

MIXED SIGNAL MICROCONTROLLER

FEATURES

- **Low Supply Voltage Range: 1.8 V to 3.6 V**
- **Ultra-Low Power Consumption**
 - Active Mode: 270 μ A at 1 MHz, 2.2 V
 - Standby Mode: 0.7 μ A
 - Off Mode (RAM Retention): 0.1 μ A
- **Ultra-Fast Wake-Up From Standby Mode in Less Than 1 μ s**
- **16-Bit RISC Architecture, 62.5-ns Instruction Cycle Time**
- **Basic Clock Module Configurations**
 - Internal Frequencies up to 16 MHz With Four Calibrated Frequencies to $\pm 1\%$
 - Internal Very-Low-Power Low-Frequency Oscillator
 - 32-kHz Crystal
 - High-Frequency (HF) Crystal up to 16 MHz
 - Resonator
 - External Digital Clock Source
 - External Resistor
- **16-Bit Timer_A With Three Capture/Compare Registers**
- **16-Bit Timer_B With Three Capture/Compare Registers**
- **Universal Serial Communication Interface**
 - Enhanced UART Supporting Auto-Baudrate Detection (LIN)
 - IrDA Encoder and Decoder
 - Synchronous SPI
 - I²C™
- **10-Bit 200-kSPS Analog-to-Digital (A/D) Converter With Internal Reference, Sample-and-Hold, Autoscan, and Data Transfer Controller**
- **Two Configurable Operational Amplifiers (MSP430F22x4 Only)**
- **Brownout Detector**
- **Serial Onboard Programming, No External Programming Voltage Needed, Programmable Code Protection by Security Fuse**
- **Bootstrap Loader**
- **On-Chip Emulation Module**
- **Family Members Include:**
 - **MSP430F2232**
 - 8KB + 256B Flash Memory
 - 512B RAM
 - **MSP430F2252**
 - 16KB + 256B Flash Memory
 - 512B RAM
 - **MSP430F2272**
 - 32KB + 256B Flash Memory
 - 1KB RAM
 - **MSP430F2234**
 - 8KB + 256B Flash Memory
 - 512B RAM
 - **MSP430F2254**
 - 16KB + 256B Flash Memory
 - 512B RAM
 - **MSP430F2274**
 - 32KB + 256B Flash Memory
 - 1KB RAM
- **Available in a 38-Pin Thin Shrink Small-Outline Package (TSSOP) (DA), 40-Pin QFN Package (RHA), and 49-Pin Ball Grid Array Package (YFF) (See [Table 1](#))**
- **For Complete Module Descriptions, See the *MSP430x2xx Family User's Guide* ([SLAU144](#))**



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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.

DESCRIPTION

The Texas Instruments MSP430™ family of ultra-low-power microcontrollers consist of several devices featuring 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 wake-up from low-power modes to active mode in less than 1 μ s.

The MSP430F22x4/MSP430F22x2 series is an ultra-low-power mixed signal microcontroller with two built-in 16-bit timers, a universal serial communication interface, 10-bit A/D converter with integrated reference and data transfer controller (DTC), two general-purpose operational amplifiers in the MSP430F22x4 devices, and 32 I/O pins.

Typical applications include sensor systems that capture analog signals, convert them to digital values, and then process the data for display or for transmission to a host system. Stand-alone radio-frequency (RF) sensor front ends are another area of application.

Table 1. Available Options

| T _A | PACKAGED DEVICES ⁽¹⁾⁽²⁾ | | |
|----------------|--|--|--|
| | PLASTIC 49-PIN BGA (YFF) | PLASTIC 38-PIN TSSOP (DA) | PLASTIC 40-PIN QFN (RHA) |
| -40°C to 85°C | MSP430F2232IYFF MSP430F2252IYFF MSP430F2272IYFF MSP430F2234IYFF MSP430F2254IYFF MSP430F2274IYFF | MSP430F2232IDA MSP430F2252IDA MSP430F2272IDA MSP430F2234IDA MSP430F2254IDA MSP430F2274IDA | MSP430F2232IRHA MSP430F2252IRHA MSP430F2272IRHA MSP430F2234IRHA MSP430F2254IRHA MSP430F2274IRHA |
| -40°C to 105°C | | MSP430F2232TDA MSP430F2252TDA MSP430F2272TDA MSP430F2234TDA MSP430F2254TDA MSP430F2274TDA | MSP430F2232TRHA MSP430F2252TRHA MSP430F2272TRHA MSP430F2234TRHA MSP430F2254TRHA MSP430F2274TRHA |

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.

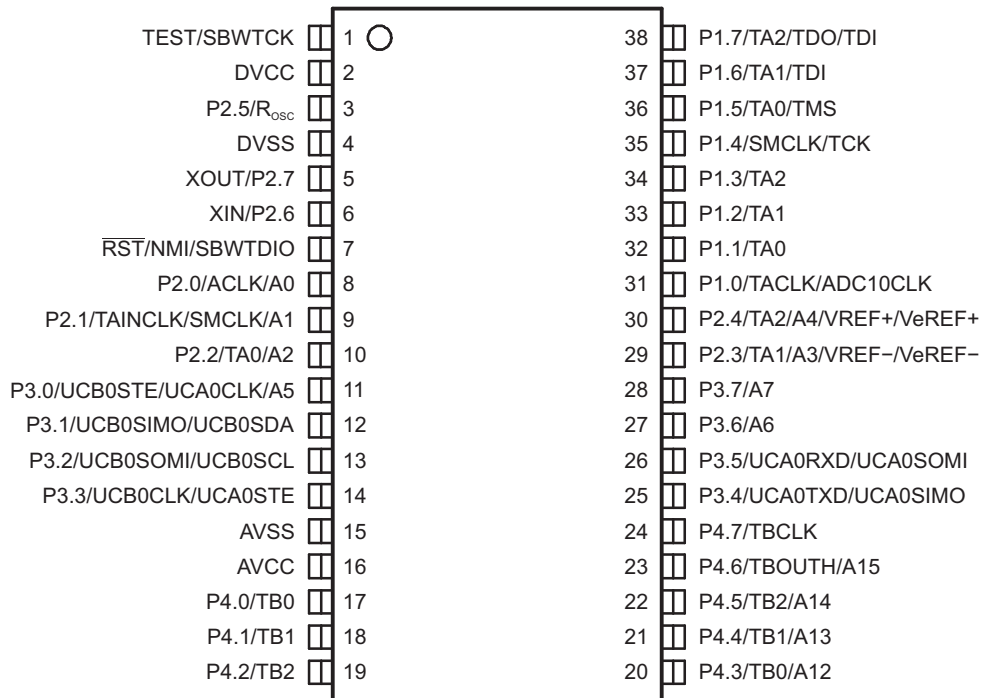
(2) Package drawings, thermal data, and symbolization are available at www.ti.com/packaging.

Development Tool Support

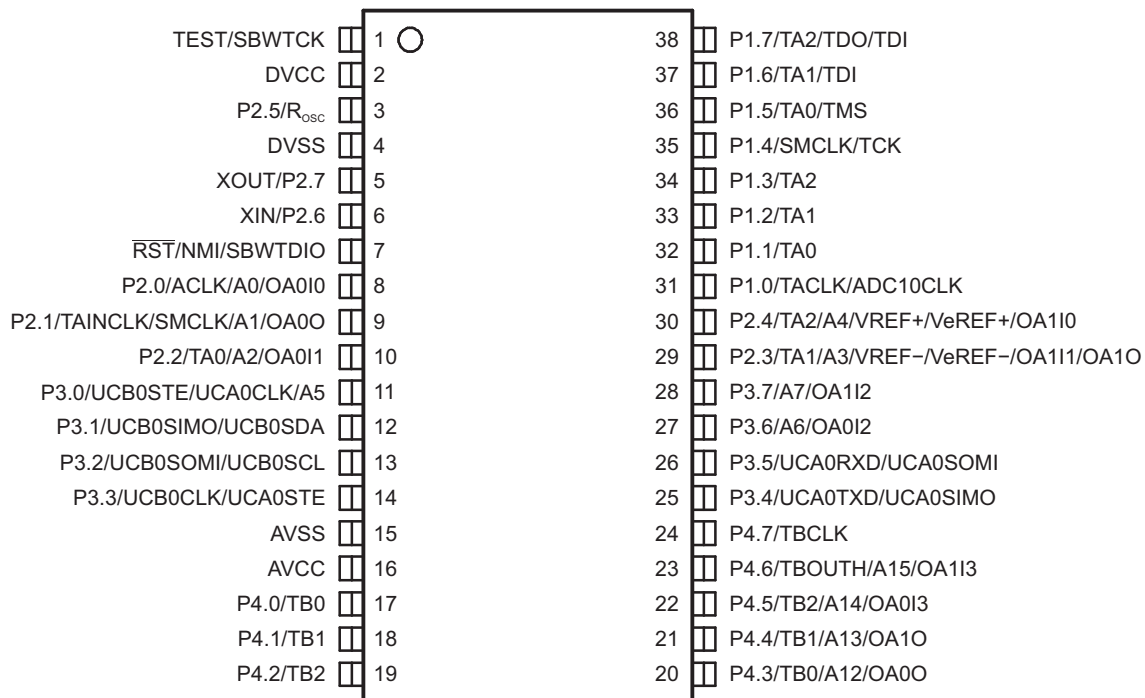
All MSP430™ microcontrollers include an Embedded Emulation Module (EEM) that allows advanced debugging and programming through easy-to-use development tools. Recommended hardware options include:

- Debugging and Programming Interface
 - MSP-FET430UIF (USB)
 - MSP-FET430PIF (Parallel Port)
- Debugging and Programming Interface with Target Board
 - MSP-FET430U38 (DA package)
- Production Programmer
 - MSP-GANG430

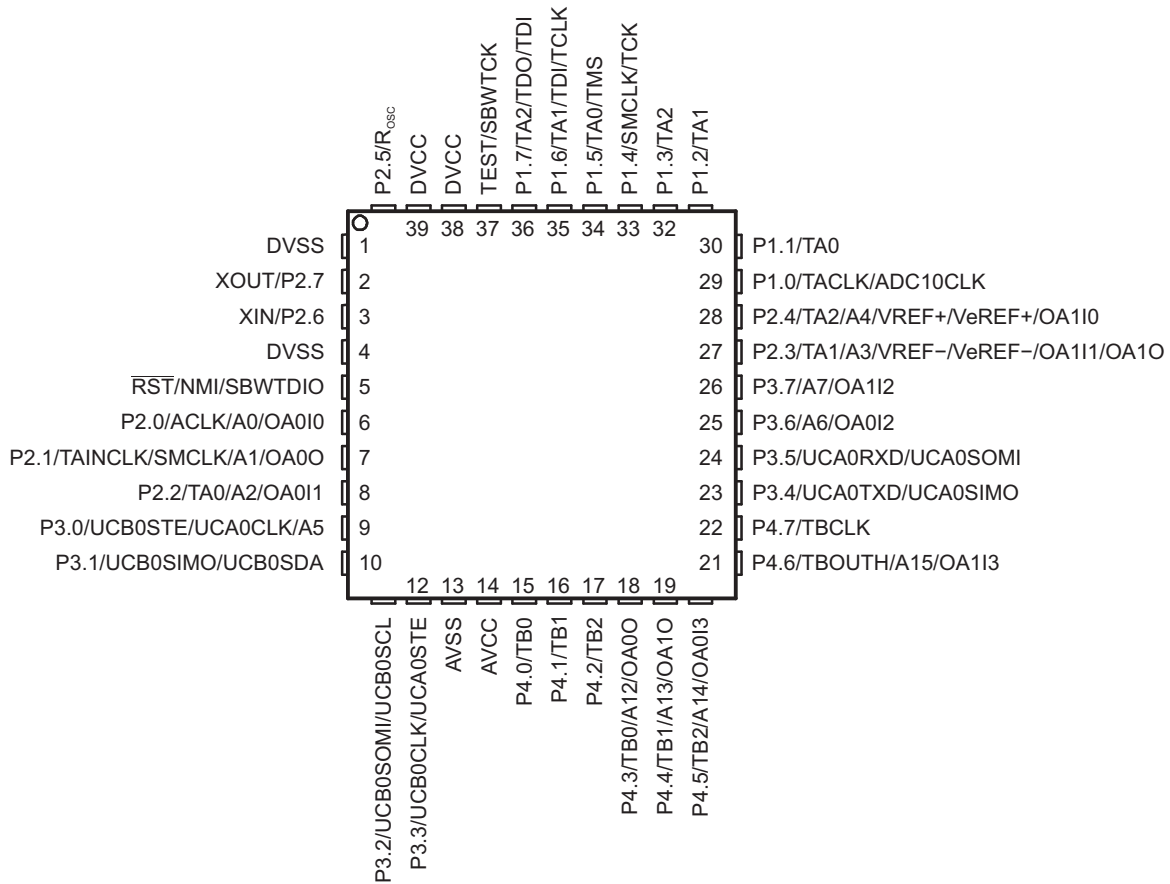
MSP430F22x2 Device Pinout, DA Package



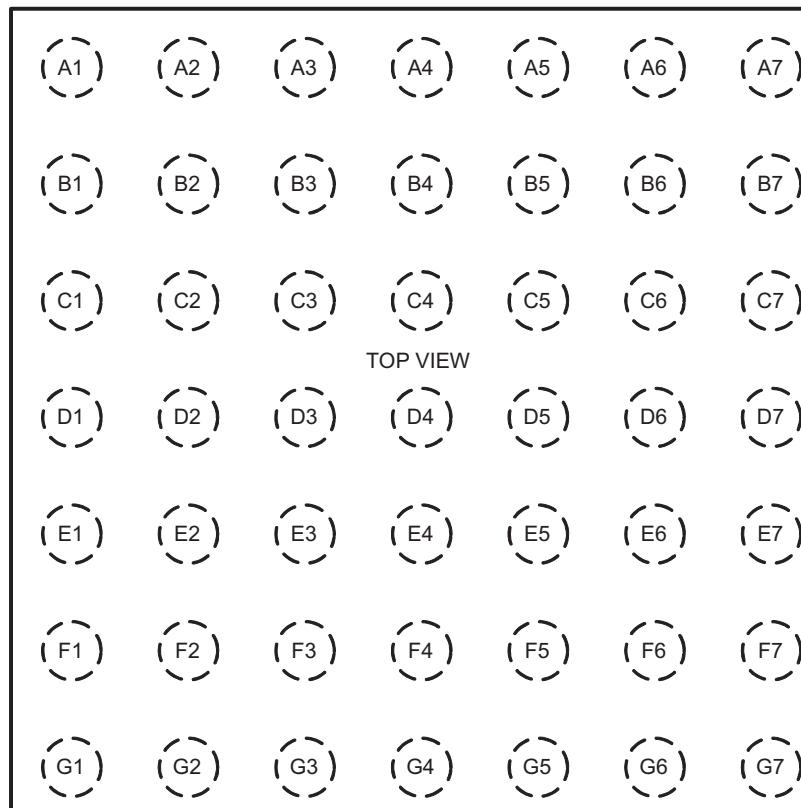
MSP430F22x4 Device Pinout, DA Package



MSP430F22x4 Device Pinout, RHA Package



MSP430F22x4, MSP430F22x2 Device Pinout, YFF Package



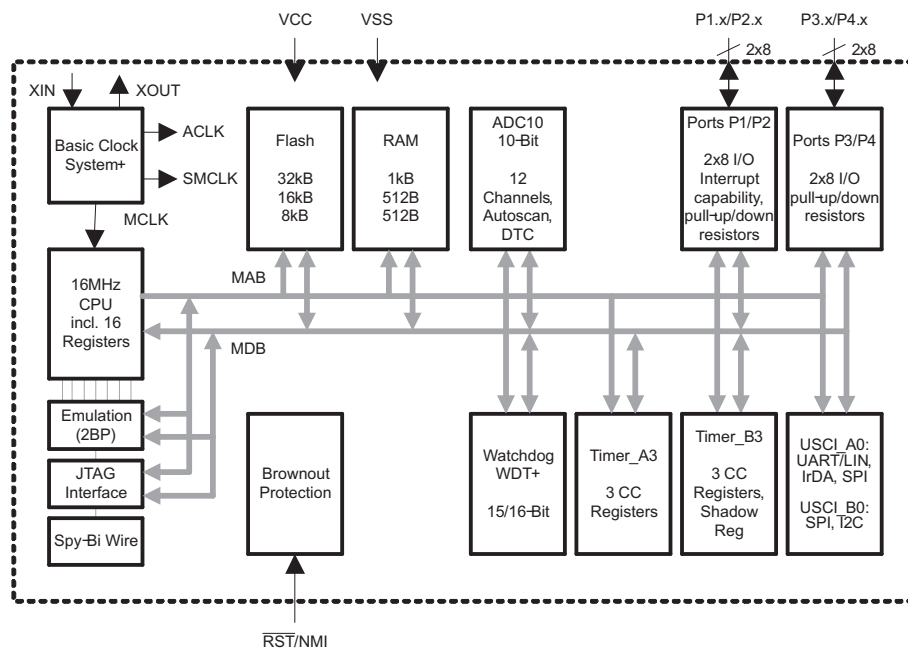
Package Dimensions

The package dimensions for this YFF package are shown in [Table 2](#). See the package drawing at the end of this data sheet for more details.

Table 2. YFF Package Dimensions

| PACKAGED DEVICES | D | E |
|----------------------------|----------------|----------------|
| MSP430F22x2 MSP430F22x4 | 3.33 ± 0.03 mm | 3.49 ± 0.03 mm |

MSP430F22x2 Functional Block Diagram



MSP430F22x4 Functional Block Diagram

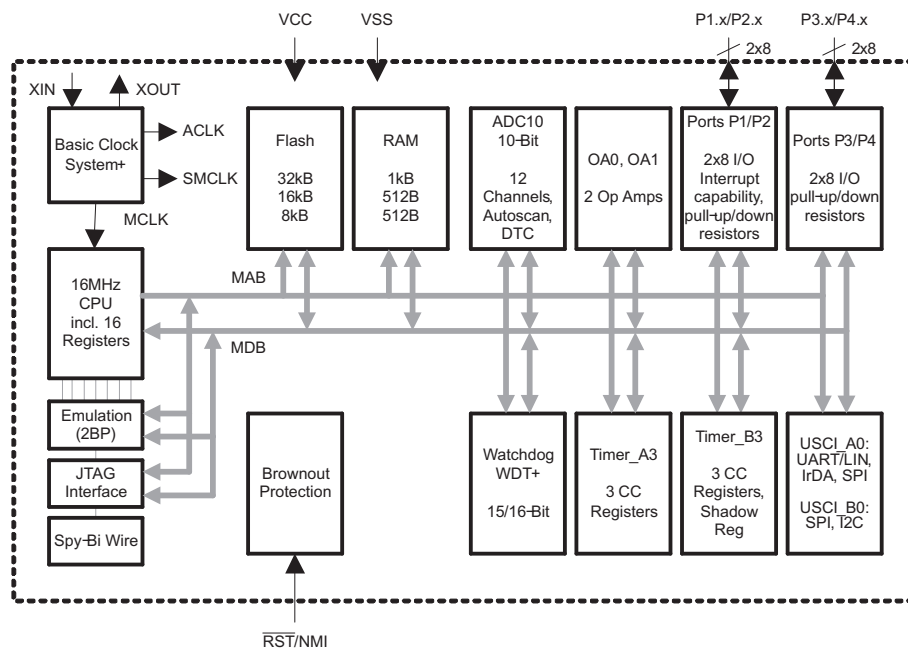


Table 3. Terminal Functions, MSP430F22x2

| TERMINAL | | | | I/O | DESCRIPTION |
|---|-----|----|-----|-----|---|
| NAME | NO. | | | | |
| | YFF | DA | RHA | | |
| P1.0/TACLK/ADC10CLK | F2 | 31 | 29 | I/O | General-purpose digital I/O pin Timer_A, clock signal TACLK input ADC10, conversion clock |
| P1.1/TA0 | G2 | 32 | 30 | I/O | General-purpose digital I/O pin Timer_A, capture: CCI0A input, compare: OUT0 output BSL transmit |
| P1.2/TA1 | E2 | 33 | 31 | I/O | General-purpose digital I/O pin Timer_A, capture: CCI1A input, compare: OUT1 output |
| P1.3/TA2 | G1 | 34 | 32 | I/O | General-purpose digital I/O pin Timer_A, capture: CCI2A input, compare: OUT2 output |
| P1.4/SMCLK/TCK | F1 | 35 | 33 | I/O | General-purpose digital I/O pin SMCLK signal output Test Clock input for device programming and test |
| P1.5/TA0/TMS | E1 | 36 | 34 | I/O | General-purpose digital I/O pin Timer_A, compare: OUT0 output Test Mode Select input for device programming and test |
| P1.6/TA1/TDI/TCLK | E3 | 37 | 35 | I/O | General-purpose digital I/O pin Timer_A, compare: OUT1 output Test Data Input or Test Clock Input for programming and test |
| P1.7/TA2/TDO/TDI ⁽¹⁾ | D2 | 38 | 36 | I/O | General-purpose digital I/O pin Timer_A, compare: OUT2 output Test Data Output or Test Data Input for programming and test |
| P2.0/ACLK/A0 | A4 | 8 | 6 | I/O | General-purpose digital I/O pin ACLK output ADC10, analog input A0 |
| P2.1/TAINCLK/SMCLK/A1 | B4 | 9 | 7 | I/O | General-purpose digital I/O pin Timer_A, clock signal at INCLK SMCLK signal output ADC10, analog input A1 |
| P2.2/TA0/A2 | A5 | 10 | 8 | I/O | General-purpose digital I/O pin Timer_A, capture: CCI0B input/BSL receive, compare: OUT0 output ADC10, analog input A2 |
| P2.3/TA1/A3/V _{REF-} /V _{eREF-} | F3 | 29 | 27 | I/O | General-purpose digital I/O pin Timer_A, capture CCI1B input, compare: OUT1 output ADC10, analog input A3 Negative reference voltage input |
| P2.4/TA2/A4/V _{REF+} /V _{eREF+} | G3 | 30 | 28 | I/O | General-purpose digital I/O pin Timer_A, compare: OUT2 output ADC10, analog input A4 Positive reference voltage output or input |
| P2.5/R _{OSC} | C2 | 3 | 40 | I/O | General-purpose digital I/O pin Input for external DCO resistor to define DCO frequency |
| XIN/P2.6 | A2 | 6 | 3 | I/O | Input terminal of crystal oscillator General-purpose digital I/O pin |

(1) TDO or TDI is selected via JTAG instruction.

Table 3. Terminal Functions, MSP430F22x2 (continued)

| TERMINAL | | | | I/O | DESCRIPTION |
|-----------------------------|-----|----|-----|-----|--|
| NAME | NO. | | | | |
| | YFF | DA | RHA | | |
| XOUT/P2.7 | A1 | 5 | 2 | I/O | Output terminal of crystal oscillator General-purpose digital I/O pin ⁽²⁾ |
| P3.0/UCB0STE/UCA0CLK/ A5 | B5 | 11 | 9 | I/O | General-purpose digital I/O pin USCI_B0 slave transmit enable USCI_A0 clock input/output ADC10, analog input A5 |
| P3.1/UCB0SIMO/ UCB0SDA | A6 | 12 | 10 | I/O | General-purpose digital I/O pin USCI_B0 SPI mode: slave in/master out USCI_B0 I2C mode: SDA I2C data |
| P3.2/UCB0SOMI/UCB0SCL | A7 | 13 | 11 | I/O | General-purpose digital I/O pin USCI_B0 SPI mode: slave out/master in USCI_B0 I2C mode: SCL I2C clock |
| P3.3/UCB0CLK/UCA0STE | B6 | 14 | 12 | I/O | General-purpose digital I/O pin USCI_B0 clock input/output USCI_A0 slave transmit enable |
| P3.4/UCA0TXD/ UCA0SIMO | G6 | 25 | 23 | I/O | General-purpose digital I/O pin USCI_A0 UART mode: transmit data output USCI_A0 SPI mode: slave in/master out |
| P3.5/UCA0RXD/ UCA0SOMI | G5 | 26 | 24 | I/O | General-purpose digital I/O pin USCI_A0 UART mode: receive data input USCI_A0 SPI mode: slave out/master in |
| P3.6/A6 | F4 | 27 | 25 | I/O | General-purpose digital I/O pin ADC10 analog input A6 |
| P3.7/A7 | G4 | 28 | 26 | I/O | General-purpose digital I/O pin ADC10 analog input A7 |
| P4.0/TB0 | D6 | 17 | 15 | I/O | General-purpose digital I/O pin Timer_B, capture: CCI0A input, compare: OUT0 output |
| P4.1/TB1 | D7 | 18 | 16 | I/O | General-purpose digital I/O pin Timer_B, capture: CCI1A input, compare: OUT1 output |
| P4.2/TB2 | E6 | 19 | 17 | I/O | General-purpose digital I/O pin Timer_B, capture: CCI2A input, compare: OUT2 output |
| P4.3/TB0/A12 | E7 | 20 | 18 | I/O | General-purpose digital I/O pin Timer_B, capture: CCI0B input, compare: OUT0 output ADC10 analog input A12 |
| P4.4/TB1/A13 | F7 | 21 | 19 | I/O | General-purpose digital I/O pin Timer_B, capture: CCI1B input, compare: OUT1 output ADC10 analog input A13 |
| P4.5/TB2/A14 | F6 | 22 | 20 | I/O | General-purpose digital I/O pin Timer_B, compare: OUT2 output ADC10 analog input A14 |
| P4.6/TBOUTH/A15 | G7 | 23 | 21 | I/O | General-purpose digital I/O pin Timer_B, switch all TB0 to TB3 outputs to high impedance ADC10 analog input A15 |

(2) If XOUT/P2.7 is used as an input, excess current flows until P2SEL.7 is cleared. This is due to the oscillator output driver connection to this pad after reset.

Table 3. Terminal Functions, MSP430F22x2 (continued)

| TERMINAL | | | | I/O | DESCRIPTION |
|-------------------------------------|--------------------------------|----|--------|-----|---|
| NAME | NO. | | | | |
| | YFF | DA | RHA | | |
| P4.7/TBCLK | F5 | 24 | 22 | I/O | General-purpose digital I/O pin Timer_B, clock signal TBCLK input |
| $\overline{\text{RST}}$ /NMI/SBWTIO | B3 | 7 | 5 | I | Reset or nonmaskable interrupt input Spy-Bi-Wire test data input/output during programming and test |
| TEST/SBWTCK | D1 | 1 | 37 | I | Selects test mode for JTAG pins on Port 1. The device protection fuse is connected to TEST. Spy-Bi-Wire test clock input during programming and test |
| DV _{CC} | C1, D3, D4, E4, E5 | 2 | 38, 39 | | Digital supply voltage |
| AV _{CC} | C6, C7, D5 | 16 | 14 | | Analog supply voltage |
| DV _{SS} | A3, B1, B2, C3, C4 | 4 | 1, 4 | | Digital ground reference |
| AV _{SS} | B7, C5 | 15 | 13 | | Analog ground reference |
| QFN Pad | NA | NA | Pad | NA | QFN package pad; connection to DV _{SS} recommended. |

Table 4. Terminal Functions, MSP430F22x4

| TERMINAL | | | | I/O | DESCRIPTION |
|--|-----|----|-----|-----|---|
| NAME | NO. | | | | |
| | YFF | DA | RHA | | |
| P1.0/TACLK/ADC10CLK | F2 | 31 | 29 | I/O | General-purpose digital I/O pin Timer_A, clock signal TACLK input ADC10, conversion clock |
| P1.1/TA0 | G2 | 32 | 30 | I/O | General-purpose digital I/O pin Timer_A, capture: CCI0A input, compare: OUT0 output BSL transmit |
| P1.2/TA1 | E2 | 33 | 31 | I/O | General-purpose digital I/O pin Timer_A, capture: CCI1A input, compare: OUT1 output |
| P1.3/TA2 | G1 | 34 | 32 | I/O | General-purpose digital I/O pin Timer_A, capture: CCI2A input, compare: OUT2 output |
| P1.4/SMCLK/TCK | F1 | 35 | 33 | I/O | General-purpose digital I/O pin SMCLK signal output Test Clock input for device programming and test |
| P1.5/TA0/TMS | E1 | 36 | 34 | I/O | General-purpose digital I/O pin Timer_A, compare: OUT0 output Test Mode Select input for device programming and test |
| P1.6/TA1/TDI/TCLK | E3 | 37 | 35 | I/O | General-purpose digital I/O pin Timer_A, compare: OUT1 output Test Data Input or Test Clock Input for programming and test |
| P1.7/TA2/TDO/TDI ⁽¹⁾ | D2 | 38 | 36 | I/O | General-purpose digital I/O pin Timer_A, compare: OUT2 output Test Data Output or Test Data Input for programming and test |
| P2.0/ACLK/A0/OA0I0 | A4 | 8 | 6 | I/O | General-purpose digital I/O pin ACLK output ADC10, analog input A0 OA0, analog input IO |
| P2.1/TAINCLK/SMCLK/ A1/OA0O | B4 | 9 | 7 | I/O | General-purpose digital I/O pin Timer_A, clock signal at INCLK SMCLK signal output ADC10, analog input A1 OA0, analog output |
| P2.2/TA0/A2/OA0I1 | A5 | 10 | 8 | I/O | General-purpose digital I/O pin Timer_A, capture: CCI0B input/BSL receive, compare: OUT0 output ADC10, analog input A2 OA0, analog input I1 |
| P2.3/TA1/A3/ V _{REF} -/V _{eREF} -/ OA1I1/OA1O | F3 | 29 | 27 | I/O | General-purpose digital I/O pin Timer_A, capture CCI1B input, compare: OUT1 output ADC10, analog input A3 Negative reference voltage input OA1, analog input I1 OA1, analog output |

(1) TDO or TDI is selected via JTAG instruction.

Table 4. Terminal Functions, MSP430F22x4 (continued)

| TERMINAL | | | | I/O | DESCRIPTION |
|--|-----|----|-----|-----|---|
| NAME | NO. | | | | |
| | YFF | DA | RHA | | |
| P2.4/TA2/A4/ V _{REF+} /V _{eREF+} /OA110 | G3 | 30 | 28 | I/O | General-purpose digital I/O pin Timer_A, compare: OUT2 output ADC10, analog input A4 Positive reference voltage output or input OA1, analog input I/O |
| P2.5/R _{OSC} | C2 | 3 | 40 | I/O | General-purpose digital I/O pin Input for external DCO resistor to define DCO frequency |
| XIN/P2.6 | A2 | 6 | 3 | I/O | Input terminal of crystal oscillator General-purpose digital I/O pin |
| XOUT/P2.7 | A1 | 5 | 2 | I/O | Output terminal of crystal oscillator General-purpose digital I/O pin ⁽²⁾ |
| P3.0/UCB0STE/UCA0CLK/ A5 | B5 | 11 | 9 | I/O | General-purpose digital I/O pin USCI_B0 slave transmit enable USCI_A0 clock input/output ADC10, analog input A5 |
| P3.1/UCB0SIMO/ UCB0SDA | A6 | 12 | 10 | I/O | General-purpose digital I/O pin USCI_B0 SPI mode: slave in/master out USCI_B0 I2C mode: SDA I2C data |
| P3.2/UCB0SOMI/UCB0SCL | A7 | 13 | 11 | I/O | General-purpose digital I/O pin USCI_B0 SPI mode: slave out/master in USCI_B0 I2C mode: SCL I2C clock |
| P3.3/UCB0CLK/UCA0STE | B6 | 14 | 12 | I/O | General-purpose digital I/O pin USCI_B0 clock input/output USCI_A0 slave transmit enable |
| P3.4/UCA0TXD/ UCA0SIMO | G6 | 25 | 23 | I/O | General-purpose digital I/O pin USCI_A0 UART mode: transmit data output USCI_A0 SPI mode: slave in/master out |
| P3.5/UCA0RXD/ UCA0SOMI | G5 | 26 | 24 | I/O | General-purpose digital I/O pin USCI_A0 UART mode: receive data input USCI_A0 SPI mode: slave out/master in |
| P3.6/A6/OA0I2 | F4 | 27 | 25 | I/O | General-purpose digital I/O pin ADC10 analog input A6 OA0 analog input I2 |
| P3.7/A7/OA1I2 | G4 | 28 | 26 | I/O | General-purpose digital I/O pin ADC10 analog input A7 OA1 analog input I2 |
| P4.0/TB0 | D6 | 17 | 15 | I/O | General-purpose digital I/O pin Timer_B, capture: CCI0A input, compare: OUT0 output |
| P4.1/TB1 | D7 | 18 | 16 | I/O | General-purpose digital I/O pin Timer_B, capture: CCI1A input, compare: OUT1 output |
| P4.2/TB2 | E6 | 19 | 17 | I/O | General-purpose digital I/O pin Timer_B, capture: CCI2A input, compare: OUT2 output |

(2) If XOUT/P2.7 is used as an input, excess current flows until P2SEL.7 is cleared. This is due to the oscillator output driver connection to this pad after reset.

Table 4. Terminal Functions, MSP430F22x4 (continued)

| TERMINAL | | | | I/O | DESCRIPTION |
|-------------------------------------|--------------------------------|----|--------|-----|---|
| NAME | NO. | | | | |
| | YFF | DA | RHA | | |
| P4.3/TB0/A12/OA00 | E7 | 20 | 18 | I/O | General-purpose digital I/O pin Timer_B, capture: CCI0B input, compare: OUT0 output ADC10 analog input A12 OA0 analog output |
| P4.4/TB1/A13/OA10 | F7 | 21 | 19 | I/O | General-purpose digital I/O pin Timer_B, capture: CCI1B input, compare: OUT1 output ADC10 analog input A13 OA1 analog output |
| P4.5/TB2/A14/OA013 | F6 | 22 | 20 | I/O | General-purpose digital I/O pin Timer_B, compare: OUT2 output ADC10 analog input A14 OA0 analog input I3 |
| P4.6/TBOUTH/A15/OA113 | G7 | 23 | 21 | I/O | General-purpose digital I/O pin Timer_B, switch all TB0 to TB3 outputs to high impedance ADC10 analog input A15 OA1 analog input I3 |
| P4.7/TBCLK | F5 | 24 | 22 | I/O | General-purpose digital I/O pin Timer_B, clock signal TBCLK input |
| $\overline{\text{RST}}$ /NMI/SBWDIO | B3 | 7 | 5 | I | Reset or nonmaskable interrupt input Spy-Bi-Wire test data input/output during programming and test |
| TEST/SBWTCK | D1 | 1 | 37 | I | Selects test mode for JTAG pins on Port 1. The device protection fuse is connected to TEST. Spy-Bi-Wire test clock input during programming and test |
| DV _{CC} | C1, D3, D4, E4, E5 | 2 | 38, 39 | | Digital supply voltage |
| AV _{CC} | C6, C7, D5 | 16 | 14 | | Analog supply voltage |
| DV _{SS} | A3, B1, B2, C3, C4 | 4 | 1, 4 | | Digital ground reference |
| AV _{SS} | B7, C5 | 15 | 13 | | Analog ground reference |
| QFN Pad | NA | NA | Pad | NA | QFN package pad; connection to DV _{SS} recommended. |

SHORT-FORM DESCRIPTION

CPU

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

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

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

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

Instruction Set

The instruction set consists of 51 instructions with three formats and seven address modes. Each instruction can operate on word and byte data. [Table 5](#) shows examples of the three types of instruction formats; [Table 6](#) shows the address modes.

| | |
|--------------------------|-----------|
| 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 |

Table 5. Instruction Word Formats

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

Table 6. Address Mode Descriptions

| ADDRESS MODE | S ⁽¹⁾ | D ⁽²⁾ | SYNTAX | EXAMPLE | OPERATION |
|------------------------|------------------|------------------|-----------------|------------------|-------------------------------|
| Register | ✓ | ✓ | MOV Rs,Rd | MOV R10,R11 | R10 → R11 |
| Indexed | ✓ | ✓ | MOV X(Rn),Y(Rm) | MOV 2(R5),6(R6) | M(2+R5) → M(6+R6) |
| Symbolic (PC relative) | ✓ | ✓ | MOV EDE,TONI | | M(EDE) → M(TONI) |
| Absolute | ✓ | ✓ | MOV &MEM,&TCDAT | | M(MEM) → M(TCDAT) |
| Indirect | ✓ | | MOV @Rn,Y(Rm) | MOV @R10,Tab(R6) | M(R10) → M(Tab+R6) |
| Indirect autoincrement | ✓ | | MOV @Rn+,Rm | MOV @R10+,R11 | M(R10) → R11 R10 + 2 → R10 |
| Immediate | ✓ | | MOV #X,TONI | MOV #45,TONI | #45 → M(TONI) |

(1) S = source

(2) D = destination

Operating Modes

The MSP430 microcontrollers have one active mode and five software-selectable low-power modes of operation. An interrupt event can wake up the device from any of the five low-power modes, service the request, and restore back to the low-power mode on return from the interrupt program.

