | P1IV     | 0Eh    |
| 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    |

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

| REGISTER DESCRIPTION          | REGISTER | OFFSET |
|-------------------------------|----------|--------|
| Port P2 drive strength        | P2DS     | 09h    |
| Port P2 selection             | P2SEL    | 0Bh    |
| 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 drive strength        | P3DS     | 08h    |
| Port P3 selection             | P3SEL    | 0Ah    |
| Port P3 interrupt vector word | P3IV     | 0Eh    |
| Port P3 interrupt edge select | P3IES    | 18h    |
| Port P3 interrupt enable      | P3IE     | 1Ah    |
| Port P3 interrupt flag        | P3IFG    | 1Ch    |
| Port P4 input                 | P4IN     | 01h    |
| Port P4 output                | P4OUT    | 03h    |
| Port P4 direction             | P4DIR    | 05h    |
| Port P4 resistor enable       | P4REN    | 07h    |
| Port P4 drive strength        | P4DS     | 09h    |
| Port P4 selection             | P4SEL    | 0Bh    |
| 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 P5, P6 Registers (Base Address: 0240h)**

| REGISTER DESCRIPTION    | REGISTER | OFFSET |
|-------------------------|----------|--------|
| Port P5 input           | P5IN     | 00h    |
| Port P5 output          | P5OUT    | 02h    |
| Port P5 direction       | P5DIR    | 04h    |
| Port P5 resistor enable | P5REN    | 06h    |
| Port P5 drive strength  | P5DS     | 08h    |
| Port P5 selection       | P5SEL    | 0Ah    |
| Port P6 input           | P6IN     | 01h    |
| Port P6 output          | P6OUT    | 03h    |
| Port P6 direction       | P6DIR    | 05h    |
| Port P6 resistor enable | P6REN    | 07h    |
| Port P6 drive strength  | P6DS     | 09h    |
| Port P6 selection       | P6SEL    | 0Bh    |

**Table 6-32. Port P7, P8 Registers (Base Address: 0260h)**

| REGISTER DESCRIPTION    | REGISTER | OFFSET |
|-------------------------|----------|--------|
| Port P7 input           | P7IN     | 00h    |
| Port P7 output          | P7OUT    | 02h    |
| Port P7 direction       | P7DIR    | 04h    |
| Port P7 resistor enable | P7REN    | 06h    |
| Port P7 drive strength  | P7DS     | 08h    |
| Port P7 selection       | P7SEL    | 0Ah    |
| Port P8 input           | P8IN     | 01h    |
| Port P8 output          | P8OUT    | 03h    |
| Port P8 direction       | P8DIR    | 05h    |
| Port P8 resistor enable | P8REN    | 07h    |
| Port P8 drive strength  | P8DS     | 09h    |
| Port P8 selection       | P8SEL    | 0Bh    |

**Table 6-33. Port P9 Register (Base Address: 0280h)**

| REGISTER DESCRIPTION    | REGISTER | OFFSET |
|-------------------------|----------|--------|
| Port P9 input           | P9IN     | 00h    |
| Port P9 output          | P9OUT    | 02h    |
| Port P9 direction       | P9DIR    | 04h    |
| Port P9 resistor enable | P9REN    | 06h    |
| Port P9 drive strength  | P9DS     | 08h    |
| Port P9 selection       | P9SEL    | 0Ah    |

**Table 6-34. 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 drive strength  | PJDS     | 08h    |

**Table 6-35. 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 6-36. 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    |
| 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 6-37. 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 6-38. 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    |
| Capture/compare control 2 | TA2CCTL2 | 06h    |
| TA2 counter               | TA2R     | 10h    |
| Capture/compare 0         | TA2CCR0  | 12h    |
| Capture/compare 1         | TA2CCR1  | 14h    |
| Capture/compare 2         | TA2CCR2  | 16h    |
| TA2 expansion 0           | TA2EX0   | 20h    |
| TA2 interrupt vector      | TA2IV    | 2Eh    |

**Table 6-39. Battery Backup Registers (Base Address: 0480h)**

| REGISTER DESCRIPTION    | REGISTER | OFFSET |
|-------------------------|----------|--------|
| Battery backup memory 0 | BAKMEM0  | 00h    |
| Battery backup memory 1 | BAKMEM1  | 02h    |
| Battery backup memory 2 | BAKMEM2  | 04h    |
| Battery backup memory 3 | BAKMEM3  | 06h    |
| Battery backup control  | BAKCTL   | 1Ch    |
| Battery charger control | BAKCHCTL | 1Eh    |

**Table 6-40. 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    | 10h    |
| RTC minutes               | RTCMIN    | 11h    |
| RTC hours                 | RTCHOUR   | 12h    |
| RTC day of week           | RTCDOW    | 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 6-41. 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    |
| 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    |

**Table 6-41. 32-Bit Hardware Multiplier Registers (Base Address: 04C0h) (continued)**

| REGISTER DESCRIPTION                                    | REGISTER  | OFFSET |
|---------------------------------------------------------|-----------|--------|
| 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 6-42. DMA Registers (Base Address DMA General Control: 0500h,  
DMA Channel 0: 0510h, DMA Channel 1: 0520h, DMA Channel 2: 0530h, DMA Channel 3: 0540h, DMA  
Channel 4: 0550h, DMA Channel 5: 0560h)**

| REGISTER DESCRIPTION                      | REGISTER | OFFSET |
|-------------------------------------------|----------|--------|
| DMA general control: DMA module control 0 | DMACTL0  | 00h    |
| DMA general control: DMA module control 1 | DMACTL1  | 02h    |
| DMA general control: DMA module control 2 | DMACTL2  | 04h    |
| DMA general control: DMA module control 3 | DMACTL3  | 06h    |
| DMA general control: DMA module control 4 | DMACTL4  | 08h    |
| DMA general control: DMA interrupt vector | DMAIV    | 0Ah    |
| 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 channel 3 control                     | DMA3CTL  | 00h    |
| DMA channel 3 source address low          | DMA3SAL  | 02h    |
| DMA channel 3 source address high         | DMA3SAH  | 04h    |
| DMA channel 3 destination address low     | DMA3DAL  | 06h    |
| DMA channel 3 destination address high    | DMA3DAH  | 08h    |
| DMA channel 3 transfer size               | DMA3SZ   | 0Ah    |
| DMA channel 4 control                     | DMA4CTL  | 00h    |

**Table 6-42. DMA Registers (Base Address DMA General Control: 0500h, DMA Channel 0: 0510h, DMA Channel 1: 0520h, DMA Channel 2: 0530h, DMA Channel 3: 0540h, DMA Channel 4: 0550h, DMA Channel 5: 0560h) (continued)**

| REGISTER DESCRIPTION                   | REGISTER | OFFSET |
|----------------------------------------|----------|--------|
| DMA channel 4 source address low       | DMA4SAL  | 02h    |
| DMA channel 4 source address high      | DMA4SAH  | 04h    |
| DMA channel 4 destination address low  | DMA4DAL  | 06h    |
| DMA channel 4 destination address high | DMA4DAH  | 08h    |
| DMA channel 4 transfer size            | DMA4SZ   | 0Ah    |
| DMA channel 5 control                  | DMA5CTL  | 00h    |
| DMA channel 5 source address low       | DMA5SAL  | 02h    |
| DMA channel 5 source address high      | DMA5SAH  | 04h    |
| DMA channel 5 destination address low  | DMA5DAL  | 06h    |
| DMA channel 5 destination address high | DMA5DAH  | 08h    |
| DMA channel 5 transfer size            | DMA5SZ   | 0Ah    |

**Table 6-43. USCI\_A0 Registers (Base Address: 05C0h)**

| REGISTER DESCRIPTION       | REGISTER   | OFFSET |
|----------------------------|------------|--------|
| USCI control 0             | UCA0CTL0   | 00h    |
| USCI control 1             | UCA0CTL1   | 01h    |
| USCI baud rate 0           | UCA0BR0    | 06h    |
| USCI baud rate 1           | UCA0BR1    | 07h    |
| USCI modulation control    | UCA0MCTL   | 08h    |
| USCI status                | UCA0STAT   | 0Ah    |
| USCI receive buffer        | UCA0RXBUF  | 0Ch    |
| USCI transmit buffer       | UCA0TXBUF  | 0Eh    |
| USCI LIN control           | UCA0ABCTL  | 10h    |
| USCI IrDA transmit control | UCA0IRTCTL | 12h    |
| USCI IrDA receive control  | UCA0IRRCTL | 13h    |
| USCI interrupt enable      | UCA0IE     | 1Ch    |
| USCI interrupt flags       | UCA0IFG    | 1Dh    |
| USCI interrupt vector word | UCA0IV     | 1Eh    |

**Table 6-44. USCI\_B0 Registers (Base Address: 05E0h)**

| REGISTER DESCRIPTION             | REGISTER  | OFFSET |
|----------------------------------|-----------|--------|
| USCI synchronous control 0       | UCB0CTL0  | 00h    |
| USCI synchronous control 1       | UCB0CTL1  | 01h    |
| USCI synchronous bit rate 0      | UCB0BR0   | 06h    |
| USCI synchronous bit rate 1      | UCB0BR1   | 07h    |
| USCI synchronous status          | UCB0STAT  | 0Ah    |
| USCI synchronous receive buffer  | UCB0RXBUF | 0Ch    |
| USCI synchronous transmit buffer | UCB0TXBUF | 0Eh    |
| USCI I2C own address             | UCB0I2COA | 10h    |
| USCI I2C slave address           | UCB0I2CSA | 12h    |
| USCI interrupt enable            | UCB0IE    | 1Ch    |
| USCI interrupt flags             | UCB0IFG   | 1Dh    |
| USCI interrupt vector word       | UCB0IV    | 1Eh    |

**Table 6-45. USCI\_A1 Registers (Base Address: 0600h)**

| REGISTER DESCRIPTION       | REGISTER   | OFFSET |
|----------------------------|------------|--------|
| USCI control 0             | UCA1CTL0   | 00h    |
| USCI control 1             | UCA1CTL1   | 01h    |
| USCI baud rate 0           | UCA1BR0    | 06h    |
| USCI baud rate 1           | UCA1BR1    | 07h    |
| USCI modulation control    | UCA1MCTL   | 08h    |
| USCI status                | UCA1STAT   | 0Ah    |
| USCI receive buffer        | UCA1RXBUF  | 0Ch    |
| USCI transmit buffer       | UCA1TXBUF  | 0Eh    |
| USCI LIN control           | UCA1ABCTL  | 10h    |
| USCI IrDA transmit control | UCA1IRTCTL | 12h    |
| USCI IrDA receive control  | UCA1IRRCTL | 13h    |
| USCI interrupt enable      | UCA1IE     | 1Ch    |
| USCI interrupt flags       | UCA1IFG    | 1Dh    |
| USCI interrupt vector word | UCA1IV     | 1Eh    |

**Table 6-46. USCI\_B1 Registers (Base Address: 0620h)**

| REGISTER DESCRIPTION             | REGISTER  | OFFSET |
|----------------------------------|-----------|--------|
| USCI synchronous control 0       | UCB1CTL0  | 00h    |
| USCI synchronous control 1       | UCB1CTL1  | 01h    |
| USCI synchronous bit rate 0      | UCB1BR0   | 06h    |
| USCI synchronous bit rate 1      | UCB1BR1   | 07h    |
| USCI synchronous status          | UCB1STAT  | 0Ah    |
| USCI synchronous receive buffer  | UCB1RXBUF | 0Ch    |
| USCI synchronous transmit buffer | UCB1TXBUF | 0Eh    |
| USCI I2C own address             | UCB1I2COA | 10h    |
| USCI I2C slave address           | UCB1I2CSA | 12h    |
| USCI interrupt enable            | UCB1IE    | 1Ch    |
| USCI interrupt flags             | UCB1IFG   | 1Dh    |
| USCI interrupt vector word       | UCB1IV    | 1Eh    |

**Table 6-47. USCI\_A2 Registers (Base Address: 0640h)**

| REGISTER DESCRIPTION       | REGISTER   | OFFSET |
|----------------------------|------------|--------|
| USCI control 0             | UCA2CTL0   | 00h    |
| USCI control 1             | UCA2CTL1   | 01h    |
| USCI baud rate 0           | UCA2BR0    | 06h    |
| USCI baud rate 1           | UCA2BR1    | 07h    |
| USCI modulation control    | UCA2MCTL   | 08h    |
| USCI status                | UCA2STAT   | 0Ah    |
| USCI receive buffer        | UCA2RXBUF  | 0Ch    |
| USCI transmit buffer       | UCA2TXBUF  | 0Eh    |
| USCI LIN control           | UCA2ABCTL  | 10h    |
| USCI IrDA transmit control | UCA2IRTCTL | 12h    |
| USCI IrDA receive control  | UCA2IRRCTL | 13h    |
| USCI interrupt enable      | UCA2IE     | 1Ch    |
| USCI interrupt flags       | UCA2IFG    | 1Dh    |
| USCI interrupt vector word | UCA2IV     | 1Eh    |

**Table 6-48. USCI\_B2 Registers (Base Address: 0660h)**

| REGISTER DESCRIPTION             | REGISTER  | OFFSET |
|----------------------------------|-----------|--------|
| USCI synchronous control 0       | UCB2CTL0  | 00h    |
| USCI synchronous control 1       | UCB2CTL1  | 01h    |
| USCI synchronous bit rate 0      | UCB2BR0   | 06h    |
| USCI synchronous bit rate 1      | UCB2BR1   | 07h    |
| USCI synchronous status          | UCB2STAT  | 0Ah    |
| USCI synchronous receive buffer  | UCB2RXBUF | 0Ch    |
| USCI synchronous transmit buffer | UCB2TXBUF | 0Eh    |
| USCI I2C own address             | UCB2I2COA | 10h    |
| USCI I2C slave address           | UCB2I2CSA | 12h    |
| USCI interrupt enable            | UCB2IE    | 1Ch    |
| USCI interrupt flags             | UCB2IFG   | 1Dh    |
| USCI interrupt vector word       | UCB2IV    | 1Eh    |

**Table 6-49. ADC12\_A Registers (Base Address: 0700h)**

| REGISTER DESCRIPTION  | REGISTER    | OFFSET |
|-----------------------|-------------|--------|
| ADC12 control 0       | ADC12CTL0   | 00h    |
| ADC12 control 1       | ADC12CTL1   | 02h    |
| ADC12 control 2       | ADC12CTL2   | 04h    |
| Interrupt flag        | ADC12IFG    | 0Ah    |
| Interrupt enable      | ADC12IE     | 0Ch    |
| Interrupt vector word | ADC12IV     | 0Eh    |
| ADC memory control 0  | ADC12MCTL0  | 10h    |
| ADC memory control 1  | ADC12MCTL1  | 11h    |
| ADC memory control 2  | ADC12MCTL2  | 12h    |
| ADC memory control 3  | ADC12MCTL3  | 13h    |
| ADC memory control 4  | ADC12MCTL4  | 14h    |
| ADC memory control 5  | ADC12MCTL5  | 15h    |
| ADC memory control 6  | ADC12MCTL6  | 16h    |
| ADC memory control 7  | ADC12MCTL7  | 17h    |
| ADC memory control 8  | ADC12MCTL8  | 18h    |
| ADC memory control 9  | ADC12MCTL9  | 19h    |
| ADC memory control 10 | ADC12MCTL10 | 1Ah    |
| ADC memory control 11 | ADC12MCTL11 | 1Bh    |
| ADC memory control 12 | ADC12MCTL12 | 1Ch    |
| ADC memory control 13 | ADC12MCTL13 | 1Dh    |
| ADC memory control 14 | ADC12MCTL14 | 1Eh    |
| ADC memory control 15 | ADC12MCTL15 | 1Fh    |
| Conversion memory 0   | ADC12MEM0   | 20h    |
| Conversion memory 1   | ADC12MEM1   | 22h    |
| Conversion memory 2   | ADC12MEM2   | 24h    |
| Conversion memory 3   | ADC12MEM3   | 26h    |
| Conversion memory 4   | ADC12MEM4   | 28h    |
| Conversion memory 5   | ADC12MEM5   | 2Ah    |
| Conversion memory 6   | ADC12MEM6   | 2Ch    |
| Conversion memory 7   | ADC12MEM7   | 2Eh    |
| Conversion memory 8   | ADC12MEM8   | 30h    |
| Conversion memory 9   | ADC12MEM9   | 32h    |

**Table 6-49. ADC12\_A Registers (Base Address: 0700h) (continued)**

| REGISTER DESCRIPTION | REGISTER   | OFFSET |
|----------------------|------------|--------|
| Conversion memory 10 | ADC12MEM10 | 34h    |
| Conversion memory 11 | ADC12MEM11 | 36h    |
| Conversion memory 12 | ADC12MEM12 | 38h    |
| Conversion memory 13 | ADC12MEM13 | 3Ah    |
| Conversion memory 14 | ADC12MEM14 | 3Ch    |
| Conversion memory 15 | ADC12MEM15 | 3Eh    |

**Table 6-50. DAC12\_A Registers (Base Address: 0780h)**

| REGISTER DESCRIPTION                  | REGISTER      | OFFSET |
|---------------------------------------|---------------|--------|
| DAC12_A channel 0 control 0           | DAC12_0CTL0   | 00h    |
| DAC12_A channel 0 control 1           | DAC12_0CTL1   | 02h    |
| DAC12_A channel 0 data                | DAC12_0DAT    | 04h    |
| DAC12_A channel 0 calibration control | DAC12_0CALCTL | 06h    |
| DAC12_A channel 0 calibration data    | DAC12_0CALDAT | 08h    |
| DAC12_A channel 1 control 0           | DAC12_1CTL0   | 10h    |
| DAC12_A channel 1 control 1           | DAC12_1CTL1   | 12h    |
| DAC12_A channel 1 data                | DAC12_1DAT    | 14h    |
| DAC12_A channel 1 calibration control | DAC12_1CALCTL | 16h    |
| DAC12_A channel 1 calibration data    | DAC12_1CALDAT | 18h    |
| DAC12_A interrupt vector word         | DAC12IV       | 1Eh    |

**Table 6-51. Comparator\_B Registers (Base Address: 08C0h)**

| REGISTER DESCRIPTION         | REGISTER | OFFSET |
|------------------------------|----------|--------|
| Comp_B control 0             | CBCTL0   | 00h    |
| Comp_B control 1             | CBCTL1   | 02h    |
| Comp_B control 2             | CBCTL2   | 04h    |
| Comp_B control 3             | CBCTL3   | 06h    |
| Comp_B interrupt             | CBINT    | 0Ch    |
| Comp_B interrupt vector word | CBIV     | 0Eh    |

**Table 6-52. USB Configuration Registers (Base Address: 0900h)**

| REGISTER DESCRIPTION      | REGISTER  | OFFSET |
|---------------------------|-----------|--------|
| USB key/ID                | USBKEYID  | 00h    |
| USB module configuration  | USBCNF    | 02h    |
| USB PHY control           | USBPHYCTL | 04h    |
| USB power control         | USBPWRCTL | 08h    |
| USB power voltage setting | USBPWRVSR | 0Ah    |
| USB PLL control           | USBPLLCTL | 10h    |
| USB PLL divider           | USBPLLDIV | 12h    |
| USB PLL interrupts        | USBPLLIR  | 14h    |

