

## 混合信号微控制器

### 特性

- 低电源电压范围: **1.8 V to 3.6 V**
- 超低功耗
  - 运行模式: **220 $\mu$ A** (在 **1MHz** 频率和 **2.2V** 电压条件下)
  - 待机模式: **0.5 $\mu$ A**
  - 关断模式 (RAM 保持): **0.1 $\mu$ A**
- **5** 种节能模式
- 可在不到 **1 $\mu$ s** 的时间里超快速地从待机模式唤醒
- **16** 位 **RISC** 架构、**62.5ns** 指令周期
- 基本时钟模块配置:
  - 高达**16 MHz** 的内部频率并具有**4** 种浮动范围在 **$\pm 1\%$** 之内的校准频率。
  - 内部超低功耗低频振荡器
  - **32-kHz** 晶体<sup>(1)</sup>
  - 外部数字时钟信号源
- 具有两个捕捉/比较寄存器的**16**位时钟\_A
- **16**位三角积分(**Sigma-Delta**) **A/D** 转换器具有差动**PGA**输入和内反射<sup>(2)</sup>
- 支持**SPI**和**I2C**的通用串行接口(**USI**)

(1) 晶体振荡器不能在温度超过**105°C**的环境中工作。

(2) ADC最高工作温度**105°C**。

- 欠压检测器
- 串行板上编程时, 无需外部编程电压, 由安全熔丝 (**Security Fuse**) 对可编程代码进行保护
- 具有 **Spy-Bi-Wire** 接口的片上仿真逻辑电路
- **2KB + 256B** 闪存; **128B** **RAM**
- 采用 **16** 引脚 **QFN** 封装
- 如需了解完整的模块说明, 请查阅 **MSP430x2xx** 系列用户指南 (**SLAU144**)

### 支持国防、航天和医疗应用

- 受控基线
- 一个组装/测试场所
- 一个制造场所
- 可在更广的温度范围内 (**-40°C/125°C**)工作<sup>(3)</sup>
- 产品生命周期有所延长
- 拓展的产品改变通知
- 产品可追溯性

(3) 可提供定制温度范围的器件

### 说明

德州仪器 (TI) **MSP430** 系列超低功耗微控制器包含多种器件, 它们具有面向多种应用的不同外设集。这种架构与 **5** 种低功耗模式相组合, 专为在便携式测量应用中延长电池的使用寿命而优化。该器件具有一个强大的 **16** 位 **RISC** CPU、**16** 位寄存器和有助于获得最大编码效率的常数发生器。数字控制振荡器 (**DCO**) 可在不到 **1 $\mu$ s** 的时间里完成从低功耗模式至运行模式的唤醒。

**MSP430F2013**是一个具有内置**16**位时钟和**10**个I/O针脚的超低功率混合信号微控制器。除此之外, **MSP430F2013**有一个使用同步协议 (**SPI** 或 **I2C**)的内置通信组件和一个**16**位的三角积分(**Sigma-Delta**)**A/D**转换器。

典型应用包括传感器系统, 此类系统负责捕获模拟信号、将之转换为数字值、随后对数据进行处理以进行显示或传送至主机系统。独立射频(**RF**)传感器前端属于另外的应用领域。

**Table 1. ORDERING INFORMATION<sup>(1)</sup>**

| T <sub>A</sub> | PACKAGE <sup>(2)</sup> | ORDERABLE PART NUMBER |
|----------------|------------------------|-----------------------|
| -40°C to 125°C | QFN (RSA)              | MSP430F2013QRSATEP    |

(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](http://www.ti.com).

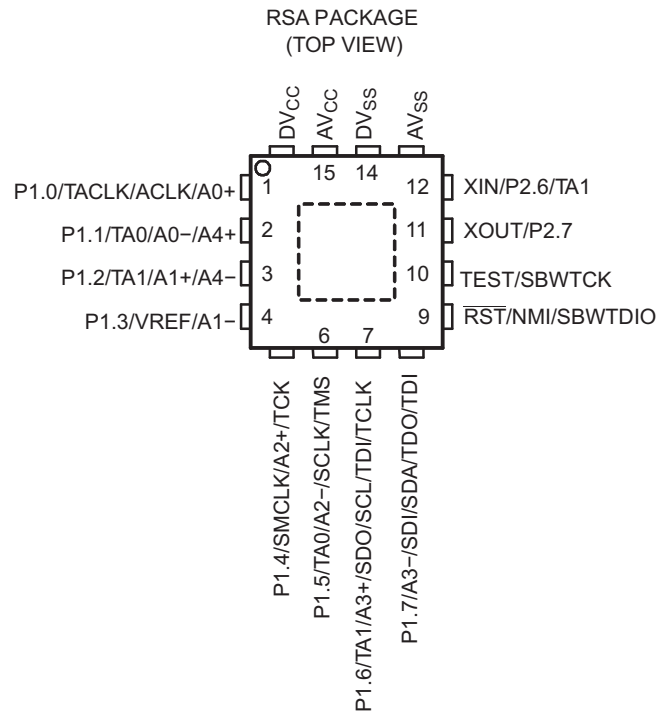
(2) Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at [www.ti.com/sc/package](http://www.ti.com/sc/package).