The following six operating modes can be configured by software:

- Active mode (AM)
 - All clocks are active.
- Low-power mode 0 (LPM0)
 - CPU is disabled.
 - ACLK and SMCLK remain active. MCLK is disabled.
- Low-power mode 1 (LPM1)
 - CPU is disabled ACLK and SMCLK remain active. MCLK is disabled.
 - DCO dc-generator is disabled if DCO not used in active mode.
- Low-power mode 2 (LPM2)
 - CPU is disabled.
 - MCLK and SMCLK are disabled.
 - DCO dc-generator remains enabled.
 - ACLK remains active.
- Low-power mode 3 (LPM3)
 - CPU is disabled.
 - MCLK and SMCLK are disabled.
 - DCO dc-generator is disabled.
 - ACLK remains active.
- Low-power mode 4 (LPM4)
 - CPU is disabled.
 - ACLK is disabled.
 - MCLK and SMCLK are disabled.
 - DCO dc-generator is disabled.
 - Crystal oscillator is stopped.

Interrupt Vector Addresses

The interrupt vectors and the power-up starting address are located in the address range of 0FFFFh to 0FFC0h. The vector contains the 16-bit address of the appropriate interrupt handler instruction sequence.

If the reset vector (located at address 0FFFEh) contains 0FFFFh (for example, if flash is not programmed), the CPU goes into LPM4 immediately after power up.

Table 7. Interrupt Vector Addresses

| INTERRUPT SOURCE | INTERRUPT FLAG | SYSTEM INTERRUPT | WORD ADDRESS | PRIORITY |
|---|---|--|------------------|-----------------|
| Power-up External reset Watchdog Flash key violation PC out-of-range ⁽¹⁾ | PORIFG RSTIFG WDTIFG KEYV ⁽²⁾ | Reset | 0FFFEh | 31, highest |
| NMI Oscillator fault Flash memory access violation | NMIIFG OFIFG ACCVIFG ⁽²⁾⁽³⁾ | (non)-maskable, (non)-maskable, (non)-maskable | 0FFFCh | 30 |
| Timer_B3 | TBCCR0 CCIFG ⁽⁴⁾ | maskable | 0FFFAh | 29 |
| Timer_B3 | TBCCR1 and TBCCR2 CCIFGs, TBIFG ⁽²⁾⁽⁴⁾ | maskable | 0FFF8h | 28 |
| | | | 0FFF6h | 27 |
| Watchdog Timer | WDTIFG | maskable | 0FFF4h | 26 |
| Timer_A3 | TACCR0 CCIFG (see Note 3) | maskable | 0FFF2h | 25 |
| Timer_A3 | TACCR1 CCIFG TACCR2 CCIFG TAIFG ⁽²⁾⁽⁴⁾ | maskable | 0FFF0h | 24 |
| USCI_A0/USCI_B0 Receive | UCA0RXIFG, UCB0RXIFG ⁽²⁾ | maskable | 0FFEEh | 23 |
| USCI_A0/USCI_B0 Transmit | UCA0TXIFG, UCB0TXIFG ⁽²⁾ | maskable | 0FFECCh | 22 |
| ADC10 | ADC10IFG ⁽⁴⁾ | maskable | 0FFEAh | 21 |
| | | | 0FFE8h | 20 |
| I/O Port P2 (eight flags) | P2IFG.0 to P2IFG.7 ⁽²⁾⁽⁴⁾ | maskable | 0FFE6h | 19 |
| I/O Port P1 (eight flags) | P1IFG.0 to P1IFG.7 ⁽²⁾⁽⁴⁾ | maskable | 0FFE4h | 18 |
| | | | 0FFE2h | 17 |
| | | | 0FFE0h | 16 |
| ⁽⁵⁾ | | | 0FFDEh | 15 |
| ⁽⁶⁾ | | | 0FFDCh to 0FFC0h | 14 to 0, lowest |

- (1) A reset is generated if the CPU tries to fetch instructions from within the module register memory address range (0h to 01FFh) or from within unused address range.
- (2) Multiple source flags
- (3) (non)-maskable: the individual interrupt-enable bit can disable an interrupt event, but the general interrupt enable cannot. Nonmaskable: neither the individual nor the general interrupt-enable bit will disable an interrupt event.
- (4) Interrupt flags are located in the module.
- (5) This location is used as bootstrap loader security key (BSLSKEY). A 0AA55h at this location disables the BSL completely. A zero (0h) disables the erasure of the flash if an invalid password is supplied.
- (6) The interrupt vectors at addresses 0FFDCh to 0FFC0h are not used in this device and can be used for regular program code if necessary.

Special Function Registers

Most interrupt and module enable bits are collected into the lowest address space. Special function register bits not allocated to a functional purpose are not physically present in the device. Simple software access is provided with this arrangement.

Legend










| | |
|---|---|
| rw | Bit can be read and written. |
| rw-0, 1 | Bit can be read and written. It is Reset or Set by PUC. |
| rw-(0), (1) | Bit can be read and written. It is Reset or Set by POR. |
|  | SFR bit is not present in device. |

Table 8. Interrupt Enable 1

| Address | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---------|---|---|--------|-------|--|---|------|-------|
| 00h |  |  | ACCVIE | NMIIE |  |  | OFIE | WDTIE |
| | | | rw-0 | rw-0 | | | rw-0 | rw-0 |




| | |
|--------|--|
| WDTIE | Watchdog timer interrupt enable. Inactive if watchdog mode is selected. Active if watchdog timer is configured in interval timer mode. |
| OFIE | Oscillator fault interrupt enable |
| NMIIE | (Non)maskable interrupt enable |
| ACCVIE | Flash access violation interrupt enable |

Table 9. Interrupt Enable 2

| Address | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---------|---|---|---|---|----------|----------|----------|----------|
| 01h |  |  |  |  | UCB0TXIE | UCB0RXIE | UCA0TXIE | UCA0RXIE |
| | | | | | rw-0 | rw-0 | rw-0 | rw-0 |





| | |
|----------|-----------------------------------|
| UCA0RXIE | USCI_A0 receive-interrupt enable |
| UCA0TXIE | USCI_A0 transmit-interrupt enable |
| UCB0RXIE | USCI_B0 receive-interrupt enable |
| UCB0TXIE | USCI_B0 transmit-interrupt enable |

Table 10. Interrupt Flag Register 1

| Address | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---------|---|---|---|--------|--------|--------|-------|--------|
| 02h |  |  |  | NMIIFG | RSTIFG | PORIFG | OFIFG | WDTIFG |
| | | | | rw-0 | rw-(0) | rw-(1) | rw-1 | rw-(0) |

| | |
|--------|--|
| WDTIFG | Set on watchdog timer overflow (in watchdog mode) or security key violation. Reset on V _{CC} power-up or a reset condition at \overline{RST}/NMI pin in reset mode. |
| OFIFG | Flag set on oscillator fault |
| RSTIFG | External reset interrupt flag. Set on a reset condition at \overline{RST}/NMI pin in reset mode. Reset on V _{CC} power up. |
| PORIFG | Power-on reset interrupt flag. Set on V _{CC} power up. |
| NMIIFG | Set via \overline{RST}/NMI pin |

Table 11. Interrupt Flag Register 2

| Address | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---------|---|---|---|---|-----------|-----------|-----------|-----------|
| 03h |  |  |  |  | UCB0TXIFG | UCB0RXIFG | UCA0TXIFG | UCA0RXIFG |
| | | | | | rw-1 | rw-0 | rw-1 | rw-0 |

| | |
|-----------|---------------------------------|
| UCA0RXIFG | USCI_A0 receive-interrupt flag |
| UCA0TXIFG | USCI_A0 transmit-interrupt flag |
| UCB0RXIFG | USCI_B0 receive-interrupt flag |
| UCB0TXIFG | USCI_B0 transmit-interrupt flag |

Memory Organization

Table 12. Memory Organization

| | | MSP430F223x | MSP430F225x | MSP430F227x |
|---|------------------------------|---|--|--|
| Memory Main: interrupt vector Main: code memory | Size Flash Flash | 8KB Flash 0FFFFh-0FFC0h 0FFFFh-0E000h | 16KB Flash 0FFFFh-0FFC0h 0FFFFh-0C000h | 32KB Flash 0FFFFh-0FFC0h 0FFFFh-08000h |
| Information memory | Size Flash | 256 Byte 010FFh-01000h | 256 Byte 010FFh-01000h | 256 Byte 010FFh-01000h |
| Boot memory | Size ROM | 1KB 0FFFh-0C00h | 1KB 0FFFh-0C00h | 1KB 0FFFh-0C00h |
| RAM | Size | 512 Byte 03FFh-0200h | 512 Byte 03FFh-0200h | 1KB 05FFh-0200h |
| Peripherals | 16-bit 8-bit 8-bit SFR | 01FFh-0100h 0FFh-010h 0Fh-00h | 01FFh-0100h 0FFh-010h 0Fh-00h | 01FFh-0100h 0FFh-010h 0Fh-00h |

Bootstrap Loader (BSL)

The MSP430 bootstrap loader (BSL) enables users to program the flash memory or RAM using a UART serial interface. Access to the MSP430 memory via the BSL is protected by user-defined password. For complete description of the features of the BSL and its implementation, see the *MSP430 Programming Via the Bootstrap Loader User's Guide* (SLAU319).

Table 13. BSL Function Pins

| BSL FUNCTION | DA PACKAGE PINS | RHA PACKAGE PINS | YFF PACKAGE PINS |
|---------------|-----------------|------------------|------------------|
| Data transmit | 32 - P1.1 | 30 - P1.1 | G3 - P1.1 |
| Data receive | 10 - P2.2 | 8 - P2.2 | A5 - P2.2 |

Flash Memory

The flash memory can be programmed via the JTAG port, the bootstrap loader, or in-system by the CPU. The CPU can perform single-byte and single-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 64 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 contains calibration data. After reset, segment A is protected against programming and erasing. It can be unlocked, but care should be taken not to erase this segment if the device-specific calibration data is required.

Peripherals

Peripherals are connected to the CPU through data, address, and control buses and can be handled using all instructions. For complete module descriptions, see the *MSP430x2xx Family User's Guide (SLAU144)*.

Oscillator and System Clock

The clock system is supported by the basic clock module that includes support for a 32768-Hz watch crystal oscillator, an internal very-low-power low-frequency oscillator, an internal digitally-controlled oscillator (DCO), and a high-frequency crystal oscillator. The basic clock module is designed to meet the requirements of both low system cost and low power consumption. The internal DCO provides a fast turn-on clock source and stabilizes in less than 1 μ s. The basic clock module provides the following clock signals:

- Auxiliary clock (ACLK), sourced from a 32768-Hz watch crystal, a high-frequency crystal, or the internal very-low-power LF oscillator.
- Main clock (MCLK), the system clock used by the CPU.
- Sub-Main clock (SMCLK), the sub-system clock used by the peripheral modules.

**Table 14. DCO Calibration Data
(Provided From Factory in Flash Information Memory Segment A)**

| DCO FREQUENCY | CALIBRATION REGISTER | SIZE | ADDRESS |
|---------------|----------------------|------|---------|
| 1 MHz | CALBC1_1MHZ | byte | 010FFh |
| | CALDCO_1MHZ | byte | 010FEh |
| 8 MHz | CALBC1_8MHZ | byte | 010FDh |
| | CALDCO_8MHZ | byte | 010FCh |
| 12 MHz | CALBC1_12MHZ | byte | 010FBh |
| | CALDCO_12MHZ | byte | 010FAh |
| 16 MHz | CALBC1_16MHZ | byte | 010F9h |
| | CALDCO_16MHZ | byte | 010F8h |

Brownout

The brownout circuit is implemented to provide the proper internal reset signal to the device during power on and power off.

Digital I/O

There are four 8-bit I/O ports implemented—ports P1, P2, P3, and P4:

- All individual I/O bits are independently programmable.
- Any combination of input, output, and interrupt condition is possible.
- Edge-selectable interrupt input capability for all eight bits of port P1 and P2.
- Read/write access to port-control registers is supported by all instructions.
- Each I/O has an individually programmable pullup/pulldown resistor.

Because there are only three I/O pins implemented from port P2, bits [5:1] of all port P2 registers read as 0, and write data is ignored.

Watchdog Timer (WDT+)

The primary function of the WDT+ 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 disabled or configured as an interval timer and can generate interrupts at selected time intervals.

Timer_A3

Timer_A3 is a 16-bit timer/counter with three capture/compare registers. Timer_A3 can support multiple capture/compares, PWM outputs, and interval timing. Timer_A3 also has extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each of the capture/compare registers.

Table 15. Timer_A3 Signal Connections

| INPUT PIN NUMBER | | | DEVICE INPUT SIGNAL | MODULE INPUT NAME | MODULE BLOCK | MODULE OUTPUT SIGNAL | OUTPUT PIN NUMBER | | |
|------------------|-----------|-----------|---------------------|-------------------|--------------|----------------------|-------------------|-----------|-----------|
| DA | RHA | YFF | | | | | DA | RHA | YFF |
| 31 - P1.0 | 29 - P1.0 | F2 - P1.0 | TACLK | TACLK | Timer | NA | | | |
| | | | ACLK | ACLK | | | | | |
| | | | SMCLK | SMCLK | | | | | |
| 9 - P2.1 | 7 - P2.1 | B4 - P2.1 | TAINCLK | INCLK | | | | | |
| 32 - P1.1 | 30 - P1.1 | G2 - P1.1 | TA0 | CC10A | CCR0 | TA0 | 32 - P1.1 | 30 - P1.1 | G2 - P1.1 |
| 10 - P2.2 | 8 - P2.2 | A5 - P2.2 | TA0 | CC10B | | | 10 - P2.2 | 8 - P2.2 | A5 - P2.2 |
| | | | V _{SS} | GND | | | 36 - P1.5 | 34 - P1.5 | E1 - P1.5 |
| | | | V _{CC} | V _{CC} | | | | | |
| 33 - P1.2 | 31 - P1.2 | E2 - P1.2 | TA1 | CC11A | CCR1 | TA1 | 33 - P1.2 | 31 - P1.2 | E2 - P1.2 |
| 29 - P2.3 | 27 - P2.3 | F3 - P2.3 | TA1 | CC11B | | | 29 - P2.3 | 27 - P2.3 | F3 - P2.3 |
| | | | V _{SS} | GND | | | 37 - P1.6 | 35 - P1.6 | E3 - P1.6 |
| | | | V _{CC} | V _{CC} | | | | | |
| 34 - P1.3 | 32 - P1.3 | G1 - P1.3 | TA2 | CC12A | CCR2 | TA2 | 34 - P1.3 | 32 - P1.3 | G1 - P1.3 |
| | | | ACLK (internal) | CC12B | | | 30 - P2.4 | 28 - P2.4 | G3 - P2.4 |
| | | | V _{SS} | GND | | | 38 - P1.7 | 36 - P1.7 | D2 - P1.7 |
| | | | V _{CC} | V _{CC} | | | | | |

Timer_B3

Timer_B3 is a 16-bit timer/counter with three capture/compare registers. Timer_B3 can support multiple capture/compares, PWM outputs, and interval timing. Timer_B3 also has extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each of the capture/compare registers.

Table 16. Timer_B3 Signal Connections

| INPUT PIN NUMBER | | | DEVICE INPUT SIGNAL | MODULE INPUT NAME | MODULE BLOCK | MODULE OUTPUT SIGNAL | OUTPUT PIN NUMBER | | |
|------------------|-----------|-----------|---------------------------|-------------------------|-----------------|----------------------------|-------------------|-----------|-----------|
| DA | RHA | YFF | | | | | DA | RHA | YFF |
| 24 - P4.7 | 22 - P4.7 | F5 - P4.7 | TBCLK | TBCLK | Timer | NA | | | |
| | | | ACLK | ACLK | | | | | |
| | | | SMCLK | SMCLK | | | | | |
| 24 - P4.7 | 22 - P4.7 | F5 - P4.7 | TBCLK | INCLK | | | | | |
| 17 - P4.0 | 15 - P4.0 | D6 - P4.0 | TB0 | CC10A | CCR0 | TB0 | 17 - P4.0 | 15 - P4.0 | D6 - P4.0 |
| 20 - P4.3 | 18 - P4.3 | E7 - P4.3 | TB0 | CC10B | | | 20 - P4.3 | 18 - P4.3 | E7 - P4.3 |
| | | | V _{SS} | GND | | | | | |
| | | | V _{CC} | V _{CC} | | | | | |
| 18 - P4.1 | 16 - P4.1 | D7 - P4.1 | TB1 | CC11A | CCR1 | TB1 | 18 - P4.1 | 16 - P4.1 | D7 - P4.1 |
| 21 - P4.4 | 19 - P4.4 | F7 - P4.4 | TB1 | CC11B | | | 21 - P4.4 | 19 - P4.4 | F7 - P4.4 |
| | | | V _{SS} | GND | | | | | |
| | | | V _{CC} | V _{CC} | | | | | |
| 19 - P4.2 | 17 - P4.2 | E6 - P4.2 | TB2 | CC12A | CCR2 | TB2 | 19 - P4.2 | 17 - P4.2 | E6 - P4.2 |
| | | | ACLK (internal) | CC12B | | | 22 - P4.5 | 20 - P4.5 | F6 - P4.5 |
| | | | V _{SS} | GND | | | | | |
| | | | V _{CC} | V _{CC} | | | | | |

Universal Serial Communications Interface (USCI)

The USCI module is used for serial data communication. The USCI module supports synchronous communication protocols like SPI (3 or 4 pin), I2C and asynchronous communication protocols such as UART, enhanced UART with automatic baudrate detection (LIN), and IrDA.

USCI_A0 provides support for SPI (3 or 4 pin), UART, enhanced UART, and IrDA.

USCI_B0 provides support for SPI (3 or 4 pin) and I2C.

ADC10

The ADC10 module supports fast, 10-bit analog-to-digital conversions. The module implements a 10-bit SAR core, sample select control, reference generator and data transfer controller, or DTC, for automatic conversion result handling allowing ADC samples to be converted and stored without any CPU intervention.

Operational Amplifier (OA) (MSP430F22x4 only)

The MSP430F22x4 has two configurable low-current general-purpose operational amplifiers. Each OA input and output terminal is software-selectable and offer a flexible choice of connections for various applications. The OA op amps primarily support front-end analog signal conditioning prior to analog-to-digital conversion.

Table 17. OA0 Signal Connections

| ANALOG INPUT PIN NUMBER | | | DEVICE INPUT SIGNAL | MODULE INPUT NAME |
|-------------------------|----------|----------|---------------------|-------------------|
| DA | RHA | YFF | | |
| 8 - A0 | 6 - A0 | B4 - A0 | OA0I0 | OAxI0 |
| 10 - A2 | 8 - A2 | B5 - A2 | OA0I1 | OA0I1 |
| 10 - A2 | 8 - A2 | B5 - A2 | OA0I1 | OAxI1 |
| 27 - A6 | 25 - A6 | F4 - A6 | OA0I2 | OAxIA |
| 22 - A14 | 20 - A14 | F6 - A14 | OA0I3 | OAxIB |

Table 18. OA1 Signal Connections

| ANALOG INPUT PIN NUMBER | | | DEVICE INPUT SIGNAL | MODULE INPUT NAME |
|-------------------------|----------|----------|---------------------|-------------------|
| DA | RHA | YFF | | |
| 30 - A4 | 28 - A4 | G3 - A4 | OA1I0 | OAxI0 |
| 10 - A2 | 8 - A2 | B5 - A2 | OA0I1 | OA0I1 |
| 29 - A3 | 27 - A3 | F3 - A3 | OA1I1 | OAxI1 |
| 28 - A7 | 26 - A7 | G4 - A7 | OA1I2 | OAxIA |
| 23 - A15 | 21 - A15 | G7 - A15 | OA1I3 | OAxIB |

Peripheral File Map
Table 19. Peripherals With Word Access

| MODULE | REGISTER NAME | SHORT NAME | ADDRESS OFFSET |
|------------------------|--------------------------------------|------------|----------------|
| ADC10 | ADC data transfer start address | ADC10SA | 1BCh |
| | ADC memory | ADC10MEM | 1B4h |
| | ADC control register 1 | ADC10CTL1 | 1B2h |
| | ADC control register 0 | ADC10CTL0 | 1B0h |
| | ADC analog enable 0 | ADC10AE0 | 04Ah |
| | ADC analog enable 1 | ADC10AE1 | 04Bh |
| | ADC data transfer control register 1 | ADC10DTC1 | 049h |
| | ADC data transfer control register 0 | ADC10DTC0 | 048h |
| Timer_B | Capture/compare register | TBCCR2 | 0196h |
| | Capture/compare register | TBCCR1 | 0194h |
| | Capture/compare register | TBCCR0 | 0192h |
| | Timer_B register | TBR | 0190h |
| | Capture/compare control | TBCCTL2 | 0186h |
| | Capture/compare control | TBCCTL1 | 0184h |
| | Capture/compare control | TBCCTL0 | 0182h |
| | Timer_B control | TBCTL | 0180h |
| | Timer_B interrupt vector | TBIV | 011Eh |
| Timer_A | Capture/compare register | TACCR2 | 0176h |
| | Capture/compare register | TACCR1 | 0174h |
| | Capture/compare register | TACCR0 | 0172h |
| | Timer_A register | TAR | 0170h |
| | Capture/compare control | TACCTL2 | 0166h |
| | Capture/compare control | TACCTL1 | 0164h |
| | Capture/compare control | TACCTL0 | 0162h |
| | Timer_A control | TACTL | 0160h |
| | Timer_A interrupt vector | TAIV | 012Eh |
| Flash Memory | Flash control 3 | FCTL3 | 012Ch |
| | Flash control 2 | FCTL2 | 012Ah |
| | Flash control 1 | FCTL1 | 0128h |
| Watchdog Timer+ | Watchdog/timer control | WDTCTL | 0120h |

Table 20. Peripherals With Byte Access

| MODULE | REGISTER NAME | SHORT NAME | ADDRESS OFFSET |
|------------------------------|--|------------------------------|----------------|
| OA1 (MSP430F22x4 only) | Operational Amplifier 1 control register 1 | OA1CTL1 | 0C3h |
| | Operational Amplifier 1 control register 1 | OA1CTL0 | 0C2h |
| OA0 (MSP430F22x4 only) | Operational Amplifier 0 control register 1 | OA0CTL1 | 0C1h |
| | Operational Amplifier 0 control register 1 | OA0CTL0 | 0C0h |
| USCI_B0 | USCI_B0 transmit buffer | UCB0TXBUF | 06Fh |
| | USCI_B0 receive buffer | UCB0RXBUF | 06Eh |
| | USCI_B0 status | UCB0STAT | 06Dh |
| | USCI_B0 bit rate control 1 | UCB0BR1 | 06Bh |
| | USCI_B0 bit rate control 0 | UCB0BR0 | 06Ah |
| | USCI_B0 control 1 | UCB0CTL1 | 069h |
| | USCI_B0 control 0 | UCB0CTL0 | 068h |
| | USCI_B0 I2C slave address | UCB0SA | 011Ah |
| | USCI_B0 I2C own address | UCB0OA | 0118h |
| USCI_A0 | USCI_A0 transmit buffer | UCA0TXBUF | 067h |
| | USCI_A0 receive buffer | UCA0RXBUF | 066h |
| | USCI_A0 status | UCA0STAT | 065h |
| | USCI_A0 modulation control | UCA0MCTL | 064h |
| | USCI_A0 baud rate control 1 | UCA0BR1 | 063h |
| | USCI_A0 baud rate control 0 | UCA0BR0 | 062h |
| | USCI_A0 control 1 | UCA0CTL1 | 061h |
| | USCI_A0 control 0 | UCA0CTL0 | 060h |
| | USCI_A0 IrDA receive control | UCA0IRRCTL | 05Fh |
| | USCI_A0 IrDA transmit control | UCA0IRTCTL | 05Eh |
| | USCI_A0 auto baud rate control | UCA0ABCTL | 05Dh |
| | Basic Clock System+ | Basic clock system control 3 | BCSCTL3 |
| Basic clock system control 2 | | BCSCTL2 | 058h |
| Basic clock system control 1 | | BCSCTL1 | 057h |
| DCO clock frequency control | | DCOCTL | 056h |
| Port P4 | Port P4 resistor enable | P4REN | 011h |
| | Port P4 selection | P4SEL | 01Fh |
| | Port P4 direction | P4DIR | 01Eh |
| | Port P4 output | P4OUT | 01Dh |
| | Port P4 input | P4IN | 01Ch |
| Port P3 | Port P3 resistor enable | P3REN | 010h |
| | Port P3 selection | P3SEL | 01Bh |
| | Port P3 direction | P3DIR | 01Ah |
| | Port P3 output | P3OUT | 019h |
| | Port P3 input | P3IN | 018h |
| Port P2 | Port P2 resistor enable | P2REN | 02Fh |
| | Port P2 selection | P2SEL | 02Eh |
| | Port P2 interrupt enable | P2IE | 02Dh |
| | Port P2 interrupt edge select | P2IES | 02Ch |
| | Port P2 interrupt flag | P2IFG | 02Bh |
| | Port P2 direction | P2DIR | 02Ah |
| | Port P2 output | P2OUT | 029h |
| Port P2 input | P2IN | 028h | |

Table 20. Peripherals With Byte Access (continued)

| MODULE | REGISTER NAME | SHORT NAME | ADDRESS OFFSET |
|-------------------------|-------------------------------|------------|----------------|
| Port P1 | Port P1 resistor enable | P1REN | 027h |
| | Port P1 selection | P1SEL | 026h |
| | Port P1 interrupt enable | P1IE | 025h |
| | Port P1 interrupt edge select | P1IES | 024h |
| | Port P1 interrupt flag | P1IFG | 023h |
| | Port P1 direction | P1DIR | 022h |
| | Port P1 output | P1OUT | 021h |
| | Port P1 input | P1IN | 020h |
| Special Function | SFR interrupt flag 2 | IFG2 | 003h |
| | SFR interrupt flag 1 | IFG1 | 002h |
| | SFR interrupt enable 2 | IE2 | 001h |
| | SFR interrupt enable 1 | IE1 | 000h |

Absolute Maximum Ratings⁽¹⁾

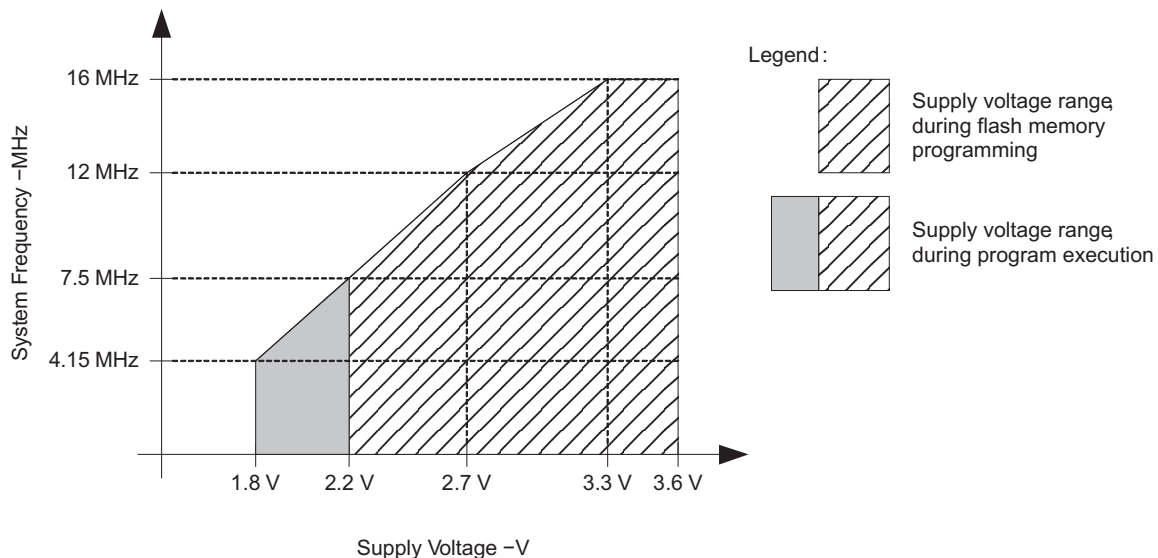
| | | |
|---|---------------------|----------------------------|
| Voltage applied at V_{CC} to V_{SS} | | -0.3 V to 4.1 V |
| Voltage applied to any pin ⁽²⁾ | | -0.3 V to $V_{CC} + 0.3$ V |
| Diode current at any device terminal | | ± 2 mA |
| Storage temperature, T_{stg} ⁽³⁾ | Unprogrammed device | -55°C to 150°C |
| | Programmed device | -55°C to 150°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} . The JTAG fuse-blow voltage, V_{FB} , is allowed to exceed the absolute maximum rating. The voltage is applied to the TEST pin when blowing the JTAG fuse.
- (3) Higher temperature may be applied during board soldering process 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.

Recommended Operating Conditions⁽¹⁾⁽²⁾

| | | | | MIN | NOM | MAX | UNIT |
|--------------|---|---|-----------------------------------|-----|------|-----|------|
| V_{CC} | Supply voltage | $AV_{CC} = DV_{CC} = V_{CC}$ | During program execution | 1.8 | | 3.6 | V |
| | | | During program/erase flash memory | 2.2 | | 3.6 | V |
| V_{SS} | Supply voltage | $AV_{SS} = DV_{SS} = V_{SS}$ | | 0 | | | V |
| T_A | Operating free-air temperature | | I version | -40 | | 85 | °C |
| | | | T version | -40 | | 105 | |
| f_{SYSTEM} | Processor frequency (maximum MCLK frequency) ⁽¹⁾⁽²⁾ (see Figure 1) | $V_{CC} = 1.8$ V, Duty cycle = 50% \pm 10% | dc | | 4.15 | MHz | |
| | | $V_{CC} = 2.7$ V, Duty cycle = 50% \pm 10% | dc | | 12 | | |
| | | $V_{CC} \geq 3.3$ V, Duty cycle = 50% \pm 10% | dc | | 16 | | |

- (1) The MSP430 CPU is clocked directly with MCLK. Both the high and low phase of MCLK must not exceed the pulse width of the specified maximum frequency.
- (2) Modules might have a different maximum input clock specification. See the specification of the respective module in this data sheet.



NOTE: Minimum processor frequency is defined by system clock. Flash program or erase operations require a minimum V_{CC} of 2.2 V.

Figure 1. Operating Area

Active Mode Supply Current (into $DV_{CC} + AV_{CC}$) Excluding External Current ⁽¹⁾⁽²⁾

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

| PARAMETER | TEST CONDITIONS | T_A | V_{CC} | MIN | TYP | MAX | UNIT |
|--|--|------------------|----------|-------|-----|-----|---------|
| $I_{AM,1MHz}$ Active mode (AM) current (1 MHz) | $f_{DCO} = f_{MCLK} = f_{SMCLK} = 1$ MHz, $f_{ACLK} = 32768$ Hz, Program executes in flash, BCSCTL1 = CALBC1_1MHZ, DCOCTL = CALDCO_1MHZ, CPUOFF = 0, SCG0 = 0, SCG1 = 0, OSCOFF = 0 | | 2.2 V | | 270 | 390 | μA |
| | | | 3 V | | 390 | 550 | |
| $I_{AM,1MHz}$ Active mode (AM) current (1 MHz) | $f_{DCO} = f_{MCLK} = f_{SMCLK} = 1$ MHz, $f_{ACLK} = 32768$ Hz, Program executes in RAM, BCSCTL1 = CALBC1_1MHZ, DCOCTL = CALDCO_1MHZ, CPUOFF = 0, SCG0 = 0, SCG1 = 0, OSCOFF = 0 | | 2.2 V | | 240 | | μA |
| | | | 3.3 V | | 340 | | |
| $I_{AM,4kHz}$ Active mode (AM) current (4 kHz) | $f_{MCLK} = f_{SMCLK} = f_{ACLK} = 32768$ Hz/8 = 4096 Hz, $f_{DCO} = 0$ Hz, Program executes in flash, SELMx = 11, SELS = 1, DIVMx = DIVSx = DIVAx = 11, CPUOFF = 0, SCG0 = 1, SCG1 = 0, OSCOFF = 0 | -40°C to 85°C | 2.2 V | | 5 | 9 | μA |
| | | | | 105°C | | | |
| | | -40°C to 85°C | 3 V | | 6 | 10 | |
| | | | | 105°C | | | |
| $I_{AM,100kHz}$ Active mode (AM) current (100 kHz) | $f_{MCLK} = f_{SMCLK} = f_{DCO(0,0)} \approx 100$ kHz, $f_{ACLK} = 0$ Hz, Program executes in flash, RSELX = 0, DCOx = 0, CPUOFF = 0, SCG0 = 0, SCG1 = 0, OSCOFF = 1 | -40°C to 85°C | 2.2 V | | 60 | 85 | μA |
| | | | | 105°C | | | |
| | | -40°C to 85°C | 3 V | | 72 | 95 | |
| | | | | 105°C | | | |

(1) All inputs are tied to 0 V or 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 is chosen to closely match the required 9 pF.