**Table 6-53. USB Control Registers (Base Address: 0920h)**

| REGISTER DESCRIPTION              | REGISTER     | OFFSET |
|-----------------------------------|--------------|--------|
| Input endpoint_0 configuration    | USBIEPCNF_0  | 00h    |
| Input endpoint_0 byte count       | USBIEPCNT_0  | 01h    |
| Output endpoint_0 configuration   | USBOEPCNFG_0 | 02h    |
| Output endpoint_0 byte count      | USBOEPCNT_0  | 03h    |
| Input endpoint interrupt enables  | USBIEPIE     | 0Eh    |
| Output endpoint interrupt enables | USBOEPIE     | 0Fh    |
| Input endpoint interrupt flags    | USBIEPIFG    | 10h    |
| Output endpoint interrupt flags   | USBOEPIFG    | 11h    |
| USB interrupt vector              | USBIV        | 12h    |
| USB maintenance                   | USBMAINT     | 16h    |
| Timestamp                         | USBTSTREG    | 18h    |
| USB frame number                  | USBFN        | 1Ah    |
| USB control                       | USBCTL       | 1Ch    |
| USB interrupt enables             | USBIE        | 1Dh    |
| USB interrupt flags               | USBIFG       | 1Eh    |
| Function address                  | USBFUNADR    | 1Fh    |

**Table 6-54. LDO and Port U Configuration Registers (Base Address: 0900h)**

| REGISTER DESCRIPTION | REGISTER  | OFFSET |
|----------------------|-----------|--------|
| LDO key/ID           | LDOKEYID  | 00h    |
| PU port control      | PUCTL     | 04h    |
| LDO power control    | LDOPWRCTL | 08h    |

**Table 6-55. LCD\_B Registers (Base Address: 0A00h)**

| REGISTER DESCRIPTION        | REGISTER   | OFFSET |
|-----------------------------|------------|--------|
| LCD_B control 0             | LCDBCTL0   | 000h   |
| LCD_B control 1             | LCDBCTL1   | 002h   |
| LCD_B blinking control      | LCDBBLKCTL | 004h   |
| LCD_B memory control        | LCDBMEMCTL | 006h   |
| LCD_B voltage control       | LCDBVCTL   | 008h   |
| LCD_B port control 0        | LCDBPCTL0  | 00Ah   |
| LCD_B port control 1        | LCDBPCTL1  | 00Ch   |
| LCD_B port control 2        | LCDBPCTL2  | 00Eh   |
| LCD_B charge pump control   | LCDBCTL0   | 012h   |
| LCD_B interrupt vector word | LCDBIV     | 01Eh   |
| LCD_B memory 1              | LCDM1      | 020h   |
| LCD_B memory 2              | LCDM2      | 021h   |
| ⋮                           | ⋮          | ⋮      |
| LCD_B memory 22             | LCDM22     | 035h   |
| LCD_B blinking memory 1     | LCDBM1     | 040h   |
| LCD_B blinking memory 2     | LCDBM2     | 041h   |
| ⋮                           | ⋮          | ⋮      |
| LCD_B blinking memory 22    | LCDBM22    | 055h   |

## 6.13 Input/Output Diagrams

### 6.13.1 Port P1 (P1.0 to P1.7) Input/Output With Schmitt Trigger

Figure 6-2 shows the port diagram. Table 6-56 summarizes selection of the pin functions.

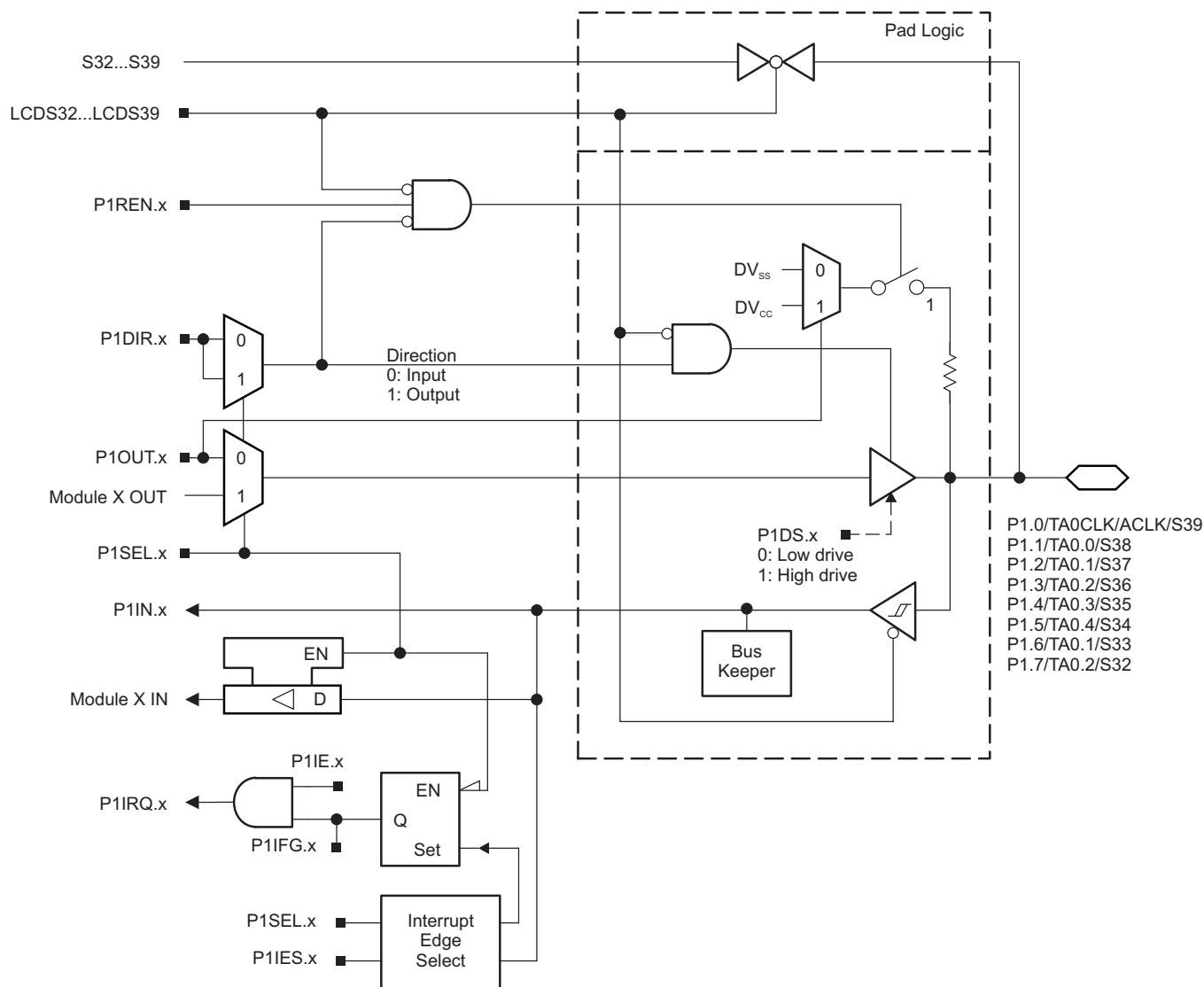


Figure 6-2. Port P1 (P1.0 to P1.7) Diagram

**Table 6-56. Port P1 (P1.0 to P1.7) Pin Functions**

| PIN NAME (P1.x)          | x | FUNCTION                      | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |                     |
|--------------------------|---|-------------------------------|----------------------------------------|---------|---------------------|
|                          |   |                               | P1DIR.x                                | P1SEL.x | LCDS32...<br>LCDS39 |
| P1.0/TA0CLK/ACLK/<br>S39 | 0 | P1.0 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                          |   | Timer TA0.TA0CLK              | 0                                      | 1       | 0                   |
|                          |   | ACLK                          | 1                                      | 1       | 0                   |
|                          |   | S39                           | X                                      | X       | 1                   |
| P1.1/TA0.0/S38           | 1 | P1.1 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                          |   | Timer TA0.CCI0A capture input | 0                                      | 1       | 0                   |
|                          |   | Timer TA0.0 output            | 1                                      | 1       | 0                   |
|                          |   | S38                           | X                                      | X       | 1                   |
| P1.2/TA0.1/S37           | 2 | P1.2 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                          |   | Timer TA0.CCI1A capture input | 0                                      | 1       | 0                   |
|                          |   | Timer TA0.1 output            | 1                                      | 1       | 0                   |
|                          |   | S37                           | X                                      | X       | 1                   |
| P1.3/TA0.2/S36           | 3 | P1.3 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                          |   | Timer TA0.CCI2A capture input | 0                                      | 1       | 0                   |
|                          |   | Timer TA0.2 output            | 1                                      | 1       | 0                   |
|                          |   | S36                           | X                                      | X       | 1                   |
| P1.4/TA0.3/S35           | 4 | P1.4 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                          |   | Timer TA0.CCI3A capture input | 0                                      | 1       | 0                   |
|                          |   | Timer TA0.3 output            | 1                                      | 1       | 0                   |
|                          |   | S35                           | X                                      | X       | 1                   |
| P1.5/TA0.4/S34           | 5 | P1.5 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                          |   | Timer TA0.CCI4A capture input | 0                                      | 1       | 0                   |
|                          |   | Timer TA0.4 output            | 1                                      | 1       | 0                   |
|                          |   | S34                           | X                                      | X       | 1                   |
| P1.6/TA0.1/S33           | 6 | P1.6 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                          |   | Timer TA0.CCI1B capture input | 0                                      | 1       | 0                   |
|                          |   | Timer TA0.1 output            | 1                                      | 1       | 0                   |
|                          |   | S33                           | X                                      | X       | 1                   |
| P1.7/TA0.2/S32           | 7 | P1.7 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                          |   | Timer TA0.CCI2B capture input | 0                                      | 1       | 0                   |
|                          |   | Timer TA0.2 output            | 1                                      | 1       | 0                   |
|                          |   | S32                           | X                                      | X       | 1                   |

(1) X = Don't care

### 6.13.2 Port P2 (P2.0 to P2.7) Input/Output With Schmitt Trigger

Figure 6-3 shows the port diagram. Table 6-57 summarizes selection of the pin functions.

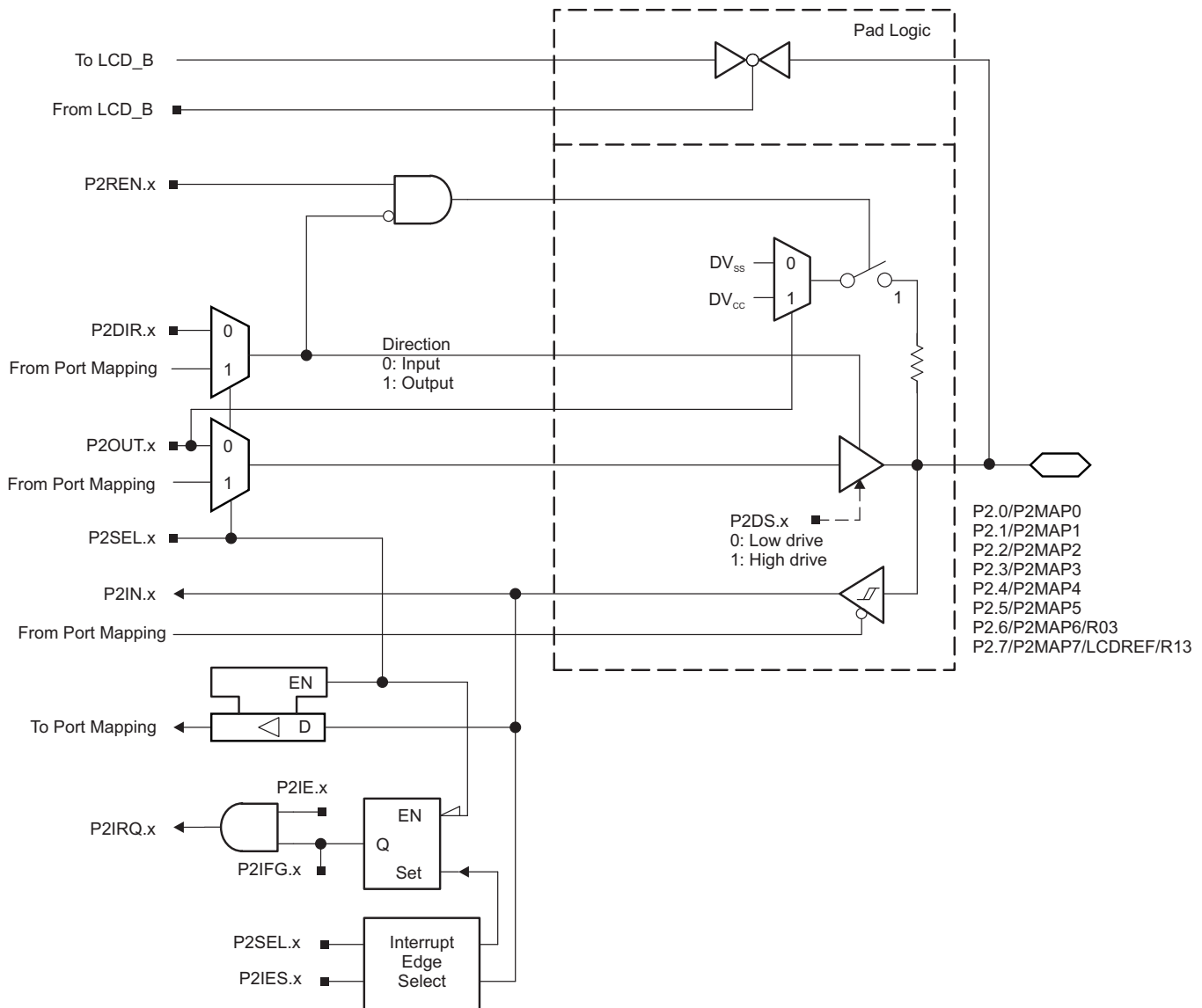


**Figure 6-3. Port P2 (P2.0 to P2.7) Diagram**

**Table 6-57. Port P2 (P2.0 to P2.7) Pin Functions**

| PIN NAME (P2.x)            | x | FUNCTION                          | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |        |
|----------------------------|---|-----------------------------------|----------------------------------------|---------|--------|
|                            |   |                                   | P2DIR.x                                | P2SEL.x | P2MAPx |
| P2.0/P2MAP0                | 0 | P2.0 (I/O)                        | I: 0; O: 1                             | 0       |        |
|                            |   | Mapped secondary digital function | X                                      | 1       | ≤ 19   |
| P2.1/P2MAP1                | 1 | P2.1 (I/O)                        | I: 0; O: 1                             | 0       |        |
|                            |   | Mapped secondary digital function | X                                      | 1       | ≤ 19   |
| P2.2/P2MAP2                | 2 | P2.2 (I/O)                        | I: 0; O: 1                             | 0       |        |
|                            |   | Mapped secondary digital function | X                                      | 1       | ≤ 19   |
| P2.3/P2MAP3                | 3 | P2.3 (I/O)                        | I: 0; O: 1                             | 0       |        |
|                            |   | Mapped secondary digital function | X                                      | 1       | ≤ 19   |
| P2.4/P2MAP4                | 4 | P2.4 (I/O)                        | I: 0; O: 1                             | 0       |        |
|                            |   | Mapped secondary digital function | X                                      | 1       | ≤ 19   |
| P2.5/P2MAP5                | 5 | P2.5 (I/O)                        | I: 0; O: 1                             | 0       |        |
|                            |   | Mapped secondary digital function | X                                      | 1       | ≤ 19   |
| P2.6/P2MAP6/R03            | 6 | P2.6 (I/O)                        | I: 0; O: 1                             | 0       |        |
|                            |   | Mapped secondary digital function | X                                      | 1       | ≤ 19   |
|                            |   | R03                               | X                                      | 1       | = 31   |
| P2.7/P2MAP7/<br>LCDREF/R13 | 7 | P2.7 (I/O)                        | I: 0; O: 1                             | 0       |        |
|                            |   | Mapped secondary digital function | X                                      | 1       | ≤ 19   |
|                            |   | LCDREF/R13                        | X                                      | 1       | = 31   |

(1) X = Don't care



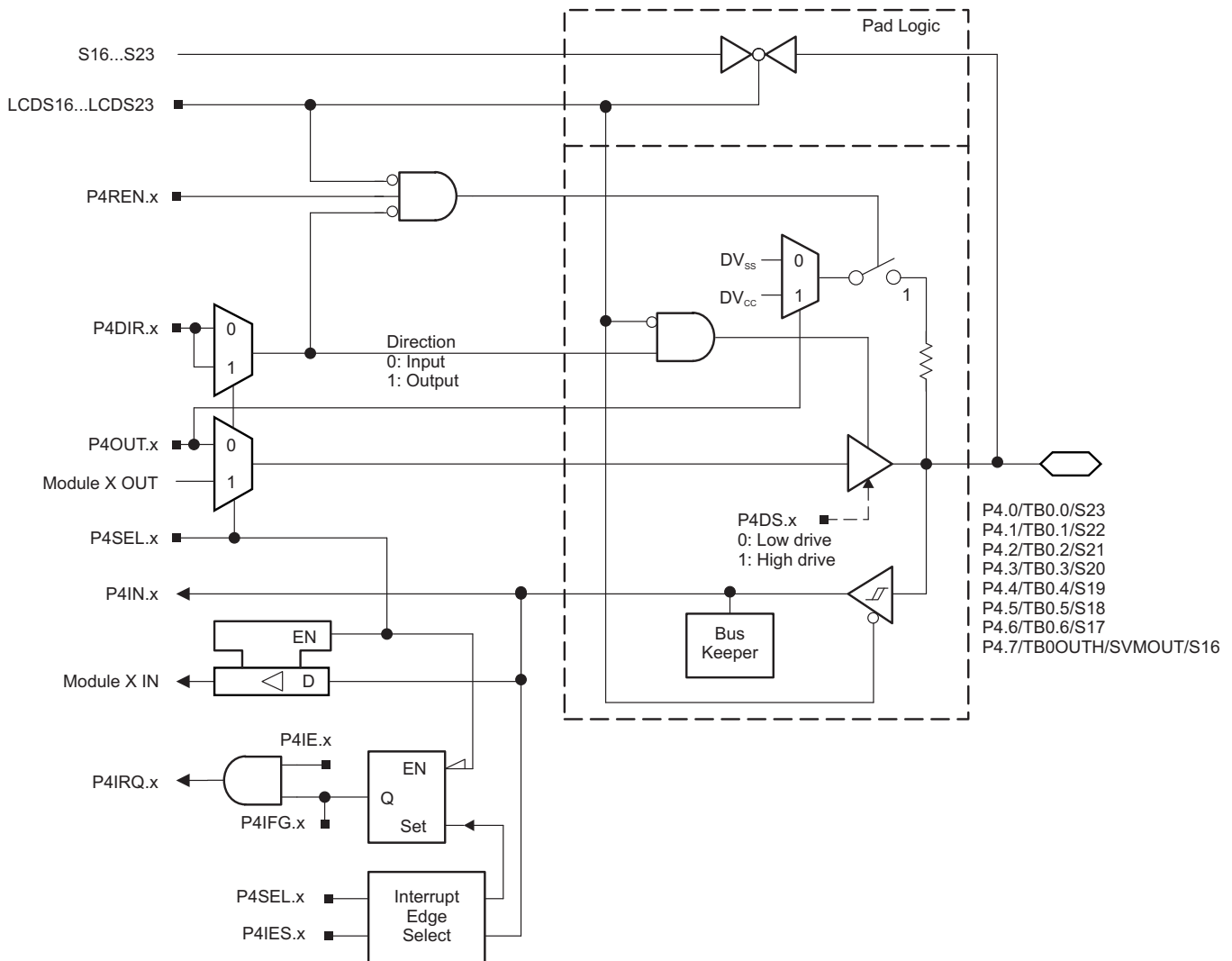
**Table 6-58. Port P3 (P3.0 to P3.7) Pin Functions**