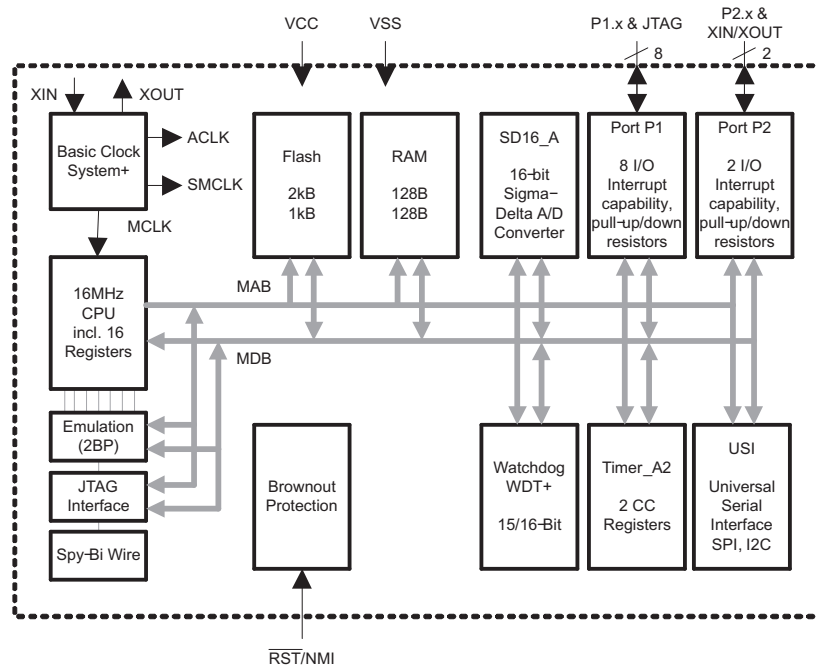
Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

## Device Pinout

See port schematics section for detailed I/O information.



## Functional Block Diagram



NOTE: See port schematics section for detailed I/O information.

**Table 2. Terminal Functions**

| TERMINAL                                    |     |     | DESCRIPTION                                                                                                                                                                                                                                              |
|---------------------------------------------|-----|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NAME                                        | NO. | I/O |                                                                                                                                                                                                                                                          |
| P1.0/TACLK/ACLK/A0+                         | 1   | I/O | General-purpose digital I/O pin<br>Timer_A, clock signal TACLK input<br>ACLK signal output<br>SD16_A positive analog input A0                                                                                                                            |
| P1.1/TA0/A0-/A4+                            | 2   | I/O | General-purpose digital I/O pin<br>Timer_A, capture: CCI0A input, compare: Out0 output<br>SD16_A negative analog input A0<br>SD16_A positive analog input A4                                                                                             |
| P1.2/TA1/A1+/A4-                            | 3   | I/O | General-purpose digital I/O pin<br>Timer_A, capture: CCI1A input, compare: Out1 output<br>SD16_A positive analog input A1<br>SD16_A negative analog input A4                                                                                             |
| P1.3/VREF/A1-                               | 4   | I/O | General-purpose digital I/O pin<br>Input for an external reference voltage/internal reference voltage output (can be used as mid-voltage)<br>SD16_A negative analog input A1                                                                             |
| P1.4/SMCLK/A2+/TCK                          | 5   | I/O | General-purpose digital I/O pin<br>SMCLK signal output<br>SD16_A positive analog input A2<br>JTAG test clock, input terminal for device programming and test                                                                                             |
| P1.5/TA0/A2-/SCLK/TMS                       | 6   | I/O | General-purpose digital I/O pin<br>Timer_A, compare: Out0 output<br>SD16_A negative analog input A2<br>USI: external clock input in SPI or I2C mode; clock output in SPI mode<br>JTAG test mode select, input terminal for device programming and test   |
| P1.6/TA1/A3+/SDO/SCL/<br>TDI/TCLK           | 7   | I/O | General-purpose digital I/O pin<br>Timer_A, capture: CCI1B input, compare: Out1 output<br>SD16_A positive analog input A3<br>USI: Data output in SPI mode; I2C clock in I2C mode<br>JTAG test data input or test clock input during programming and test |
| P1.7/A3-/SDI/SDA/<br>TDO/TDI <sup>(1)</sup> | 8   | I/O | General-purpose digital I/O pin<br>SD16_A negative analog input A3<br>USI: Data input in SPI mode; I2C data in I2C mode<br>JTAG test data output terminal or test data input during programming and test                                                 |
| XIN/P2.6/TA1                                | 12  | I/O | Input terminal of crystal oscillator<br>General-purpose digital I/O pin<br>Timer_A, compare: Out1 output                                                                                                                                                 |
| XOUT/P2.7                                   | 11  | I/O | Output terminal of crystal oscillator<br>General-purpose digital I/O pin <sup>(2)</sup>                                                                                                                                                                  |
| $\overline{\text{RST}}$ /NMI/SBWDIO         | 9   | I   | Reset or nonmaskable interrupt input<br>Spy-Bi-Wire test data input/output during programming and test                                                                                                                                                   |
| TEST/SBWTK                                  | 10  | I   | Selects test mode for JTAG pins on Port 1. The device protection fuse is connected to TEST.<br>Spy-Bi-Wire test clock input during programming and test                                                                                                  |
| DV <sub>CC</sub>                            | 16  |     | Digital supply voltage                                                                                                                                                                                                                                   |
| AV <sub>CC</sub>                            | 15  |     | Analog supply voltage                                                                                                                                                                                                                                    |
| DV <sub>SS</sub>                            | 14  |     | Digital ground reference                                                                                                                                                                                                                                 |
| AV <sub>SS</sub>                            | 13  |     | Analog ground reference                                                                                                                                                                                                                                  |
| QFN Pad                                     | Pad | NA  | QFN package pad. Connection to VSS is recommended.                                                                                                                                                                                                       |