Typical Characteristics - Active-Mode Supply Current (Into DV_{CC} + AV_{CC})

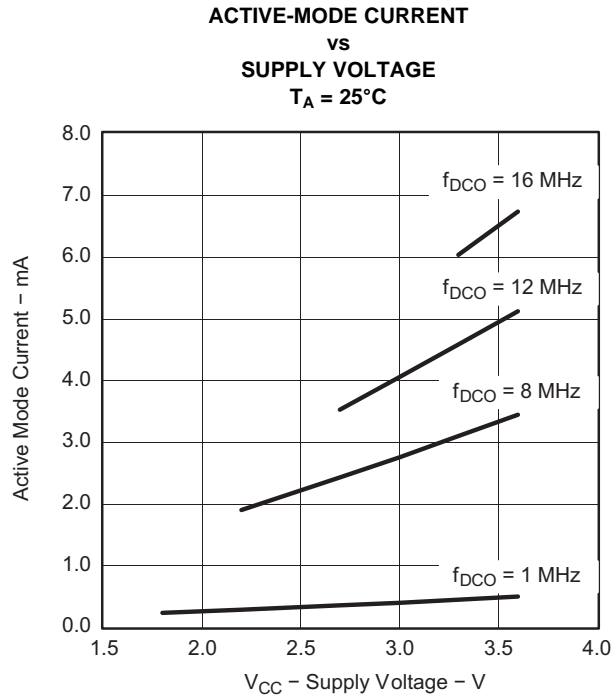


Figure 2.

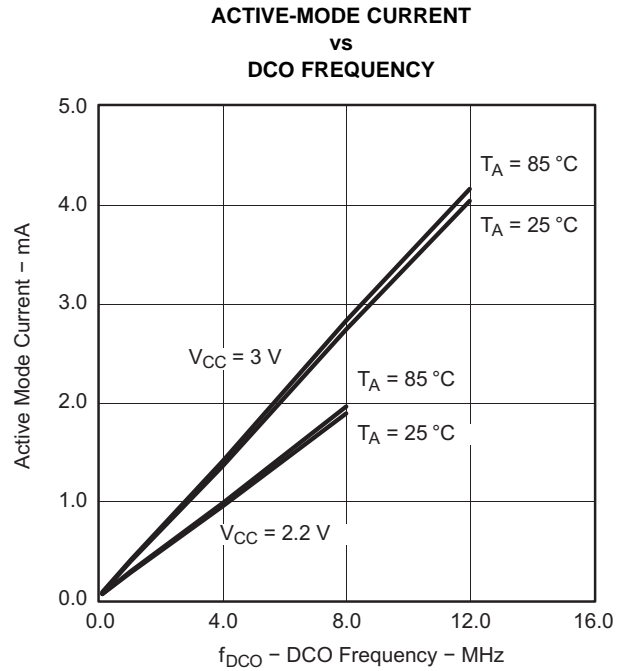


Figure 3.

Low-Power-Mode Supply Currents (Into V_{CC}) Excluding External Current ⁽¹⁾⁽²⁾

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

| PARAMETER | TEST CONDITIONS | T_A | V_{CC} | MIN | TYP | MAX | UNIT |
|-------------------|---|-------|---------------|---------------|-----|-----|---------|
| $I_{LPM0,1MHz}$ | Low-power mode 0 (LPM0) current ⁽³⁾ $f_{MCLK} = 0$ MHz, $f_{SMCLK} = f_{DCO} = 1$ MHz, $f_{ACLK} = 32768$ Hz, BCSCTL1 = CALBC1_1MHZ, DCOCTL = CALDCO_1MHZ, CPUOFF = 1, SCG0 = 0, SCG1 = 0, OSCOFF = 0 | | 2.2 V | | 75 | 90 | μ A |
| | | | 3 V | | 90 | 120 | |
| $I_{LPM0,100kHz}$ | Low-power mode 0 (LPM0) current ⁽³⁾ $f_{MCLK} = 0$ MHz, $f_{SMCLK} = f_{DCO(0,0)} \approx 100$ kHz, $f_{ACLK} = 0$ Hz, RSELX = 0, DCOX = 0, CPUOFF = 1, SCG0 = 0, SCG1 = 0, OSCOFF = 1 | | 2.2 V | | 37 | 48 | μ A |
| | | | 3 V | | 41 | 65 | |
| I_{LPM2} | Low-power mode 2 (LPM2) current ⁽⁴⁾ $f_{MCLK} = f_{SMCLK} = 0$ MHz, $f_{DCO} = 1$ MHz, $f_{ACLK} = 32768$ Hz, BCSCTL1 = CALBC1_1MHZ, DCOCTL = CALDCO_1MHZ, CPUOFF = 1, SCG0 = 0, SCG1 = 1, OSCOFF = 0 | | 2.2 V | -40°C to 85°C | 22 | 29 | μ A |
| | | | | 105°C | | 31 | |
| | | | 3 V | -40°C to 85°C | 25 | 32 | |
| | | | | 105°C | | 34 | |
| $I_{LPM3,LFXT1}$ | Low-power mode 3 (LPM3) current ⁽⁴⁾ $f_{DCO} = f_{MCLK} = f_{SMCLK} = 0$ MHz, $f_{ACLK} = 32768$ Hz, CPUOFF = 1, SCG0 = 1, SCG1 = 1, OSCOFF = 0 | | 2.2 V | -40°C | 0.7 | 1.4 | μ A |
| | | | | 25°C | 0.7 | 1.4 | |
| | | | | 85°C | 2.4 | 3.3 | |
| | | | | 105°C | 5 | 10 | |
| | | | 3 V | -40°C | 0.9 | 1.5 | |
| | | | | 25°C | 0.9 | 1.5 | |
| | | | | 85°C | 2.6 | 3.8 | |
| | | | | 105°C | 6 | 12 | |
| $I_{LPM3,VLO}$ | Low-power mode 3 current, (LPM3) ⁽⁴⁾ $f_{DCO} = f_{MCLK} = f_{SMCLK} = 0$ MHz, f_{ACLK} from internal LF oscillator (VLO), CPUOFF = 1, SCG0 = 1, SCG1 = 1, OSCOFF = 0 | | 2.2 V | -40°C | 0.4 | 1 | μ A |
| | | | | 25°C | 0.5 | 1 | |
| | | | | 85°C | 1.8 | 2.9 | |
| | | | | 105°C | 4.5 | 9 | |
| | | | 3 V | -40°C | 0.5 | 1.2 | |
| | | | | 25°C | 0.6 | 1.2 | |
| | | | | 85°C | 2.1 | 3.3 | |
| | | | | 105°C | 5.5 | 11 | |
| I_{LPM4} | Low-power mode 4 (LPM4) current ⁽⁵⁾ $f_{DCO} = f_{MCLK} = f_{SMCLK} = 0$ MHz, $f_{ACLK} = 0$ Hz, CPUOFF = 1, SCG0 = 1, SCG1 = 1, OSCOFF = 1 | | 2.2 V/ 3 V | -40°C | 0.1 | 0.5 | μ A |
| | | | | 25°C | 0.1 | 0.5 | |
| | | | 3 V | 85°C | 1.5 | 3 | |
| | | | | 105°C | 4.5 | 9 | |

(1) All inputs are tied to 0 V or 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 is chosen to closely match the required 9 pF.

(3) Current for brownout and WDT clocked by SMCLK included.

(4) Current for brownout and WDT clocked by ACLK included.

(5) Current for brownout included.

Schmitt-Trigger Inputs (Ports P1, P2, P3, P4, and $\overline{\text{RST/NMI}}$)

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|-------------------|---|--|-----------------|----------------------|------|----------------------|------|
| V _{IT+} | Positive-going input threshold voltage | | | 0.45 V _{CC} | | 0.75 V _{CC} | V |
| | | | 2.2 V | 1 | 1.65 | | |
| | | | 3 V | 1.35 | 2.25 | | |
| V _{IT-} | Negative-going input threshold voltage | | | 0.25 V _{CC} | | 0.55 V _{CC} | V |
| | | | 2.2 V | 0.55 | 1.20 | | |
| | | | 3 V | 0.75 | 1.65 | | |
| V _{hys} | Input voltage hysteresis (V _{IT+} - V _{IT-}) | | 2.2 V | 0.1 | | 1 | V |
| | | | 3 V | 0.3 | | 1 | |
| R _{Pull} | Pullup/pulldown resistor | For pullup: V _{IN} = V _{SS} , For pulldown: V _{IN} = V _{CC} | 3 V | 20 | 35 | 50 | kΩ |
| C _I | Input capacitance | V _{IN} = V _{SS} or V _{CC} | | | 5 | | pF |

Inputs (Ports P1, P2)

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|--------------------|---------------------------|--|-----------------|-----|-----|-----|------|
| t _(int) | External interrupt timing | Port P1, P2: P1.x to P2.x, External trigger pulse width to set interrupt flag ⁽¹⁾ | 2.2 V, 3 V | 20 | | | ns |

- (1) An external signal sets the interrupt flag every time the minimum interrupt pulse width t_(int) is met. It may be set even with trigger signals shorter than t_(int).

Leakage Current (Ports P1, P2, P3, and P4)

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|------------------------|--------------------------------|-----------------|-----------------|-----|-----|-----|------|
| I _{lkg(Px.y)} | High-impedance leakage current | (1) (2) | 2.2 V, 3 V | | | ±50 | nA |

- (1) The leakage current is measured with V_{SS} or V_{CC} 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/pulldown resistor is disabled.

Outputs (Ports P1, P2, P3, and P4)

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | MAX | UNIT |
|-----------------|---------------------------|---|-----------------|------------------------|------------------------|------|
| V _{OH} | High-level output voltage | I _{OH(max)} = -1.5 mA ⁽¹⁾ | 2.2 V | V _{CC} - 0.25 | V _{CC} | V |
| | | I _{OH(max)} = -6 mA ⁽²⁾ | | V _{CC} - 0.6 | V _{CC} | |
| | | I _{OH(max)} = -1.5 mA ⁽¹⁾ | 3 V | V _{CC} - 0.25 | V _{CC} | |
| | | I _{OH(max)} = -6 mA ⁽²⁾ | | V _{CC} - 0.6 | V _{CC} | |
| V _{OL} | Low-level output voltage | I _{OL(max)} = 1.5 mA ⁽¹⁾ | 2.2 V | V _{SS} | V _{SS} + 0.25 | V |
| | | I _{OL(max)} = 6 mA ⁽²⁾ | | V _{SS} | V _{SS} + 0.6 | |
| | | I _{OL(max)} = 1.5 mA ⁽¹⁾ | 3 V | V _{SS} | V _{SS} + 0.25 | |
| | | I _{OL(max)} = 6 mA ⁽²⁾ | | V _{SS} | V _{SS} + 0.6 | |

(1) The maximum total current, I_{OH(max)} and I_{OL(max)}, for all outputs combined, should not exceed ±12 mA to hold the maximum voltage drop specified.

(2) The maximum total current, I_{OH(max)} and I_{OL(max)}, for all outputs combined, should not exceed ±48 mA to hold the maximum voltage drop specified.

Output Frequency (Ports P1, P2, P3, and P4)

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|-----------------------|-----------------------------------|---|-----------------|-----|-----|-----|------|
| f _{Px,y} | Port output frequency (with load) | P1.4/SMCLK, C _L = 20 pF, R _L = 1 kΩ against V _{CC} /2 ⁽¹⁾⁽²⁾ | 2.2 V | | | 10 | MHz |
| | | | 3 V | | | 12 | |
| f _{Port_CLK} | Clock output frequency | P2.0/ACLK, P1.4/SMCLK, C _L = 20 pF ⁽²⁾ | 2.2 V | | | 12 | MHz |
| | | | 3 V | | | 16 | |

(1) Alternatively, a resistive divider with two 2-kΩ resistors between V_{CC} and V_{SS} is used as load. The output is connected to the center tap of the divider.

(2) The output voltage reaches at least 10% and 90% V_{CC} at the specified toggle frequency.

Typical Characteristics - Outputs

One output loaded at a time.

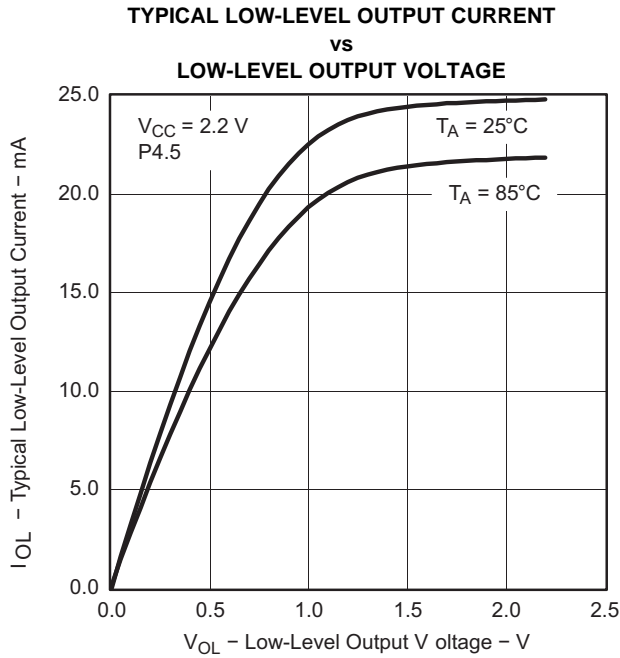


Figure 4.

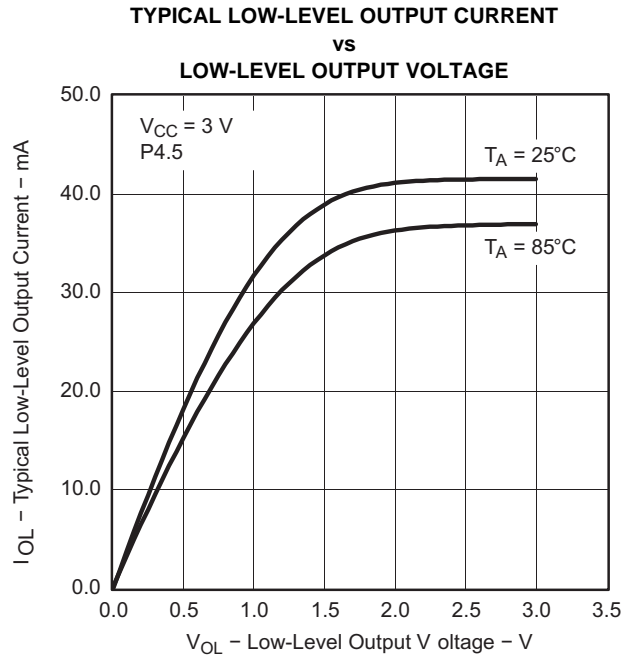


Figure 5.

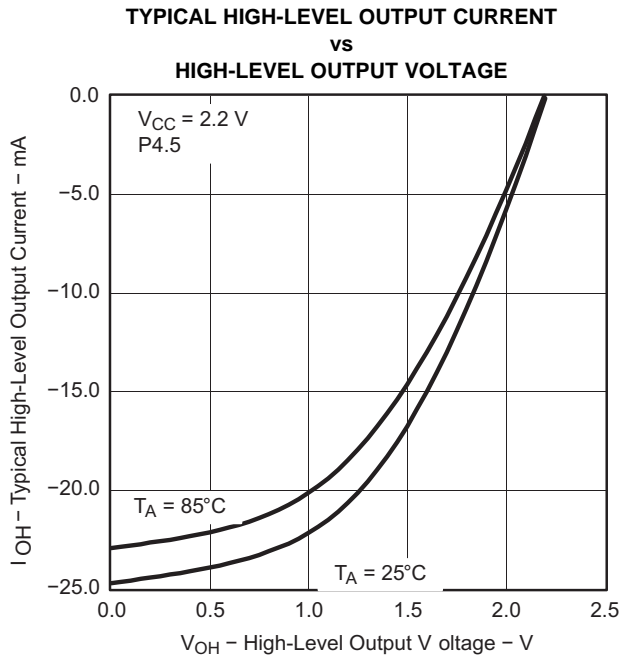


Figure 6.

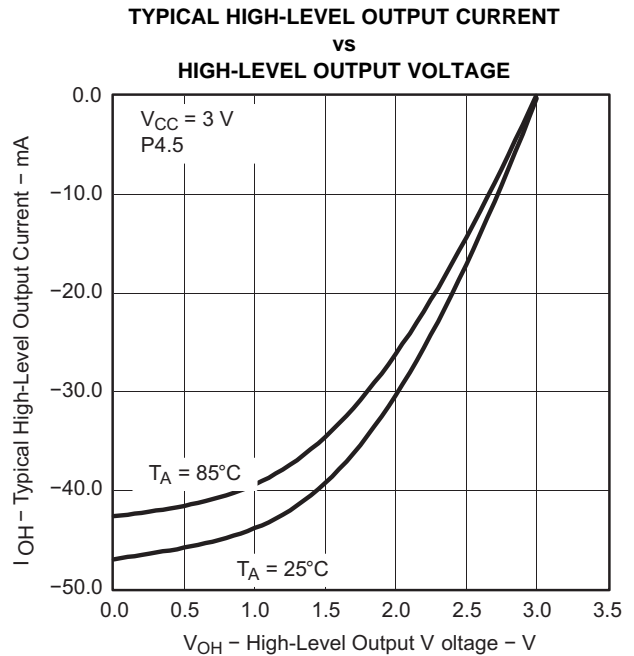


Figure 7.

POR/Brownout Reset (BOR) (1) (2)

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|-------------------------|--|------------------------------|-----------------|-----|----------------------------|------|------|
| V _{CC(start)} | See Figure 8 | dV _{CC} /dt ≤ 3 V/s | | | 0.7 × V _(B_IT-) | | V |
| V _(B_IT-) | See Figure 8 through Figure 10 | dV _{CC} /dt ≤ 3 V/s | | | | 1.71 | V |
| V _{hys(B_IT-)} | See Figure 8 | dV _{CC} /dt ≤ 3 V/s | | 70 | 130 | 210 | mV |
| t _{d(BOR)} | See Figure 8 | | | | | 2000 | μs |
| t _(reset) | Pulse length needed at $\overline{\text{RST}}/\text{NMI}$ pin to accepted reset internally | | 3 V | 2 | | | μs |

- (1) The current consumption of the brownout module is already included in the I_{CC} current consumption data. The voltage level V_(B_IT-) + V_{hys(B_IT-)} is ≤ 1.8 V.
- (2) During power up, the CPU begins code execution following a period of t_{d(BOR)} after V_{CC} = V_(B_IT-) + V_{hys(B_IT-)}. The default DCO settings must not be changed until V_{CC} ≥ V_{CC(min)}, where V_{CC(min)} is the minimum supply voltage for the desired operating frequency.



Figure 8. POR/Brownout Reset (BOR) vs Supply Voltage

Typical Characteristics - POR/Brownout Reset (BOR)

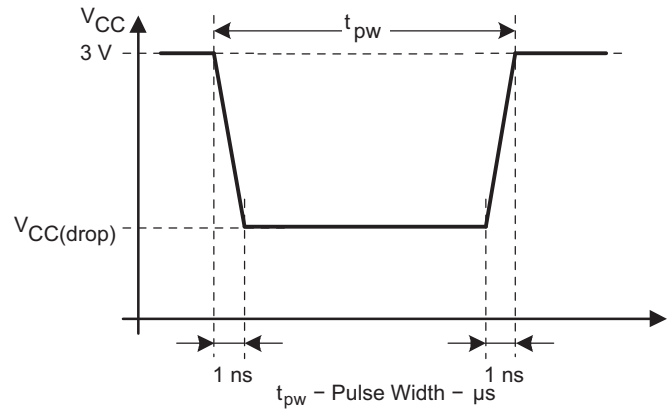
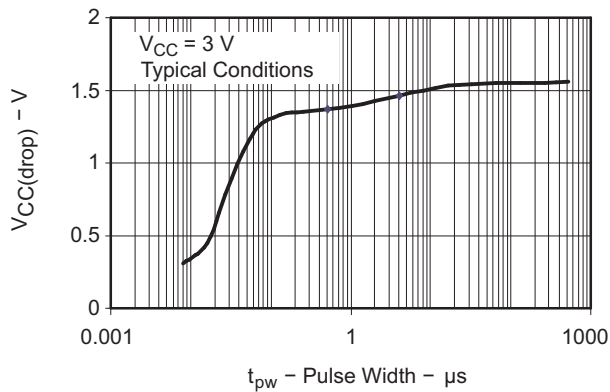


Figure 9. $V_{CC(drop)}$ Level With a Square Voltage Drop to Generate a POR/Brownout Signal

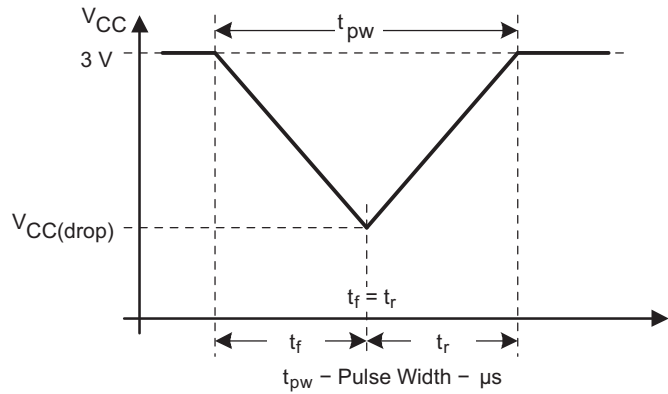
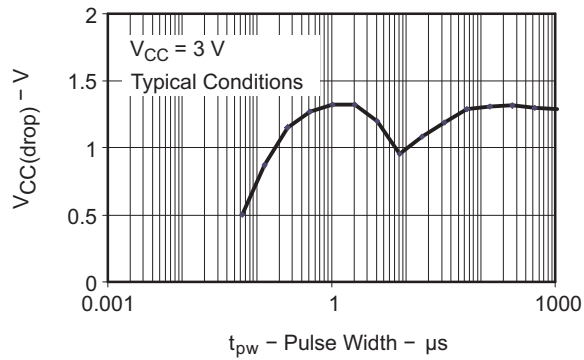


Figure 10. $V_{CC(drop)}$ Level With a Triangle Voltage Drop to Generate a POR/Brownout Signal

Main DCO Characteristics

- All ranges selected by RSELx overlap with RSELx + 1: RSELx = 0 overlaps RSELx = 1, ... RSELx = 14 overlaps RSELx = 15.
- DCO control bits DCOx have a step size as defined by parameter S_{DCO}.
- Modulation control bits MODx select how often f_{DCO(RSEL,DCO+1)} is used within the period of 32 DCOCLK cycles. The frequency f_{DCO(RSEL,DCO)} is used for the remaining cycles. The frequency is an average equal to:

$$f_{\text{average}} = \frac{32 \times f_{\text{DCO(RSEL,DCO)}} \times f_{\text{DCO(RSEL,DCO+1)}}}{\text{MOD} \times f_{\text{DCO(RSEL,DCO)}} + (32 - \text{MOD}) \times f_{\text{DCO(RSEL,DCO+1)}}}$$

DCO Frequency

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|------------------------|--|---|-----------------|------|------|------|-------|
| V _{CC} | Supply voltage range | RSELx < 14 | | 1.8 | | 3.6 | V |
| | | RSELx = 14 | | 2.2 | | 3.6 | |
| | | RSELx = 15 | | 3.0 | | 3.6 | |
| f _{DCO(0,0)} | DCO frequency (0, 0) | RSELx = 0, DCOx = 0, MODx = 0 | 2.2 V, 3 V | 0.06 | | 0.14 | MHz |
| f _{DCO(0,3)} | DCO frequency (0, 3) | RSELx = 0, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 0.07 | | 0.17 | MHz |
| f _{DCO(1,3)} | DCO frequency (1, 3) | RSELx = 1, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 0.10 | | 0.20 | MHz |
| f _{DCO(2,3)} | DCO frequency (2, 3) | RSELx = 2, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 0.14 | | 0.28 | MHz |
| f _{DCO(3,3)} | DCO frequency (3, 3) | RSELx = 3, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 0.20 | | 0.40 | MHz |
| f _{DCO(4,3)} | DCO frequency (4, 3) | RSELx = 4, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 0.28 | | 0.54 | MHz |
| f _{DCO(5,3)} | DCO frequency (5, 3) | RSELx = 5, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 0.39 | | 0.77 | MHz |
| f _{DCO(6,3)} | DCO frequency (6, 3) | RSELx = 6, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 0.54 | | 1.06 | MHz |
| f _{DCO(7,3)} | DCO frequency (7, 3) | RSELx = 7, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 0.80 | | 1.50 | MHz |
| f _{DCO(8,3)} | DCO frequency (8, 3) | RSELx = 8, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 1.10 | | 2.10 | MHz |
| f _{DCO(9,3)} | DCO frequency (9, 3) | RSELx = 9, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 1.60 | | 3.00 | MHz |
| f _{DCO(10,3)} | DCO frequency (10, 3) | RSELx = 10, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 2.50 | | 4.30 | MHz |
| f _{DCO(11,3)} | DCO frequency (11, 3) | RSELx = 11, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 3.00 | | 5.50 | MHz |
| f _{DCO(12,3)} | DCO frequency (12, 3) | RSELx = 12, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 4.30 | | 7.30 | MHz |
| f _{DCO(13,3)} | DCO frequency (13, 3) | RSELx = 13, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 6.00 | | 9.60 | MHz |
| f _{DCO(14,3)} | DCO frequency (14, 3) | RSELx = 14, DCOx = 3, MODx = 0 | 2.2 V, 3 V | 8.60 | | 13.9 | MHz |
| f _{DCO(15,3)} | DCO frequency (15, 3) | RSELx = 15, DCOx = 3, MODx = 0 | 3 V | 12.0 | | 18.5 | MHz |
| f _{DCO(15,7)} | DCO frequency (15, 7) | RSELx = 15, DCOx = 7, MODx = 0 | 3 V | 16.0 | | 26.0 | MHz |
| S _{RSEL} | Frequency step between range RSEL and RSEL+1 | S _{RSEL} = f _{DCO(RSEL+1,DCO)} / f _{DCO(RSEL,DCO)} | 2.2 V, 3 V | | | 1.55 | ratio |
| S _{DCO} | Frequency step between tap DCO and DCO+1 | S _{DCO} = f _{DCO(RSEL,DCO+1)} / f _{DCO(RSEL,DCO)} | 2.2 V, 3 V | 1.05 | 1.08 | 1.12 | ratio |
| | Duty cycle | Measured at P1.4/SMCLK | 2.2 V, 3 V | 40 | 50 | 60 | % |

Calibrated DCO Frequencies - Tolerance at Calibration

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

| PARAMETER | TEST CONDITIONS | T _A | V _{CC} | MIN | TYP | MAX | UNIT |
|--|--|----------------|-----------------|-------|------|-------|------|
| Frequency tolerance at calibration | | 25°C | 3 V | -1 | ±0.2 | +1 | % |
| f _{CAL(1MHz)} 1-MHz calibration value | BCSCTL1 = CALBC1_1MHZ, DCOCTL = CALDCO_1MHZ, Gating time: 5 ms | 25°C | 3 V | 0.990 | 1 | 1.010 | MHz |
| f _{CAL(8MHz)} 8-MHz calibration value | BCSCTL1 = CALBC1_8MHZ, DCOCTL = CALDCO_8MHZ, Gating time: 5 ms | 25°C | 3 V | 7.920 | 8 | 8.080 | MHz |
| f _{CAL(12MHz)} 12-MHz calibration value | BCSCTL1 = CALBC1_12MHZ, DCOCTL = CALDCO_12MHZ, Gating time: 5 ms | 25°C | 3 V | 11.88 | 12 | 12.12 | MHz |
| f _{CAL(16MHz)} 16-MHz calibration value | BCSCTL1 = CALBC1_16MHZ, DCOCTL = CALDCO_16MHZ, Gating time: 2 ms | 25°C | 3 V | 15.84 | 16 | 16.16 | MHz |

Calibrated DCO Frequencies - Tolerance Over Temperature 0°C to 85°C

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

| PARAMETER | TEST CONDITIONS | T _A | V _{CC} | MIN | TYP | MAX | UNIT |
|--|--|----------------|-----------------|-------|------|-------|------|
| 1-MHz tolerance over temperature | | 0°C to 85°C | 3 V | -2.5 | ±0.5 | +2.5 | % |
| 8-MHz tolerance over temperature | | 0°C to 85°C | 3 V | -2.5 | ±1.0 | +2.5 | % |
| 12-MHz tolerance over temperature | | 0°C to 85°C | 3 V | -2.5 | ±1.0 | +2.5 | % |
| 16-MHz tolerance over temperature | | 0°C to 85°C | 3 V | -3 | ±2.0 | +3 | % |
| f _{CAL(1MHz)} 1-MHz calibration value | BCSCTL1 = CALBC1_1MHZ, DCOCTL = CALDCO_1MHZ, Gating time: 5 ms | 0°C to 85°C | 2.2 V | 0.97 | 1 | 1.03 | MHz |
| | | | 3 V | 0.975 | 1 | 1.025 | |
| | | | 3.6 V | 0.97 | 1 | 1.03 | |
| f _{CAL(8MHz)} 8-MHz calibration value | BCSCTL1 = CALBC1_8MHZ, DCOCTL = CALDCO_8MHZ, Gating time: 5 ms | 0°C to 85°C | 2.2 V | 7.76 | 8 | 8.4 | MHz |
| | | | 3 V | 7.8 | 8 | 8.2 | |
| | | | 3.6 V | 7.6 | 8 | 8.24 | |
| f _{CAL(12MHz)} 12-MHz calibration value | BCSCTL1 = CALBC1_12MHZ, DCOCTL = CALDCO_12MHZ, Gating time: 5 ms | 0°C to 85°C | 2.2 V | 11.7 | 12 | 12.3 | MHz |
| | | | 3 V | 11.7 | 12 | 12.3 | |
| | | | 3.6 V | 11.7 | 12 | 12.3 | |
| f _{CAL(16MHz)} 16-MHz calibration value | BCSCTL1 = CALBC1_16MHZ, DCOCTL = CALDCO_16MHZ, Gating time: 2 ms | 0°C to 85°C | 3 V | 15.52 | 16 | 16.48 | MHz |
| | | | 3.6 V | 15 | 16 | 16.48 | |

Calibrated DCO Frequencies - Tolerance Over Supply Voltage V_{CC}

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

| PARAMETER | TEST CONDITIONS | T_A | V_{CC} | MIN | TYP | MAX | UNIT |
|---|--|-------|----------------|-------|-----|-------|------|
| 1-MHz tolerance over V_{CC} | | 25°C | 1.8 V to 3.6 V | -3 | ±2 | +3 | % |
| 8-MHz tolerance over V_{CC} | | 25°C | 1.8 V to 3.6 V | -3 | ±2 | +3 | % |
| 12-MHz tolerance over V_{CC} | | 25°C | 2.2 V to 3.6 V | -3 | ±2 | +3 | % |
| 16-MHz tolerance over V_{CC} | | 25°C | 3 V to 3.6 V | -6 | ±2 | +3 | % |
| $f_{CAL(1MHz)}$ 1-MHz calibration value | BCSCTL1 = CALBC1_1MHZ, DCOCTL = CALDCO_1MHZ, Gating time: 5 ms | 25°C | 1.8 V to 3.6 V | 0.97 | 1 | 1.03 | MHz |
| $f_{CAL(8MHz)}$ 8-MHz calibration value | BCSCTL1 = CALBC1_8MHZ, DCOCTL = CALDCO_8MHZ, Gating time: 5 ms | 25°C | 1.8 V to 3.6 V | 7.76 | 8 | 8.24 | MHz |
| $f_{CAL(12MHz)}$ 12-MHz calibration value | BCSCTL1 = CALBC1_12MHZ, DCOCTL = CALDCO_12MHZ, Gating time: 5 ms | 25°C | 2.2 V to 3.6 V | 11.64 | 12 | 12.36 | MHz |
| $f_{CAL(16MHz)}$ 16-MHz calibration value | BCSCTL1 = CALBC1_16MHZ, DCOCTL = CALDCO_16MHZ, Gating time: 2 ms | 25°C | 3 V to 3.6 V | 15 | 16 | 16.48 | MHz |

Calibrated DCO Frequencies - Overall Tolerance

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

| PARAMETER | TEST CONDITIONS | T_A | V_{CC} | MIN | TYP | MAX | UNIT |
|---|--|---------------------------------------|----------------|------|-----|------|------|
| 1-MHz tolerance overall | | I: -40°C to 85°C T: -40°C to 105°C | 1.8 V to 3.6 V | -5 | ±2 | +5 | % |
| 8-MHz tolerance overall | | I: -40°C to 85°C T: -40°C to 105°C | 1.8 V to 3.6 V | -5 | ±2 | +5 | % |
| 12-MHz tolerance overall | | I: -40°C to 85°C T: -40°C to 105°C | 2.2 V to 3.6 V | -5 | ±2 | +5 | % |
| 16-MHz tolerance overall | | I: -40°C to 85°C T: -40°C to 105°C | 3 V to 3.6 V | -6 | ±3 | +6 | % |
| $f_{CAL(1MHz)}$ 1-MHz calibration value | BCSCTL1 = CALBC1_1MHZ, DCOCTL = CALDCO_1MHZ, Gating time: 5 ms | I: -40°C to 85°C T: -40°C to 105°C | 1.8 V to 3.6 V | 0.95 | 1 | 1.05 | MHz |
| $f_{CAL(8MHz)}$ 8-MHz calibration value | BCSCTL1 = CALBC1_8MHZ, DCOCTL = CALDCO_8MHZ, Gating time: 5 ms | I: -40°C to 85°C T: -40°C to 105°C | 1.8 V to 3.6 V | 7.6 | 8 | 8.4 | MHz |
| $f_{CAL(12MHz)}$ 12-MHz calibration value | BCSCTL1 = CALBC1_12MHZ, DCOCTL = CALDCO_12MHZ, Gating time: 5 ms | I: -40°C to 85°C T: -40°C to 105°C | 2.2 V to 3.6 V | 11.4 | 12 | 12.6 | MHz |
| $f_{CAL(16MHz)}$ 16-MHz calibration value | BCSCTL1 = CALBC1_16MHZ, DCOCTL = CALDCO_16MHZ, Gating time: 2 ms | I: -40°C to 85°C T: -40°C to 105°C | 3 V to 3.6 V | 15 | 16 | 17 | MHz |

Typical Characteristics - Calibrated 1-MHz DCO Frequency

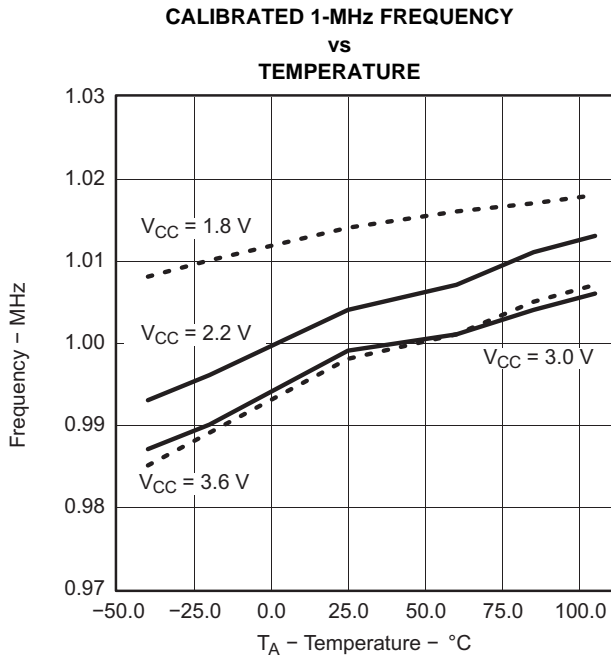


Figure 11.