| PIN NAME (P3.x)           | x | FUNCTION                      | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |                     |
|---------------------------|---|-------------------------------|----------------------------------------|---------|---------------------|
|                           |   |                               | P3DIR.x                                | P3SEL.x | LCDS24...<br>LCDS31 |
| P3.0/TA1CLK/CBOUT/<br>S31 | 0 | P3.0 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                           |   | Timer TA1.TA1CLK              | 0                                      | 1       | 0                   |
|                           |   | CBOUT                         | 1                                      | 1       | 0                   |
|                           |   | S31                           | X                                      | X       | 1                   |
| P3.1/TA1.0/S30            | 1 | P3.1 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                           |   | Timer TA1.CCI0A capture input | 0                                      | 1       | 0                   |
|                           |   | Timer TA1.0 output            | 1                                      | 1       | 0                   |
|                           |   | S30                           | X                                      | X       | 1                   |
| P3.2/TA1.1/S29            | 2 | P3.2 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                           |   | Timer TA1.CCI1A capture input | 0                                      | 1       | 0                   |
|                           |   | Timer TA1.1 output            | 1                                      | 1       | 0                   |
|                           |   | S29                           | X                                      | X       | 1                   |
| P3.3/TA1.2/S28            | 3 | P3.3 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                           |   | Timer TA1.CCI2A capture input | 0                                      | 1       | 0                   |
|                           |   | Timer TA1.2 output            | 1                                      | 1       | 0                   |
|                           |   | S28                           | X                                      | X       | 1                   |
| P3.4/TA2CLK/SMCLK/<br>S27 | 4 | P3.4 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                           |   | Timer TA2.TA2CLK              | 0                                      | 1       | 0                   |
|                           |   | SMCLK                         | 1                                      | 1       | 0                   |
|                           |   | S27                           | X                                      | X       | 1                   |
| P3.5/TA2.0/S26            | 5 | P3.5 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                           |   | Timer TA2.CCI0A capture input | 0                                      | 1       | 0                   |
|                           |   | Timer TA2.0 output            | 1                                      | 1       | 0                   |
|                           |   | S26                           | X                                      | X       | 1                   |
| P3.6/TA2.1/S25            | 6 | P3.6 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                           |   | Timer TA2.CCI1A capture input | 0                                      | 1       | 0                   |
|                           |   | Timer TA2.1 output            | 1                                      | 1       | 1                   |
|                           |   | S25                           | X                                      | X       | 1                   |
| P3.7/TA2.2/S24            | 7 | P3.7 (I/O)                    | I: 0; O: 1                             | 0       | 0                   |
|                           |   | Timer TA2.CCI2A capture input | 0                                      | 1       | 0                   |
|                           |   | Timer TA2.2 output            | 1                                      | 1       | 0                   |
|                           |   | S24                           | X                                      | X       | 1                   |

(1) X = Don't care

#### 6.13.4 Port P4 (P4.0 to P4.7) Input/Output With Schmitt Trigger

Figure 6-5 shows the port diagram. Table 6-59 summarizes selection of the pin functions.



### Figure 6-5. Port P4 (P4.0 to P4.7) Diagram

**Table 6-59. Port P4 (P4.0 to P4.7) Pin Functions**

| PIN NAME (P4.x)             | x | FUNCTION                          | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |                     |
|-----------------------------|---|-----------------------------------|----------------------------------------|---------|---------------------|
|                             |   |                                   | P4DIR.x                                | P4SEL.x | LCDS16...<br>LCDS23 |
| P4.0/TB0.0/S23              | 0 | P4.0 (I/O)                        | I: 0; O: 1                             | 0       | 0                   |
|                             |   | Timer TB0.CCI0A capture input     | 0                                      | 1       | 0                   |
|                             |   | Timer TB0.0 output <sup>(2)</sup> | 1                                      | 1       | 0                   |
|                             |   | S23                               | X                                      | X       | 1                   |
| P4.1/TB0.1/S22              | 1 | P4.1 (I/O)                        | I: 0; O: 1                             | 0       | 0                   |
|                             |   | Timer TB0.CCI1A capture input     | 0                                      | 1       | 0                   |
|                             |   | Timer TB0.1 output <sup>(2)</sup> | 1                                      | 1       | 0                   |
|                             |   | S22                               | X                                      | X       | 1                   |
| P4.2/TB0.2/S21              | 2 | P4.2 (I/O)                        | I: 0; O: 1                             | 0       | 0                   |
|                             |   | Timer TB0.CCI2A capture input     | 0                                      | 1       | 0                   |
|                             |   | Timer TB0.2 output <sup>(2)</sup> | 1                                      | 1       | 0                   |
|                             |   | S21                               | X                                      | X       | 1                   |
| P4.3/TB0.3/S20              | 3 | P4.3 (I/O)                        | I: 0; O: 1                             | 0       | 0                   |
|                             |   | Timer TB0.CCI3A capture input     | 0                                      | 1       | 0                   |
|                             |   | Timer TB0.3 output <sup>(2)</sup> | 1                                      | 1       | 0                   |
|                             |   | S20                               | X                                      | X       | 1                   |
| P4.4/TB0.4/S19              | 4 | P4.4 (I/O)                        | I: 0; O: 1                             | 0       | 0                   |
|                             |   | Timer TB0.CCI4A capture input     | 0                                      | 1       | 0                   |
|                             |   | Timer TB0.4 output <sup>(2)</sup> | 1                                      | 1       | 0                   |
|                             |   | S19                               | X                                      | X       | 1                   |
| P4.5/TB0.5/S18              | 5 | P4.5 (I/O)                        | I: 0; O: 1                             | 0       | 0                   |
|                             |   | Timer TB0.CCI5A capture input     | 0                                      | 1       | 0                   |
|                             |   | Timer TB0.5 output <sup>(2)</sup> | 1                                      | 1       | 0                   |
|                             |   | S18                               | X                                      | X       | 1                   |
| P4.6/TB0.6/S17              | 6 | P4.6 (I/O)                        | I: 0; O: 1                             | 0       | 0                   |
|                             |   | Timer TB0.CCI6A capture input     | 0                                      | 1       | 0                   |
|                             |   | Timer TB0.6 output <sup>(2)</sup> | 1                                      | 1       | 0                   |
|                             |   | S17                               | X                                      | X       | 1                   |
| P4.7/TB0OUTH/<br>SVMOUT/S16 | 7 | P4.7 (I/O)                        | I: 0; O: 1                             | 0       | 0                   |
|                             |   | Timer TB0.TB0OUTH                 | 0                                      | 1       | 0                   |
|                             |   | SVMOUT                            | 1                                      | 1       | 0                   |
|                             |   | S16                               | X                                      | X       | 1                   |

(1) X = Don't care

(2) Setting TB0OUTH causes all Timer\_B configured outputs to be set to high impedance.

### 6.13.5 Port P5 (P5.0 and P5.1) Input/Output With Schmitt Trigger

Figure 6-6 shows the port diagram. Table 6-60 summarizes selection of the pin functions.

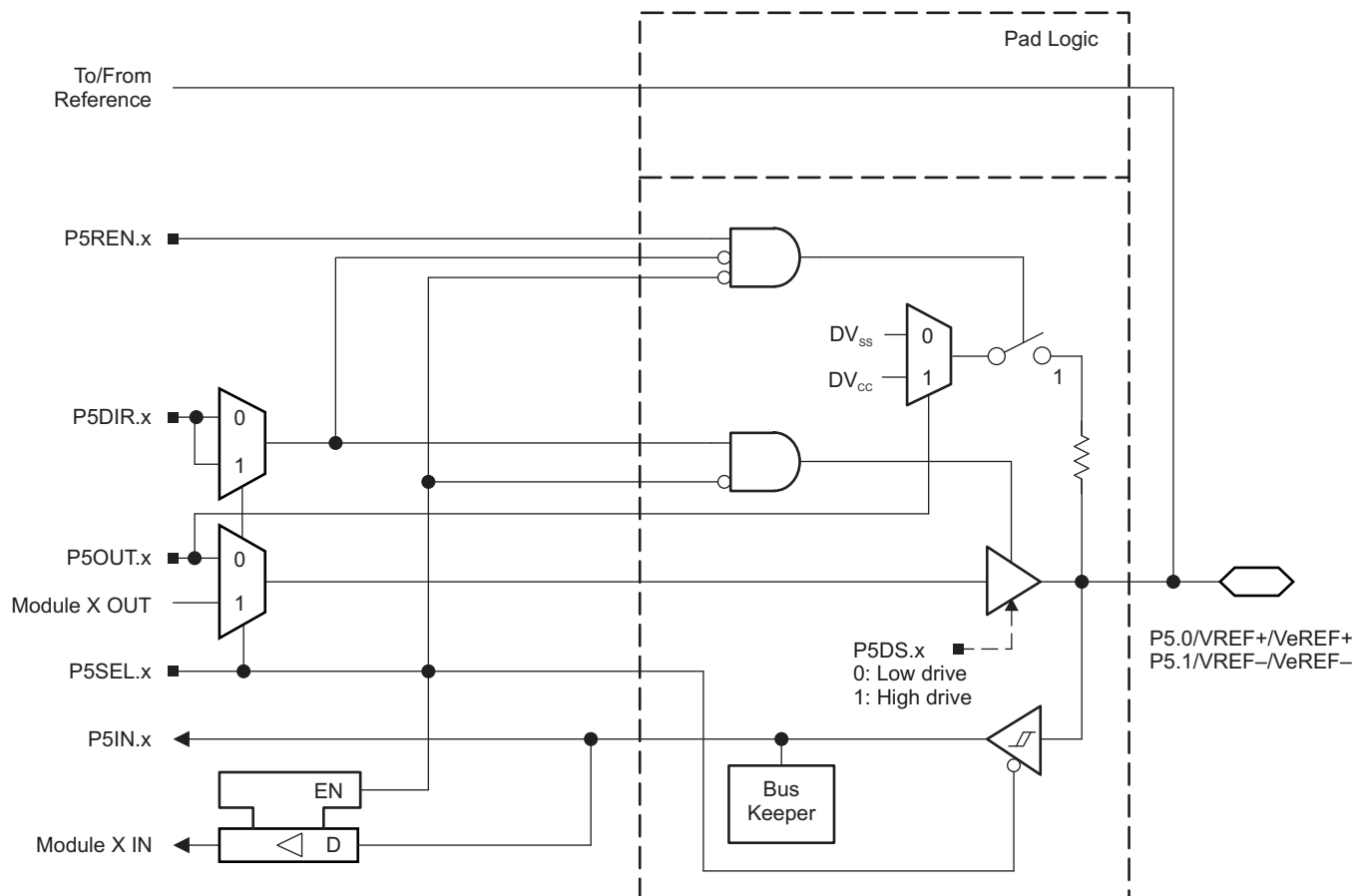


Figure 6-6. Port P5 (P5.0 and P5.1) Diagram

Table 6-60. Port P5 (P5.0 and P5.1) Pin Functions

| PIN NAME (P5.x)   | x | FUNCTION                  | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |        |
|-------------------|---|---------------------------|----------------------------------------|---------|--------|
|                   |   |                           | P5DIR.x                                | P5SEL.x | REFOUT |
| P5.0/VREF+/VeREF+ | 0 | P5.0 (I/O) <sup>(2)</sup> | I: 0; O: 1                             | 0       | X      |
|                   |   | VeREF+ <sup>(3)</sup>     | X                                      | 1       | 0      |
|                   |   | VREF+ <sup>(4)</sup>      | X                                      | 1       | 1      |
| P5.1/VREF-/VeREF- | 1 | P5.1 (I/O) <sup>(2)</sup> | I: 0; O: 1                             | 0       | X      |
|                   |   | VeREF- <sup>(5)</sup>     | X                                      | 1       | 0      |
|                   |   | VREF- <sup>(6)</sup>      | X                                      | 1       | 1      |

(1) X = Don't care

(2) Default condition

(3) Setting the P5SEL.0 bit disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals. An external voltage can be applied to VeREF+ and used as the reference for the ADC12\_A, Comparator\_B, or DAC12\_A.

(4) Setting the P5SEL.0 bit disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals. The ADC12\_A, VREF+ reference is available at the pin.

(5) Setting the P5SEL.1 bit disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals. An external voltage can be applied to VeREF- and used as the reference for the ADC12\_A, Comparator\_B, or DAC12\_A.

(6) Setting the P5SEL.1 bit disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals. The ADC12\_A, VREF- reference is available at the pin.

### 6.13.6 Port P5 (P5.2 to P5.7) Input/Output With Schmitt Trigger

Figure 6-7 shows the port diagram. Table 6-61 summarizes selection of the pin functions.

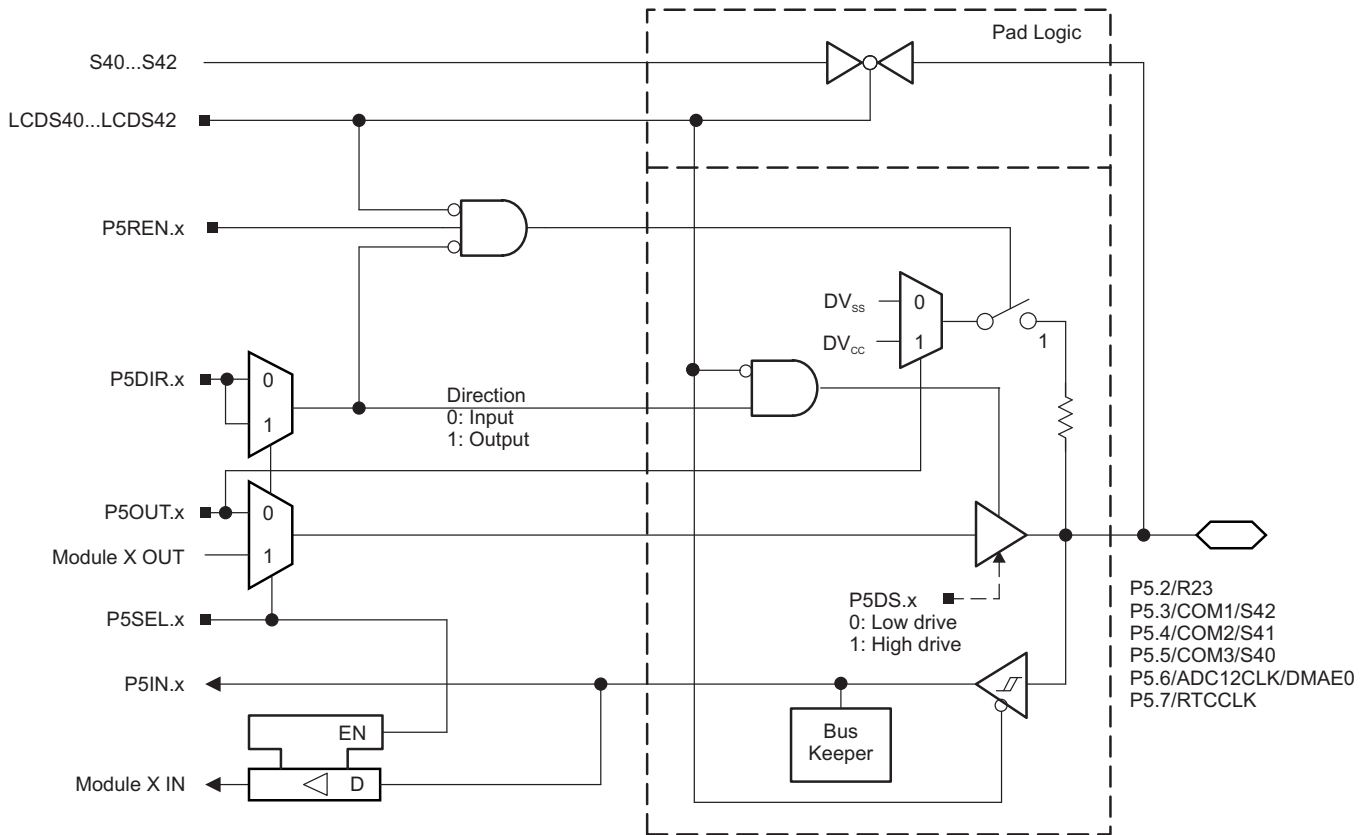


**Figure 6-7. Port P5 (P5.2 to P5.7) Diagram**

**Table 6-61. Port P5 (P5.2 to P5.7) Pin Functions**

| PIN NAME (P5.x)     | x | FUNCTION   | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |                     |
|---------------------|---|------------|----------------------------------------|---------|---------------------|
|                     |   |            | P5DIR.x                                | P5SEL.x | LCDS40...<br>LCDS42 |
| P5.2/R23            | 2 | P5.2 (I/O) | I: 0; O: 1                             | 0       | N/A                 |
|                     |   | R23        | X                                      | 1       | N/A                 |
| P5.3/COM1/S42       | 3 | P5.3 (I/O) | I: 0; O: 1                             | 0       | 0                   |
|                     |   | COM1       | X                                      | 1       | X                   |
|                     |   | S42        | X                                      | 0       | 1                   |
| P5.4/COM2/S41       | 4 | P5.4 (I/O) | I: 0; O: 1                             | 0       | 0                   |
|                     |   | COM2       | X                                      | 1       | X                   |
|                     |   | S41        | X                                      | 0       | 1                   |
| P5.5/COM3/S40       | 5 | P5.5 (I/O) | I: 0; O: 1                             | 0       | 0                   |
|                     |   | COM3       | X                                      | 1       | X                   |
|                     |   | S40        | X                                      | 0       | 1                   |
| P5.6/ADC12CLK/DMAE0 | 6 | P5.6 (I/O) | I: 0; O: 1                             | 0       | N/A                 |
|                     |   | ADC12CLK   | 1                                      | 1       | N/A                 |
|                     |   | DMAE0      | 0                                      | 1       | N/A                 |

(1) X = Don't care

**Table 6-61. Port P5 (P5.2 to P5.7) Pin Functions (continued)**

| PIN NAME (P5.x) | x | FUNCTION   | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |                     |
|-----------------|---|------------|----------------------------------------|---------|---------------------|
|                 |   |            | P5DIR.x                                | P5SEL.x | LCDS40...<br>LCDS42 |
| P5.7/RTCCLK     | 7 | P5.7 (I/O) | I: 0; O: 1                             | 0       | N/A                 |
|                 |   | RTCCLK     | 1                                      | 1       | N/A                 |

### 6.13.7 Port P6 (P6.0 to P6.7) Input/Output With Schmitt Trigger

Figure 6-8 shows the port diagram. Table 6-62 summarizes selection of the pin functions.

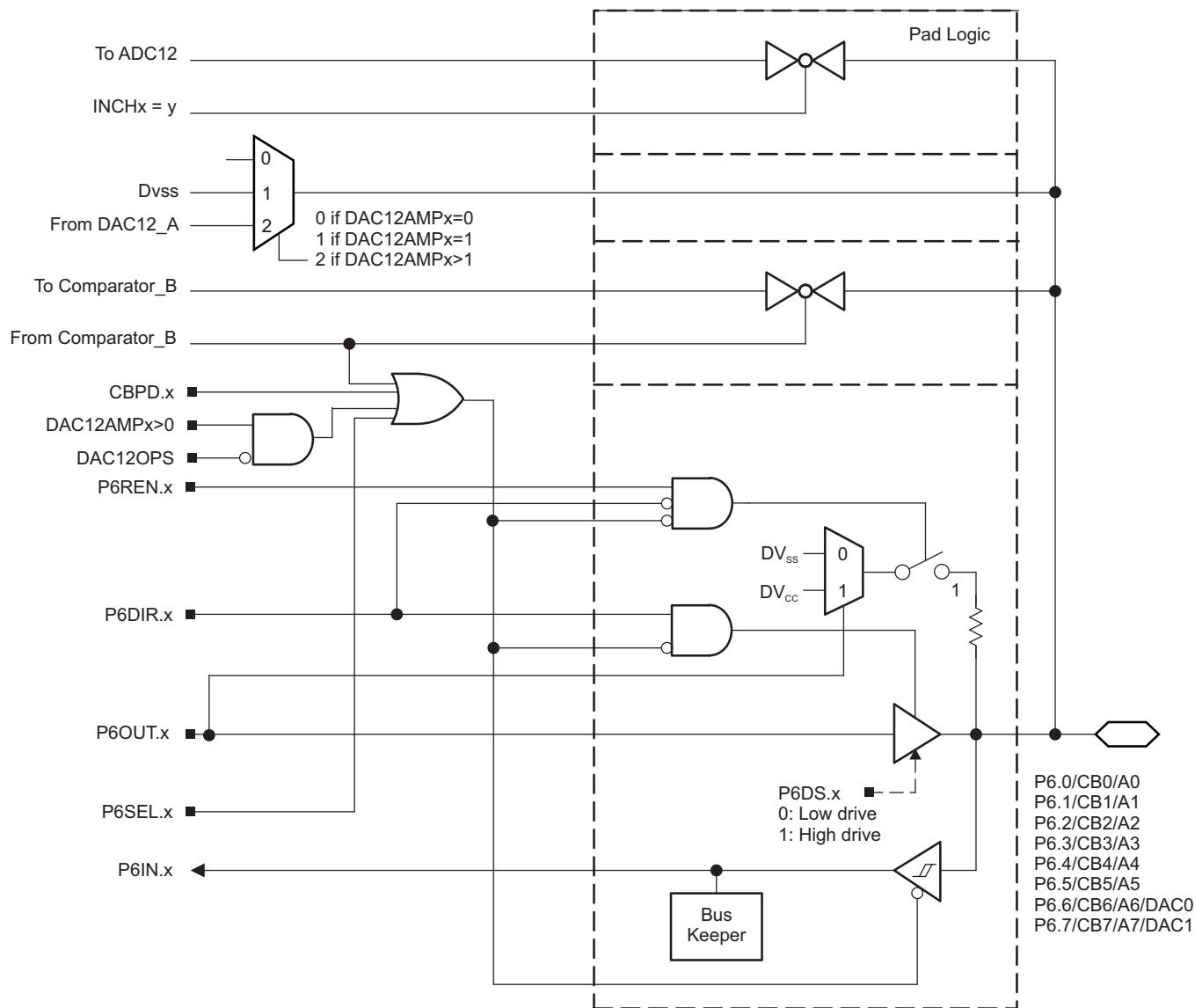


**Figure 6-8. Port P6 (P6.0 to P6.7) Diagram**

**Table 6-62. Port P6 (P6.0 to P6.7) Pin Functions**

| PIN NAME (P6.x)  | x | FUNCTION             | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |        |          |           |
|------------------|---|----------------------|----------------------------------------|---------|--------|----------|-----------|
|                  |   |                      | P6DIR.x                                | P6SEL.x | CBPD.x | DAC12OPS | DAC12AMPx |
| P6.0/CB0/A0      | 0 | P6.0 (I/O)           | I: 0; O: 1                             | 0       | 0      | N/A      | N/A       |
|                  |   | CB0                  | X                                      | X       | 1      | N/A      | N/A       |
|                  |   | A0 <sup>(2)(3)</sup> | X                                      | 1       | X      | N/A      | N/A       |
| P6.1/CB1/A1      | 1 | P6.1 (I/O)           | I: 0; O: 1                             | 0       | 0      | N/A      | N/A       |
|                  |   | CB1                  | X                                      | X       | 1      | N/A      | N/A       |
|                  |   | A1 <sup>(2)(3)</sup> | X                                      | 1       | X      | N/A      | N/A       |
| P6.2/CB2/A2      | 2 | P6.2 (I/O)           | I: 0; O: 1                             | 0       | 0      | N/A      | N/A       |
|                  |   | CB2                  | X                                      | X       | 1      | N/A      | N/A       |
|                  |   | A2 <sup>(2)(3)</sup> | X                                      | 1       | X      | N/A      | N/A       |
| P6.3/CB3/A3      | 3 | P6.3 (I/O)           | I: 0; O: 1                             | 0       | 0      | N/A      | N/A       |
|                  |   | CB3                  | X                                      | X       | 1      | N/A      | N/A       |
|                  |   | A3 <sup>(2)(3)</sup> | X                                      | 1       | X      | N/A      | N/A       |
| P6.4/CB4/A4      | 4 | P6.4 (I/O)           | I: 0; O: 1                             | 0       | 0      | N/A      | N/A       |
|                  |   | CB4                  | X                                      | X       | 1      | N/A      | N/A       |
|                  |   | A4 <sup>(2)(3)</sup> | X                                      | 1       | X      | N/A      | N/A       |
| P6.5/CB5/A5      | 5 | P6.5 (I/O)           | I: 0; O: 1                             | 0       | 0      | N/A      | N/A       |
|                  |   | CB5                  | X                                      | X       | 1      | N/A      | N/A       |
|                  |   | A5 <sup>(2)(3)</sup> | X                                      | 1       | X      | N/A      | N/A       |
| P6.6/CB6/A6/DAC0 | 6 | P6.6 (I/O)           | I: 0; O: 1                             | 0       | 0      | X        | 0         |
|                  |   | CB6                  | X                                      | X       | 1      | X        | 0         |
|                  |   | A6 <sup>(2)(3)</sup> | X                                      | 1       | X      | X        | 0         |
|                  |   | DAC0                 | X                                      | X       | X      | 0        | >1        |
| P6.7/CB7/A7/DAC1 | 7 | P6.7 (I/O)           | I: 0; O: 1                             | 0       | 0      | X        | 0         |
|                  |   | CB7                  | X                                      | X       | 1      | X        | 0         |
|                  |   | A7 <sup>(2)(3)</sup> | X                                      | 1       | X      | X        | 0         |
|                  |   | DAC1                 | X                                      | X       | X      | 0        | >1        |

(1) X = Don't care

(2) Setting the P6SEL.x bit disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

(3) The ADC12\_A channel Ax is connected internally to AV<sub>SS</sub> if not selected by the respective INCHx bits.

### 6.13.8 Port P7 (P7.2) Input/Output With Schmitt Trigger

Figure 6-9 shows the port diagram. Table 6-63 summarizes selection of the pin functions.

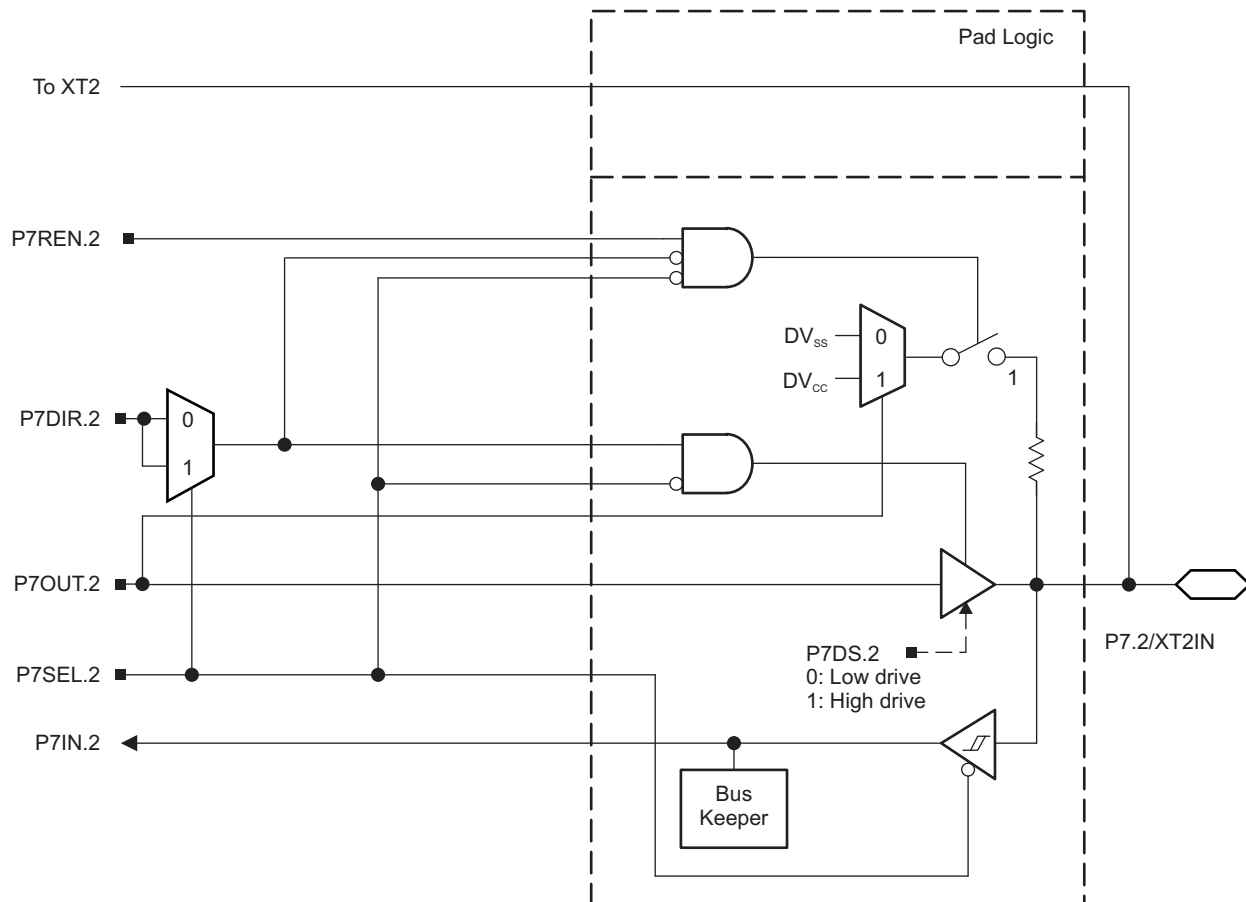
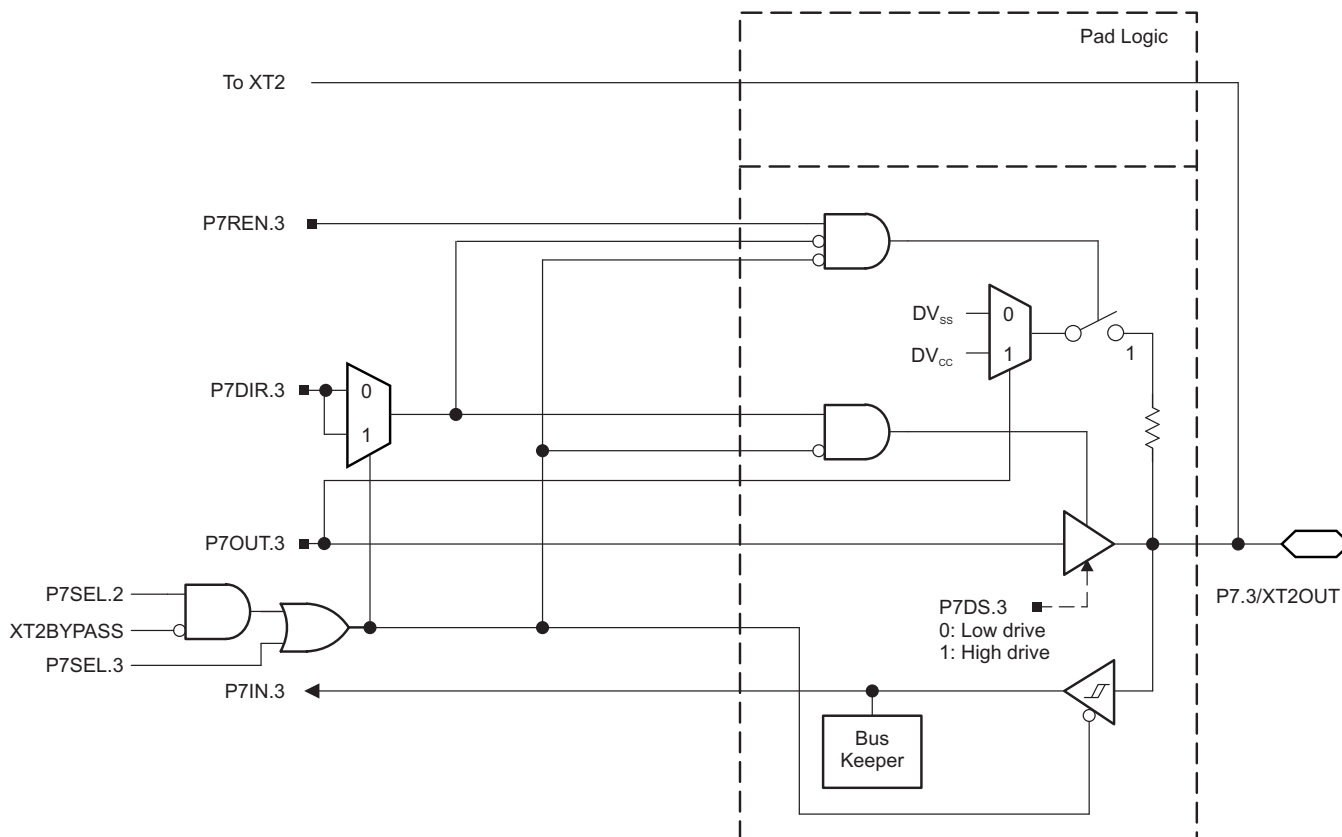


Figure 6-9. Port P7 (P7.2) Diagram

### 6.13.9 Port P7 (P7.3) Input/Output With Schmitt Trigger

Figure 6-10 shows the port diagram. Table 6-63 summarizes selection of the pin functions.



### Figure 6-10. Port P7 (P7.3) Diagram

### Table 6-63. Port P7 (P7.2 and P7.3) Pin Functions

| PIN NAME (P7.x) | x | FUNCTION                           | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |         |           |
|-----------------|---|------------------------------------|----------------------------------------|---------|---------|-----------|
|                 |   |                                    | P7DIR.x                                | P7SEL.2 | P7SEL.3 | XT2BYPASS |
| P7.2/XT2IN      | 2 | P7.2 (I/O)                         | I: 0; O: 1                             | 0       | X       | X         |
|                 |   | XT2IN crystal mode <sup>(2)</sup>  | X                                      | 1       | X       | 0         |
|                 |   | XT2IN bypass mode <sup>(2)</sup>   | X                                      | 1       | X       | 1         |
| P7.3/XT2OUT     | 3 | P7.3 (I/O)                         | I: 0; O: 1                             | 0       | 0       | X         |
|                 |   | XT2OUT crystal mode <sup>(3)</sup> | X                                      | 1       | X       | 0         |
|                 |   | P7.3 (I/O) <sup>(3)</sup>          | X                                      | 1       | 0       | 1         |

(1)  $X = \text{Don't care}$

(2) Setting P7SEL.2 causes the general-purpose I/O to be disabled. Pending the setting of XT2BYPASS, P7.2 is configured for crystal mode or bypass mode.

(3) Setting P7SEL.2 causes the general-purpose I/O to be disabled in crystal mode. When using bypass mode, P7.3 can be used as general-purpose I/O.

### 6.13.10 Port P7 (P7.4 to P7.7) Input/Output With Schmitt Trigger

Figure 6-11 shows the port diagram. Table 6-64 summarizes selection of the pin functions.

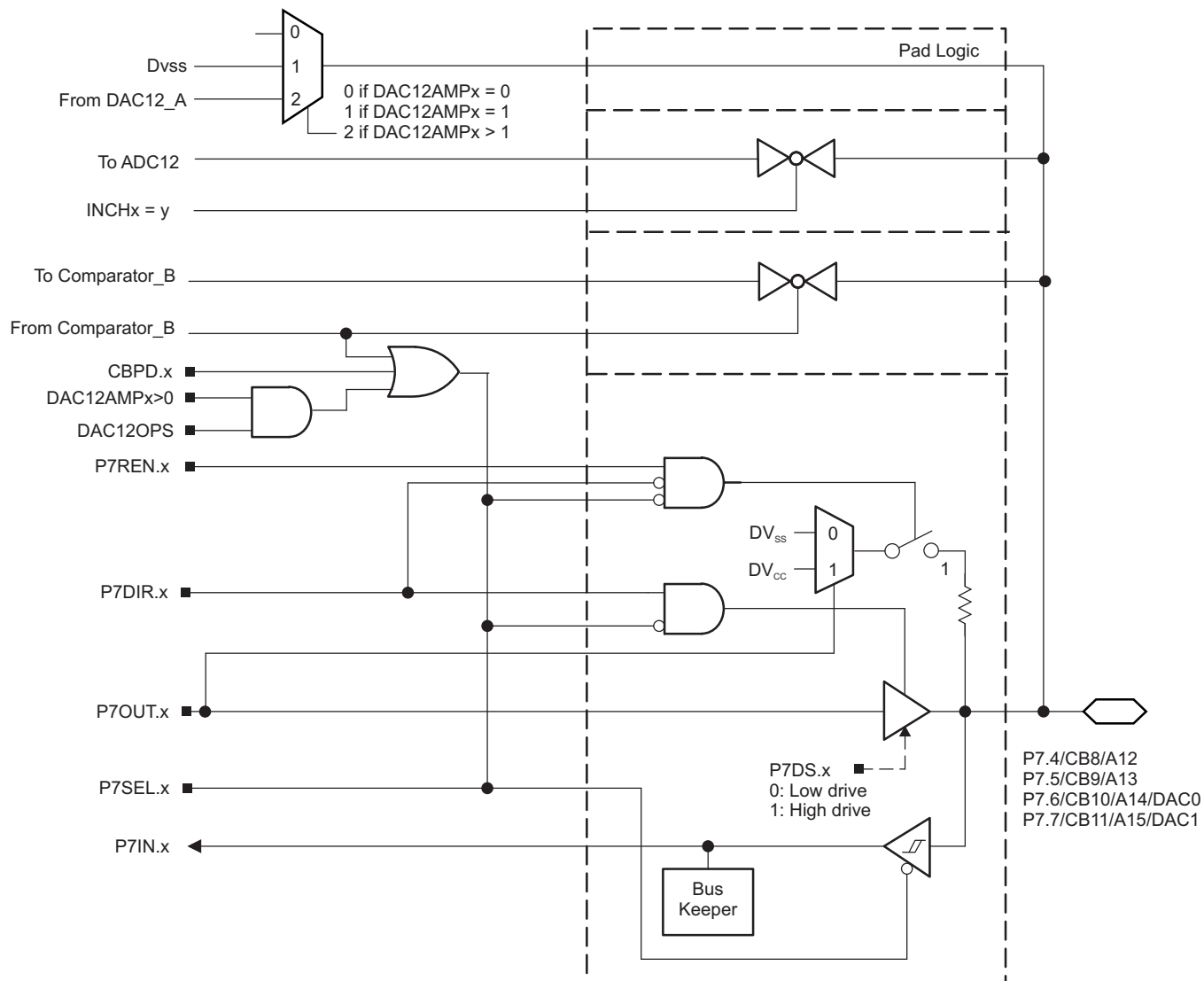


Figure 6-11. Port P7 (P7.4 to P7.7) Diagram

**Table 6-64. Port P7 (P7.4 to P7.7) Pin Functions**

| PIN NAME (P7.x)    | x | FUNCTION                | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |        |          |           |
|--------------------|---|-------------------------|----------------------------------------|---------|--------|----------|-----------|
|                    |   |                         | P7DIR.x                                | P7SEL.x | CBPD.x | DAC12OPS | DAC12AMPx |
| P7.4/CB8/A12       | 4 | P7.4 (I/O)              | I: 0; O: 1                             | 0       | 0      | N/A      | N/A       |
|                    |   | Comparator_B input CB8  | X                                      | X       | 1      | N/A      | N/A       |
|                    |   | A12 <sup>(2)(3)</sup>   | X                                      | 1       | X      | N/A      | N/A       |
| P7.5/CB9/A13       | 5 | P7.5 (I/O)              | I: 0; O: 1                             | 0       | 0      | N/A      | N/A       |
|                    |   | Comparator_B input CB9  | X                                      | X       | 1      | N/A      | N/A       |
|                    |   | A13 <sup>(2)(3)</sup>   | X                                      | 1       | X      | N/A      | N/A       |
| P7.6/CB10/A14/DAC0 | 6 | P7.6 (I/O)              | I: 0; O: 1                             | 0       | 0      | X        | 0         |
|                    |   | Comparator_B input CB10 | X                                      | X       | 1      | X        | 0         |
|                    |   | A14 <sup>(2)(3)</sup>   | X                                      | 1       | X      | X        | 0         |
|                    |   | DAC12_A output DAC0     | X                                      | X       | X      | 1        | >1        |
| P7.7/CB11/A15/DAC1 | 7 | P7.7 (I/O)              | I: 0; O: 1                             | 0       | 0      | X        | 0         |
|                    |   | A15 <sup>(2)(3)</sup>   | X                                      | 1       | X      | X        | 0         |
|                    |   | DAC12_A output DAC1     | X                                      | X       | X      | 1        | >1        |

(1) X = Don't care

(2) Setting the P7SEL.x bit disables the output driver and the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

(3) The ADC12\_A channel Ax is connected internally to AV<sub>SS</sub> if not selected by the respective INCHx bits.