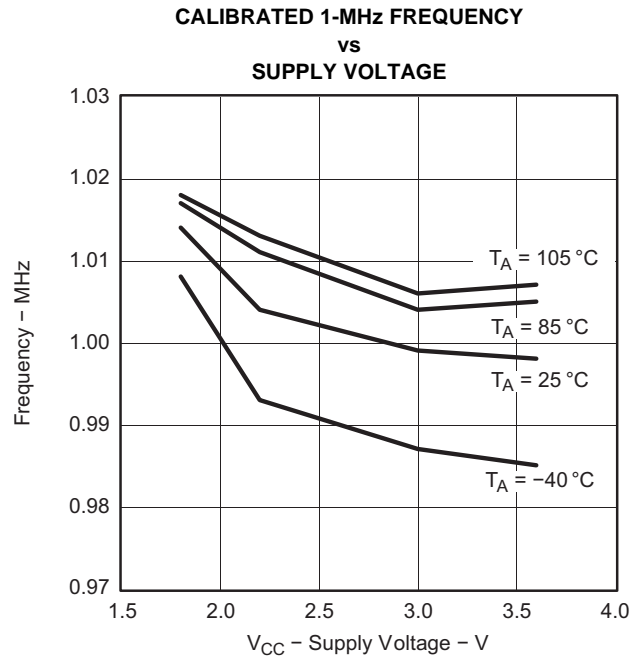


Figure 12.

Wake-Up From Lower-Power Modes (LPM3/4)

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

| PARAMETER | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|--|--|-----------------|-----|--|-----|------|
| t _{DCO,LPM3/4} DCO clock wake-up time from LPM3/4 ⁽¹⁾ | BCSCTL1 = CALBC1_1MHZ, DCOCTL = CALDCO_1MHZ | 2.2 V, 3 V | | | 2 | μs |
| | BCSCTL1 = CALBC1_8MHZ, DCOCTL = CALDCO_8MHZ | | | 1.5 | | |
| | BCSCTL1 = CALBC1_12MHZ, DCOCTL = CALDCO_12MHZ | | | 1 | | |
| | BCSCTL1 = CALBC1_16MHZ, DCOCTL = CALDCO_16MHZ | 3 V | | 1 | | |
| t _{CPU,LPM3/4} CPU wake-up time from LPM3/4 ⁽²⁾ | | | | 1 / f _{MCLK} + t _{Clock,LPM3/4} | | |

- (1) The DCO clock wake-up time is measured from the edge of an external wake-up signal (for example, a port interrupt) to the first clock edge observable externally on a clock pin (MCLK or SMCLK).
- (2) Parameter applicable only if DCOCLK is used for MCLK.

Typical Characteristics - DCO Clock Wake-Up Time From LPM3/4

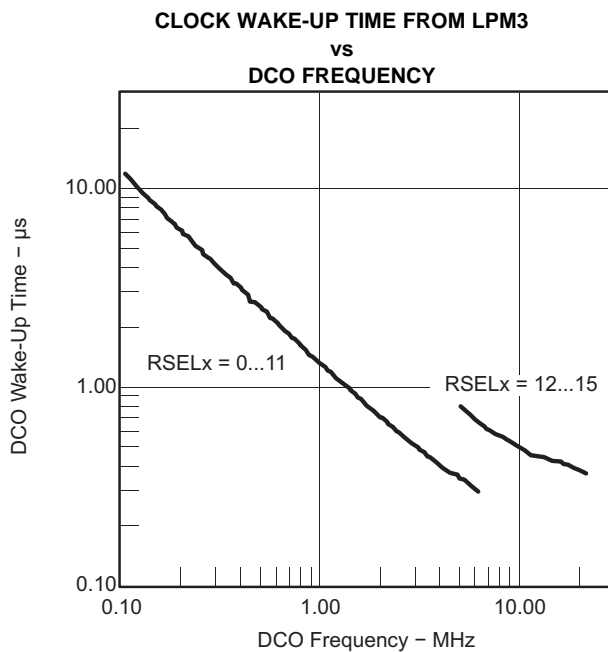


Figure 13.

DCO With External Resistor R_{OSC} ⁽¹⁾

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

| PARAMETER | TEST CONDITIONS | V_{CC} | MIN | TYP | MAX | UNIT |
|--|---|--------------|-----|-------------|-----|---------------|
| $f_{DCO,ROSC}$ DCO output frequency with R_{OSC} | DCOR = 1, RSELx = 4, DCOx = 3, MODx = 0, $T_A = 25^\circ C$ | 2.2 V 3 V | | 1.8 1.95 | | MHz |
| D_T Temperature drift | DCOR = 1, RSELx = 4, DCOx = 3, MODx = 0 | 2.2 V, 3 V | | ± 0.1 | | %/ $^\circ C$ |
| D_V Drift with V_{CC} | DCOR = 1, RSELx = 4, DCOx = 3, MODx = 0 | 2.2 V, 3 V | | 10 | | %/V |

(1) $R_{OSC} = 100\text{ k}\Omega$. Metal film resistor, type 0257, 0.6 W with 1% tolerance and $T_K = \pm 50\text{ ppm}/^\circ C$.

Typical Characteristics - DCO With External Resistor R_{OSC}

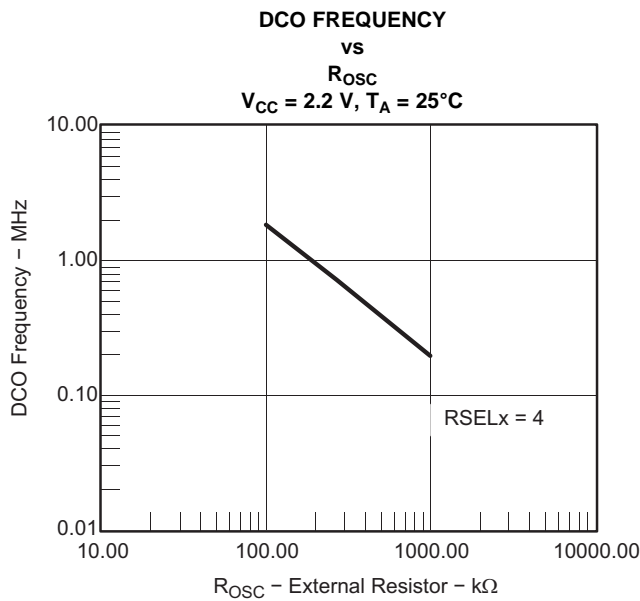


Figure 14.

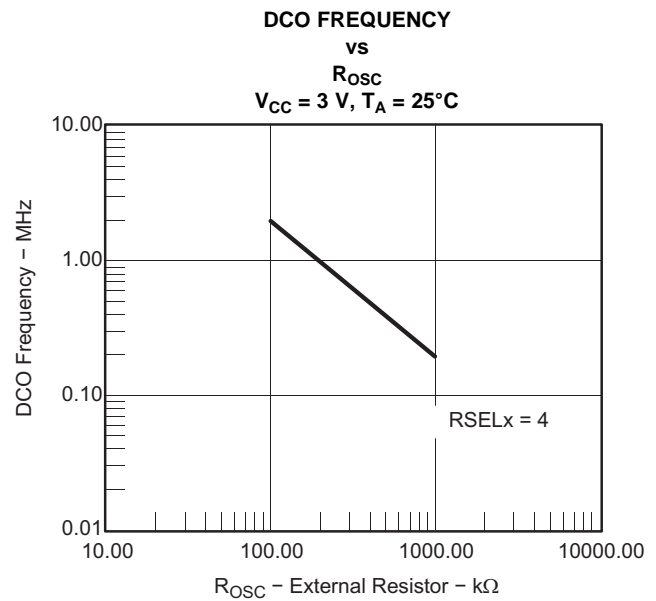


Figure 15.

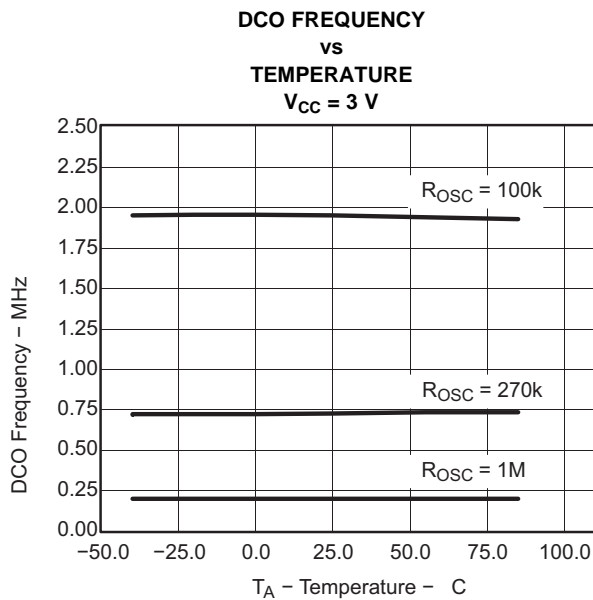


Figure 16.

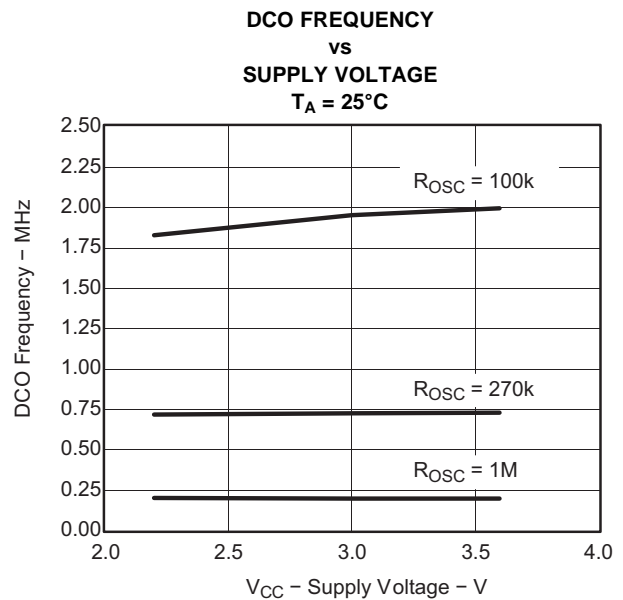


Figure 17.

Crystal Oscillator LFXT1, Low-Frequency Mode⁽¹⁾

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|-----------------------------|---|--|-----------------|-------|-------|-------|------|
| f _{LFXT1,LF} | LFXT1 oscillator crystal frequency, LF mode 0, 1 | XTS = 0, LFXT1Sx = 0 or 1 | 1.8 V to 3.6 V | | 32768 | | Hz |
| f _{LFXT1,LF,logic} | LFXT1 oscillator logic level square wave input frequency, LF mode | XTS = 0, LFXT1Sx = 3 | 1.8 V to 3.6 V | 10000 | 32768 | 50000 | Hz |
| O _{A,LF} | Oscillation allowance for LF crystals | XTS = 0, LFXT1Sx = 0, f _{LFXT1,LF} = 32768 Hz, C _{L,eff} = 6 pF | | | 500 | | kΩ |
| | | XTS = 0, LFXT1Sx = 0, f _{LFXT1,LF} = 32768 Hz, C _{L,eff} = 12 pF | | | 200 | | |
| C _{L,eff} | Integrated effective load capacitance, LF mode ⁽²⁾ | XTS = 0, XCAPx = 0 | | | 1 | | pF |
| | | XTS = 0, XCAPx = 1 | | | 5.5 | | |
| | | XTS = 0, XCAPx = 2 | | | 8.5 | | |
| | | XTS = 0, XCAPx = 3 | | | 11 | | |
| | Duty cycle, LF mode | XTS = 0, Measured at P2.0/ACLK, f _{LFXT1,LF} = 32768 Hz | 2.2 V, 3 V | 30 | 50 | 70 | % |
| f _{Fault,LF} | Oscillator fault frequency, LF mode ⁽³⁾ | XTS = 0, LFXT1Sx = 3 ⁽⁴⁾ | 2.2 V, 3 V | 10 | | 10000 | Hz |

- (1) To improve EMI on the XT1 oscillator, the following guidelines should be observed.
 - (a) Keep the trace between the device and the crystal as short as possible.
 - (b) Design a good ground plane around the oscillator pins.
 - (c) Prevent crosstalk from other clock or data lines into oscillator pins XIN and XOUT.
 - (d) Avoid running PCB traces underneath or adjacent to the XIN and XOUT pins.
 - (e) Use assembly materials and praxis to avoid any parasitic load on the oscillator XIN and XOUT pins.
 - (f) If conformal coating is used, ensure that it does not induce capacitive or resistive leakage between the oscillator pins.
 - (g) Do not route the XOUT line to the JTAG header to support the serial programming adapter as shown in other documentation. This signal is no longer required for the serial programming adapter.
- (2) Includes parasitic bond and package capacitance (approximately 2 pF per pin).
Because the PCB adds additional capacitance, it is recommended to verify the correct load by measuring the ACLK frequency. For a correct setup, the effective load capacitance should always match the specification of the crystal that is used.
- (3) Frequencies below the MIN specification set the fault flag. Frequencies above the MAX specification do not set the fault flag. Frequencies in between might set the flag.
- (4) Measured with logic-level input frequency but also applies to operation with crystals.

Internal Very-Low-Power Low-Frequency Oscillator (VLO)

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

| PARAMETER | | T _A | V _{CC} | MIN | TYP | MAX | UNIT |
|-------------------------------------|---|---------------------------------------|-----------------|-----|-----|-----|------|
| f _{VLO} | VLO frequency | -40°C to 85°C | 2.2 V, 3 V | 4 | 12 | 20 | kHz |
| | | 105°C | | | | | |
| df _{VLO} /dT | VLO frequency temperature drift ⁽¹⁾ | I: -40°C to 85°C T: -40°C to 105°C | 2.2 V, 3 V | | 0.5 | | %/°C |
| df _{VLO} /dV _{CC} | VLO frequency supply voltage drift ⁽²⁾ | 25°C | 1.8 V to 3.6 V | | 4 | | %/V |

- (1) Calculated using the box method:
I version: [MAX(-40...85°C) - MIN(-40...85°C)]/MIN(-40...85°C)/[85°C - (-40°C)]
T version: [MAX(-40...105°C) - MIN(-40...105°C)]/MIN(-40...105°C)/[105°C - (-40°C)]
- (2) Calculated using the box method: [MAX(1.8...3.6 V) - MIN(1.8...3.6 V)]/MIN(1.8...3.6 V)/(3.6 V - 1.8 V)

Crystal Oscillator LFXT1, High-Frequency Mode⁽¹⁾

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|-----------------------------|---|--|-----------------|-----|------|-----|------|
| f _{LFXT1,HF0} | LFXT1 oscillator crystal frequency, HF mode 0 | XTS = 1, LFXT1Sx = 0 | 1.8 V to 3.6 V | 0.4 | | 1 | MHz |
| f _{LFXT1,HF1} | LFXT1 oscillator crystal frequency, HF mode 1 | XTS = 1, LFXT1Sx = 1 | 1.8 V to 3.6 V | 1 | | 4 | MHz |
| f _{LFXT1,HF2} | LFXT1 oscillator crystal frequency, HF mode 2 | XTS = 1, LFXT1Sx = 2 | 1.8 V to 3.6 V | 2 | | 10 | MHz |
| | | | 2.2 V to 3.6 V | 2 | | 12 | |
| | | | 3 V to 3.6 V | 2 | | 16 | |
| f _{LFXT1,HF,logic} | LFXT1 oscillator logic-level square-wave input frequency, HF mode | XTS = 1, LFXT1Sx = 3 | 1.8 V to 3.6 V | 0.4 | | 10 | MHz |
| | | | 2.2 V to 3.6 V | 0.4 | | 12 | |
| | | | 3 V to 3.6 V | 0.4 | | 16 | |
| O _{AHF} | Oscillation allowance for HF crystals (see Figure 18 and Figure 19) | XTS = 1, LFXT1Sx = 0, f _{LFXT1,HF} = 1 MHz, C _{L,eff} = 15 pF | | | 2700 | | Ω |
| | | XTS = 1, LFXT1Sx = 1, f _{LFXT1,HF} = 4 MHz, C _{L,eff} = 15 pF | | | 800 | | |
| | | XTS = 1, LFXT1Sx = 2, f _{LFXT1,HF} = 16 MHz, C _{L,eff} = 15 pF | | | 300 | | |
| C _{L,eff} | Integrated effective load capacitance, HF mode ⁽²⁾ | XTS = 1 ⁽³⁾ | | | 1 | | pF |
| | Duty cycle, HF mode | XTS = 1, Measured at P2.0/ACLK, f _{LFXT1,HF} = 10 MHz | 2.2 V, 3 V | 40 | 50 | 60 | % |
| | | XTS = 1, Measured at P2.0/ACLK, f _{LFXT1,HF} = 16 MHz | | 40 | 50 | 60 | |
| f _{Fault,HF} | Oscillator fault frequency ⁽⁴⁾ | XTS = 1, LFXT1Sx = 3 ⁽⁵⁾ | 2.2 V, 3 V | 30 | | 300 | kHz |

- (1) To improve EMI on the XT1 oscillator the following guidelines should be observed:
 - (a) Keep the trace between the device and the crystal as short as possible.
 - (b) Design a good ground plane around the oscillator pins.
 - (c) Prevent crosstalk from other clock or data lines into oscillator pins XIN and XOUT.
 - (d) Avoid running PCB traces underneath or adjacent to the XIN and XOUT pins.
 - (e) Use assembly materials and praxis to avoid any parasitic load on the oscillator XIN and XOUT pins.
 - (f) If conformal coating is used, ensure that it does not induce capacitive or resistive leakage between the oscillator pins.
 - (g) Do not route the XOUT line to the JTAG header to support the serial programming adapter as shown in other documentation. This signal is no longer required for the serial programming adapter.
- (2) Includes parasitic bond and package capacitance (approximately 2 pF per pin). Because the PCB adds additional capacitance, it is recommended to 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.
- (3) Requires external capacitors at both terminals. Values are specified by crystal manufacturers.
- (4) Frequencies below the MIN specification set the fault flag, frequencies above the MAX specification do not set the fault flag, and frequencies in between might set the flag.
- (5) Measured with logic-level input frequency, but also applies to operation with crystals.

Typical Characteristics - LFXT1 Oscillator in HF Mode (XTS = 1)

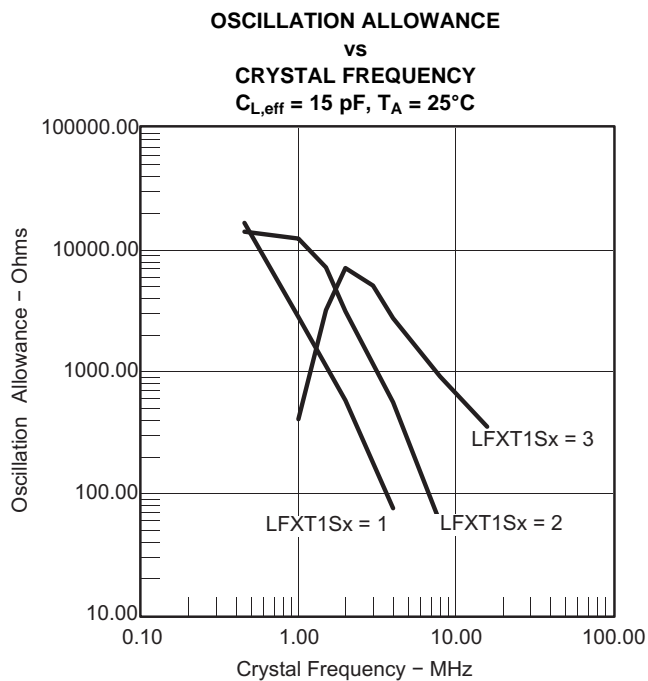


Figure 18.

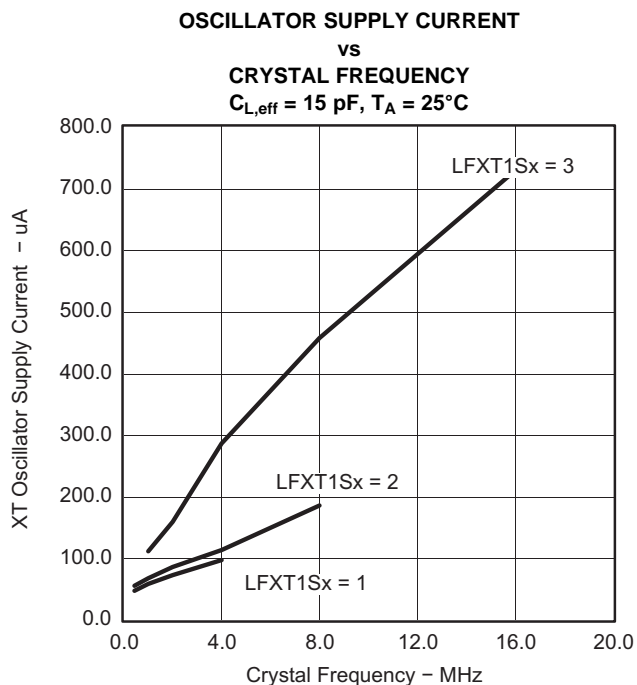


Figure 19.

Timer_A

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

| PARAMETER | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|--|---|-----------------|-----|-----|-----|------|
| f _{TA} Timer_A clock frequency | Internal: SMCLK, ACLK External: TACLK, INCLK Duty cycle = 50% ± 10% | 2.2 V | | | 10 | MHz |
| | | 3 V | | | 16 | |
| t _{TA,cap} Timer_A capture timing | TA0, TA1, TA2 | 2.2 V, 3 V | 20 | | | ns |

Timer_B

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

| PARAMETER | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|--|---|-----------------|-----|-----|-----|------|
| f _{TB} Timer_B clock frequency | Internal: SMCLK, ACLK External: TACLK, INCLK Duty cycle = 50% ± 10% | 2.2 V | | | 10 | MHz |
| | | 3 V | | | 16 | |
| t _{TB,cap} Timer_B capture timing | TB0, TB1, TB2 | 2.2 V, 3 V | 20 | | | ns |

USCI (UART Mode)

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

| PARAMETER | | CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|---------------------|---|---|-----------------|-----|-----|---------------------|------|
| f _{USCI} | USCI input clock frequency | Internal: SMCLK, ACLK External: UCLK Duty cycle = 50% ± 10% | | | | f _{SYSTEM} | MHz |
| f _{BITCLK} | BITCLK clock frequency (equals baud rate in Mbaud) | | 2.2 V, 3 V | | | 1 | MHz |
| t _r | UART receive deglitch time ⁽¹⁾ | | 2.2 V | 50 | 150 | 600 | ns |
| | | | 3 V | 50 | 100 | 600 | |

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

USCI (SPI Master Mode)⁽¹⁾

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

(see [Figure 20](#) and [Figure 21](#))

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|-----------------------|-----------------------------|--|-----------------|-----|-----|---------------------|------|
| f _{USCI} | USCI input clock frequency | SMCLK, ACLK Duty cycle = 50% ± 10% | | | | f _{SYSTEM} | MHz |
| t _{SU,MI} | SOMI input data setup time | | 2.2 V | 110 | | | ns |
| | | | 3 V | 75 | | | |
| t _{HD,MI} | SOMI input data hold time | | 2.2 V | 0 | | | ns |
| | | | 3 V | 0 | | | |
| t _{VALID,MO} | SIMO output data valid time | UCLK edge to SIMO valid, C _L = 20 pF | 2.2 V | | | 30 | ns |
| | | | 3 V | | | 20 | |

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

USCI (SPI Slave Mode)⁽¹⁾

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

(see [Figure 22](#) and [Figure 23](#))

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|-----------------------|---|--|-----------------|-----|-----|-----|------|
| t _{STE,LEAD} | STE lead time, STE low to clock | | 2.2 V, 3 V | | 50 | | ns |
| t _{STE,LAG} | STE lag time, Last clock to STE high | | 2.2 V, 3 V | 10 | | | ns |
| t _{STE,ACC} | STE access time, STE low to SOMI data out | | 2.2 V, 3 V | | 50 | | ns |
| t _{STE,DIS} | STE disable time, STE high to SOMI high impedance | | 2.2 V, 3 V | | 50 | | ns |
| t _{SU,SI} | SIMO input data setup time | | 2.2 V | 20 | | | ns |
| | | | 3 V | 15 | | | |
| t _{HD,SI} | SIMO input data hold time | | 2.2 V | 10 | | | ns |
| | | | 3 V | 10 | | | |
| t _{VALID,SO} | SOMI output data valid time | UCLK edge to SOMI valid, C _L = 20 pF | 2.2 V | | 75 | 110 | ns |
| | | | 3 V | | 50 | 75 | |

(1) f_{UCxCLK} = 1/2t_{LO/HI} with t_{LO/HI} ≥ max(t_{VALID,MO}(Master) + t_{SU,SI}(USCI), t_{SU,MI}(Master) + t_{VALID,SO}(USCI)).
For the master's parameters t_{SU,MI}(Master) and t_{VALID,MO}(Master) refer to the SPI parameters of the attached slave.

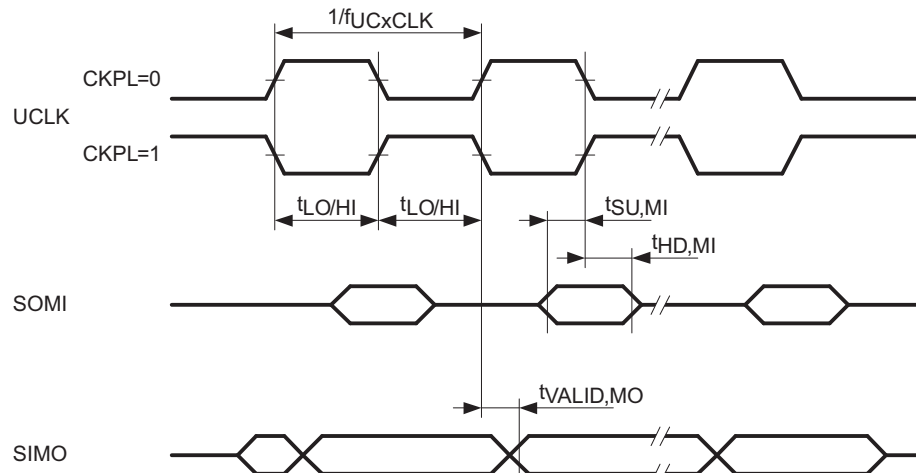


Figure 20. SPI Master Mode, CKPH = 0

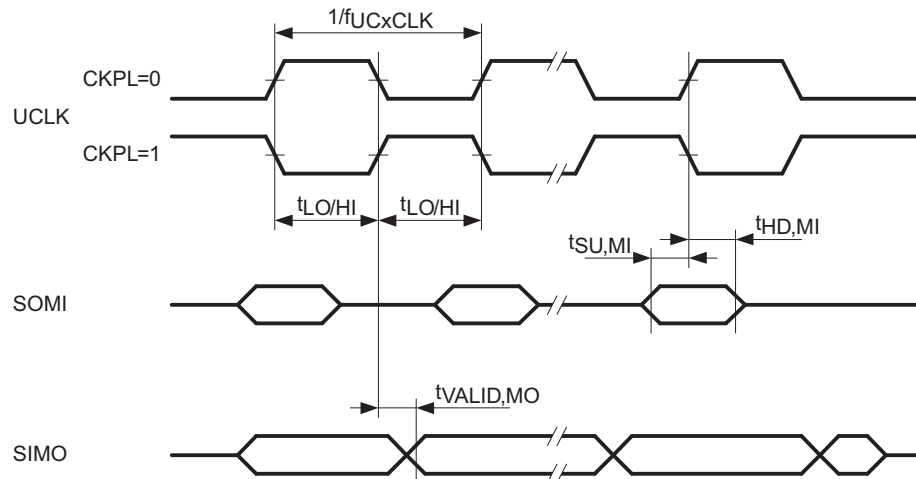


Figure 21. SPI Master Mode, CKPH = 1

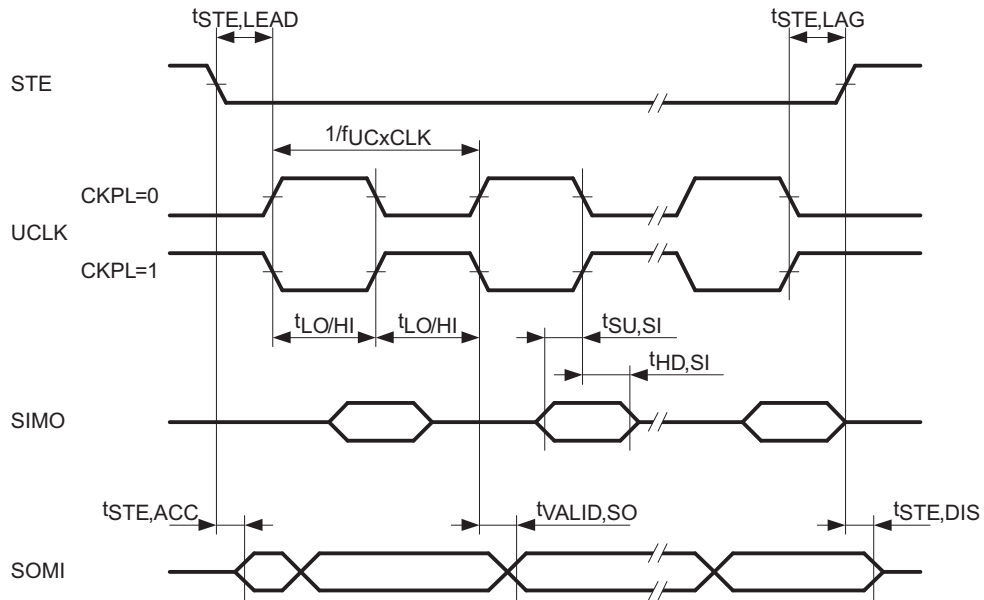


Figure 22. SPI Slave Mode, CKPH = 0

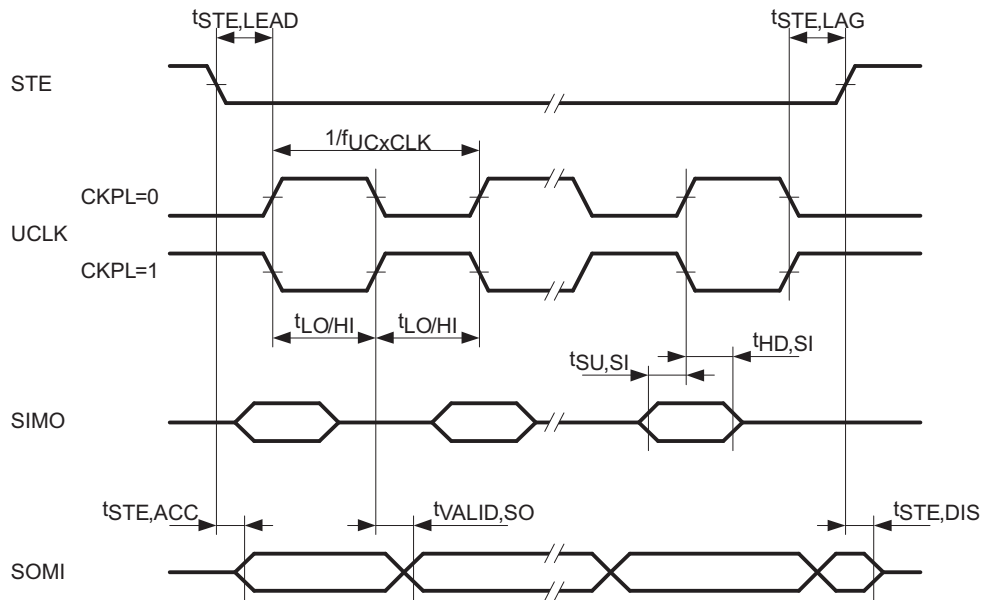


Figure 23. SPI Slave Mode, CKPH = 1

USCI (I2C Mode)

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see [Figure 24](#))

| PARAMETER | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT | |
|---------------------|--|--|--------------|------------|---------------------|------------|----|
| f _{USCI} | USCI input clock frequency | | | | f _{SYSTEM} | MHz | |
| f _{SCL} | SCL clock frequency | 2.2 V, 3 V | 0 | | 400 | kHz | |
| t _{HD,STA} | Hold time (repeated) START | f _{SCL} ≤ 100 kHz f _{SCL} > 100 kHz | 2.2 V, 3 V | 4 0.6 | | μs | |
| t _{SU,STA} | Setup time for a repeated START | f _{SCL} ≤ 100 kHz f _{SCL} > 100 kHz | 2.2 V, 3 V | 4.7 0.6 | | μs | |
| t _{HD,DAT} | Data hold time | | 2.2 V, 3 V | 0 | | ns | |
| t _{SU,DAT} | Data setup time | | 2.2 V, 3 V | 250 | | ns | |
| t _{SU,STO} | Setup time for STOP | | 2.2 V, 3 V | 4 | | μs | |
| t _{SP} | Pulse width of spikes suppressed by input filter | | 2.2 V 3 V | 50 50 | 150 100 | 600 600 | ns |

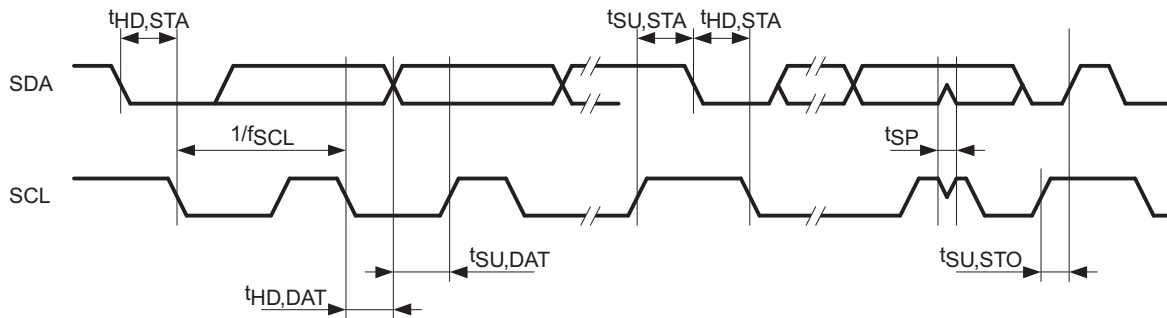


Figure 24. I2C Mode Timing

10-Bit ADC, Power Supply and Input Range Conditions⁽¹⁾

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

| PARAMETER | TEST CONDITIONS | T _A | V _{CC} | MIN | TYP | MAX | UNIT |
|---------------------|--|---|-----------------|------------|------|-----------------|------|
| V _{CC} | Analog supply voltage range | V _{SS} = 0 V | | 2.2 | | 3.6 | V |
| V _{Ax} | Analog input voltage range ⁽²⁾ | All Ax terminals, Analog inputs selected in ADC10AE register | | 0 | | V _{CC} | V |
| I _{ADC10} | ADC10 supply current ⁽³⁾ | f _{ADC10CLK} = 5 MHz, ADC10ON = 1, REFON = 0, ADC10SHT0 = 1, ADC10SHT1 = 0, ADC10DIV = 0 | -40°C to 85°C | 2.2 V | 0.52 | 1.05 | mA |
| | | | -40°C to 105°C | 3 V | 0.6 | 1.2 | |
| I _{REF+} | Reference supply current, reference buffer disabled ⁽⁴⁾ | f _{ADC10CLK} = 5 MHz, ADC10ON = 0, REF2_5V = 0, REFON = 1, REFOUT = 0 | -40°C to 85°C | 2.2 V, 3 V | 0.25 | 0.4 | mA |
| | | | -40°C to 105°C | 3 V | 0.25 | 0.4 | |
| I _{REFB,0} | Reference buffer supply current with ADC10SR = 0 ⁽⁴⁾ | f _{ADC10CLK} = 5 MHz, ADC10ON = 0, REFON = 1, REF2_5V = 0, REFOUT = 1, ADC10SR = 0 | -40°C to 85°C | 2.2 V, 3 V | 1.1 | 1.4 | mA |
| | | | 105°C | 2.2 V, 3 V | | 1.8 | |
| I _{REFB,1} | Reference buffer supply current with ADC10SR = 1 ⁽⁴⁾ | f _{ADC10CLK} = 5 MHz, ADC10ON = 0, REFON = 1, REF2_5V = 0, REFOUT = 1, ADC10SR = 1 | -40°C to 85°C | 2.2 V, 3 V | 0.5 | 0.7 | mA |
| | | | 105°C | 2.2 V, 3 V | | 0.8 | |
| C _i | Input capacitance | Only one terminal Ax selected at a time | | | | 27 | pF |
| R _i | Input MUX ON resistance | 0 V ≤ V _{Ax} ≤ V _{CC} | | | | 2000 | Ω |

- (1) The leakage current is defined in the leakage current table with P_{x.x}/A_x parameter.
- (2) The analog input voltage range must be within the selected reference voltage range V_{R+} to V_{R-} for valid conversion results.
- (3) The internal reference supply current is not included in current consumption parameter I_{ADC10}.
- (4) The internal reference current is supplied via terminal V_{CC}. Consumption is independent of the ADC10ON control bit, unless a conversion is active. The REFON bit enables the built-in reference to settle before starting an A/D conversion.