### 6.13.11 Port P8 (P8.0 to P8.7) Input/Output With Schmitt Trigger

Figure 6-12 shows the port diagram. Table 6-65 summarizes selection of the pin functions.

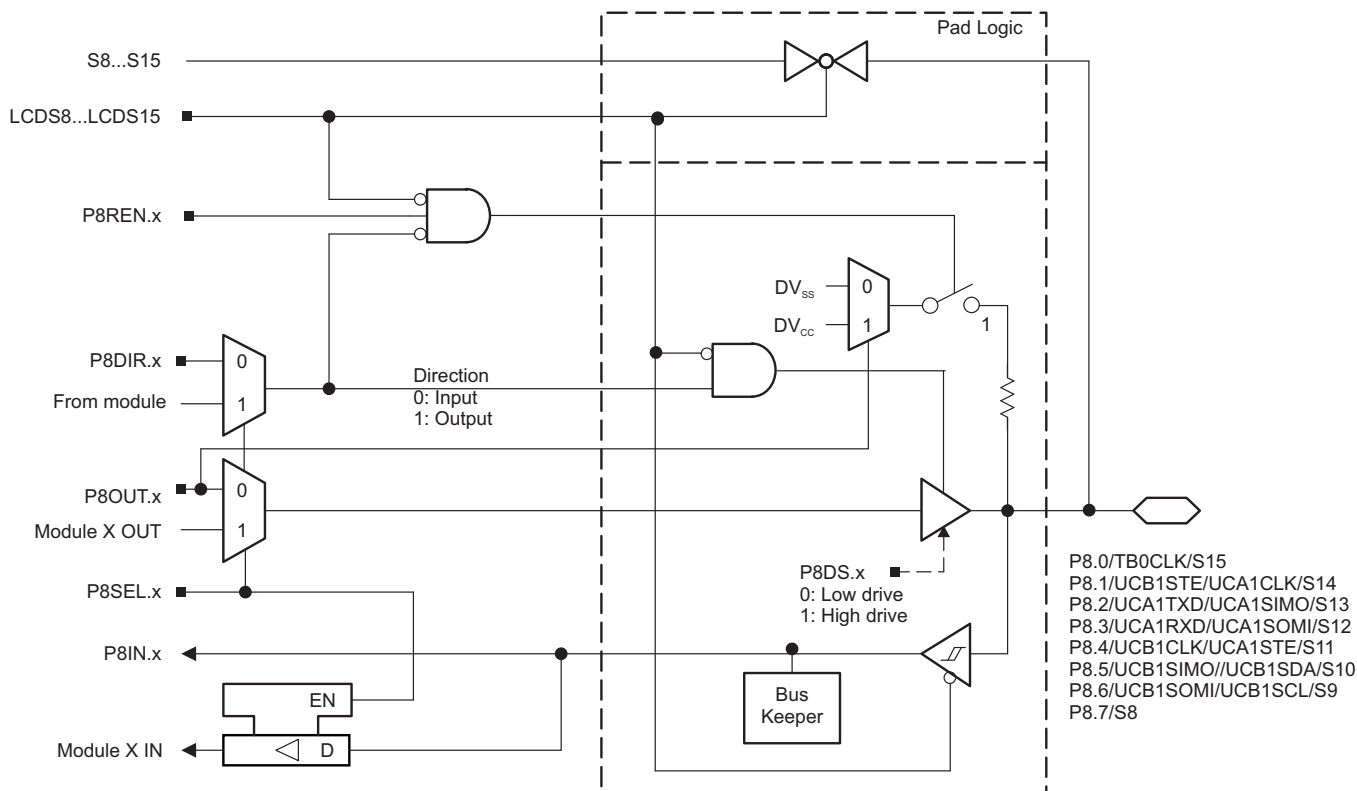


Figure 6-12. Port P8 (P8.0 to P8.7) Diagram

**Table 6-65. Port P8 (P8.0 to P8.7) Pin Functions**

| PIN NAME (P9.x)           | x | FUNCTION                     | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |                    |
|---------------------------|---|------------------------------|----------------------------------------|---------|--------------------|
|                           |   |                              | P8DIR.x                                | P8SEL.x | LCDS8...<br>LCDS15 |
| P8.0/TB0CLK/S15           | 0 | P8.0 (I/O)                   | I: 0; O: 1                             | 0       | 0                  |
|                           |   | Timer TB0.TB0CLK clock input | 0                                      | 1       | 0                  |
|                           |   | S15                          | X                                      | X       | 1                  |
| P8.1/UCB1STE/UCA1CLK/S14  | 1 | P8.1 (I/O)                   | I: 0; O: 1                             | 0       | 0                  |
|                           |   | UCB1STE/UCA1CLK              | X                                      | 1       | 0                  |
|                           |   | S14                          | X                                      | X       | 1                  |
| P8.2/UCA1TXD/UCA1SIMO/S13 | 2 | P8.2 (I/O)                   | I: 0; O: 1                             | 0       | 0                  |
|                           |   | UCA1TXD/UCA1SIMO             | X                                      | 1       | 0                  |
|                           |   | S13                          | X                                      | X       | 1                  |
| P8.3/UCA1RXD/UCA1SOMI/S12 | 3 | P8.3 (I/O)                   | I: 0; O: 1                             | 0       | 0                  |
|                           |   | UCA1RXD/UCA1SOMI             | X                                      | 1       | 0                  |
|                           |   | S12                          | X                                      | X       | 1                  |
| P8.4/UCB1CLK/UCA1STE/S11  | 4 | P8.4 (I/O)                   | I: 0; O: 1                             | 0       | 0                  |
|                           |   | UCB1CLK/UCA1STE              | X                                      | 1       | 0                  |
|                           |   | S11                          | X                                      | X       | 1                  |
| P8.5/UCB1SIMO/UCB1SDA/S10 | 5 | P8.5 (I/O)                   | I: 0; O: 1                             | 0       | 0                  |
|                           |   | UCB1SIMO/UCB1SDA             | X                                      | 1       | 0                  |
|                           |   | S10                          | X                                      | X       | 1                  |
| P8.6/UCB1SOMI/UCB1SCL/S9  | 6 | P8.6 (I/O)                   | I: 0; O: 1                             | 0       | 0                  |
|                           |   | UCB1SOMI/UCB1SCL             | X                                      | 1       | 0                  |
|                           |   | S9                           | X                                      | X       | 1                  |
| P8.7/S8                   | 7 | P8.7 (I/O)                   | I: 0; O: 1                             | 0       | 0                  |
|                           |   | S8                           | X                                      | X       | 1                  |

(1) X = Don't care

### 6.13.12 Port P9 (P9.0 to P9.7) Input/Output With Schmitt Trigger

Figure 6-13 shows the port diagram. Table 6-66 summarizes selection of the pin functions.

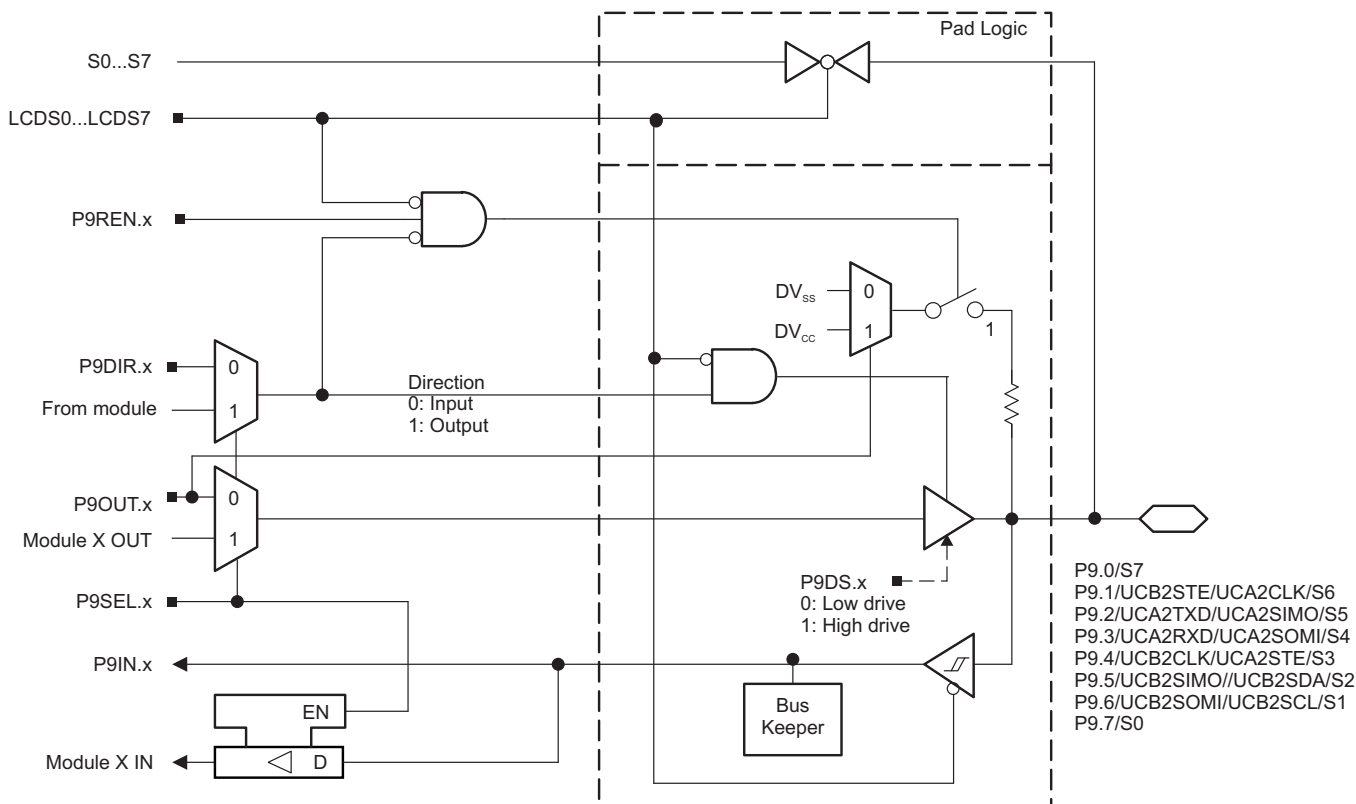


Figure 6-13. Port P9 (P9.0 to P9.7) Diagram

**Table 6-66. Port P9 (P9.0 to P9.7) Pin Functions**

| PIN NAME (P9.x)           | x | FUNCTION          | CONTROL BITS OR SIGNALS <sup>(1)</sup> |         |                   |
|---------------------------|---|-------------------|----------------------------------------|---------|-------------------|
|                           |   |                   | P9DIR.x                                | P9SEL.x | LCDS0...<br>LCDS7 |
| P9.0/S7                   | 0 | P9.0 (I/O)        | I: 0; O: 1                             | 0       | 0                 |
|                           |   | S7                | X                                      | X       | 1                 |
| P9.1/UCB2STE/UCA2CLK/S6   | 1 | P9.1 (I/O)        | I: 0; O: 1                             | 0       | 0                 |
|                           |   | UCB2STE/UCA2CLK   | X                                      | 1       | 0                 |
|                           |   | S6                | X                                      | X       | 1                 |
| P9.2/UCA2TXD/UCA2SIMO/S5  | 2 | P9.2 (I/O)        | I: 0; O: 1                             | 0       | 0                 |
|                           |   | UCA2TXD/UCA2SIMO  | X                                      | 1       | 0                 |
|                           |   | S5                | X                                      | X       | 1                 |
| P9.3/UCA2RXD/UCA2SOMI/S4  | 3 | P9.3 (I/O)        | I: 0; O: 1                             | 0       | 0                 |
|                           |   | UCA2RXD/UCA2SOMI  | X                                      | 1       | 0                 |
|                           |   | S4                | X                                      | X       | 1                 |
| P9.4/UCB2CLK/UCA2STE/S3   | 4 | P9.4 (I/O)        | I: 0; O: 1                             | 0       | 0                 |
|                           |   | UCB2CLK/UCA2STE   | X                                      | 1       | 0                 |
|                           |   | S3                | X                                      | X       | 1                 |
| P9.5/UCB2SIMO/UCB2SDA/S2  | 5 | P9.5 (I/O)        | I: 0; O: 1                             | 0       | 0                 |
|                           |   | UCB2SIMO/UCB2SDA  | X                                      | 1       | 0                 |
|                           |   | S2                | X                                      | X       | 1                 |
| P9.6/UCB2SOMI/UCB2SCLK/S1 | 6 | P9.6 (I/O)        | I: 0; O: 1                             | 0       | 0                 |
|                           |   | UCB2SOMI/UCB2SCLK | X                                      | 1       | 0                 |
|                           |   | S1                | X                                      | X       | 1                 |
| P9.7/S0                   | 7 | P9.7 (I/O)        | I: 0; O: 1                             | 0       | 0                 |
|                           |   | S0                | X                                      | X       | 1                 |

(1) X = Don't care

### 6.13.13 Port PU (PU.0/DP, PU.1/DM, PUR) USB Ports (F665x, F565x)

Figure 6-14 shows the port diagram. Table 6-67 and Table 6-68 summarize selection of the pin functions.

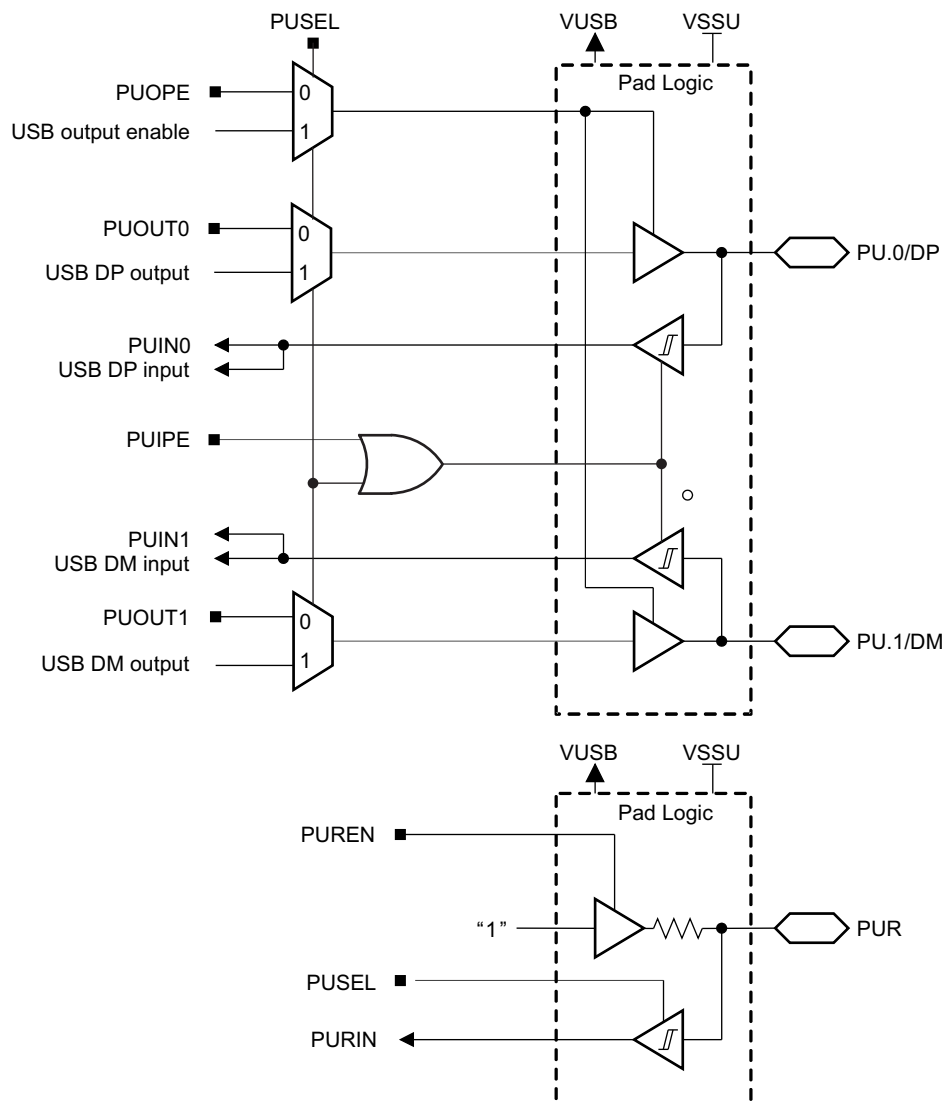


Figure 6-14. Port PU (PU.0 and PU.1) Diagram (F665x, F565x)

**Table 6-67. Port PU (PU.0, PU.1) Functions (F665x, F565x)**

| PUSEL | PUIPE | PUOPE | PUOUT1 | PUOUT0 | PU.1/DM       | PU.0/DP       | PORT U FUNCTION             |
|-------|-------|-------|--------|--------|---------------|---------------|-----------------------------|
| 0     | 0     | 1     | 0      | 0      | Output low    | Output low    | Outputs enabled             |
| 0     | 0     | 1     | 0      | 1      | Output low    | Output high   | Outputs enabled             |
| 0     | 0     | 1     | 1      | 0      | Output high   | Output low    | Outputs enabled             |
| 0     | 0     | 1     | 1      | 1      | Output high   | Output high   | Outputs enabled             |
| 0     | 1     | 0     | X      | X      | Input enabled | Input enabled | Inputs enabled              |
| 0     | 0     | 0     | X      | X      | Hi-Z          | Hi-Z          | Outputs and inputs disabled |
| 1     | X     | X     | X      | X      | DM            | DP            | Direction set by USB module |

**Table 6-68. Port PU (PUR) Input Functions (F665x, F565x)**

| CONTROL BITS |       | FUNCTION                          |
|--------------|-------|-----------------------------------|
| PUSEL        | PUREN |                                   |
| 0            | 0     | Input disabled<br>Pullup disabled |
| 0            | 1     | Input disabled<br>Pullup enabled  |
| 1            | 0     | Input enabled<br>Pullup disabled  |
| 1            | 1     | Input enabled<br>Pullup enabled   |

#### 6.13.14 Port PU (PU.0 and PU.1) Ports (F645x, F535x)

Figure 6-15 shows the port diagram. Table 6-69 summarizes selection of the pin functions.

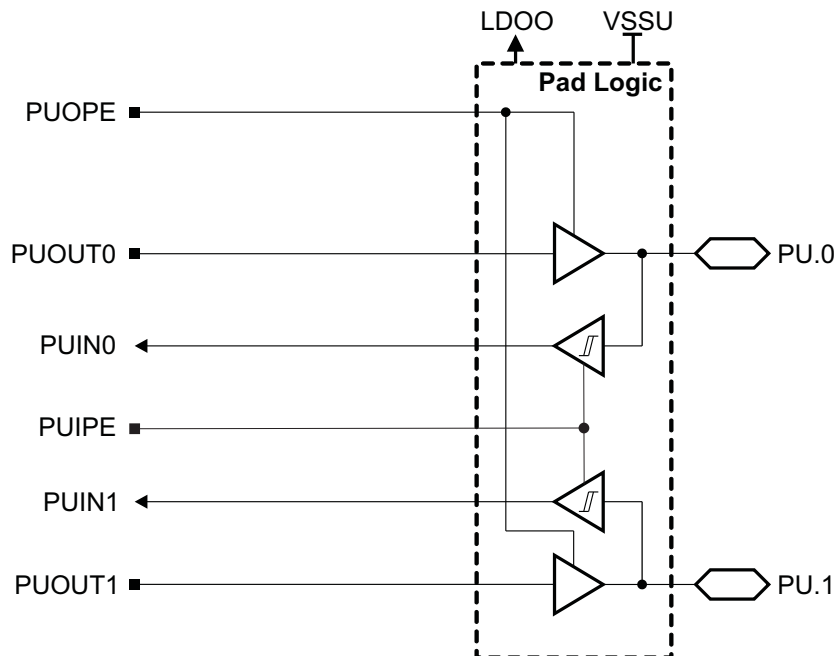


**Figure 6-15. Port PU (PU.0 and PU.1) Diagram (F645x, F535x)**

**Table 6-69. Port PU (PU.0 and PU.1) Functions (F645x, F535x)<sup>(1)</sup>**

| PUIPE | PUOPE | PUOUT1 | PUOUT0 | PU.1          | PU.0          | PORT U FUNCTION             |
|-------|-------|--------|--------|---------------|---------------|-----------------------------|
| 0     | 1     | 0      | 0      | Output low    | Output low    | Outputs enabled             |
| 0     | 1     | 0      | 1      | Output low    | Output high   | Outputs enabled             |
| 0     | 1     | 1      | 0      | Output high   | Output low    | Outputs enabled             |
| 0     | 1     | 1      | 1      | Output high   | Output high   | Outputs enabled             |
| 1     | 0     | X      | X      | Input enabled | Input enabled | Inputs enabled              |
| 0     | 0     | X      | X      | Hi-Z          | Hi-Z          | Outputs and inputs disabled |

(1) PU.1 and PU.0 inputs and outputs are supplied from LDOO. LDOO can be generated by the device using the integrated 3.3-V LDO when enabled. LDOO can also be supplied externally when the 3.3-V LDO is not being used and is disabled.

### 6.13.15 Port PJ (PJ.0) JTAG Pin TDO, Input/Output With Schmitt Trigger or Output

Figure 6-16 shows the port diagram. Table 6-70 summarizes selection of the pin functions.

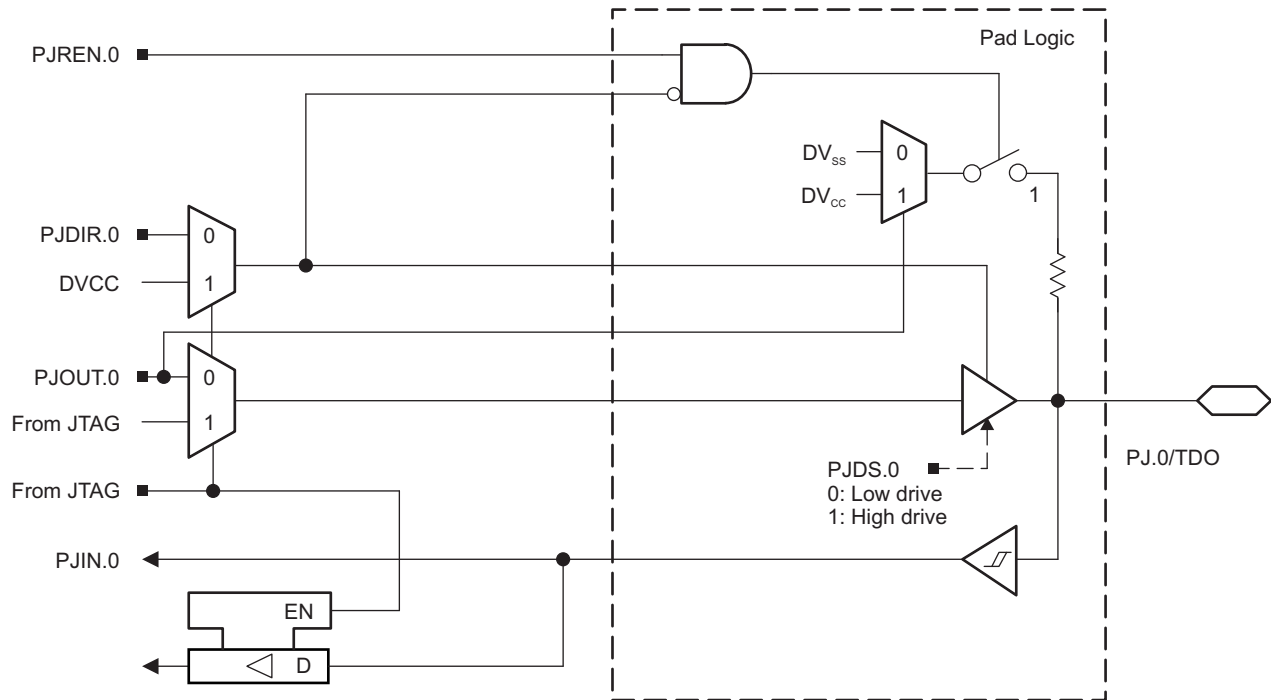


Figure 6-16. Port PJ (PJ.0) Diagram

### 6.13.16 Port PJ (PJ.1 to PJ.3) JTAG Pins TMS, TCK, TDI/TCLK, Input/Output With Schmitt Trigger or Output

Figure 6-17 shows the port diagram. Table 6-70 summarizes selection of the pin functions.

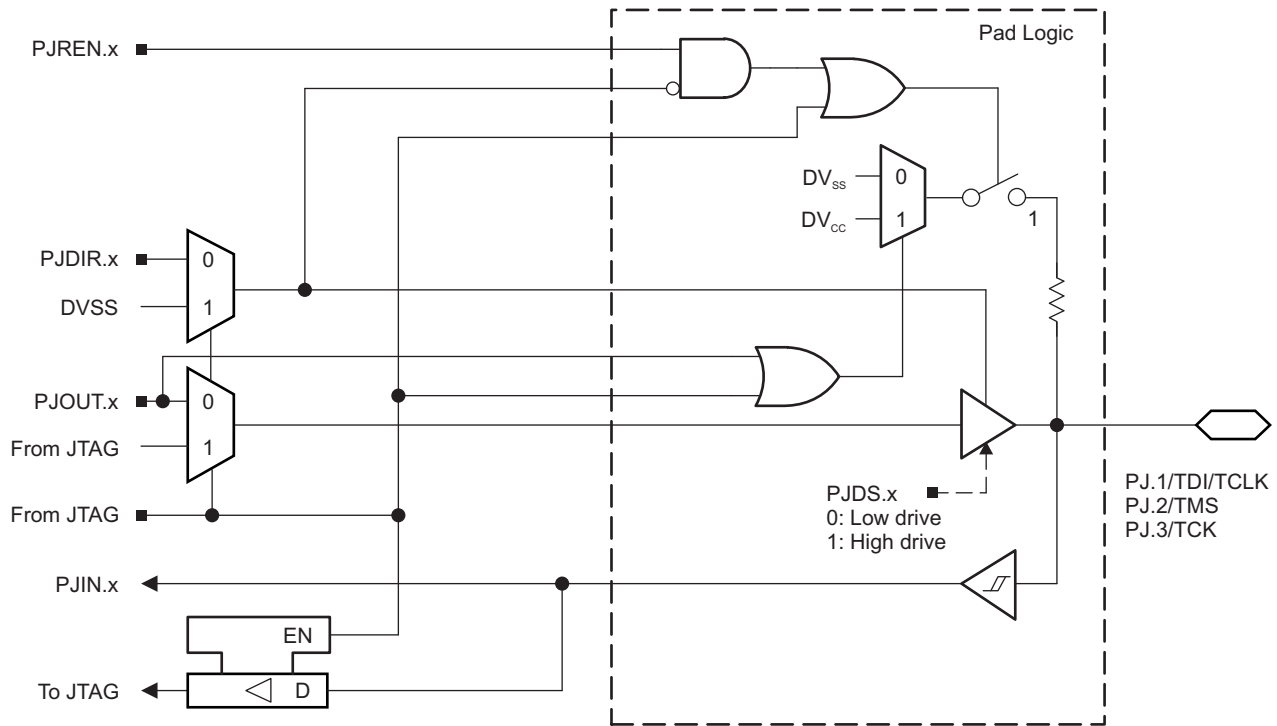


Figure 6-17. Port PJ (PJ.1 to PJ.3) Diagram

Table 6-70. Port PJ (PJ.0 to PJ.3) Pin Functions

| PIN NAME (PJ.x) | x | FUNCTION                    | CONTROL BITS OR SIGNALS <sup>(1)</sup> |
|-----------------|---|-----------------------------|----------------------------------------|
|                 |   |                             | PJDIR.x                                |
| PJ.0/TDO        | 0 | PJ.0 (I/O) <sup>(2)</sup>   | I: 0; O: 1                             |
|                 |   | TDO <sup>(3)</sup>          | X                                      |
| PJ.1/TDI/TCLK   | 1 | PJ.1 (I/O) <sup>(2)</sup>   | I: 0; O: 1                             |
|                 |   | TDI/TCLK <sup>(3) (4)</sup> | X                                      |
| PJ.2/TMS        | 2 | PJ.2 (I/O) <sup>(2)</sup>   | I: 0; O: 1                             |
|                 |   | TMS <sup>(3) (4)</sup>      | X                                      |
| PJ.3/TCK        | 3 | PJ.3 (I/O) <sup>(2)</sup>   | I: 0; O: 1                             |
|                 |   | TCK <sup>(3) (4)</sup>      | X                                      |

(1) X = Don't care

(2) Default condition

(3) The pin direction is controlled by the JTAG module.

(4) In JTAG mode, pullups are activated automatically on TMS, TCK, and TDI/TCLK. PJREN.x are do not care.

## 6.14 Device Descriptors

Table 6-71 lists the contents of the device descriptor tag-length-value (TLV) structure for each device type.

**Table 6-71. Device Descriptor Table<sup>(1)</sup>**

| DESCRIPTION       |                                             | ADDRESS | SIZE<br>(bytes) | VALUE    |          |          |          |          |          |          |          |
|-------------------|---------------------------------------------|---------|-----------------|----------|----------|----------|----------|----------|----------|----------|----------|
|                   |                                             |         |                 | F6659    | F6658    | F6459    | F6458    | F5659    | F5658    | F5359    | F5358    |
| Info Block        | Info length                                 | 01A00h  | 1               | 06h      | 06h      | 06h      | 06h      | 06h      | 06h      | 06h      | 06h      |
|                   | CRC length                                  | 01A01h  | 1               | 06h      | 06h      | 06h      | 06h      | 06h      | 06h      | 06h      | 06h      |
|                   | CRC value                                   | 01A02h  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | Device ID                                   | 01A04h  | 2               | 812Bh    | 812Ch    | 812Dh    | 812Eh    | 8130h    | 8131h    | 8132h    | 8133h    |
|                   | Hardware revision                           | 01A06h  | 1               | 10h      | 10h      | 10h      | 10h      | 10h      | 10h      | 10h      | 10h      |
|                   | Firmware revision                           | 01A07h  | 1               | 10h      | 10h      | 10h      | 10h      | 10h      | 10h      | 10h      | 10h      |
| Die Record        | Die record tag                              | 01A08h  | 1               | 08h      | 08h      | 08h      | 08h      | 08h      | 08h      | 08h      | 08h      |
|                   | Die record length                           | 01A09h  | 1               | 0Ah      | 0Ah      | 0Ah      | 0Ah      | 0Ah      | 0Ah      | 0Ah      | 0Ah      |
|                   | Lot/wafer ID                                | 01A0Ah  | 4               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | Die X position                              | 01A0Eh  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | Die Y position                              | 01A10h  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | Test results                                | 01A12h  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
| ADC12 Calibration | ADC12 calibration tag                       | 01A14h  | 1               | 11h      | 11h      | 11h      | 11h      | 11h      | 11h      | 11h      | 11h      |
|                   | ADC12 calibration length                    | 01A15h  | 1               | 10h      | 10h      | 10h      | 10h      | 10h      | 10h      | 10h      | 10h      |
|                   | ADC gain factor                             | 01A16h  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | ADC offset                                  | 01A18h  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | ADC 1.5-V reference temperature sensor 30°C | 01A1Ah  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | ADC 1.5-V reference temperature sensor 85°C | 01A1Ch  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | ADC 2.0-V reference temperature sensor 30°C | 01A1Eh  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | ADC 2.0-V reference temperature sensor 85°C | 01A20h  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | ADC 2.5-V reference temperature sensor 30°C | 01A22h  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | ADC 2.5-V reference temperature sensor 85°C | 01A24h  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
| REF Calibration   | REF calibration tag                         | 01A26h  | 1               | 12h      | 12h      | 12h      | 12h      | 12h      | 12h      | 12h      | 12h      |
|                   | REF calibration length                      | 01A27h  | 1               | 06h      | 06h      | 06h      | 06h      | 06h      | 06h      | 06h      | 06h      |
|                   | REF 1.5-V reference factor                  | 01A28h  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | REF 2.0-V reference factor                  | 01A2Ah  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |
|                   | REF 2.5-V reference factor                  | 01A2Ch  | 2               | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit | Per unit |

(1) N/A = Not applicable

## 7 Device and Documentation Support

### 7.1 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 [MSP430 ultra-low-power sensing and measurement MCUs overview](#).

### 7.2 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 7-1](#) provides a legend for reading the complete device name.

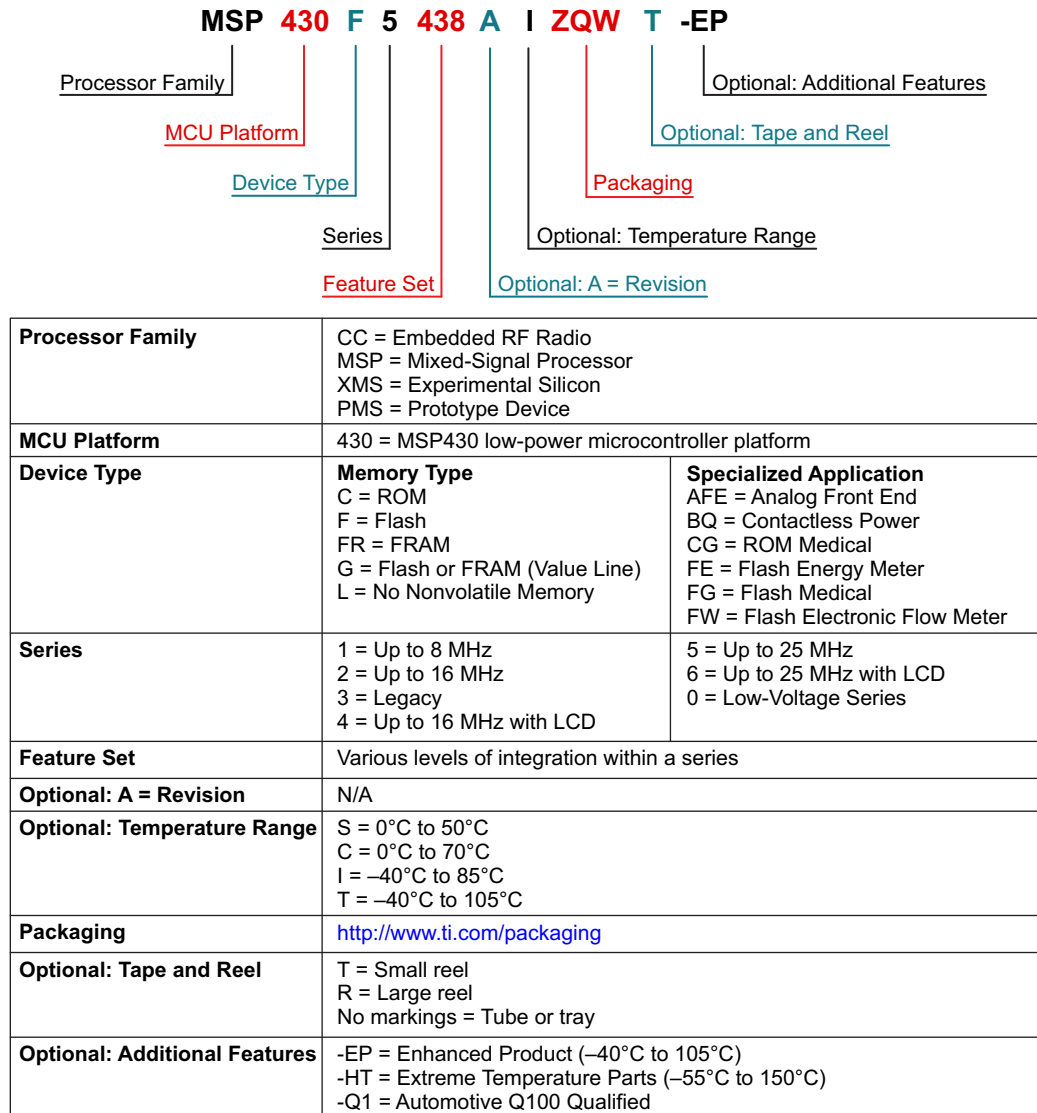


**Figure 7-1. Device Nomenclature**

## 7.3 Tools and Software

All MSP microcontrollers are supported by a wide variety of software and hardware development tools. Tools are available from TI and various third parties. See them all at [MSP430 Ultra-Low-Power MCUs – Tools & software](#).