10-Bit ADC, Built-In Voltage Reference

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

| PARAMETER | | TEST CONDITIONS | | V _{CC} | MIN | TYP | MAX | UNIT |
|---|---|---|-------------|-----------------|------|-----|------|--------|
| V _{CC,REF+} | Positive built-in reference analog supply voltage range | I _{VREF+} ≤ 1 mA, REF2_5V = 0 | | | 2.2 | | | V |
| | | I _{VREF+} ≤ 0.5 mA, REF2_5V = 1 | | | 2.8 | | | |
| | | I _{VREF+} ≤ 1 mA, REF2_5V = 1 | | | 2.9 | | | |
| V _{REF+} | Positive built-in reference voltage | I _{VREF+} ≤ I _{VREF+,max} , REF2_5V = 0 | | 2.2 V, 3 V | 1.41 | 1.5 | 1.59 | V |
| | | I _{VREF+} ≤ I _{VREF+,max} , REF2_5V = 1 | | 3 V | 2.35 | 2.5 | 2.65 | |
| I _{LD,VREF+} | Maximum V _{REF+} load current | | | 2.2 V | ±0.5 | | | mA |
| | | | | 3 V | ±1 | | | |
| V _{REF+} load regulation | V _{REF+} load regulation | I _{VREF+} = 500 μA ± 100 μA, Analog input voltage V _{AX} ≈ 0.75 V, REF2_5V = 0 | | 2.2 V, 3 V | ±2 | | | LSB |
| | | I _{VREF+} = 500 μA ± 100 μA, Analog input voltage V _{AX} ≈ 1.25 V, REF2_5V = 1 | | 3 V | ±2 | | | |
| V _{REF+} load regulation response time | V _{REF+} load regulation response time | I _{VREF+} = 100 μA to 900 μA, V _{AX} ≈ 0.5 × V _{REF+} , Error of conversion result ≤ 1 LSB | ADC10SR = 0 | 3 V | 400 | | | ns |
| | | | ADC10SR = 1 | | 2000 | | | |
| C _{VREF+} | Maximum capacitance at pin V _{REF+} ⁽¹⁾ | I _{VREF+} ≤ ±1 mA, REFON = 1, REFOUT = 1 | | 2.2 V, 3 V | 100 | | | pF |
| T _{CREF+} | Temperature coefficient ⁽²⁾ | I _{VREF+} = constant with 0 mA ≤ I _{VREF+} ≤ 1 mA | | 2.2 V, 3 V | ±100 | | | ppm/°C |
| t _{REFON} | Settling time of internal reference voltage ⁽³⁾ | I _{VREF+} = 0.5 mA, REF2_5V = 0, REFON = 0 to 1 | | 3.6 V | 30 | | | μs |
| t _{REFBURST} | Settling time of reference buffer ⁽³⁾ | I _{VREF+} = 0.5 mA, REF2_5V = 0, REFON = 1, REFBURST = 1 | ADC10SR = 0 | 2.2 V | 1 | | | μs |
| | | | ADC10SR = 1 | | 2.5 | | | |
| | | I _{VREF+} = 0.5 mA, REF2_5V = 1, REFON = 1, REFBURST = 1 | ADC10SR = 0 | 3 V | 2 | | | |
| | | | ADC10SR = 1 | | 4.5 | | | |

(1) The capacitance applied to the internal buffer operational amplifier, if switched to terminal P2.4/TA 2/A4/V_{REF+}/V_{eREF+} (REFOUT = 1), must be limited; the reference buffer may become unstable otherwise.

(2) Calculated using the box method:

I temperature: (MAX(-40 to 85°C) – MIN(-40 to 85°C)) / MIN(-40 to 85°C) / (85°C – (-40°C))

T temperature: (MAX(-40 to 105°C) – MIN(-40 to 105°C)) / MIN(-40 to 105°C) / (105°C – (-40°C))

(3) The condition is that the error in a conversion started after t_{REFON} or t_{RefBuf} is less than ±0.5 LSB.

10-Bit ADC, External Reference⁽¹⁾

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | MAX | UNIT |
|--------------------|---|--|-----------------|-----|-----------------|------|
| V _{eREF+} | Positive external reference input voltage range ⁽²⁾ | V _{eREF+} > V _{eREF-} , SREF1 = 1, SREF0 = 0 | | 1.4 | V _{CC} | V |
| | | V _{eREF-} ≤ V _{eREF+} ≤ V _{CC} - 0.15 V, SREF1 = 1, SREF0 = 1 ⁽³⁾ | | 1.4 | 3 | |
| V _{eREF-} | Negative external reference input voltage range ⁽⁴⁾ | V _{eREF+} > V _{eREF-} | | 0 | 1.2 | V |
| ΔV _{eREF} | Differential external reference input voltage range ΔV _{eREF} = V _{eREF+} - V _{eREF-} | V _{eREF+} > V _{eREF-} ⁽⁵⁾ | | 1.4 | V _{CC} | V |
| I _{vREF+} | Static input current into V _{eREF+} | 0 V ≤ V _{eREF+} ≤ V _{CC} , SREF1 = 1, SREF0 = 0 | 2.2 V, 3 V | ±1 | | μA |
| | | 0 V ≤ V _{eREF+} ≤ V _{CC} - 0.15 V ≤ 3 V, SREF1 = 1, SREF0 = 1 ⁽³⁾ | | 0 | | |
| I _{vREF-} | Static input current into V _{eREF-} | 0 V ≤ V _{eREF-} ≤ V _{CC} | 2.2 V, 3 V | ±1 | | μA |

- (1) The external reference is used during conversion to charge and discharge the capacitance array. The input capacitance, C_I, is also the dynamic load for an external reference during conversion. The dynamic impedance of the reference supply should follow the recommendations on analog-source impedance to allow the charge to settle for 10-bit accuracy.
- (2) The accuracy limits the minimum positive external reference voltage. Lower reference voltage levels may be applied with reduced accuracy requirements.
- (3) Under this condition, the external reference is internally buffered. The reference buffer is active and requires the reference buffer supply current I_{REFB}. The current consumption can be limited to the sample and conversion period with REBURST = 1.
- (4) The accuracy limits the maximum negative external reference voltage. Higher reference voltage levels may be applied with reduced accuracy requirements.
- (5) The accuracy limits the minimum external differential reference voltage. Lower differential reference voltage levels may be applied with reduced accuracy requirements.

10-Bit ADC, Timing Parameters

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|-----------------------|---|---|-----------------|------|---|------|------|
| f _{ADC10CLK} | ADC10 input clock frequency | For specified performance of ADC10 linearity parameters | 2.2 V, 3 V | 0.45 | | 6.3 | MHz |
| | | | | | | 1.5 | |
| f _{ADC10OSC} | ADC10 built-in oscillator frequency | ADC10DIVx = 0, ADC10SSELx = 0, f _{ADC10CLK} = f _{ADC10OSC} | 2.2 V, 3 V | 3.7 | | 6.3 | MHz |
| t _{CONVERT} | Conversion time | ADC10 built-in oscillator, ADC10SSELx = 0, f _{ADC10CLK} = f _{ADC10OSC} | 2.2 V, 3 V | 2.06 | | 3.51 | μs |
| | | f _{ADC10CLK} from ACLK, MCLK or SMCLK, ADC10SSELx ≠ 0 | | | 13 × ADC10DIVx × 1 / f _{ADC10CLK} | | |
| t _{ADC10ON} | Turn on settling time of the ADC ⁽¹⁾ | | | | | 100 | ns |

- (1) The condition is that the error in a conversion started after t_{ADC10ON} is less than ±0.5 LSB. The reference and input signal are already settled.

10-Bit ADC, Linearity Parameters

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 | | 2.2 V, 3 V | | | ±1 | LSB |
| E _D | Differential linearity error | | 2.2 V, 3 V | | | ±1 | LSB |
| E _O | Offset error | Source impedance R _S < 100 Ω | 2.2 V, 3 V | | | ±1 | LSB |
| E _G | Gain error | SREFx = 010, unbuffered external reference, V _{eREF+} = 1.5 V | 2.2 V | | ±1.1 | ±2 | LSB |
| | | SREFx = 010, unbuffered external reference, V _{eREF+} = 2.5 V | 3 V | | ±1.1 | ±2 | |
| | | SREFx = 011, buffered external reference ⁽¹⁾ , V _{eREF+} = 1.5 V | 2.2 V | | ±1.1 | ±4 | |
| | | SREFx = 011, buffered external reference ⁽¹⁾ , V _{eREF+} = 2.5 V | 3 V | | ±1.1 | ±3 | |
| E _T | Total unadjusted error | SREFx = 010, unbuffered external reference, V _{eREF+} = 1.5 V | 2.2 V | | ±2 | ±5 | LSB |
| | | SREFx = 010, unbuffered external reference, V _{eREF+} = 2.5 V | 3 V | | ±2 | ±5 | |
| | | SREFx = 011, buffered external reference ⁽¹⁾ , V _{eREF+} = 1.5 V | 2.2 V | | ±2 | ±7 | |
| | | SREFx = 011, buffered external reference ⁽¹⁾ , V _{eREF+} = 2.5 V | 3 V | | ±2 | ±6 | |

(1) The reference buffer offset adds to the gain and total unadjusted error.

10-Bit ADC, Temperature Sensor and Built-In V_{MID}⁽¹⁾

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT | |
|-----------------------------|---|---|-----------------|------|------|------|-------|----|
| I _{SENSOR} | Temperature sensor supply current ⁽¹⁾ | REFON = 0, INCHx = 0Ah, T _A = 25°C | 2.2 V | | 40 | 120 | μA | |
| | | | 3 V | | 60 | 160 | | |
| TC _{SENSOR} | | ADC10ON = 1, INCHx = 0Ah ⁽²⁾ | 2.2 V, 3 V | 3.44 | 3.55 | 3.66 | mV/°C | |
| V _{Offset, Sensor} | Sensor offset voltage | ADC10ON = 1, INCHx = 0Ah ⁽²⁾ | | -100 | | 100 | mV | |
| V _{SENSOR} | Sensor output voltage ⁽³⁾ | Temperature sensor voltage at T _A = 105°C (T version only) | 2.2 V, 3 V | | 1265 | 1365 | 1465 | mV |
| | | Temperature sensor voltage at T _A = 85°C | | | 1195 | 1295 | 1395 | |
| | | Temperature sensor voltage at T _A = 25°C | | | 985 | 1085 | 1185 | |
| | | Temperature sensor voltage at T _A = 0°C | | | 895 | 995 | 1095 | |
| t _{SENSOR(sample)} | Sample time required if channel 10 is selected ⁽⁴⁾ | ADC10ON = 1, INCHx = 0Ah, Error of conversion result ≤ 1 LSB | 2.2 V, 3 V | 30 | | | μs | |
| I _{VMID} | Current into divider at channel 11 ⁽⁴⁾ | ADC10ON = 1, INCHx = 0Bh | 2.2 V | | | N/A | μA | |
| | | | 3 V | | | N/A | | |
| V _{MID} | V _{CC} divider at channel 11 | ADC10ON = 1, INCHx = 0Bh, V _{MID} ≈ 0.5 × V _{CC} | 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 ⁽⁵⁾ | ADC10ON = 1, INCHx = 0Bh, Error of conversion result ≤ 1 LSB | 2.2 V | 1400 | | | ns | |
| | | | 3 V | 1220 | | | | |

(1) The sensor current I_{SENSOR} is consumed if (ADC10ON = 1 and REFON = 1), or (ADC10ON = 1 and INCH = 0Ah and sample signal is high). When REFON = 1, I_{SENSOR} is included in I_{REF+}. When REFON = 0, I_{SENSOR} applies during conversion of the temperature sensor input (INCH = 0Ah).

(2) The following formula can be used to calculate the temperature sensor output voltage:

$$V_{\text{Sensor, typ}} = TC_{\text{Sensor}} (273 + T [^{\circ}\text{C}]) + V_{\text{Offset, sensor}} [\text{mV}] \text{ or}$$

$$V_{\text{Sensor, typ}} = TC_{\text{Sensor}} T [^{\circ}\text{C}] + V_{\text{Sensor}}(T_A = 0^{\circ}\text{C}) [\text{mV}]$$

(3) Results based on characterization and/or production test, not TC_{Sensor} or V_{Offset, sensor}.

(4) No additional current is needed. The V_{MID} is used during sampling.

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

Operational Amplifier (OA) Supply Specifications (MSP430F22x4 Only)

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|-----------------|-------------------------------|-----------------|-----------------|-----|-----|-----|------|
| V _{CC} | Supply voltage range | | | 2.2 | | 3.6 | V |
| I _{CC} | Supply current ⁽¹⁾ | Fast Mode | 2.2 V, 3 V | | 180 | 290 | μA |
| | | Medium Mode | | | 110 | 190 | |
| | | Slow Mode | | | 50 | 80 | |
| PSRR | Power-supply rejection ratio | Noninverting | 2.2 V, 3 V | | 70 | | dB |

(1) Corresponding pins configured as OA inputs and outputs, respectively.

Operational Amplifier (OA) Input/Output Specifications (MSP430F22x4 Only)

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT | |
|-----------------------|---|---|-----------------|------------------------------|------|-----------------------|--------|--|
| V _{I/P} | Input voltage range | | | -0.1 | | V _{CC} - 1.2 | V | |
| I _{ikg} | Input leakage current ⁽¹⁾ ⁽²⁾ | T _A = -40 to +55°C | 2.2 V, 3 V | -5 | ±0.5 | 5 | nA | |
| | | T _A = +55 to +85°C | | -20 | ±5 | 20 | | |
| | | T _A = +85 to +105°C | | -50 | | 50 | | |
| V _n | Voltage noise density, I/P | Fast Mode | | | 50 | | nV/√Hz | |
| | | Medium Mode | | f _{V(I/P)} = 1 kHz | | 80 | | |
| | | Slow Mode | | | | 140 | | |
| | | Fast Mode | | f _{V(I/P)} = 10 kHz | | 30 | | |
| | | Medium Mode | | | | 50 | | |
| | | Slow Mode | | | | 65 | | |
| V _{IO} | Offset voltage, I/P | | 2.2 V, 3 V | | | ±10 | mV | |
| | Offset temperature drift, I/P ⁽³⁾ | | 2.2 V, 3 V | | ±10 | | μV/°C | |
| | Offset voltage drift with supply, I/P | 0.3 V ≤ V _{IN} ≤ V _{CC} - 1.0 V ΔV _{CC} ≤ ±10%, T _A = 25°C | 2.2 V, 3 V | | | ±1.5 | mV/V | |
| V _{OH} | High-level output voltage, O/P | Fast Mode, I _{SOURCE} ≤ -500 μA | 2.2 V, 3 V | V _{CC} - 0.2 | | V _{CC} | V | |
| | | Slow Mode, I _{SOURCE} ≤ -150 μA | | V _{CC} - 0.1 | | V _{CC} | | |
| V _{OL} | Low-level output voltage, O/P | Fast Mode, I _{SOURCE} ≤ 500 μA | 2.2 V, 3 V | V _{SS} | | 0.2 | V | |
| | | Slow Mode, I _{SOURCE} ≤ 150 μA | | V _{SS} | | 0.1 | | |
| R _{O/P(OAx)} | Output resistance ⁽⁴⁾ (see Figure 25) | R _{Load} = 3 kΩ, C _{Load} = 50 pF, V _{O/P(OAx)} < 0.2 V | 2.2 V, 3 V | | 150 | 250 | Ω | |
| | | R _{Load} = 3 kΩ, C _{Load} = 50 pF, V _{O/P(OAx)} > V _{CC} - 1.2 V | | | 150 | 250 | | |
| | | R _{Load} = 3 kΩ, C _{Load} = 50 pF, 0.2 V ≤ V _{O/P(OAx)} ≤ V _{CC} - 0.2 V | | | 0.1 | 4 | | |
| CMRR | Common-mode rejection ratio | Noninverting | 2.2 V, 3 V | | 70 | | dB | |

(1) ESD damage can degrade input current leakage.

(2) The input bias current is overridden by the input leakage current.

(3) Calculated using the box method

(4) Specification valid for voltage-follower OAx configuration

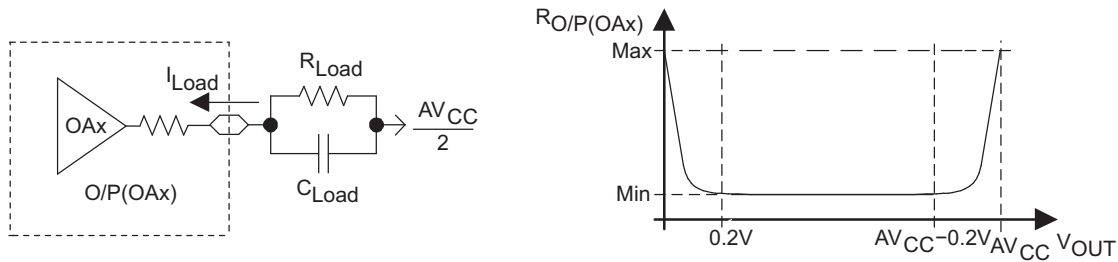


Figure 25. OAx Output Resistance Tests

Operational Amplifier (OA) Dynamic Specifications (MSP430F22x4 Only)

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|------------------------|---|---|-----------------|-----|-----|-----|------|
| SR | Slew rate | Fast Mode | 2.2 V, 3 V | | 1.2 | | V/μs |
| | | Medium Mode | | | 0.8 | | |
| | | Slow Mode | | | 0.3 | | |
| Open-loop voltage gain | | | | | 100 | | dB |
| φ _m | Phase margin | C _L = 50 pF | | | 60 | | deg |
| Gain margin | | C _L = 50 pF | | | 20 | | dB |
| GBW | Gain-bandwidth product (see Figure 26 and Figure 27) | Noninverting, Fast Mode, R _L = 47 kΩ, C _L = 50 pF | 2.2 V, 3 V | | 2.2 | | MHz |
| | | Noninverting, Medium Mode, R _L = 300 kΩ, C _L = 50 pF | | | 1.4 | | |
| | | Noninverting, Slow Mode, R _L = 300 kΩ, C _L = 50 pF | | | 0.5 | | |
| t _{en(on)} | Enable time on | t _{on} , noninverting, Gain = 1 | 2.2 V, 3 V | | 10 | 20 | μs |
| t _{en(off)} | Enable time off | | 2.2 V, 3 V | | | 1 | μs |

TYPICAL OPEN-LOOP GAIN
vs
FREQUENCY

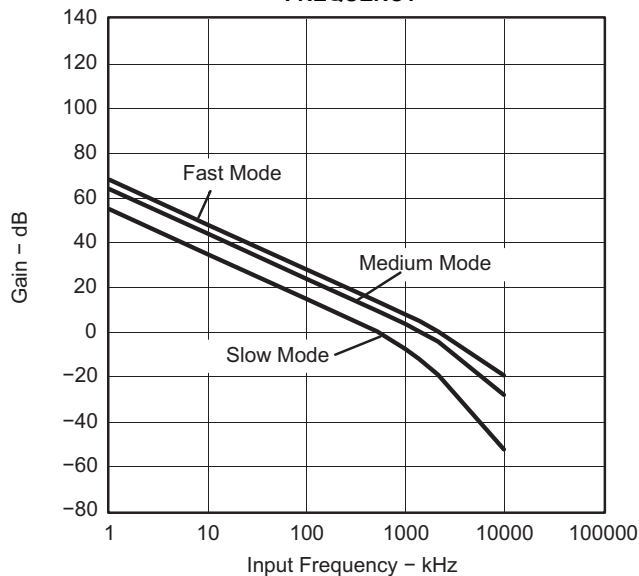


Figure 26.

TYPICAL PHASE
vs
FREQUENCY

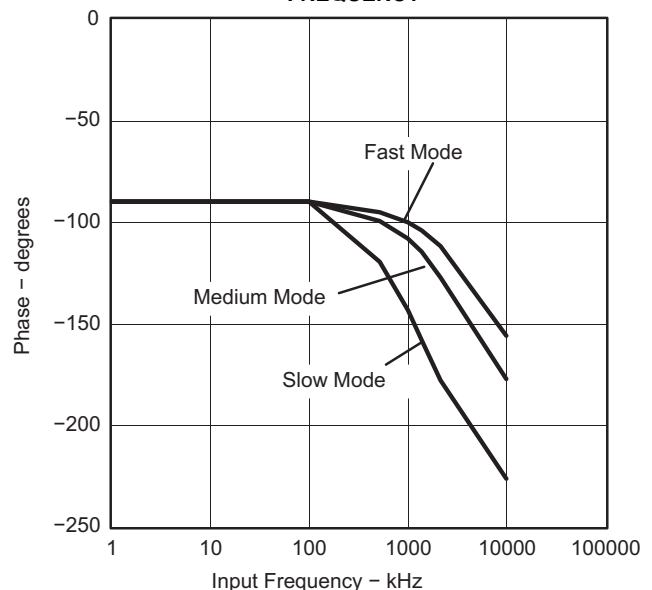


Figure 27.

Operational Amplifier OA Feedback Network, Resistor Network (MSP430F22x4 Only)⁽¹⁾

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|--------------------|---|-----------------|-----------------|-----|-----|-----|------|
| R _{total} | Total resistance of resistor string | | | 76 | 96 | 128 | kΩ |
| R _{unit} | Unit resistor of resistor string ⁽²⁾ | | | 4.8 | 6 | 8 | kΩ |

- (1) A single resistor string is composed of 4 R_{unit} + 4 R_{unit} + 2 R_{unit} + 2 R_{unit} + 1 R_{unit} + 1 R_{unit} + 1 R_{unit} + 1 R_{unit} = 16 R_{unit} = R_{total}.
- (2) For the matching (that is, the relative accuracy) of the unit resistors on a device, see the gain and level specifications of the respective configurations.

Operational Amplifier (OA) Feedback Network, Comparator Mode (OAFcx = 3) (MSP430F22x4 Only)

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|--|--|-------------------------------|-----------------|--------------------|--------|-------|-----------------|
| V _{Level} | Comparator level | OAFBRx = 1, OARRIP = 0 | 2.2 V, 3 V | 0.245 | 0.25 | 0.255 | V _{CC} |
| | | OAFBRx = 2, OARRIP = 0 | | 0.495 | 0.5 | 0.505 | |
| | | OAFBRx = 3, OARRIP = 0 | | 0.619 | 0.625 | 0.631 | |
| | | OAFBRx = 4, OARRIP = 0 | | N/A ⁽¹⁾ | | | |
| | | OAFBRx = 5, OARRIP = 0 | | N/A ⁽¹⁾ | | | |
| | | OAFBRx = 6, OARRIP = 0 | | N/A ⁽¹⁾ | | | |
| | | OAFBRx = 7, OARRIP = 0 | | N/A ⁽¹⁾ | | | |
| | | OAFBRx = 1, OARRIP = 1 | | 0.061 | 0.0625 | 0.065 | |
| | | OAFBRx = 2, OARRIP = 1 | | 0.122 | 0.125 | 0.128 | |
| | | OAFBRx = 3, OARRIP = 1 | | 0.184 | 0.1875 | 0.192 | |
| | | OAFBRx = 4, OARRIP = 1 | | 0.245 | 0.25 | 0.255 | |
| | | OAFBRx = 5, OARRIP = 1 | | 0.367 | 0.375 | 0.383 | |
| | | OAFBRx = 6, OARRIP = 1 | | 0.495 | 0.5 | 0.505 | |
| | | OAFBRx = 7, OARRIP = 1 | | N/A ⁽¹⁾ | | | |
| t _{PLH} , t _{PHL} | Propagation delay (low-high and high-low) | Fast Mode, Overdrive 10 mV | 2.2 V, 3 V | 40 | | | μs |
| | | Fast Mode, Overdrive 100 mV | | 4 | | | |
| | | Fast Mode, Overdrive 500 mV | | 3 | | | |
| | | Medium Mode, Overdrive 10 mV | | 60 | | | |
| | | Medium Mode, Overdrive 100 mV | | 6 | | | |
| | | Medium Mode, Overdrive 500 mV | | 5 | | | |
| | | Slow Mode, Overdrive 10 mV | | 160 | | | |
| | | Slow Mode, Overdrive 100 mV | | 20 | | | |
| | | Slow Mode, Overdrive 500 mV | | 15 | | | |

- (1) The level is not available due to the analog input voltage range of the operational amplifier.

Operational Amplifier (OA) Feedback Network, Noninverting Amplifier Mode (OAF_{Cx} = 4) (MSP430F22x4 Only)

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|---------------------|--|------------------------|-----------------|-------|-------|-------|------|
| G | Gain | OAFBR _x = 0 | 2.2 V, 3 V | 0.998 | 1 | 1.002 | |
| | | OAFBR _x = 1 | | 1.328 | 1.334 | 1.340 | |
| | | OAFBR _x = 2 | | 1.985 | 2.001 | 2.017 | |
| | | OAFBR _x = 3 | | 2.638 | 2.667 | 2.696 | |
| | | OAFBR _x = 4 | | 3.94 | 4 | 4.06 | |
| | | OAFBR _x = 5 | | 5.22 | 5.33 | 5.44 | |
| | | OAFBR _x = 6 | | 7.76 | 7.97 | 8.18 | |
| | | OAFBR _x = 7 | | 15 | 15.8 | 16.6 | |
| THD | Total harmonic distortion/nonlinearity | All gains | 2.2 V | -60 | | | dB |
| | | | 3 V | -70 | | | |
| t _{Settle} | Settling time ⁽¹⁾ | All power modes | 2.2 V, 3 V | 7 | 12 | | μs |

(1) The settling time specifies the time until an ADC result is stable. This includes the minimum required sampling time of the ADC. The settling time of the amplifier itself might be faster.

Operational Amplifier (OA) Feedback Network, Inverting Amplifier Mode (OAF_{Cx} = 6) (MSP430F22x4 Only)⁽¹⁾

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|---------------------|--|------------------------|-----------------|--------|--------|--------|------|
| G | Gain | OAFBR _x = 1 | 2.2 V, 3 V | -0.345 | -0.335 | -0.325 | |
| | | OAFBR _x = 2 | | -1.023 | -1.002 | -0.979 | |
| | | OAFBR _x = 3 | | -1.712 | -1.668 | -1.624 | |
| | | OAFBR _x = 4 | | -3.1 | -3 | -2.9 | |
| | | OAFBR _x = 5 | | -4.51 | -4.33 | -4.15 | |
| | | OAFBR _x = 6 | | -7.37 | -6.97 | -6.57 | |
| | | OAFBR _x = 7 | | -16.3 | -14.8 | -13.1 | |
| THD | Total harmonic distortion/nonlinearity | All gains | 2.2 V | -60 | | | dB |
| | | | 3 V | -70 | | | |
| t _{Settle} | Settling time ⁽²⁾ | All power modes | 2.2 V, 3 V | 7 | 12 | | μs |

(1) This includes the 2 OA configuration "inverting amplifier with input buffer". Both OA needs to be set to the same power mode OAPM_x.

(2) The settling time specifies the time until an ADC result is stable. This includes the minimum required sampling time of the ADC. The settling time of the amplifier itself might be faster.

Flash Memory

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | MIN | TYP | MAX | UNIT |
|-----------------------------|---|-----------------------|-----------------|-----------------|-----------------|-----|------------------|
| V _{CC (PGM/ERASE)} | Program and erase supply voltage | | | 2.2 | | 3.6 | V |
| f _{FTG} | Flash timing generator frequency | | | 257 | | 476 | kHz |
| I _{PGM} | Supply current from V _{CC} during program | | 2.2 V, 3.6 V | | 1 | 5 | mA |
| I _{ERASE} | Supply current from V _{CC} during erase | | 2.2 V, 3.6 V | | 1 | 7 | mA |
| t _{CPT} | Cumulative program time ⁽¹⁾ | | 2.2 V, 3.6 V | | | 10 | ms |
| t _{CMErase} | Cumulative mass erase time | | 2.2 V, 3.6 V | 20 | | | ms |
| | Program/Erase endurance | | | 10 ⁴ | 10 ⁵ | | cycles |
| t _{Retention} | Data retention duration | T _J = 25°C | | 100 | | | years |
| t _{Word} | Word or byte program time | (2) | | | 30 | | t _{FTG} |
| t _{Block, 0} | Block program time for first byte or word | (2) | | | 25 | | t _{FTG} |
| t _{Block, 1-63} | Block program time for each additional byte or word | (2) | | | 18 | | t _{FTG} |
| t _{Block, End} | Block program end-sequence wait time | (2) | | | 6 | | t _{FTG} |
| t _{Mass Erase} | Mass erase time | (2) | | | 10593 | | t _{FTG} |
| t _{Seg Erase} | Segment erase time | (2) | | | 4819 | | t _{FTG} |

- (1) The cumulative program time must not be exceeded when writing to a 64-byte flash block. This parameter applies to all programming methods: individual word/byte write and block write modes.
 (2) These values are hardwired into the flash controller's state machine (t_{FTG} = 1/f_{FTG}).

RAM

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

| PARAMETER | | TEST CONDITIONS | MIN | MAX | UNIT |
|---------------------|---|-----------------|-----|-----|------|
| V _(RAMh) | RAM retention supply voltage ⁽¹⁾ | CPU halted | 1.6 | | V |

- (1) This parameter defines the minimum supply voltage V_{CC} when the data in RAM remains unchanged. No program execution should happen during this supply voltage condition.

JTAG and Spy-Bi-Wire Interface

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

| PARAMETER | | TEST CONDITIONS | V _{CC} | 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 length | | 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 ⁽¹⁾) | | 2.2 V, 3 V | | | 1 | μs |
| t _{SBW,Ret} | Spy-Bi-Wire return to normal operation time | | 2.2 V, 3 V | 15 | | 100 | μs |
| f _{TCK} | TCK input frequency ⁽²⁾ | | 2.2 V | 0 | | 5 | MHz |
| | | | 3 V | 0 | | 10 | MHz |
| R _{Internal} | Internal pulldown resistance on TEST | | 2.2 V, 3 V | 25 | 60 | 90 | kΩ |

- (1) Tools accessing the Spy-Bi-Wire interface need to wait for the maximum t_{SBW,En} time after pulling the TEST/SBWCLK pin high before applying the first SBWCLK clock edge.
- (2) f_{TCK} may be restricted to meet the timing requirements of the module selected.

JTAG Fuse⁽¹⁾

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

| PARAMETER | | TEST CONDITIONS | MIN | MAX | UNIT |
|---------------------|---|-----------------------|-----|-----|------|
| V _{CC(FB)} | Supply voltage during fuse-blow condition | T _A = 25°C | 2.5 | | V |
| V _{FB} | Voltage level on TEST for fuse blow | | 6 | 7 | V |
| I _{FB} | Supply current into TEST during fuse blow | | | 100 | mA |
| t _{FB} | Time to blow fuse | | | 1 | ms |

- (1) Once the fuse is blown, no further access to the JTAG/Test, Spy-Bi-Wire, and emulation feature is possible, and JTAG is switched to bypass mode.