Table 7-1 lists the debug features of the MSP430F665x, MSP430F645x, MSP430F565x, and MSP430F535x MCUs. See the [Code Composer Studio for MSP430 User's Guide](#) for details on the available features.

**Table 7-1. Hardware Debug Features**

| MSP430<br>ARCHITECTURE | 4-WIRE<br>JTAG | 2-WIRE<br>JTAG | BREAK-<br>POINTS<br>(N) | RANGE<br>BREAK-<br>POINTS | CLOCK<br>CONTROL | STATE<br>SEQUENCER | TRACE<br>BUFFER | LPMx.5<br>DEBUGGING<br>SUPPORT |
|------------------------|----------------|----------------|-------------------------|---------------------------|------------------|--------------------|-----------------|--------------------------------|
| MSP430Xv2              | Yes            | Yes            | 8                       | Yes                       | Yes              | Yes                | Yes             | Yes                            |

### Design Kits and Evaluation Modules

#### [MSP-TS430PZ100USB - 100-pin Target Development Board for MSP430F5x and MSP430F6x MCUs](#)

The MSP-TS430PZ100USB is a stand-alone 100-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.

#### [100-pin Target Development Board and MSP-FET Programmer Bundle for MSP430F5x and MSP430F6x MCUs](#)

The MSP-TS430PZ100USB is a stand-alone 100-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. The MSP-FET is a powerful flash emulation tool to quickly begin application development on the MSP430 MCU. It includes USB debugging interface used to program and debug the MSP430 in-system through the JTAG interface or the pin saving Spy Bi-Wire (2-wire JTAG) protocol.

[MSP430F5529 USB LaunchPad Evaluation Kit](#) Develop low power, PC-connected applications with integrated Full-speed USB 2.0 (HID/MSC/CDC). The MSP-EXP430F5529LP LaunchPad is an inexpensive, simple microcontroller development kit for the MSP430F5529 USB microcontroller. It's an easy way to start developing on the MSP430 MCU, with an on-board emulation for programming and debugging, as well as buttons and LEDs for simple user interface.

### 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.

[MSP430F665x, MSP430F565x Code Examples](#) C code examples that configure each of the integrated peripherals for various application needs.

[MSP Driver Library](#) Driver Library's abstracted API keeps you above the bits and bytes of the MSP430 hardware by providing easy-to-use function calls. 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 application's energy profile 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 utilize 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 squeeze every last nano amp out of your application. At build time, ULP Advisor will provide 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 be useful in assisting customers in complying 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 brings you MSPMATHLIB. Leveraging the intelligent peripherals of our devices, this floating point math library of scalar functions brings you up to 26x better performance. Mathlib is easy to integrate into your designs. This library is free and is integrated in both Code Composer Studio and IAR IDEs. Read the user's guide for an in depth look at the math library and relevant benchmarks.

## Development Tools

**Code Composer Studio™ Integrated Development Environment for MSP Microcontrollers** Code Composer Studio is an integrated development environment (IDE) that supports all MSP microcontroller devices. Code Composer Studio comprises a suite of embedded software utilities used to develop and debug embedded applications. It includes an optimizing C/C++ compiler, source code editor, project build environment, debugger, profiler, and many other features. The intuitive IDE provides a single user interface taking you through each step of the application development flow. Familiar utilities and interfaces allow users to get started faster than ever before. Code Composer Studio combines the advantages of the Eclipse software framework with advanced embedded debug capabilities from TI resulting in a compelling feature-rich development environment for embedded developers. When using CCS with an MSP MCU, a unique and powerful set of plugins and embedded software utilities are made available to fully leverage the MSP microcontroller.

**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) files 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 allows users to quickly begin application development on MSP low-power microcontrollers (MCU). Creating MCU software usually requires downloading the resulting binary program to the MSP device for validation and debugging. The MSP-FET provides a debug communication pathway between a host computer and the target MSP. Furthermore, the MSP-FET also provides a Backchannel UART connection between the computer's USB interface and the MSP UART. This affords the MSP programmer a convenient method for communicating serially between the MSP and a terminal running on the computer. It also supports loading programs (often called firmware) to the MSP target using the BSL (bootloader) through the UART and I<sup>2</sup>C communication protocols.

**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 allow the user to fully customize the process. The MSP Gang Programmer is provided with an expansion board, called the Gang Splitter, that implements the interconnections between the MSP Gang Programmer and multiple target devices. Eight cables are provided that connect the expansion board to eight target devices (through JTAG or Spy-Bi-Wire connectors). The programming can be done with a PC or as a stand-alone device. A PC-side graphical user interface is also available and is DLL-based.

## 7.4 Documentation Support

The following documents describe the MSP430F665x, MSP430F645x, MSP430F565x, and MSP430F535x MCUs. Copies of these documents are available on the Internet at [www.ti.com](http://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](http://ti.com) (for links to the product folders, see [Section 7.5](#)). 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

**MSP430F6659 Device Erratasheet** Describes the known exceptions to the functional specifications for all silicon revisions of this device.

**MSP430F6658 Device Erratasheet** Describes the known exceptions to the functional specifications for all silicon revisions of this device.

**MSP430F6459 Device Erratasheet** Describes the known exceptions to the functional specifications for all silicon revisions of this device.

**MSP430F6458 Device Erratasheet** Describes the known exceptions to the functional specifications for all silicon revisions of this device.

**MSP430F5659 Device Erratasheet** Describes the known exceptions to the functional specifications for all silicon revisions of this device.

**MSP430F5658 Device Erratasheet** Describes the known exceptions to the functional specifications for all silicon revisions of this device.

**MSP430F5359 Device Erratasheet** Describes the known exceptions to the functional specifications for all silicon revisions of this device.

**MSP430F5358 Device Erratasheet** Describes the known exceptions to the functional specifications for all silicon revisions of this device.

### User's Guides

**MSP430F5xx and MSP430F6xx Family User's Guide** Detailed information on the modules and peripherals available in this device family.

**MSP430 Flash Device Bootloader (BSL) User's Guide** The MSP430 bootloader (BSL) lets users communicate with embedded memory in the MSP430 microcontroller during the prototyping phase, final production, and in service. Both the programmable memory (flash memory) and the data memory (RAM) can be modified as required. Do not confuse the bootloader with the bootstrap loader programs found in some digital signal processors (DSPs) that automatically load program code (and data) from external memory to the internal memory of the DSP.

**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.

### Application Reports

**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 as silicon technology scales to lower voltages and the need for designing cost-effective and ultra-low-power components. This application report addresses three ESD topics to help board designers and OEMs understand and design robust system-level designs: (1) Component-level ESD testing and system-level ESD testing; (2) General design guidelines for system-level ESD protection; (3) Introduction to System Efficient ESD Design (SEED), a co-design methodology of on-board and on-chip ESD protection. A few real-world system-level ESD protection design examples and their results are discussed.

## 7.5 Related Links

[Table 7-2](#) lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

**Table 7-2. Related Links**

| PARTS       | PRODUCT FOLDER             | ORDER NOW                  | TECHNICAL DOCUMENTS        | TOOLS & SOFTWARE           | SUPPORT & COMMUNITY        |
|-------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| MSP430F6659 | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> |
| MSP430F6658 | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> |
| MSP430F6459 | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> |
| MSP430F6458 | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> |
| MSP430F5659 | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> |
| MSP430F5658 | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> |
| MSP430F5359 | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> |
| MSP430F5358 | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> | <a href="#">Click here</a> |

## 7.6 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](http://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.

## 7.7 Trademarks

MicroStar Junior, MSP430, MSP430Ware, EnergyTrace, ULP Advisor, Code Composer Studio, E2E are trademarks of Texas Instruments.

All other trademarks are the property of their respective owners.

## 7.8 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.

## 7.9 Export Control Notice

Recipient agrees to not knowingly export or re-export, directly or indirectly, any product or technical data (as defined by the U.S., EU, and other Export Administration Regulations) including software, or any controlled product restricted by other applicable national regulations, received from disclosing party under nondisclosure obligations (if any), or any direct product of such technology, to any destination to which such export or re-export is restricted or prohibited by U.S. or other applicable laws, without obtaining prior authorization from U.S. Department of Commerce and other competent Government authorities to the extent required by those laws.

## 7.10 Glossary

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

## 8 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.

**PACKAGING INFORMATION**

| Orderable Device | Status<br>(1) | Package Type               | Package<br>Drawing | Pins | Package<br>Qty | Eco Plan<br>(2)            | Lead/Ball Finish<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|----------------------------|--------------------|------|----------------|----------------------------|-------------------------|----------------------|--------------|-------------------------|-------------------------|
| MSP430F5358IPZ   | ACTIVE        | LQFP                       | PZ                 | 100  | 90             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F5358                   | <a href="#">Samples</a> |
| MSP430F5358IPZR  | ACTIVE        | LQFP                       | PZ                 | 100  | 1000           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F5358                   | <a href="#">Samples</a> |
| MSP430F5358IZQWR | ACTIVE        | BGA<br>MICROSTAR<br>JUNIOR | ZQW                | 113  | 2500           | Green (RoHS<br>& no Sb/Br) | SNAGCU                  | Level-3-260C-168 HR  | -40 to 85    | F5358                   | <a href="#">Samples</a> |
| MSP430F5358IZQWT | ACTIVE        | BGA<br>MICROSTAR<br>JUNIOR | ZQW                | 113  | 250            | Green (RoHS<br>& no Sb/Br) | SNAGCU                  | Level-3-260C-168 HR  | -40 to 85    | F5358                   | <a href="#">Samples</a> |
| MSP430F5359IPZ   | ACTIVE        | LQFP                       | PZ                 | 100  | 90             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F5359                   | <a href="#">Samples</a> |
| MSP430F5359IPZR  | ACTIVE        | LQFP                       | PZ                 | 100  | 1000           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F5359                   | <a href="#">Samples</a> |
| MSP430F5359IZQWR | ACTIVE        | BGA<br>MICROSTAR<br>JUNIOR | ZQW                | 113  | 2500           | Green (RoHS<br>& no Sb/Br) | SNAGCU                  | Level-3-260C-168 HR  | -40 to 85    | F5359                   | <a href="#">Samples</a> |
| MSP430F5359IZQWT | ACTIVE        | BGA<br>MICROSTAR<br>JUNIOR | ZQW                | 113  | 250            | Green (RoHS<br>& no Sb/Br) | SNAGCU                  | Level-3-260C-168 HR  | -40 to 85    | F5359                   | <a href="#">Samples</a> |
| MSP430F5658IPZ   | ACTIVE        | LQFP                       | PZ                 | 100  | 90             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F5658                   | <a href="#">Samples</a> |
| MSP430F5658IPZR  | ACTIVE        | LQFP                       | PZ                 | 100  | 1000           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F5658                   | <a href="#">Samples</a> |
| MSP430F5658IZQWR | ACTIVE        | BGA<br>MICROSTAR<br>JUNIOR | ZQW                | 113  | 2500           | Green (RoHS<br>& no Sb/Br) | SNAGCU                  | Level-3-260C-168 HR  | -40 to 85    | F5658                   | <a href="#">Samples</a> |
| MSP430F5658IZQWT | ACTIVE        | BGA<br>MICROSTAR<br>JUNIOR | ZQW                | 113  | 250            | Green (RoHS<br>& no Sb/Br) | SNAGCU                  | Level-3-260C-168 HR  | -40 to 85    | F5658                   | <a href="#">Samples</a> |
| MSP430F5659IPZ   | ACTIVE        | LQFP                       | PZ                 | 100  | 90             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F5659                   | <a href="#">Samples</a> |
| MSP430F5659IPZR  | ACTIVE        | LQFP                       | PZ                 | 100  | 1000           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F5659                   | <a href="#">Samples</a> |

| Orderable Device | Status<br>(1) | Package Type               | Package<br>Drawing | Pins | Package<br>Qty | Eco Plan<br>(2)            | Lead/Ball Finish<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|----------------------------|--------------------|------|----------------|----------------------------|-------------------------|----------------------|--------------|-------------------------|-------------------------|
| MSP430F5659IZQWR | ACTIVE        | BGA<br>MICROSTAR<br>JUNIOR | ZQW                | 113  | 2500           | Green (RoHS<br>& no Sb/Br) | SNAGCU                  | Level-3-260C-168 HR  | -40 to 85    | F5659                   | <a href="#">Samples</a> |
| MSP430F5659IZQWT | ACTIVE        | BGA<br>MICROSTAR<br>JUNIOR | ZQW                | 113  | 250            | Green (RoHS<br>& no Sb/Br) | SNAGCU                  | Level-3-260C-168 HR  | -40 to 85    | F5659                   | <a href="#">Samples</a> |
| MSP430F6458IPZ   | ACTIVE        | LQFP                       | PZ                 | 100  | 90             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F6458                   | <a href="#">Samples</a> |
| MSP430F6459IPZ   | ACTIVE        | LQFP                       | PZ                 | 100  | 90             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F6459                   | <a href="#">Samples</a> |
| MSP430F6459IPZR  | ACTIVE        | LQFP                       | PZ                 | 100  | 1000           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F6459                   | <a href="#">Samples</a> |
| MSP430F6459IZQWT | ACTIVE        | BGA<br>MICROSTAR<br>JUNIOR | ZQW                | 113  | 250            | Green (RoHS<br>& no Sb/Br) | SNAGCU                  | Level-3-260C-168 HR  | -40 to 85    | F6459                   | <a href="#">Samples</a> |
| MSP430F6658IPZ   | ACTIVE        | LQFP                       | PZ                 | 100  | 90             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F6658                   | <a href="#">Samples</a> |
| MSP430F6659IPZ   | ACTIVE        | LQFP                       | PZ                 | 100  | 90             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F6659                   | <a href="#">Samples</a> |
| MSP430F6659IPZR  | ACTIVE        | LQFP                       | PZ                 | 100  | 1000           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-3-260C-168 HR  | -40 to 85    | F6659                   | <a href="#">Samples</a> |
| MSP430F6659IZQWR | ACTIVE        | BGA<br>MICROSTAR<br>JUNIOR | ZQW                | 113  | 2500           | Green (RoHS<br>& no Sb/Br) | SNAGCU                  | Level-3-260C-168 HR  | -40 to 85    | F6659                   | <a href="#">Samples</a> |
| MSP430F6659IZQWT | ACTIVE        | BGA<br>MICROSTAR<br>JUNIOR | ZQW                | 113  | 250            | Green (RoHS<br>& no Sb/Br) | SNAGCU                  | Level-3-260C-168 HR  | -40 to 85    | F6659                   | <a href="#">Samples</a> |

<sup>(1)</sup> 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.

<sup>(2)</sup> **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".

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**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  $\leq 1000$ ppm threshold. Antimony trioxide based flame retardants must also meet the  $\leq 1000$ ppm threshold requirement.

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

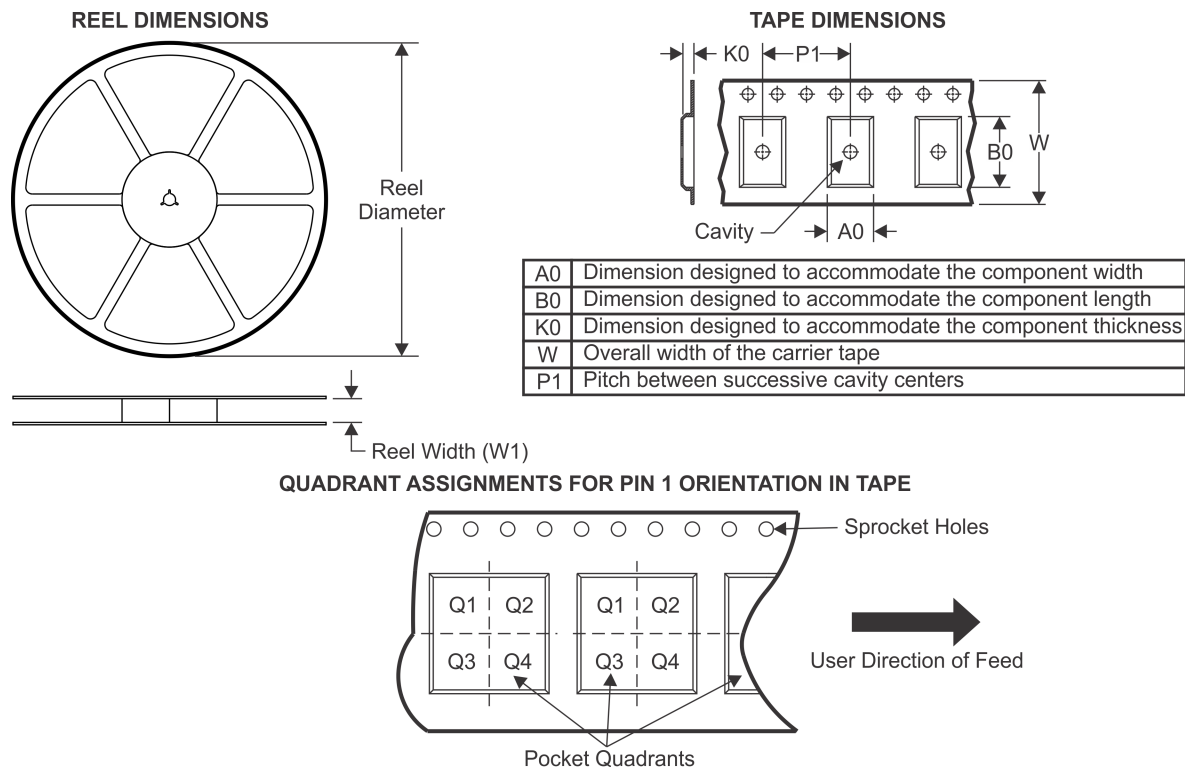
<sup>(4)</sup> There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

<sup>(5)</sup> 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.

<sup>(6)</sup> 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.