APPLICATION INFORMATION

Port P1 Pin Schematic: P1.0 to P1.3, Input/Output With Schmitt Trigger

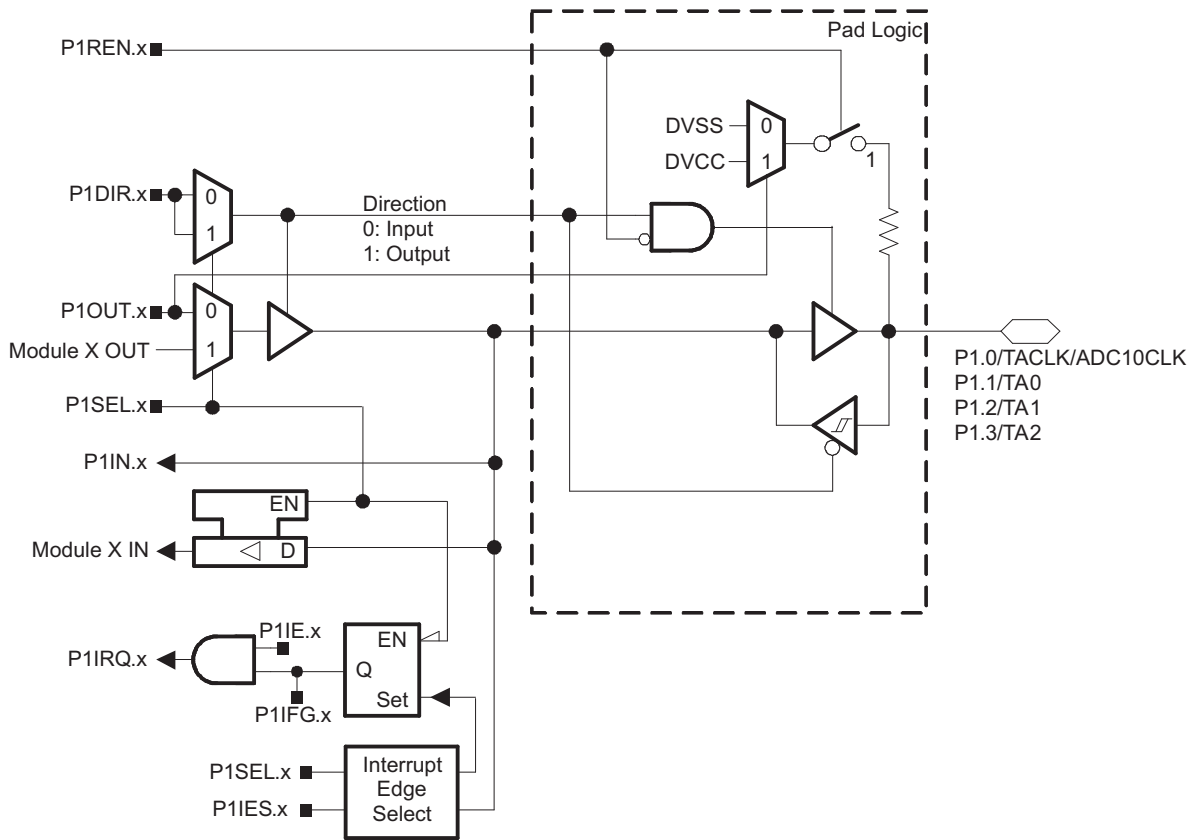


Table 21. Port P1 (P1.0 to P1.3) Pin Functions

| PIN NAME (P1.x) | x | FUNCTION | CONTROL BITS/SIGNALS | |
|---------------------|---|---------------------------|----------------------|---------|
| | | | P1DIR.x | P1SEL.x |
| P1.0/TACLK/ADC10CLK | 0 | P1.0 ⁽¹⁾ | I: 0; O: 1 | 0 |
| | | Timer_A3.TACLK | 0 | 1 |
| | | ADC10CLK | 1 | 1 |
| P1.1/TA0 | 1 | P1.1 ⁽¹⁾ (I/O) | I: 0; O: 1 | 0 |
| | | Timer_A3.CCI0A | 0 | 1 |
| | | Timer_A3.TA0 | 1 | 1 |
| P1.2/TA1 | 2 | P1.2 ⁽¹⁾ (I/O) | I: 0; O: 1 | 0 |
| | | Timer_A3.CCI1A | 0 | 1 |
| | | Timer_A3.TA1 | 1 | 1 |
| P1.3/TA2 | 3 | P1.3 ⁽¹⁾ (I/O) | I: 0; O: 1 | 0 |
| | | Timer_A3.CCI2A | 0 | 1 |
| | | Timer_A3.TA2 | 1 | 1 |

(1) Default after reset (PUC/POR)

Port P1 Pin Schematic: P1.4 to P1.6, Input/Output With Schmitt Trigger and In-System Access Features

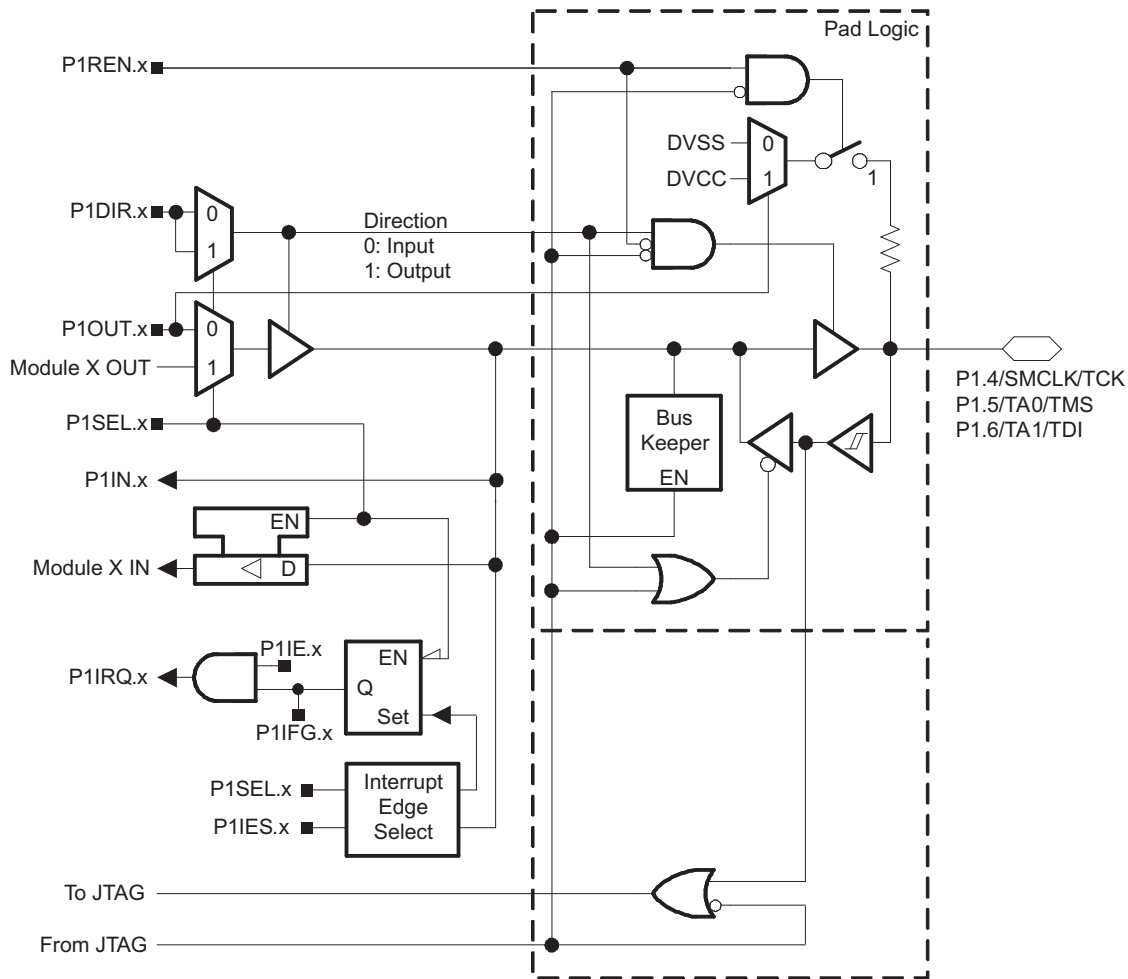


Table 22. Port P1 (P1.4 to P1.6) Pin Functions

| PIN NAME (P1.x) | x | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|-------------------|---|---------------------------|-------------------------------------|---------|-------------|
| | | | P1DIR.x | P1SEL.x | 4-Wire JTAG |
| P1.4/SMCLK/TCK | 4 | P1.4 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | SMCLK | 1 | 1 | 0 |
| | | TCK | X | X | 1 |
| P1.5/TA0/TMS | 5 | P1.5 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | Timer_A3.TA0 | 1 | 1 | 0 |
| | | TMS | X | X | 1 |
| P1.6/TA1/TDI/TCLK | 6 | P1.6 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | Timer_A3.TA1 | 1 | 1 | 0 |
| | | TDI/TCLK ⁽³⁾ | X | X | 1 |

- (1) X = Don't care
- (2) Default after reset (PUC/POR)
- (3) Function controlled by JTAG

Port P1 Pin Schematic: P1.7, Input/Output With Schmitt Trigger and In-System Access Features

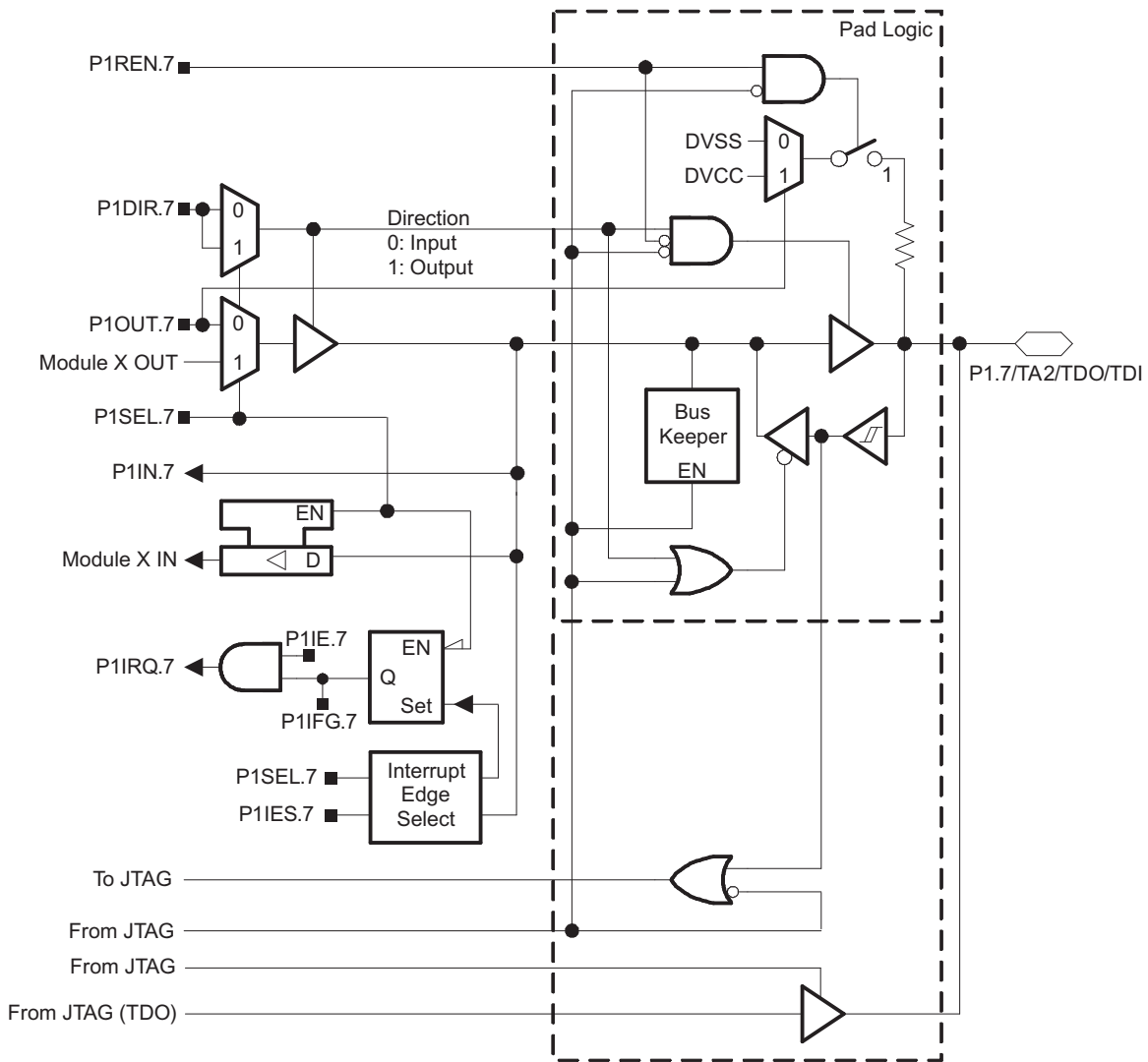


Table 23. Port P1 (P1.7) Pin Functions

| PIN NAME (P1.x) | x | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|------------------|---|---------------------------|-------------------------------------|---------|-------------|
| | | | P1DIR.x | P1SEL.x | 4-Wire JTAG |
| P1.7/TA2/TDO/TDI | 7 | P1.7 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | Timer_A3.TA2 | 1 | 1 | 0 |
| | | TDO/TDI ⁽³⁾ | X | X | 1 |

(1) X = Don't care
 (2) Default after reset (PUC/POR)
 (3) Function controlled by JTAG

Port P2 Pin Schematic: P2.0, P2.2, Input/Output With Schmitt Trigger

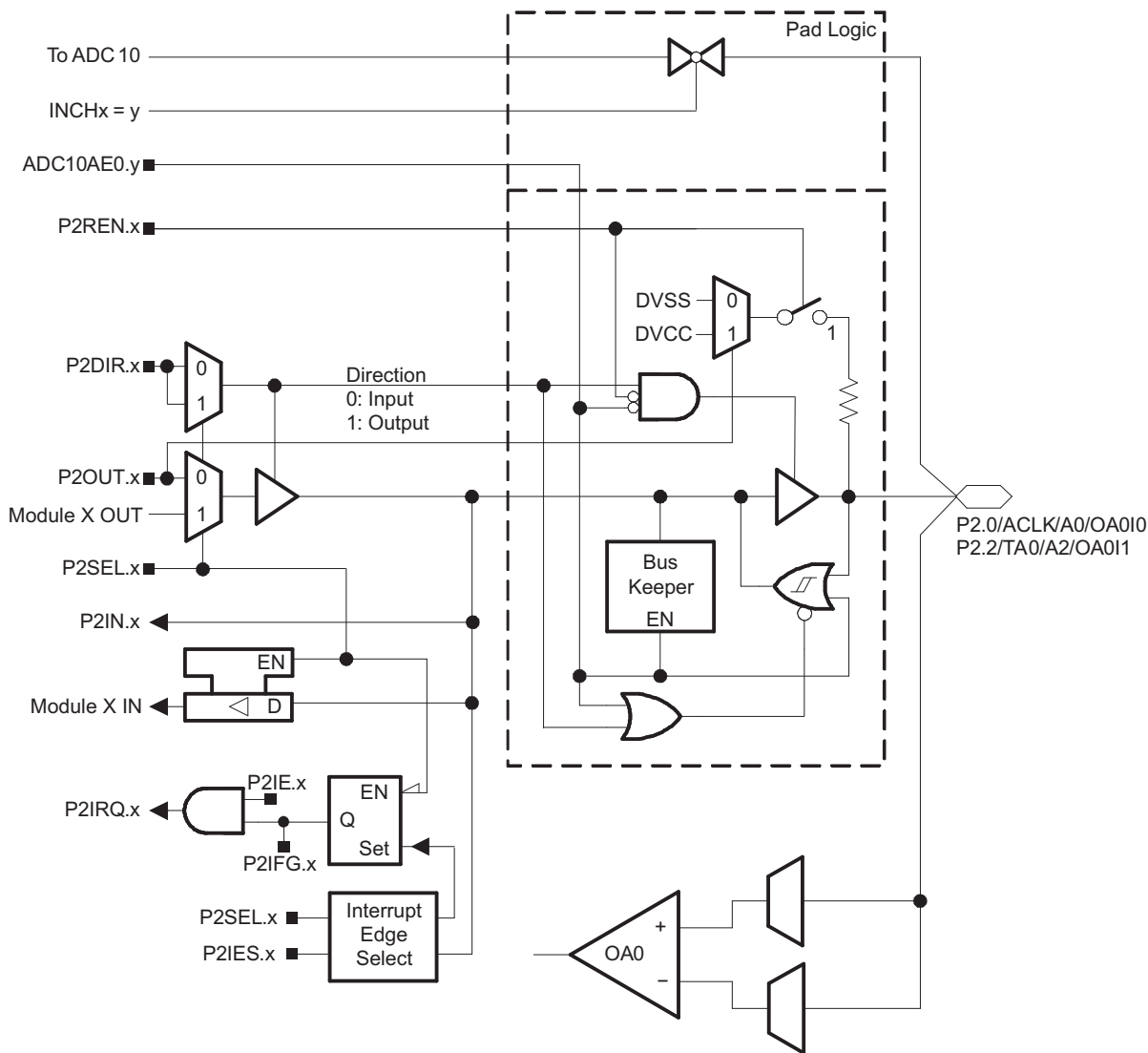


Table 24. Port P2 (P2.0, P2.2) Pin Functions

| Pin Name (P2.x) | x | y | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|--------------------|---|---|---------------------------|-------------------------------------|---------|------------|
| | | | | P2DIR.x | P2SEL.x | ADC10AE0.y |
| P2.0/ACLK/A0/OA0I0 | 0 | 0 | P2.0 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | ACLK | 1 | 1 | 0 |
| | | | A0/OA0I0 ⁽³⁾ | X | X | 1 |
| P2.2/TA0/A2/OA0I1 | 2 | 2 | P2.2 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | Timer_A3.CCI0B | 0 | 1 | 0 |
| | | | Timer_A3.TA0 | 1 | 1 | 0 |
| | | | A2/OA0I1 ⁽³⁾ | X | X | 1 |

- (1) X = Don't care
- (2) Default after reset (PUC/POR)
- (3) Setting the ADC10AE0.y bit disables the output driver as well as the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

Port P2 Pin Schematic: P2.1, Input/Output With Schmitt Trigger

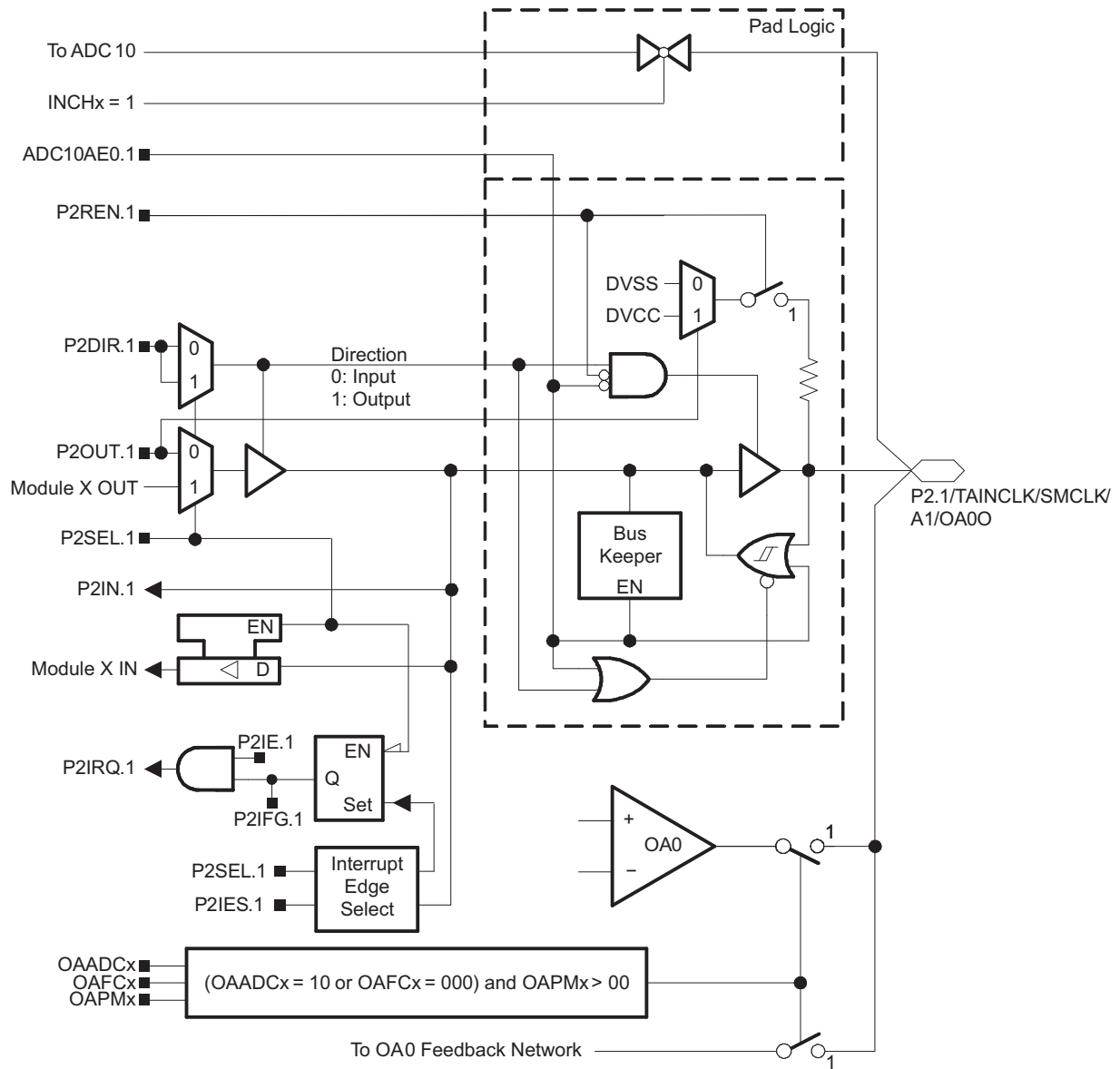


Table 25. Port P2 (P2.1) Pin Functions

| PIN NAME (P2.x) | x | y | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|----------------------------|---|---|---------------------------|-------------------------------------|---------|------------|
| | | | | P2DIR.x | P2SEL.x | ADC10AE0.y |
| P2.1/TAINCLK/SMCLK/A1/OA00 | 1 | 1 | P2.1 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | Timer_A3.INCLK | 0 | 1 | 0 |
| | | | SMCLK | 1 | 1 | 0 |
| | | | A1/OA00 ⁽³⁾ | X | X | 1 |

(1) X = Don't care

(2) Default after reset (PUC/POR)

(3) Setting the ADC10AE0.y bit disables the output driver as well as the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

Port P2 Pin Schematic: P2.3, Input/Output With Schmitt Trigger

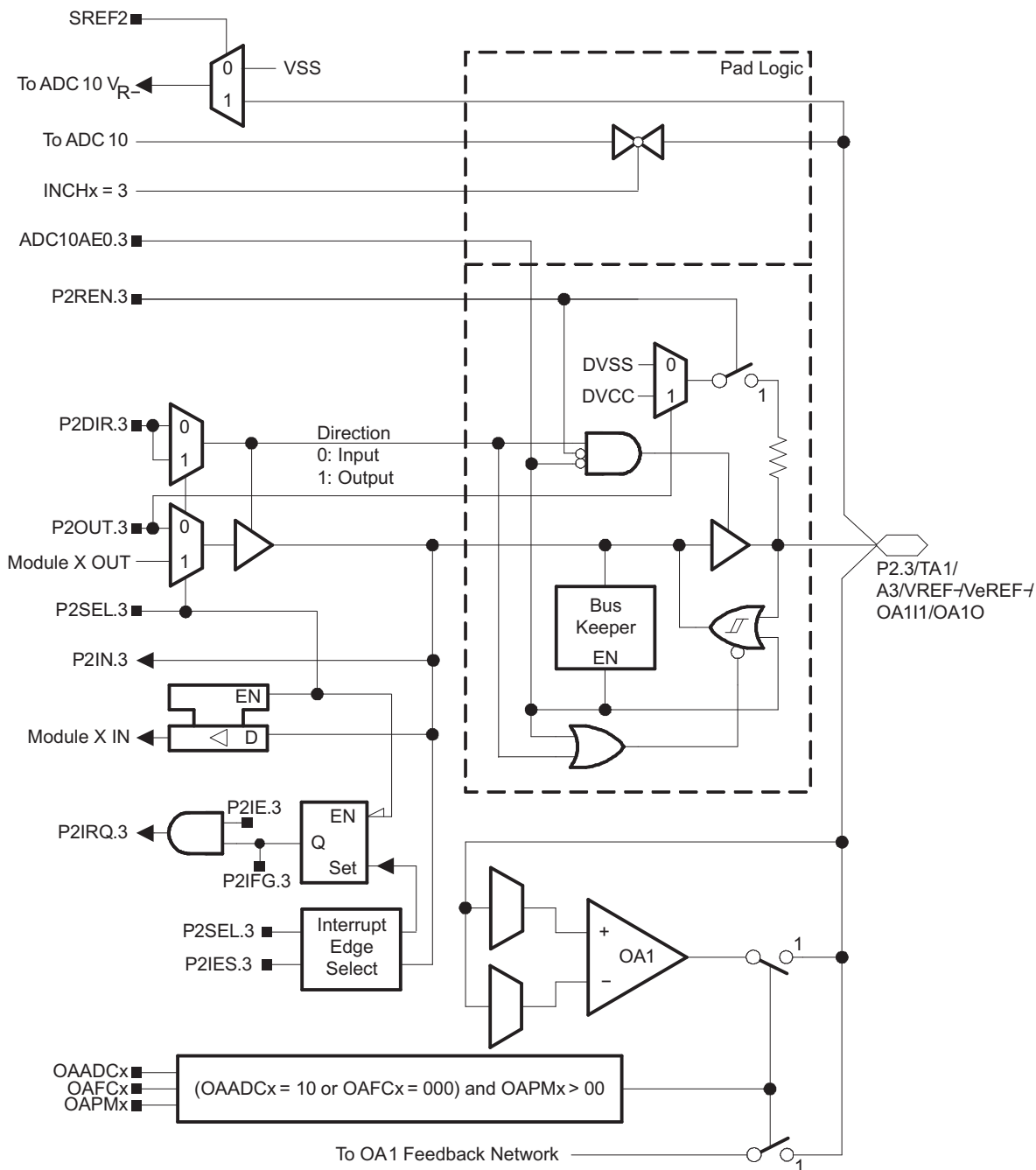


Table 26. Port P2 (P2.3) Pin Functions

| PIN NAME (P2.x) | x | y | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|---|---|---|---|-------------------------------------|---------|------------|
| | | | | P2DIR.x | P2SEL.x | ADC10AE0.y |
| P2.3/TA1/A3/V _{REF-} /V _{eREF-} /OA111/OA1O | 3 | 3 | P2.3 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | Timer_A3.CCI1B | 0 | 1 | 0 |
| | | | Timer_A3.TA1 | 1 | 1 | 0 |
| | | | A3/V _{REF-} /V _{eREF-} /OA111/OA1O ⁽³⁾ | X | X | 1 |

- (1) X = Don't care
- (2) Default after reset (PUC/POR)
- (3) Setting the ADC10AE0.y bit disables the output driver as well as the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

Port P2 Pin Schematic: P2.4, Input/Output With Schmitt Trigger

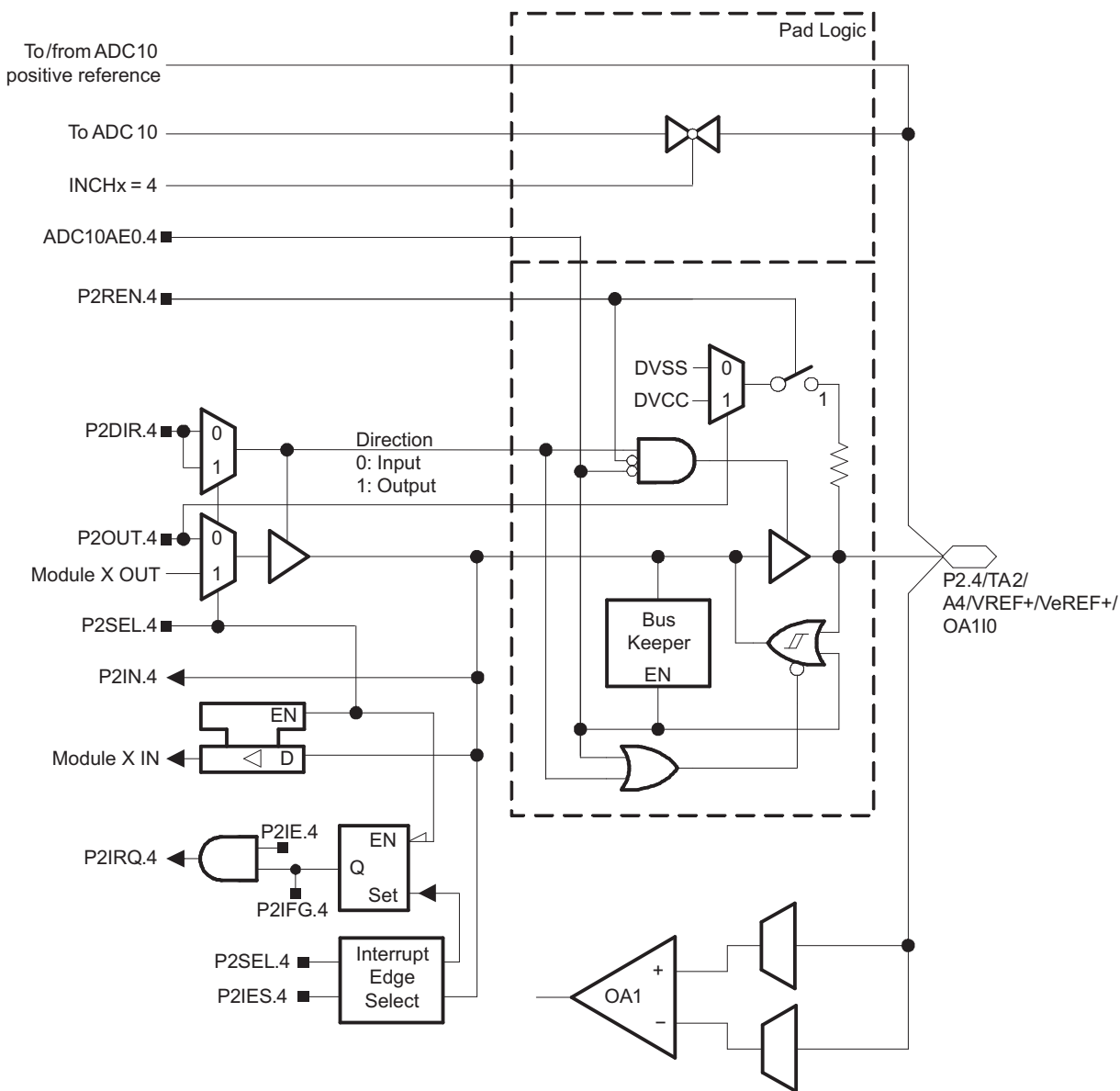


Table 27. Port P2 (P2.4) Pin Functions

| PIN NAME (P2.x) | x | y | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|---|---|---|--|-------------------------------------|---------|------------|
| | | | | P2DIR.x | P2SEL.x | ADC10AE0.y |
| P2.4/TA2/A4/V _{REF+} / V _{eREF+} / OA110 | 4 | 4 | P2.4 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | Timer_A3.TA2 | 1 | 1 | 0 |
| | | | A4/V _{REF+} /V _{eREF+} /OA110 ⁽³⁾ | X | X | 1 |

- (1) X = Don't care
- (2) Default after reset (PUC/POR)
- (3) Setting the ADC10AE0.y bit disables the output driver as well as the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

Port P2 Pin Schematic: P2.5, Input/Output With Schmitt Trigger and External R_{OSC} for DCO

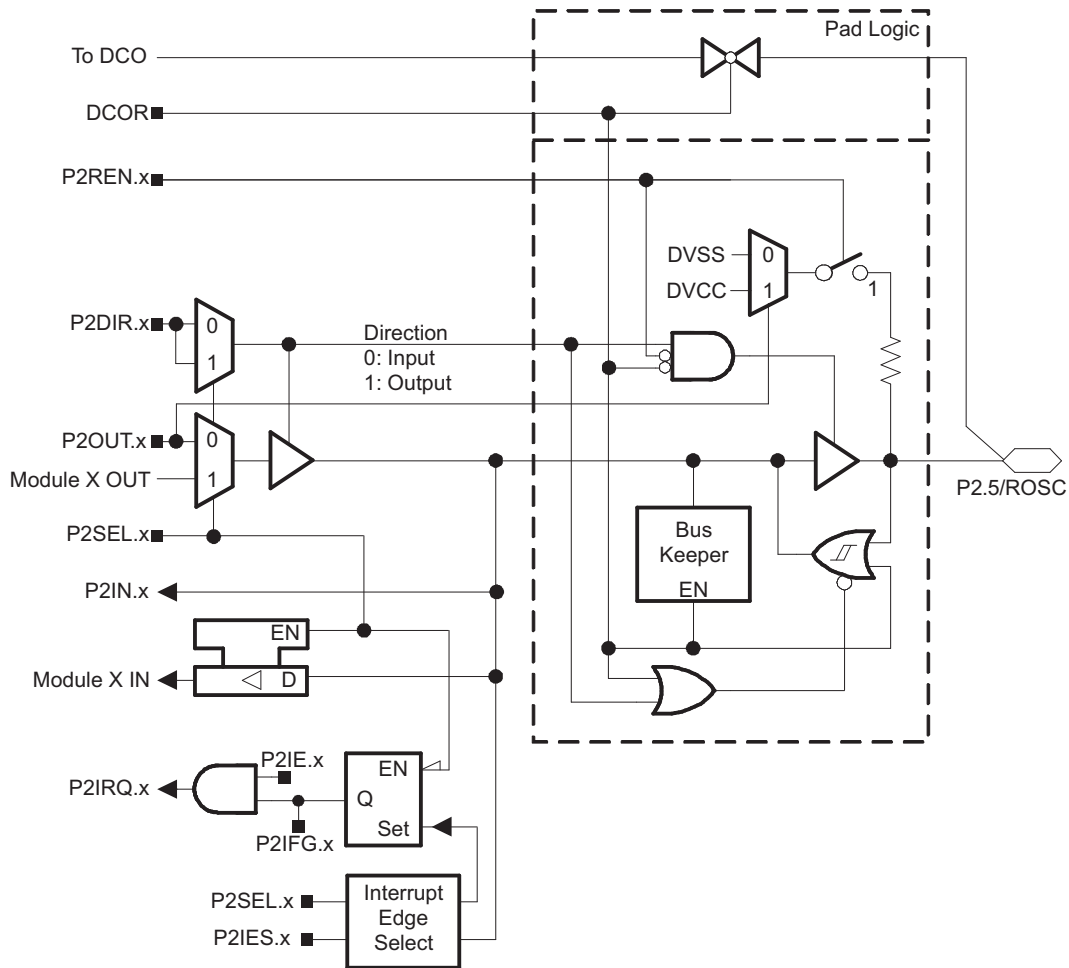


Table 28. Port P2 (P2.5) Pin Functions

| PIN NAME (P2.x) | x | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|-----------------------|---|---------------------------|-------------------------------------|---------|------|
| | | | P2DIR.x | P2SEL.x | DCOR |
| P2.5/R _{osc} | 5 | P2.5 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | N/A ⁽³⁾ | 0 | 1 | 0 |
| | | DV _{SS} | 1 | 1 | 0 |
| | | R _{osc} | X | X | 1 |

- (1) X = Don't care
- (2) Default after reset (PUC/POR)
- (3) N/A = Not available or not applicable

Port P2 Pin Schematic: P2.6, Input/Output With Schmitt Trigger and Crystal Oscillator Input

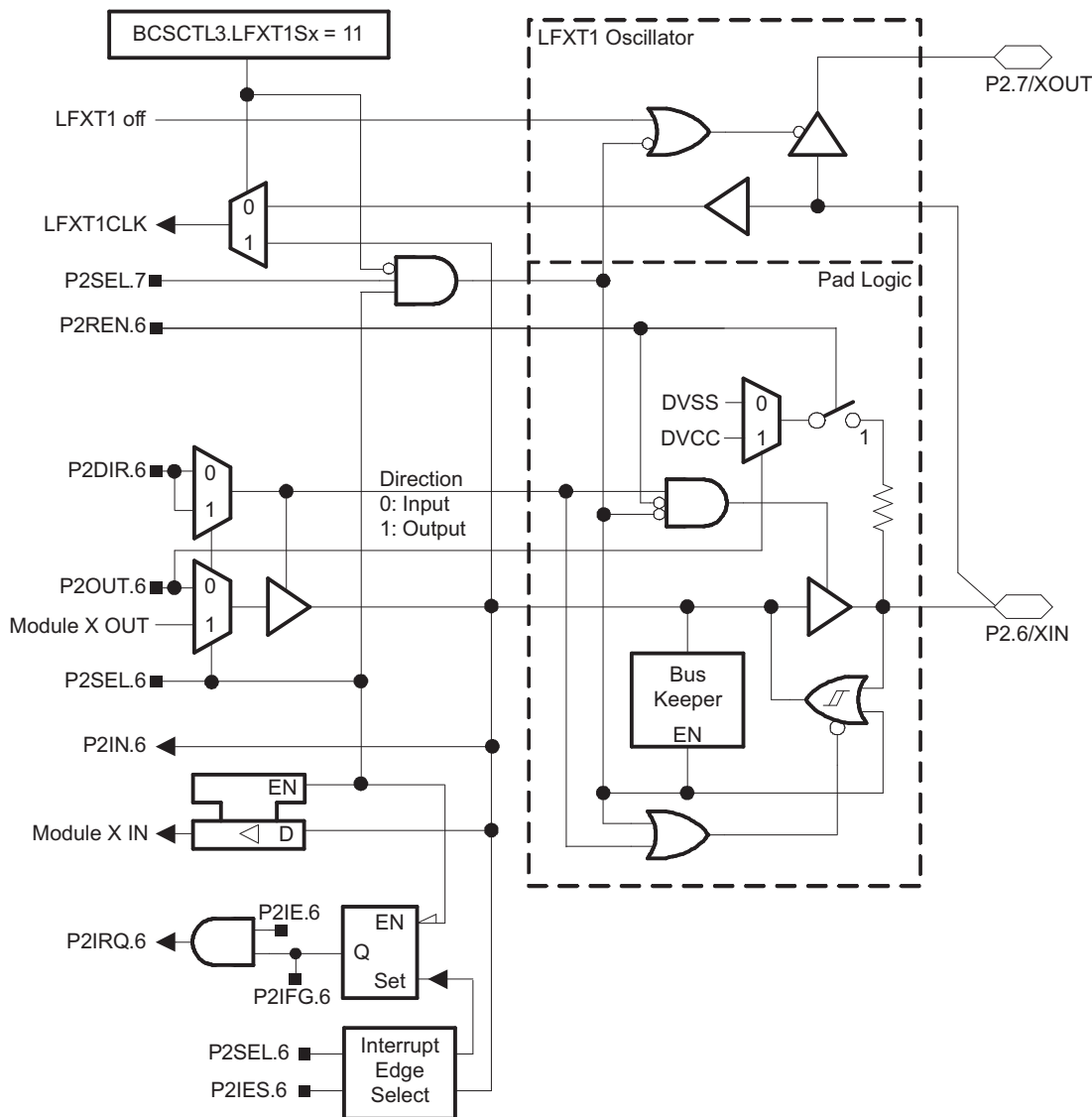


Table 29. Port P2 (P2.6) Pin Functions

| PIN NAME (P2.x) | x | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | |
|-----------------|---|--------------------|-------------------------------------|---------|
| | | | P2DIR.x | P2SEL.x |
| P2.6/XIN | 6 | P2.6 (I/O) | I: 0; O: 1 | 0 |
| | | XIN ⁽²⁾ | X | 1 |

(1) X = Don't care
(2) Default after reset (PUC/POR)

Port P2 Pin Schematic: P2.7, Input/Output With Schmitt Trigger and Crystal Oscillator Output

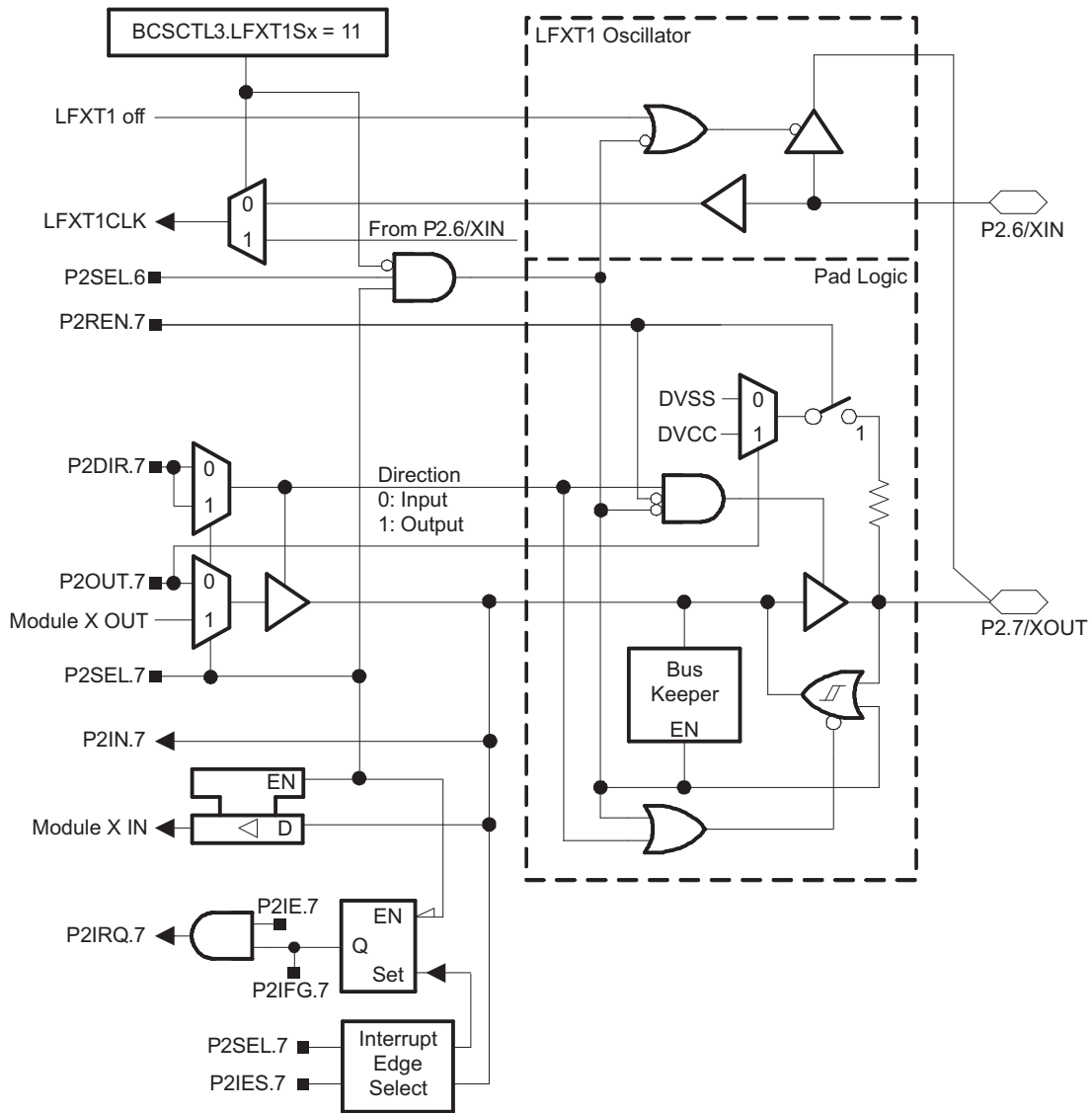


Table 30. Port P2 (P2.7) Pin Functions

| PIN NAME (P2.x) | x | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | |
|-----------------|---|-------------------------|-------------------------------------|---------|
| | | | P2DIR.x | P2SEL.x |
| XOUT/P2.7 | 7 | P2.7 (I/O) | I: 0; O: 1 | 0 |
| | | XOUT ^{(2) (3)} | X | 1 |

(1) X = Don't care

(2) Default after reset (PUC/POR)

(3) If the pin XOUT/P2.7 is used as an input a current can flow until P2SEL.7 is cleared due to the oscillator output driver connection to this pin after reset.

Port P3 Pin Schematic: P3.0, Input/Output With Schmitt Trigger

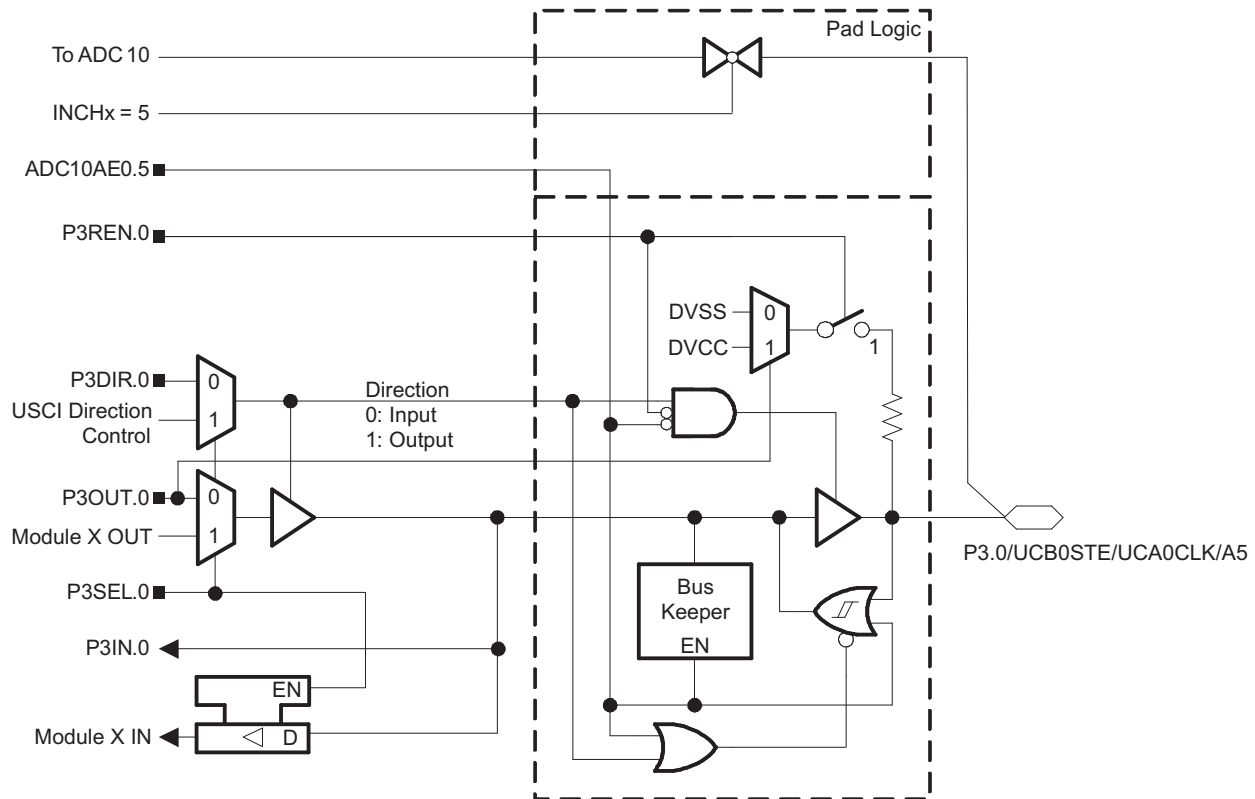


Table 31. Port P3 (P3.0) Pin Functions

| PIN NAME (P1.x) | x | y | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|-----------------------------|---|---|------------------------------------|-------------------------------------|---------|------------|
| | | | | P3DIR.x | P3SEL.x | ADC10AE0.y |
| P3.0/UCB0STE/ UCA0CLK/A5 | 0 | 5 | P3.0 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | UCB0STE/UCA0CLK ^{(3) (4)} | X | 1 | 0 |
| | | | A5 ⁽⁵⁾ | X | X | 1 |

- (1) X = Don't care
- (2) Default after reset (PUC/POR)
- (3) The pin direction is controlled by the USCI module.
- (4) UCA0CLK function takes precedence over UCB0STE function. If the pin is required as UCA0CLK input or output, USCI_B0 is forced to 3-wire SPI mode if 4-wire SPI mode is selected.
- (5) Setting the ADC10AE0.y bit disables the output driver as well as the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

Port P3 Pin Schematic: P3.1 to P3.5, Input/Output With Schmitt Trigger

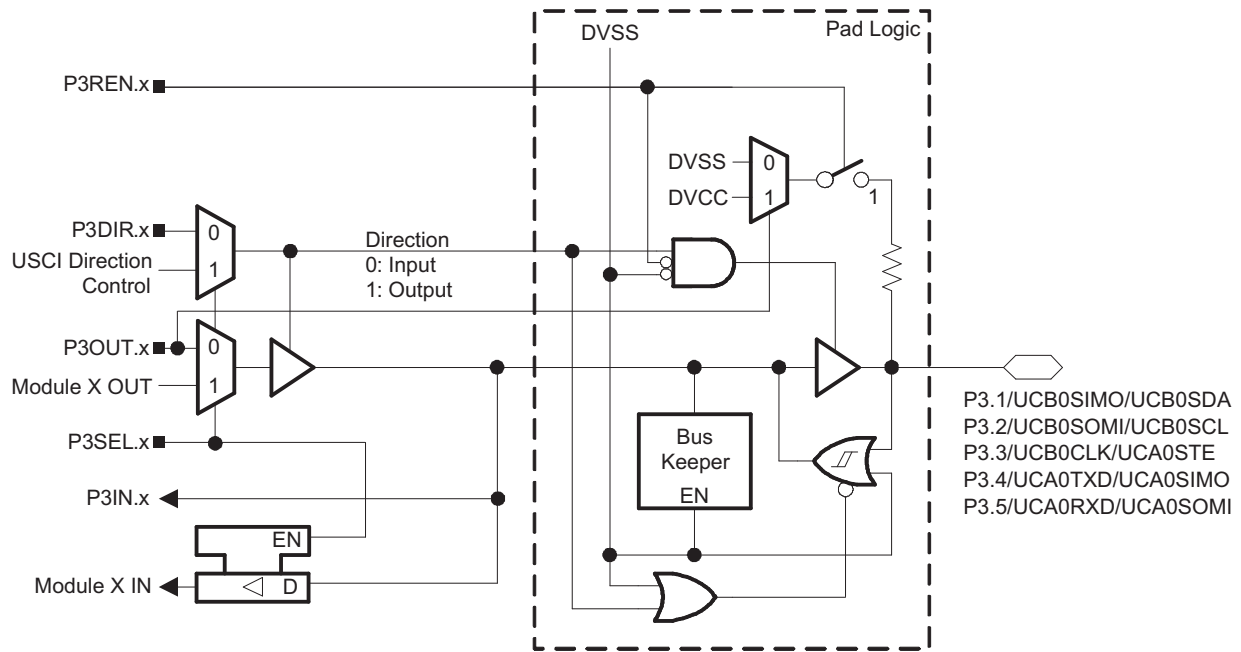


Table 32. Port P3 (P3.1 to P3.5) Pin Functions

| PIN NAME (P3.x) | x | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | |
|-----------------------|---|------------------------------------|-------------------------------------|---------|
| | | | P3DIR.x | P3SEL.x |
| P3.1/UCB0SIMO/UCB0SDA | 1 | P3.1 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 |
| | | UCB0SIMO/UCB0SDA ⁽³⁾ | X | 1 |
| P3.2/UCB0SOMI/UCB0SCL | 2 | P3.2 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 |
| | | UCB0SOMI/UCB0SCL ⁽³⁾ | X | 1 |
| P3.3/UCB0CLK/UCA0STE | 3 | P3.3 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 |
| | | UCB0CLK/UCA0STE ^{(3) (4)} | X | 1 |
| P3.4/UCA0TXD/UCA0SIMO | 4 | P3.4 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 |
| | | UCA0TXD/UCA0SIMO ⁽³⁾ | X | 1 |
| P3.5/UCA0RXD/UCA0SOMI | 5 | P3.5 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 |
| | | UCA0RXD/UCA0SOMI ⁽³⁾ | X | 1 |

(1) X = Don't care

(2) Default after reset (PUC/POR)

(3) The pin direction is controlled by the USC1 module.

(4) UCB0CLK function takes precedence over UCA0STE function. If the pin is required as UCB0CLK input or output, USC1_A0 is forced to 3-wire SPI mode even if 4-wire SPI mode is selected.

Port P3 Pin Schematic: P3.6 to P3.7, Input/Output With Schmitt Trigger

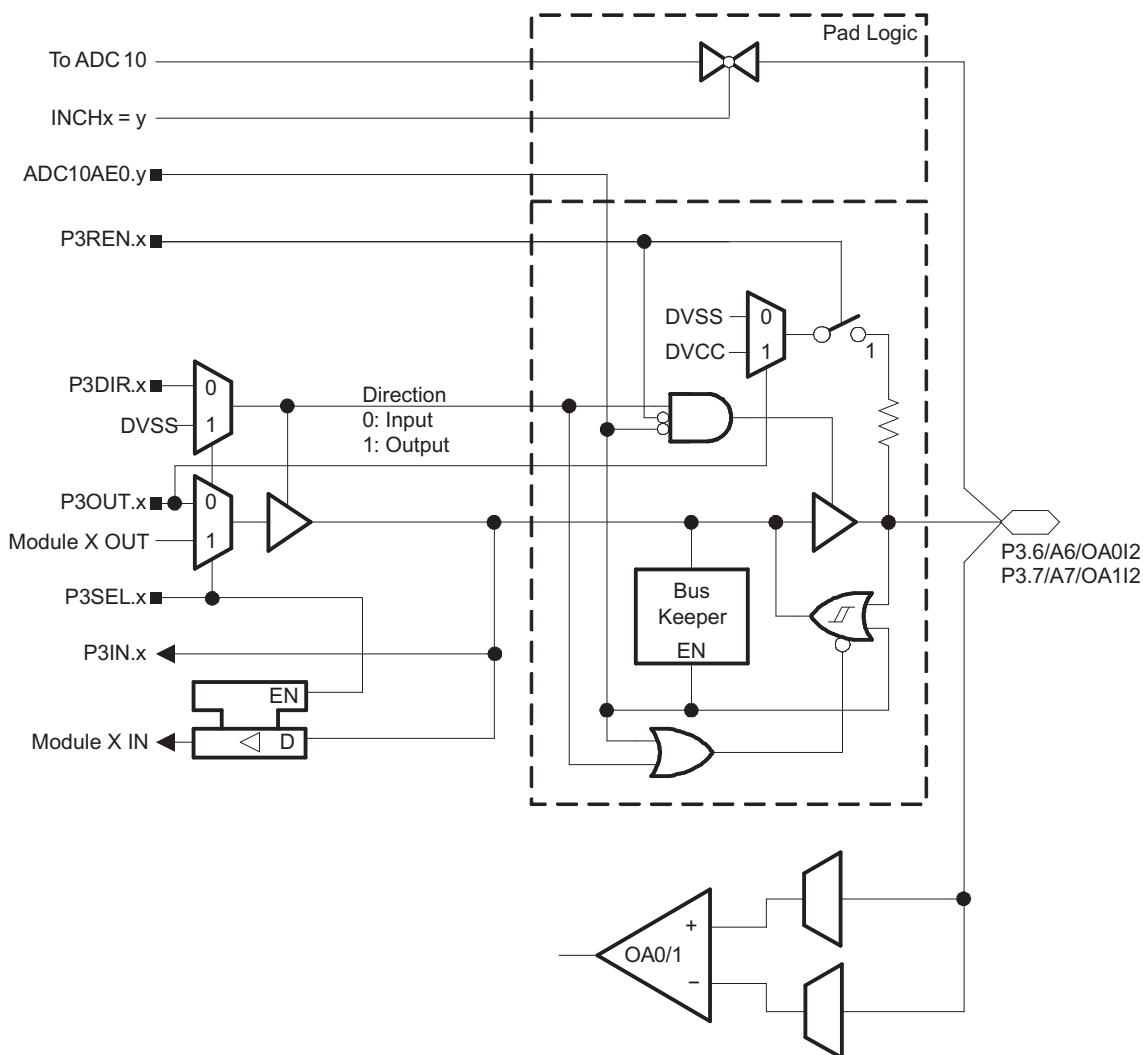


Table 33. Port P3 (P3.6, P3.7) Pin Functions

| PIN NAME (P3.x) | x | y | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|-----------------|---|---|---------------------------|-------------------------------------|---------|------------|
| | | | | P3DIR.x | P3SEL.x | ADC10AE0.y |
| P3.6/A6/OA0I2 | 6 | 6 | P3.6 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | A6/OA0I2 ⁽³⁾ | X | X | 1 |
| P3.7/A7/OA1I2 | 7 | 7 | P3.7 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | A7/OA1I2 ⁽³⁾ | X | X | 1 |

- (1) X = Don't care
- (2) Default after reset (PUC/POR)
- (3) Setting the ADC10AE0.y bit disables the output driver as well as the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

Port P4 Pin Schematic: P4.0 to P4.2, Input/Output With Schmitt Trigger

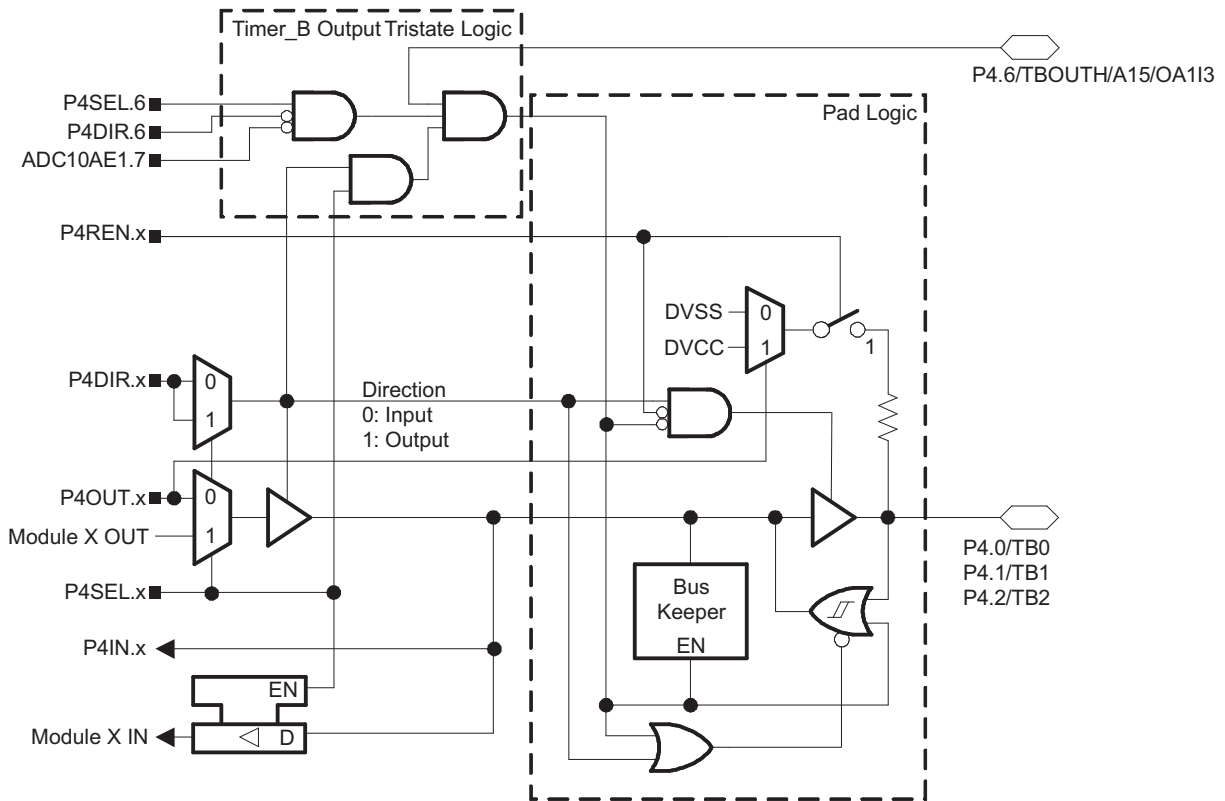
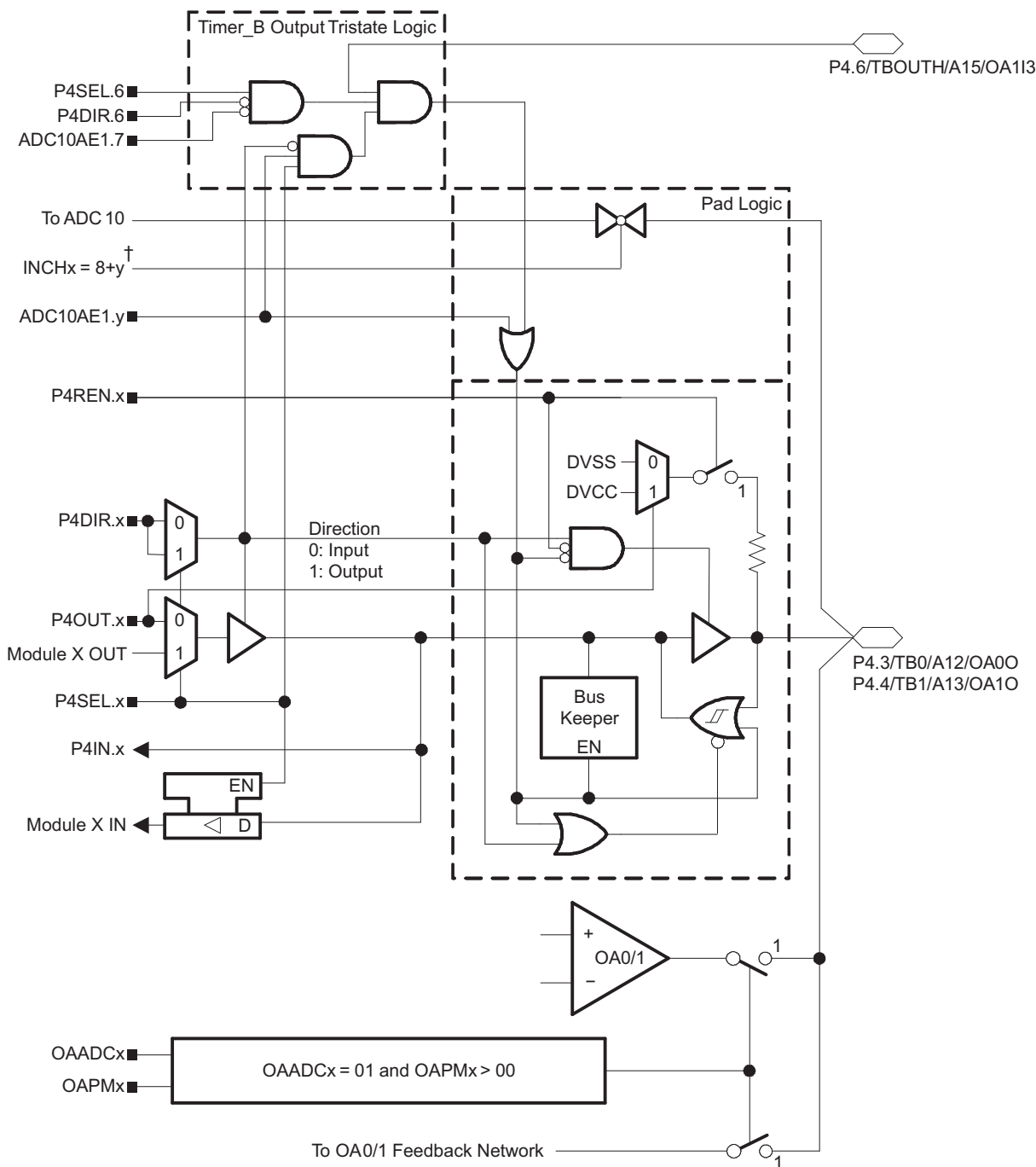


Table 34. Port P4 (P4.0 to P4.2) Pin Functions

| PIN NAME (P4.x) | x | FUNCTION | CONTROL BITS/SIGNALS | |
|-----------------|---|---------------------------|----------------------|---------|
| | | | P4DIR.x | P4SEL.x |
| P4.0/TB0 | 0 | P4.0 ⁽¹⁾ (I/O) | I: 0; O: 1 | 0 |
| | | Timer_B3.CCI0A | 0 | 1 |
| | | Timer_B3.TB0 | 1 | 1 |
| P4.1/TB1 | 1 | P4.1 ⁽¹⁾ (I/O) | I: 0; O: 1 | 0 |
| | | Timer_B3.CCI1A | 0 | 1 |
| | | Timer_B3.TB1 | 1 | 1 |
| P4.2/TB2 | 2 | P4.2 ⁽¹⁾ (I/O) | I: 0; O: 1 | 0 |
| | | Timer_B3.CCI2A | 0 | 1 |
| | | Timer_B3.TB2 | 1 | 1 |

(1) Default after reset (PUC/POR)

Port P4 Pin Schematic: P4.3 to P4.4, Input/Output With Schmitt Trigger



†If $OAADCx = 11$ and not $OAFcx = 000$, the ADC input A12 or A13 is internally connected to the OA0 or OA1 output, respectively, and the connections from the ADC and the operational amplifiers to the pad are disabled.

Table 35. Port P4 (P4.3 to P4.4) Pin Functions

| PIN NAME (P4.x) | x | y | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|-------------------|---|---|---------------------------|-------------------------------------|---------|------------|
| | | | | P4DIR.x | P4SEL.x | ADC10AE1.y |
| P4.3/TB0/A12/OA00 | 3 | 4 | P4.3 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | Timer_B3.CCI0B | 0 | 1 | 0 |
| | | | Timer_B3.TB0 | 1 | 1 | 0 |
| | | | A12/OA00 ⁽³⁾ | X | X | 1 |
| P4.4/TB1/A13/OA10 | 4 | 5 | P4.4 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | Timer_B3.CCI1B | 0 | 1 | 0 |
| | | | Timer_B3.TB1 | 1 | 1 | 0 |
| | | | A13/OA10 ⁽³⁾ | X | X | 1 |

- (1) X = Don't care
- (2) Default after reset (PUC/POR)
- (3) Setting the ADC10AE1.y bit disables the output driver as well as the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

Port P4 Pin Schematic: P4.5, Input/Output With Schmitt Trigger

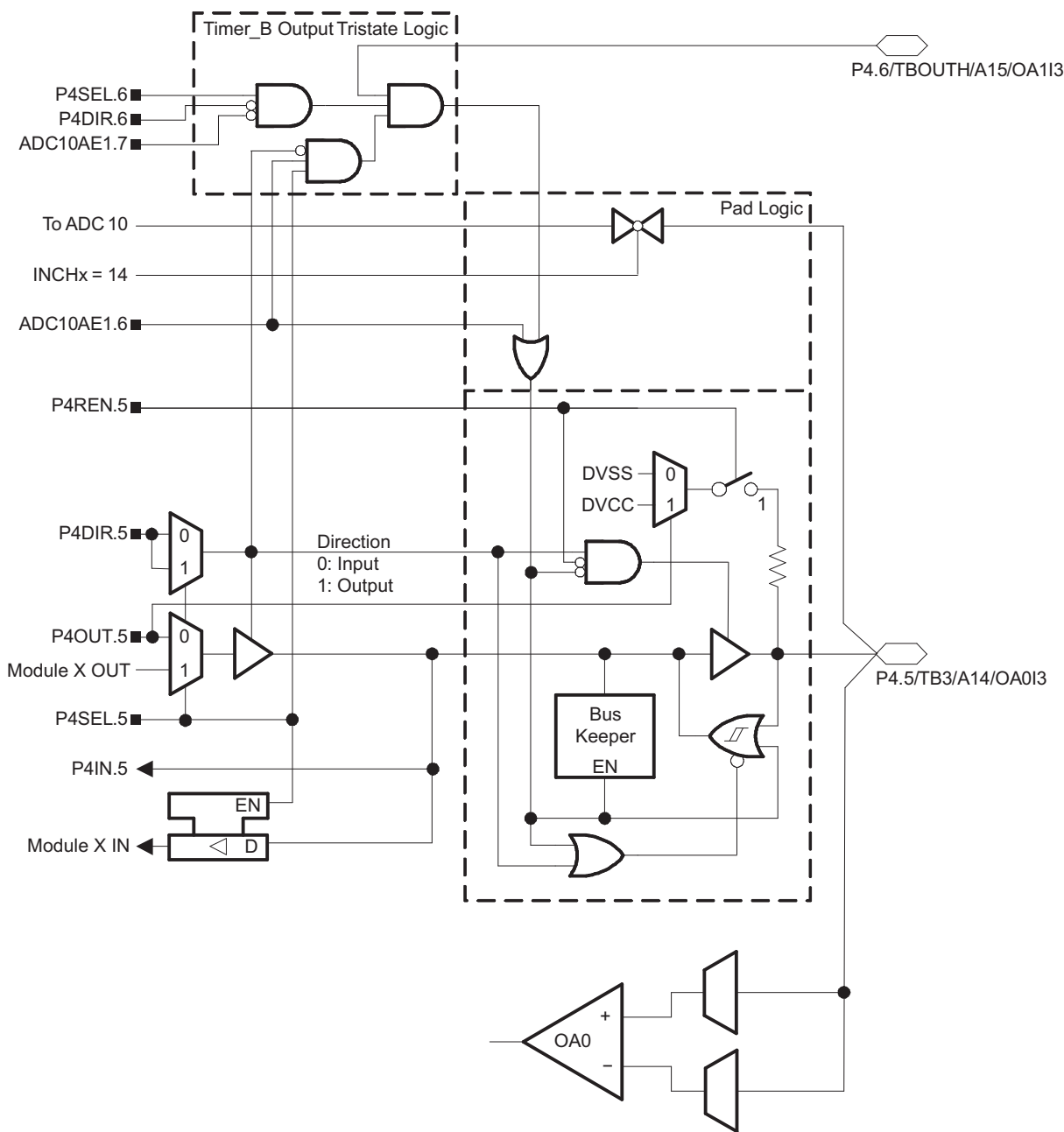


Table 36. Port P4 (P4.5) Pin Functions

| PIN NAME (P4.x) | x | y | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|--------------------|---|---|---------------------------|-------------------------------------|---------|------------|
| | | | | P4DIR.x | P4SEL.x | ADC10AE1.y |
| P4.5/TB3/A14/OA0I3 | 5 | 6 | P4.5 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | Timer_B3.TB2 | 1 | 1 | 0 |
| | | | A14/OA0I3 ⁽³⁾ | X | X | 1 |

(1) X = Don't care

(2) Default after reset (PUC/POR)

(3) Setting the ADC10AE1.y bit disables the output driver as well as the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