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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

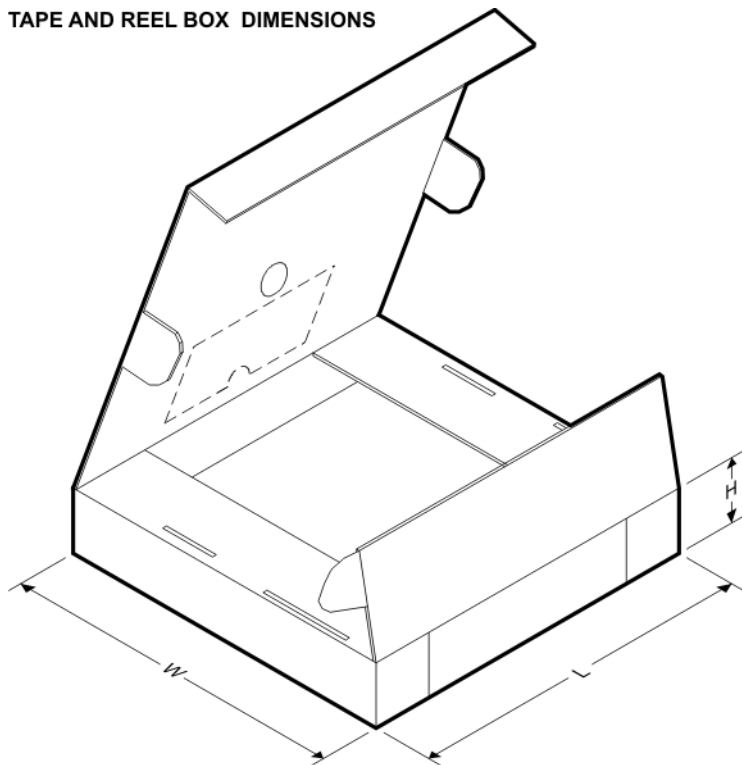
**TAPE AND REEL INFORMATION**


\*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 |
|------------------|----------------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| MSP430F5358IPZR  | LQFP                 | PZ              | 100  | 1000 | 330.0              | 24.4               | 17.0    | 17.0    | 2.1     | 20.0    | 24.0   | Q2            |
| MSP430F5358IZQWR | BGA MICROSTAR JUNIOR | ZQW             | 113  | 2500 | 330.0              | 16.4               | 7.3     | 7.3     | 1.5     | 12.0    | 16.0   | Q1            |
| MSP430F5358IZQWT | BGA MICROSTAR JUNIOR | ZQW             | 113  | 250  | 180.0              | 16.4               | 7.3     | 7.3     | 1.5     | 12.0    | 16.0   | Q1            |
| MSP430F5359IPZR  | LQFP                 | PZ              | 100  | 1000 | 330.0              | 24.4               | 17.0    | 17.0    | 2.1     | 20.0    | 24.0   | Q2            |
| MSP430F5359IZQWR | BGA MICROSTAR JUNIOR | ZQW             | 113  | 2500 | 330.0              | 16.4               | 7.3     | 7.3     | 1.5     | 12.0    | 16.0   | Q1            |
| MSP430F5359IZQWT | BGA MICROSTAR JUNIOR | ZQW             | 113  | 250  | 180.0              | 16.4               | 7.3     | 7.3     | 1.5     | 12.0    | 16.0   | Q1            |
| MSP430F5658IPZR  | LQFP                 | PZ              | 100  | 1000 | 330.0              | 24.4               | 17.0    | 17.0    | 2.1     | 20.0    | 24.0   | Q2            |
| MSP430F5658IZQWR | BGA MICROSTAR JUNIOR | ZQW             | 113  | 2500 | 330.0              | 16.4               | 7.3     | 7.3     | 1.5     | 12.0    | 16.0   | Q1            |

| 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 |
|------------------|----------------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
|                  | OR                   |                 |      |      |                    |                    |         |         |         |         |        |               |
| MSP430F5658IZQWT | BGA MICROSTAR JUNIOR | ZQW             | 113  | 250  | 180.0              | 16.4               | 7.3     | 7.3     | 1.5     | 12.0    | 16.0   | Q1            |
| MSP430F5659IPZR  | LQFP                 | PZ              | 100  | 1000 | 330.0              | 24.4               | 17.0    | 17.0    | 2.1     | 20.0    | 24.0   | Q2            |
| MSP430F5659IZQWR | BGA MICROSTAR JUNIOR | ZQW             | 113  | 2500 | 330.0              | 16.4               | 7.3     | 7.3     | 1.5     | 12.0    | 16.0   | Q1            |
| MSP430F5659IZQWT | BGA MICROSTAR JUNIOR | ZQW             | 113  | 250  | 180.0              | 16.4               | 7.3     | 7.3     | 1.5     | 12.0    | 16.0   | Q1            |
| MSP430F6459IPZR  | LQFP                 | PZ              | 100  | 1000 | 330.0              | 24.4               | 17.0    | 17.0    | 2.1     | 20.0    | 24.0   | Q2            |
| MSP430F6459IZQWT | BGA MICROSTAR JUNIOR | ZQW             | 113  | 250  | 180.0              | 16.4               | 7.3     | 7.3     | 1.5     | 12.0    | 16.0   | Q1            |
| MSP430F6659IPZR  | LQFP                 | PZ              | 100  | 1000 | 330.0              | 24.4               | 17.0    | 17.0    | 2.1     | 20.0    | 24.0   | Q2            |
| MSP430F6659IZQWR | BGA MICROSTAR JUNIOR | ZQW             | 113  | 2500 | 330.0              | 16.4               | 7.3     | 7.3     | 1.5     | 12.0    | 16.0   | Q1            |
| MSP430F6659IZQWT | BGA MICROSTAR JUNIOR | ZQW             | 113  | 250  | 180.0              | 16.4               | 7.3     | 7.3     | 1.5     | 12.0    | 16.0   | Q1            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

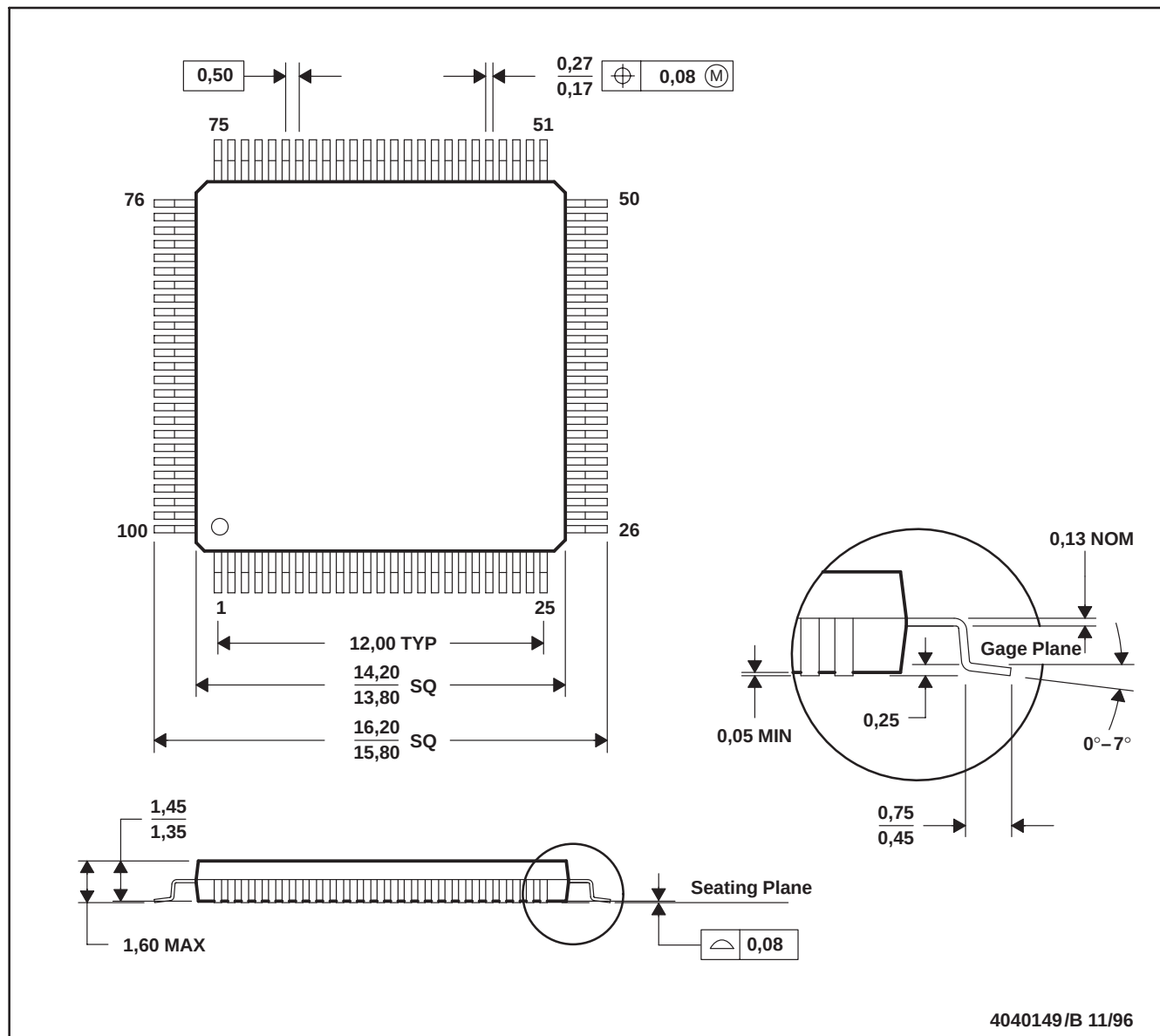
| Device           | Package Type         | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|------------------|----------------------|-----------------|------|------|-------------|------------|-------------|
| MSP430F5358IPZR  | LQFP                 | PZ              | 100  | 1000 | 350.0       | 350.0      | 43.0        |
| MSP430F5358IZQWR | BGA MICROSTAR JUNIOR | ZQW             | 113  | 2500 | 350.0       | 350.0      | 43.0        |
| MSP430F5358IZQWT | BGA MICROSTAR JUNIOR | ZQW             | 113  | 250  | 213.0       | 191.0      | 55.0        |
| MSP430F5359IPZR  | LQFP                 | PZ              | 100  | 1000 | 350.0       | 350.0      | 43.0        |
| MSP430F5359IZQWR | BGA MICROSTAR JUNIOR | ZQW             | 113  | 2500 | 350.0       | 350.0      | 43.0        |
| MSP430F5359IZQWT | BGA MICROSTAR JUNIOR | ZQW             | 113  | 250  | 213.0       | 191.0      | 55.0        |
| MSP430F5658IPZR  | LQFP                 | PZ              | 100  | 1000 | 350.0       | 350.0      | 43.0        |
| MSP430F5658IZQWR | BGA MICROSTAR JUNIOR | ZQW             | 113  | 2500 | 350.0       | 350.0      | 43.0        |
| MSP430F5658IZQWT | BGA MICROSTAR JUNIOR | ZQW             | 113  | 250  | 213.0       | 191.0      | 55.0        |
| MSP430F5659IPZR  | LQFP                 | PZ              | 100  | 1000 | 350.0       | 350.0      | 43.0        |
| MSP430F5659IZQWR | BGA MICROSTAR JUNIOR | ZQW             | 113  | 2500 | 350.0       | 350.0      | 43.0        |
| MSP430F5659IZQWT | BGA MICROSTAR JUNIOR | ZQW             | 113  | 250  | 213.0       | 191.0      | 55.0        |
| MSP430F6459IPZR  | LQFP                 | PZ              | 100  | 1000 | 350.0       | 350.0      | 43.0        |
| MSP430F6459IZQWT | BGA MICROSTAR JUNIOR | ZQW             | 113  | 250  | 213.0       | 191.0      | 55.0        |

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| Device           | Package Type            | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|------------------|-------------------------|-----------------|------|------|-------------|------------|-------------|
| MSP430F6659IPZR  | LQFP                    | PZ              | 100  | 1000 | 350.0       | 350.0      | 43.0        |
| MSP430F6659IZQWR | BGA MICROSTAR<br>JUNIOR | ZQW             | 113  | 2500 | 350.0       | 350.0      | 43.0        |
| MSP430F6659IZQWT | BGA MICROSTAR<br>JUNIOR | ZQW             | 113  | 250  | 213.0       | 191.0      | 55.0        |

## PZ (S-PQFP-G100)

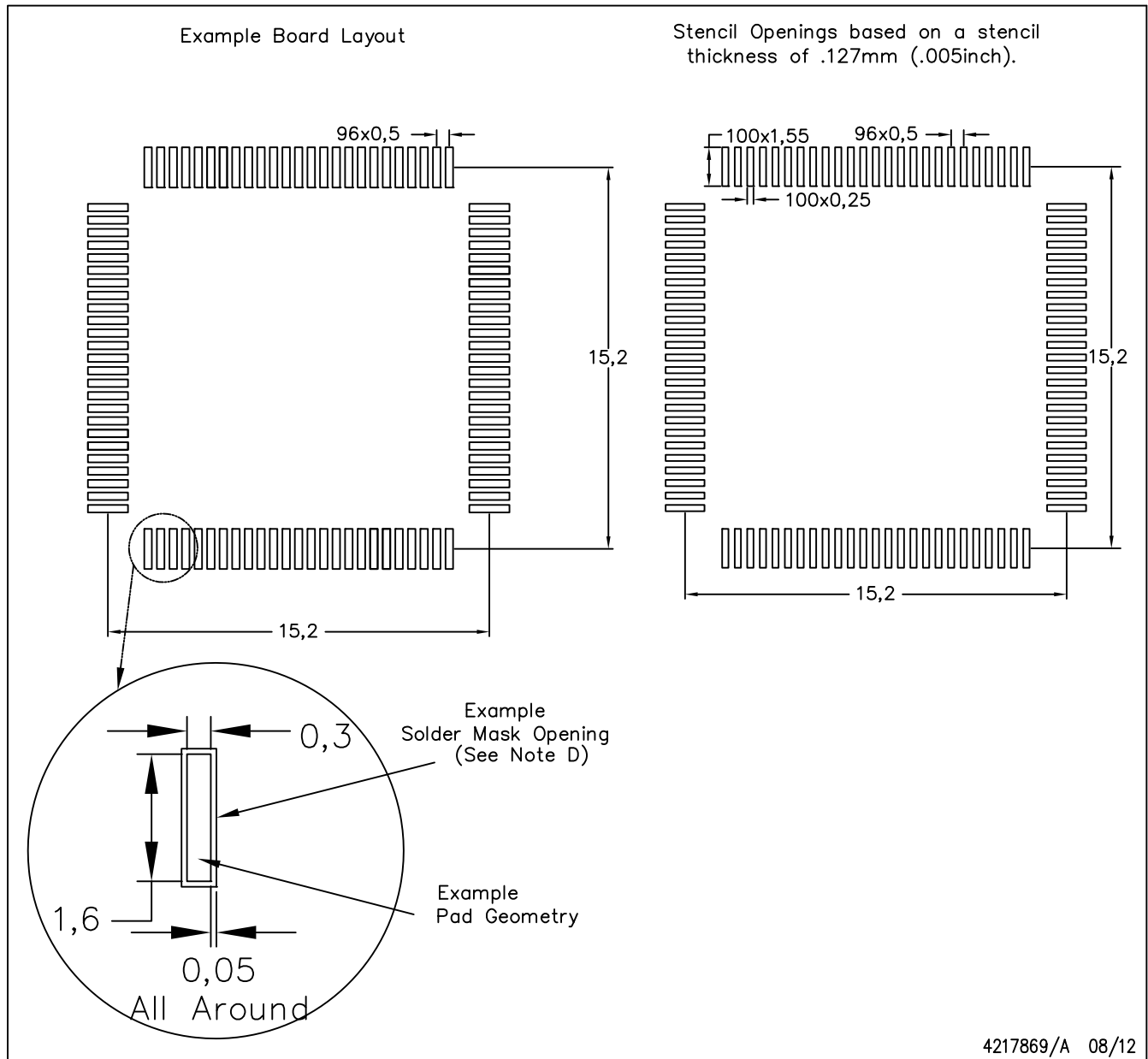
## PLASTIC QUAD FLATPACK



- NOTES: A. All linear dimensions are in millimeters.  
 B. This drawing is subject to change without notice.  
 C. Falls within JEDEC MS-026

PZ (S-PQFP-G100)

PLASTIC QUAD FLAT PACK

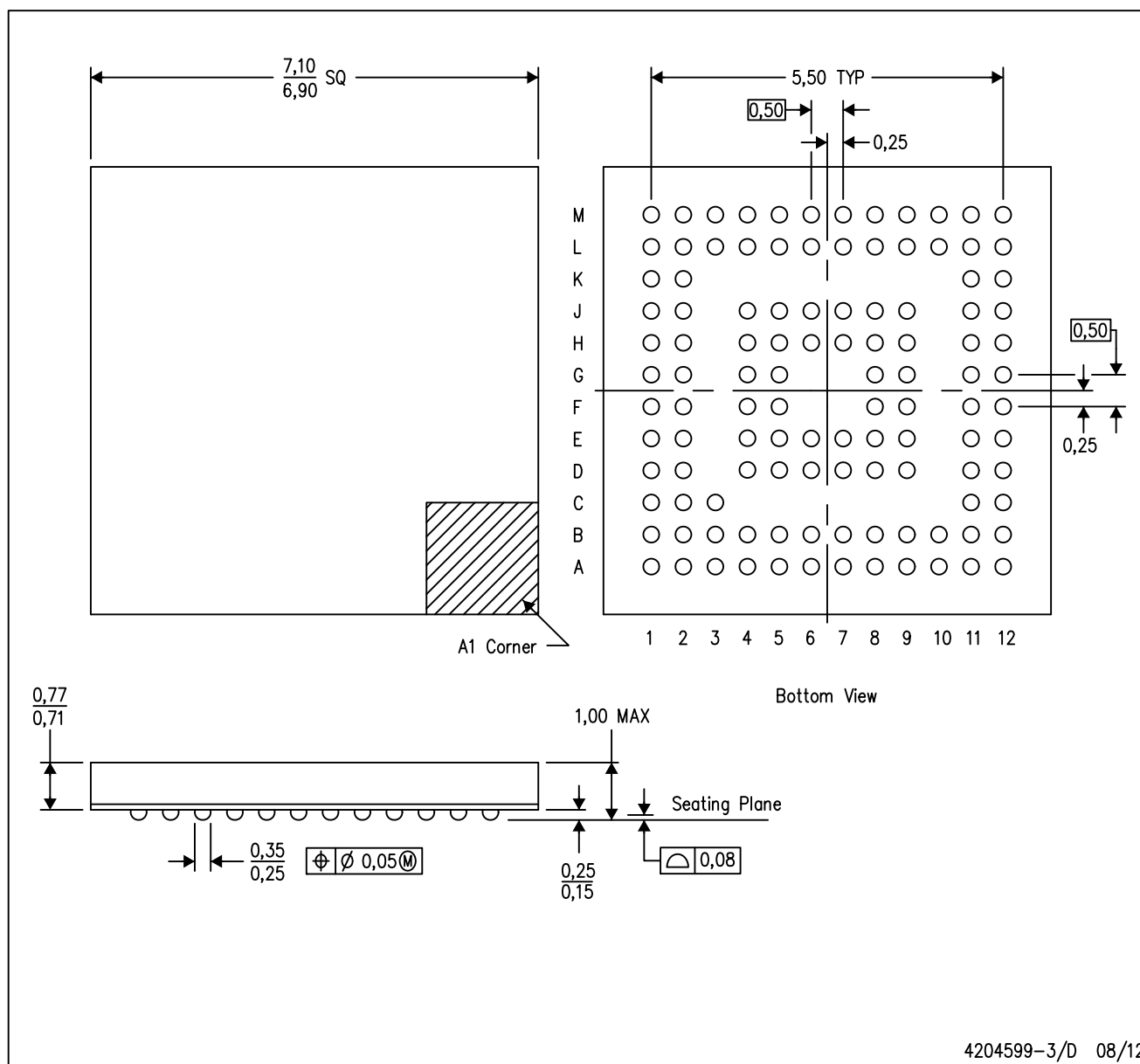


NOTES:

- All linear dimensions are in millimeters.
- This drawing is subject to change without notice.
- 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.
- Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

ZQW (S-PBGA-N113)

PLASTIC BALL GRID ARRAY



- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Falls within JEDEC MO-225
  - D. This is a Pb-free solder ball design.

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