Port P4 Pin Schematic: P4.6, Input/Output With Schmitt Trigger

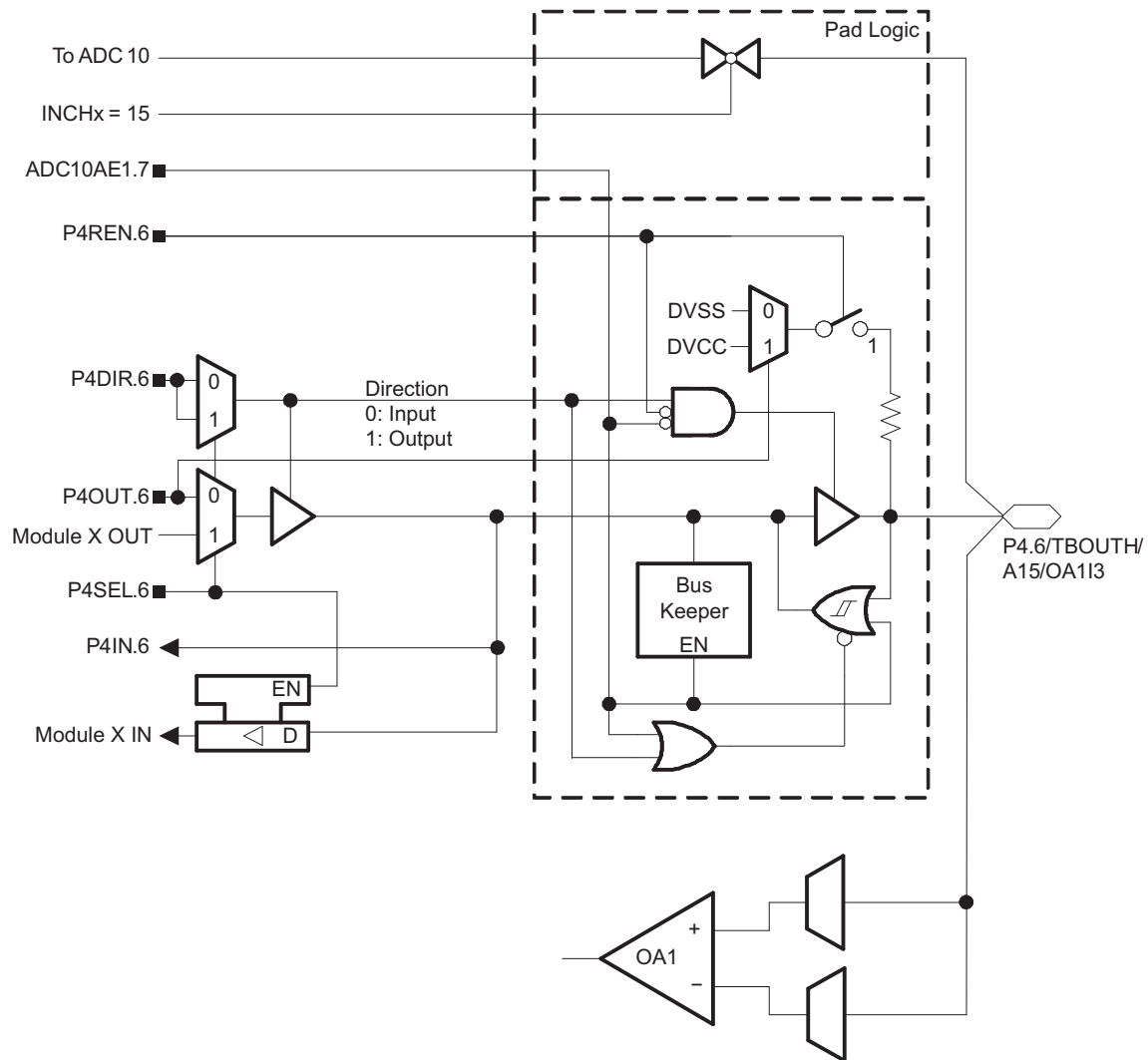


Table 37. Port P4 (P4.6) Pin Functions

| PIN NAME (P4.x) | x | y | FUNCTION | CONTROL BITS/SIGNALS ⁽¹⁾ | | |
|-----------------------|---|---|---------------------------|-------------------------------------|---------|------------|
| | | | | P4DIR.x | P4SEL.x | ADC10AE1.y |
| P4.6/TBOUTH/A15/OA113 | 6 | 7 | P4.6 ⁽²⁾ (I/O) | I: 0; O: 1 | 0 | 0 |
| | | | TBOUTH | 0 | 1 | 0 |
| | | | DV _{SS} | 1 | 1 | 0 |
| | | | A15/OA113 ⁽³⁾ | X | X | 1 |

(1) X = Don't care

(2) Default after reset (PUC/POR)

(3) Setting the ADC10AE1.y bit disables the output driver as well as the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

Port P4 Pin Schematic: P4.7, Input/Output With Schmitt Trigger

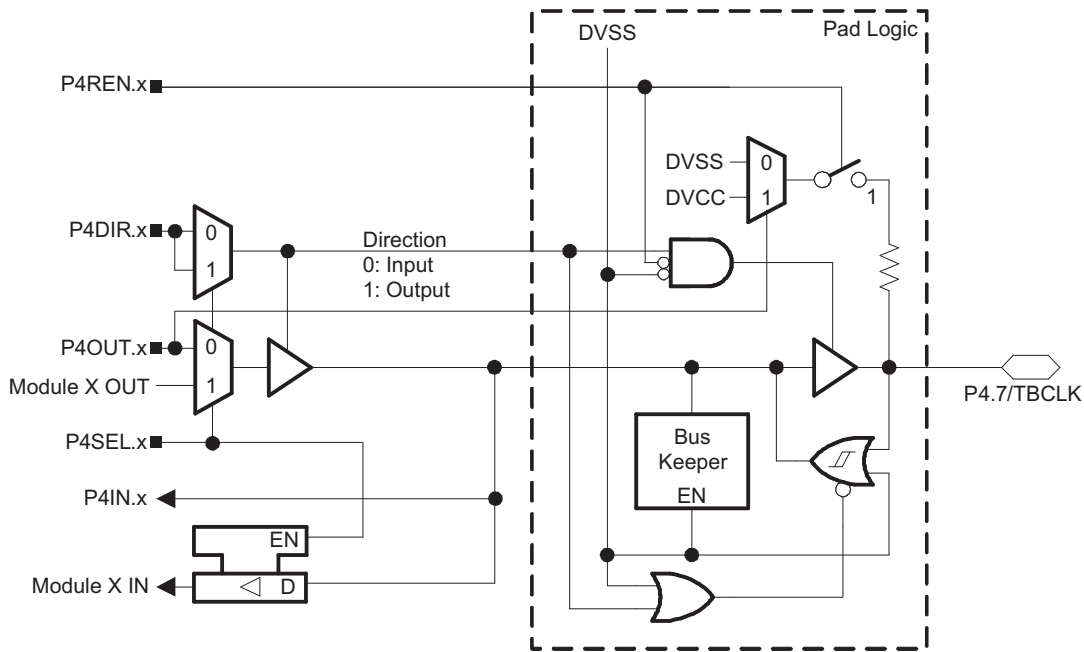


Table 38. Port P4 (Pr.7) Pin Functions

| PIN NAME (P4.x) | x | FUNCTION | CONTROL BITS/SIGNALS | |
|-----------------|---|---------------------------|----------------------|---------|
| | | | P4DIR.x | P4SEL.x |
| P4.7/TBCLK | 7 | P4.7 ⁽¹⁾ (I/O) | I: 0; O: 1 | 0 |
| | | Timer_B3.TBCLK | 0 | 1 |
| | | DV _{SS} | 1 | 1 |

(1) Default after reset (PUC/POR)

JTAG Fuse Check Mode

MSP430 devices that have the fuse on the TEST terminal have a fuse check mode that tests the continuity of the fuse the first time the JTAG port is accessed after a power-on reset (POR). When activated, a fuse check current, I_{TF} , of 1 mA at 3 V, 2.5 mA at 5 V can flow from the TEST pin to ground if the fuse is not burned. Care must be taken to avoid accidentally activating the fuse check mode and increasing overall system power consumption.

When the TEST pin is again taken low after a test or programming session, the fuse check mode and sense currents are terminated.

Activation of the fuse check mode occurs with the first negative edge on the TMS pin after power up or if TMS is being held low during power up. The second positive edge on the TMS pin deactivates the fuse check mode. After deactivation, the fuse check mode remains inactive until another POR occurs. After each POR the fuse check mode has the potential to be activated.

The fuse check current flows only when the fuse check mode is active and the TMS pin is in a low state (see [Figure 28](#)). Therefore, the additional current flow can be prevented by holding the TMS pin high (default condition).

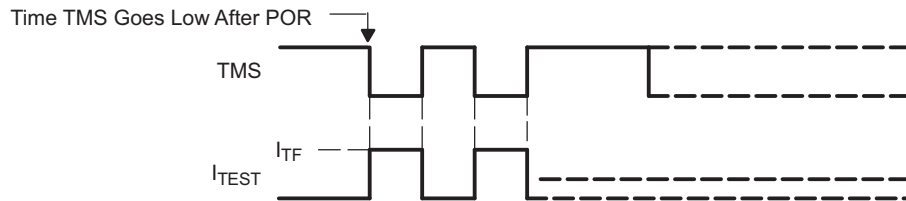


Figure 28. Fuse Check Mode Current

NOTE

The CODE and RAM data protection is ensured if the JTAG fuse is blown and the 256-bit bootloader access key is used. Also, see the [Bootstrap Loader](#) section for more information.

REVISION HISTORY

| Literature Number | Summary |
|-------------------|--|
| SLAS504 | Preliminary data sheet release |
| SLAS504A | Production data sheet release Updated specification and added characterization graphs Updated/corrected port pin schematics |
| SLAS504B | Maximum low-power mode supply current limits decreased Added note concerning f_{UCxCLK} to USCI SPI parameters |
| SLAS504C | Added Development Tool Support section (page 2) Changed T_{stg} for programmed devices from "-40°C to 105°C" to "-55°C to 105°C" (page 23) |
| SLAS504D | Corrected pin names in "Port P3 pin schematic: P3.0" and "Port P3 (P3.0) pin functions" (page 68) Corrected pin names in "Port P3 pin schematic: P3.1 to P3.5" and "Port P3 (P3.1 to P3.5) pin functions" (page 69) Corrected signal names in "Port P2 pin schematic: P2.5, input/output" (page 65) (D1) Corrected values in "x" column in "Port P3 (P3.1 to P3.5) pin functions" (page 69) (D2) |
| SLAS504E | Added information for YFF package |
| SLAS504F | Correct signal names for P3.6 and P3.7 in MSP430F22x2 pinouts – DA package , RHA package Changed Storage temperature range limit in Absolute Maximum Ratings Corrected Test Conditions in Crystal Oscillator LFXT1, High-Frequency Mode Corrected signal names in Port P1 (P1.0 to P1.3) Pin Functions Corrected typo in note 1 on Crystal Oscillator LFXT1, High-Frequency Mode table |
| SLAS504G | Terminal Functions tables, Corrected description of V_{REF-}/V_{eREF-} pins. Added note on TC_{REF+} in 10-Bit ADC, Built-In Voltage Reference . |

PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead finish/ Ball material (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|------------------|---------------|--------------|-----------------|------|-------------|-----------------|--------------------------------------|----------------------|--------------|-------------------------|-------------------------|
| MSP430F2232IDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2232 | Samples |
| MSP430F2232IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2232 | Samples |
| MSP430F2232IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2232 | Samples |
| MSP430F2232IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2232 | Samples |
| MSP430F2232TDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2232T | Samples |
| MSP430F2232TDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2232T | Samples |
| MSP430F2232TRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 105 | M430 F2232T | Samples |
| MSP430F2232TRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 105 | M430 F2232T | Samples |
| MSP430F2234IDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2234 | Samples |
| MSP430F2234IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2234 | Samples |
| MSP430F2234IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2234 | Samples |
| MSP430F2234IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2234 | Samples |
| MSP430F2234TDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2234T | Samples |
| MSP430F2234TDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2234T | Samples |
| MSP430F2234TRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 105 | M430 F2234T | Samples |
| MSP430F2252IDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2252 | Samples |
| MSP430F2252IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2252 | Samples |
| MSP430F2252IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2252 | Samples |

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead finish/ Ball material (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|------------------|---------------|--------------|--------------------|------|----------------|-----------------|--------------------------------------|----------------------|--------------|-------------------------|-------------------------|
| MSP430F2252IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2252 | Samples |
| MSP430F2252IYFFR | ACTIVE | DSBGA | YFF | 49 | 2500 | RoHS & Green | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | M430F2252 | Samples |
| MSP430F2252TDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2252T | Samples |
| MSP430F2252TDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2252T | Samples |
| MSP430F2252TRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 105 | M430 F2252T | Samples |
| MSP430F2252TRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 105 | M430 F2252T | Samples |
| MSP430F2254IDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2254 | Samples |
| MSP430F2254IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2254 | Samples |
| MSP430F2254IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2254 | Samples |
| MSP430F2254IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2254 | Samples |
| MSP430F2254TDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2254T | Samples |
| MSP430F2254TDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2254T | Samples |
| MSP430F2254TRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 105 | M430 F2254T | Samples |
| MSP430F2254TRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 105 | M430 F2254T | Samples |
| MSP430F2272IDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2272 | Samples |
| MSP430F2272IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2272 | Samples |
| MSP430F2272IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2272 | Samples |
| MSP430F2272IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2272 | Samples |
| MSP430F2272IYFFR | ACTIVE | DSBGA | YFF | 49 | 2500 | RoHS & Green | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | M430F2272 | Samples |

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead finish/ Ball material (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|------------------|---------------|--------------|-----------------|------|-------------|-----------------|--------------------------------------|----------------------|--------------|-------------------------|-------------------------|
| MSP430F2272IYFFT | ACTIVE | DSBGA | YFF | 49 | 250 | RoHS & Green | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | M430F2272 | Samples |
| MSP430F2272TDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2272T | Samples |
| MSP430F2272TDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2272T | Samples |
| MSP430F2272TRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 105 | M430 F2272T | Samples |
| MSP430F2272TRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 105 | M430 F2272T | Samples |
| MSP430F2274IDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2274 | Samples |
| MSP430F2274IDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | M430F2274 | Samples |
| MSP430F2274IRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2274 | Samples |
| MSP430F2274IRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 85 | M430 F2274 | Samples |
| MSP430F2274IYFFR | ACTIVE | DSBGA | YFF | 49 | 2500 | RoHS & Green | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | M430F2274 | Samples |
| MSP430F2274IYFFT | ACTIVE | DSBGA | YFF | 49 | 250 | RoHS & Green | SNAGCU | Level-1-260C-UNLIM | -40 to 85 | M430F2274 | Samples |
| MSP430F2274TDA | ACTIVE | TSSOP | DA | 38 | 40 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2274T | Samples |
| MSP430F2274TDAR | ACTIVE | TSSOP | DA | 38 | 2000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 105 | M430F2274T | Samples |
| MSP430F2274TRHAR | ACTIVE | VQFN | RHA | 40 | 2500 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 105 | M430 F2274T | Samples |
| MSP430F2274TRHAT | ACTIVE | VQFN | RHA | 40 | 250 | RoHS & Green | NIPDAU | Level-3-260C-168 HR | -40 to 105 | M430 F2274T | Samples |

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

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSELETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of ≤ 1000 ppm threshold. Antimony trioxide based flame retardants must also meet the ≤ 1000 ppm threshold requirement.

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

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

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

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

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OTHER QUALIFIED VERSIONS OF MSP430F2252, MSP430F2272, MSP430F2274 :

● Automotive: [MSP430F2252-Q1](#), [MSP430F2272-Q1](#)

● Enhanced Product: [MSP430F2274-EP](#)

NOTE: Qualified Version Definitions:

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects
- Enhanced Product - Supports Defense, Aerospace and Medical Applications

TAPE AND REEL INFORMATION



QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|------------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| MSP430F2232IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430F2232IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2232IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2232IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2232IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2232TRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2232TRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2232TRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2232TRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2234IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430F2234IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2234IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2234IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2234IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2234TRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2252IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | 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 |
|------------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| MSP430F2252IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2252IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2252IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2252IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2252IYFFR | DSBGA | YFF | 49 | 2500 | 330.0 | 12.4 | 3.5 | 3.7 | 0.81 | 8.0 | 12.0 | Q2 |
| MSP430F2252TRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2252TRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2252TRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2254IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430F2254IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2254IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2254IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2254IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2254TRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2254TRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2254TRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2254TRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2272IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430F2272IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2272IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2272IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2272IYFFR | DSBGA | YFF | 49 | 2500 | 330.0 | 12.4 | 3.5 | 3.7 | 0.81 | 8.0 | 12.0 | Q2 |
| MSP430F2272IYFFT | DSBGA | YFF | 49 | 250 | 180.0 | 12.4 | 3.5 | 3.7 | 0.81 | 8.0 | 12.0 | Q2 |
| MSP430F2272TDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430F2272TRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2272TRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2272TRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2272TRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2274IDAR | TSSOP | DA | 38 | 2000 | 330.0 | 24.4 | 8.6 | 13.0 | 1.8 | 12.0 | 24.0 | Q1 |
| MSP430F2274IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2274IRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2274IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2274IRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2274IYFFR | DSBGA | YFF | 49 | 2500 | 330.0 | 12.4 | 3.5 | 3.7 | 0.81 | 8.0 | 12.0 | Q2 |
| MSP430F2274IYFFT | DSBGA | YFF | 49 | 250 | 180.0 | 12.4 | 3.5 | 3.7 | 0.81 | 8.0 | 12.0 | Q2 |
| MSP430F2274TRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2274TRHAR | VQFN | RHA | 40 | 2500 | 330.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2274TRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |
| MSP430F2274TRHAT | VQFN | RHA | 40 | 250 | 180.0 | 16.4 | 6.3 | 6.3 | 1.1 | 12.0 | 16.0 | Q2 |

TAPE AND REEL BOX DIMENSIONS


*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|------------------|--------------|-----------------|------|------|-------------|------------|-------------|
| MSP430F2232IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430F2232IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430F2232IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430F2232IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2232IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2232TRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430F2232TRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430F2232TRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2232TRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2234IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430F2234IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430F2234IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430F2234IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2234IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2234TRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2252IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430F2252IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430F2252IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|------------------|--------------|-----------------|------|------|-------------|------------|-------------|
| MSP430F2252IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2252IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2252IYFFR | DSBGA | YFF | 49 | 2500 | 335.0 | 335.0 | 25.0 |
| MSP430F2252TRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430F2252TRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2252TRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2254IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430F2254IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430F2254IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430F2254IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2254IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2254TRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430F2254TRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430F2254TRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2254TRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2272IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430F2272IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430F2272IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2272IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2272IYFFR | DSBGA | YFF | 49 | 2500 | 335.0 | 335.0 | 25.0 |
| MSP430F2272IYFFT | DSBGA | YFF | 49 | 250 | 182.0 | 182.0 | 20.0 |
| MSP430F2272TDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430F2272TRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430F2272TRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430F2272TRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2272TRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2274IDAR | TSSOP | DA | 38 | 2000 | 350.0 | 350.0 | 43.0 |
| MSP430F2274IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430F2274IRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430F2274IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2274IRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2274IYFFR | DSBGA | YFF | 49 | 2500 | 335.0 | 335.0 | 25.0 |
| MSP430F2274IYFFT | DSBGA | YFF | 49 | 250 | 182.0 | 182.0 | 20.0 |
| MSP430F2274TRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 38.0 |
| MSP430F2274TRHAR | VQFN | RHA | 40 | 2500 | 367.0 | 367.0 | 35.0 |
| MSP430F2274TRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |
| MSP430F2274TRHAT | VQFN | RHA | 40 | 250 | 210.0 | 185.0 | 35.0 |

TUBE


*All dimensions are nominal

| Device | Package Name | Package Type | Pins | SPQ | L (mm) | W (mm) | T (μm) | B (mm) |
|----------------|--------------|--------------|------|-----|--------|--------|--------|--------|
| MSP430F2232IDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |
| MSP430F2232TDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |
| MSP430F2234IDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |
| MSP430F2234TDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |
| MSP430F2252IDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |
| MSP430F2252TDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |
| MSP430F2254IDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |
| MSP430F2254TDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |
| MSP430F2272IDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |
| MSP430F2272TDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |
| MSP430F2274IDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |
| MSP430F2274TDA | DA | TSSOP | 38 | 40 | 530 | 11.89 | 3600 | 4.9 |

DA (R-PDSO-G**)
 38 PIN SHOWN

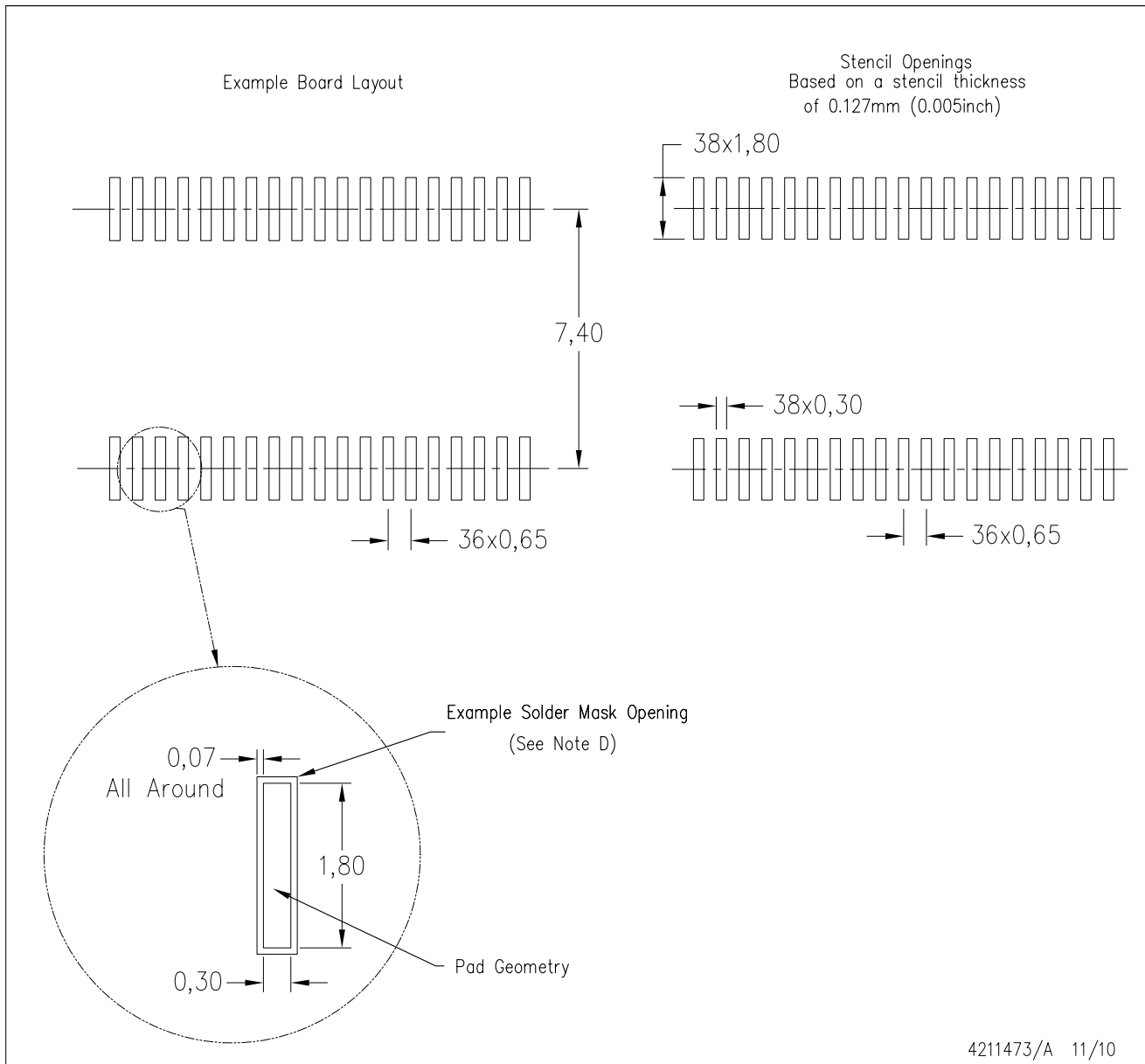
PLASTIC SMALL-OUTLINE PACKAGE



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

DA (R-PDSO-G38)

PLASTIC SMALL OUTLINE



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

GENERIC PACKAGE VIEW

RHA 40

VQFN - 1 mm max height

6 x 6, 0.5 mm pitch

PLASTIC QUAD FLATPACK - NO LEAD

This image is a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.



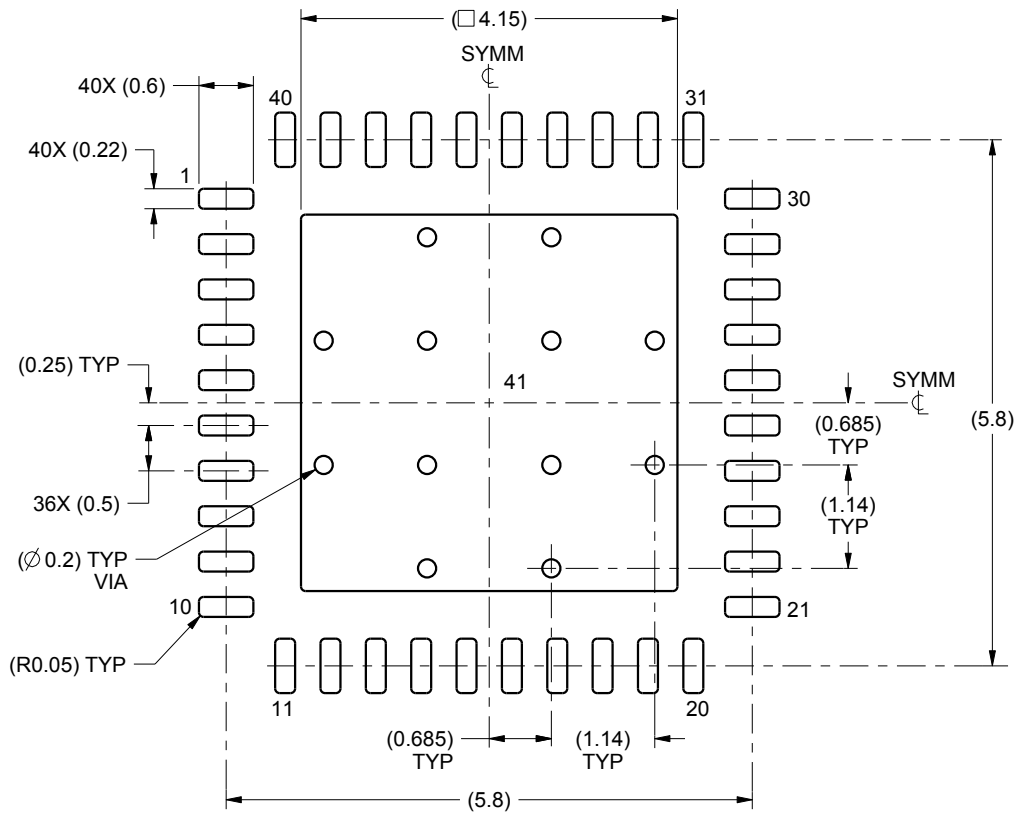
4225870/A

EXAMPLE BOARD LAYOUT

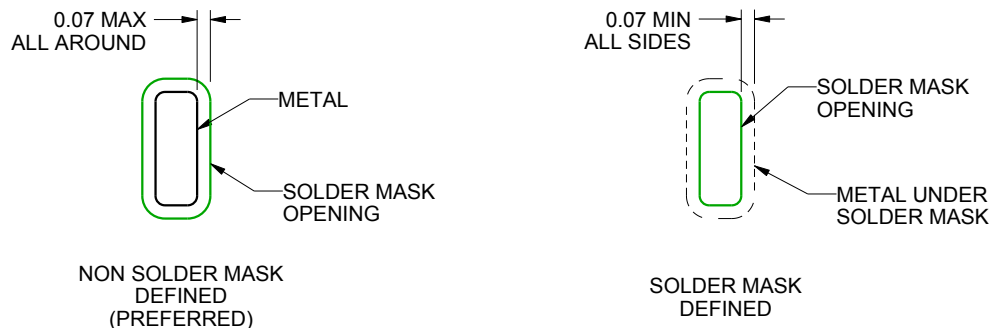
RHA0040B

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



LAND PATTERN EXAMPLE
SCALE:12X



SOLDER MASK DETAILS

4219052/A 06/2016

NOTES: (continued)

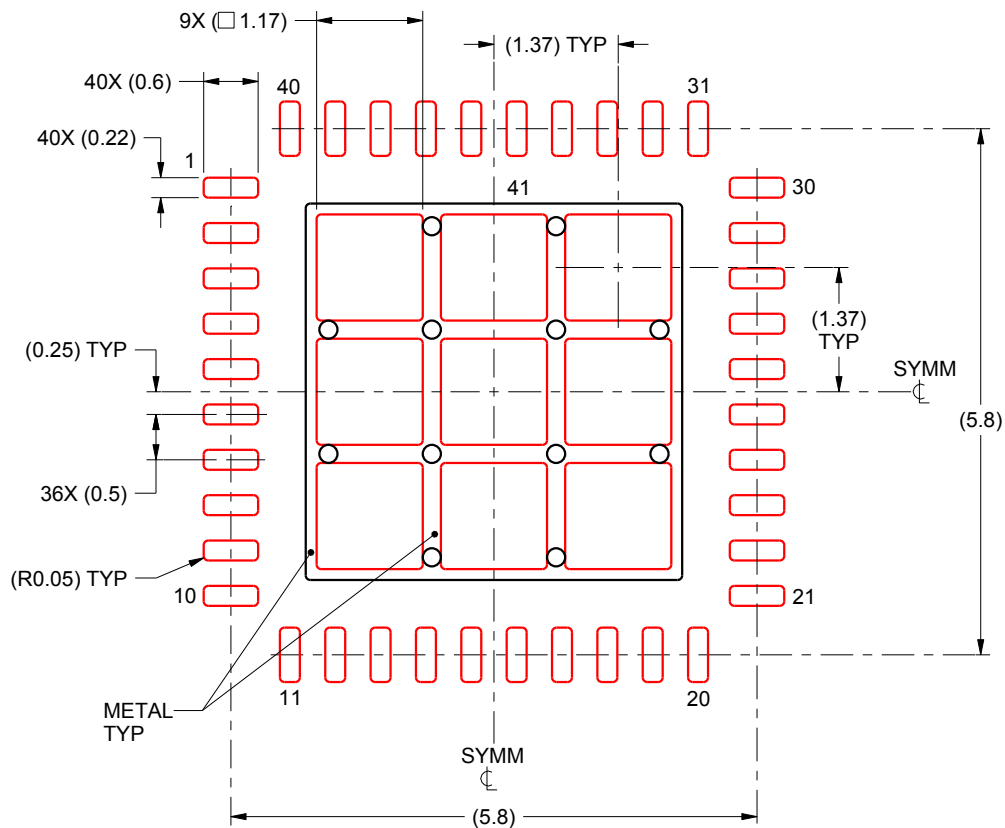
4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).

EXAMPLE STENCIL DESIGN

RHA0040B

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 41:
72% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
SCALE:12X

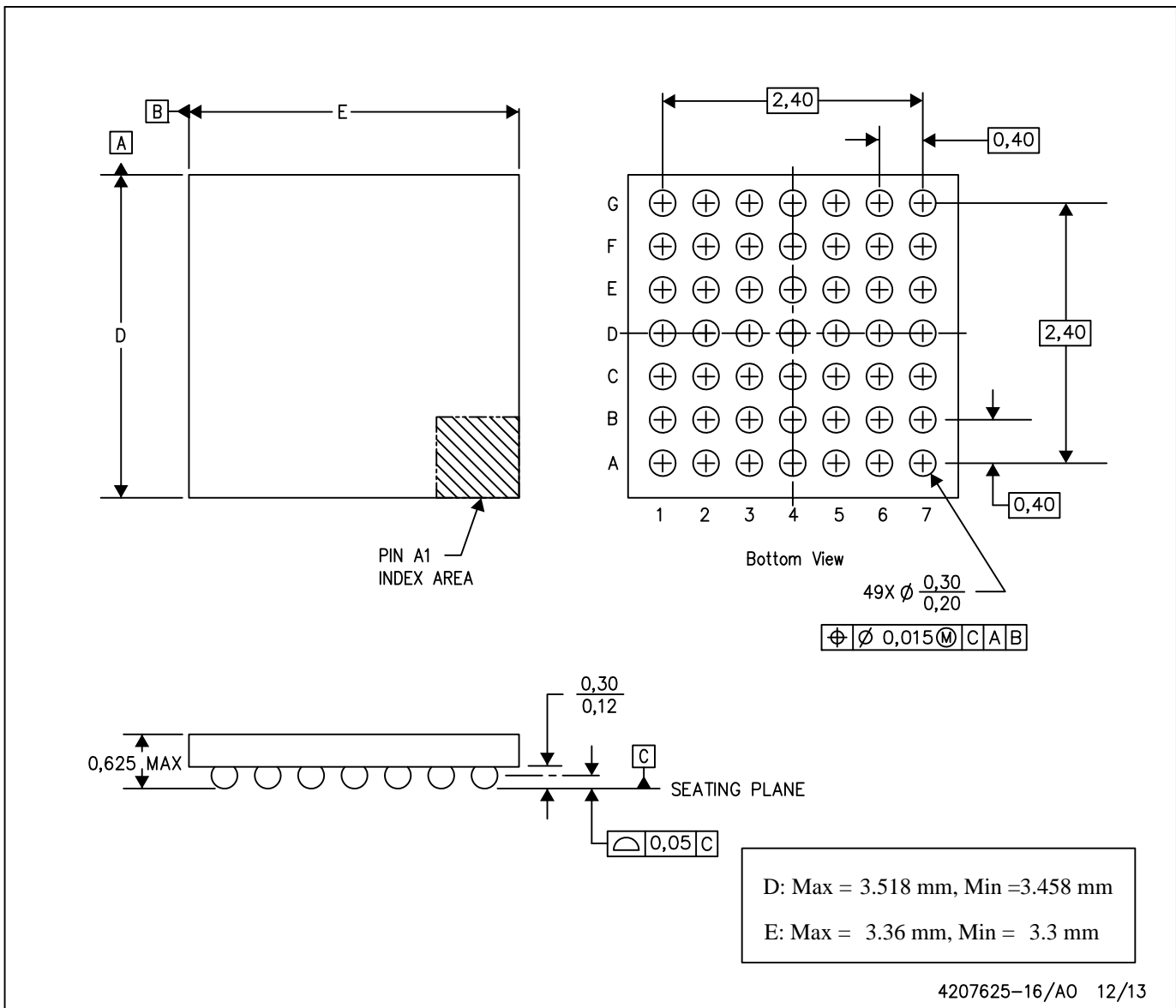
4219052/A 06/2016

NOTES: (continued)

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

YFF (R-XBGA-N49)

DIE-SIZE BALL GRID ARRAY



- NOTES: A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
B. This drawing is subject to change without notice.
C. NanoFree™ package configuration.

NanoFree is a trademark of Texas Instruments.

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