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

(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.

## 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 3](#) shows examples of the three types of instruction formats; [Table 4](#) 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 3. 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, un/conditional     | JNE       | Jump-on-equal bit = 0 |

**Table 4. Address Mode Descriptions**

| ADDRESS MODE           | S <sup>(1)</sup> | D <sup>(1)</sup> | 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<br>R10 + 2--> R10 |
| Immediate              | ✓                |                  | MOV #X,TONI     | MOV #45,TONI     | #45 --> M(TONI)                  |

(1) S = source, D = destination

## Operating Modes

The MSP430 has one active mode and five software-selectable low-power modes of operation. An interrupt event can wake 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's 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's dc-generator remains enabled
  - ACLK remains active
- Low-power mode 3 (LPM3)
  - CPU is disabled
  - MCLK and SMCLK are disabled
  - DCO's dc-generator is disabled
  - ACLK remains active
- Low-power mode 4 (LPM4)
  - CPU is disabled
  - ACLK is disabled
  - MCLK and SMCLK are disabled
  - DCO's 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, flash is not programmed) the CPU goes into LPM4 immediately after power-up.

**Table 5. Interrupt Sources**

| INTERRUPT SOURCE                                                                                       | INTERRUPT FLAG                                              | SYSTEM INTERRUPT                                     | WORD ADDRESS     | PRIORITY        |
|--------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|------------------------------------------------------|------------------|-----------------|
| Power-up<br>External reset<br>Watchdog Timer+<br>Flash key violation<br>PC out-of-range <sup>(1)</sup> | PORIFG<br>RSTIFG<br>WDTIFG<br>KEYV<br>See <sup>(2)</sup>    | Reset                                                | 0FFFEh           | 31, highest     |
| NMI<br>Oscillator fault<br>Flash memory access violation                                               | NMIIFG<br>OFIFG<br>ACCVIFG <sup>(2)(3)</sup>                | (non)-maskable,<br>(non)-maskable,<br>(non)-maskable | 0FFFCh           | 30              |
|                                                                                                        |                                                             |                                                      | 0FFFAh           | 29              |
|                                                                                                        |                                                             |                                                      | 0FFF8h           | 28              |
| Watchdog Timer+                                                                                        | WDTIFG                                                      | maskable                                             | 0FFF4h           | 26              |
| Timer_A2                                                                                               | TACCR0 CCIFG <sup>(4)</sup>                                 | maskable                                             | 0FFF2h           | 25              |
| Timer_A2                                                                                               | TACCR1 CCIFG.TAIFG <sup>(2)(4)</sup>                        | maskable                                             | 0FFF0h           | 24              |
|                                                                                                        |                                                             |                                                      | 0FFEEh           | 23              |
|                                                                                                        |                                                             |                                                      | 0FFECCh          | 22              |
| SD16_A                                                                                                 | SD16CCTL0 SD16OVIFG,<br>SD16CCTL0 SD16IFG <sup>(2)(4)</sup> | maskable                                             |                  |                 |
| USI                                                                                                    | USIIFG, USISTTIFG <sup>(2)(4)</sup>                         | maskable                                             | 0FFE8h           | 20              |
| I/O Port P2 (two flags)                                                                                | P2IFG.6 to P2IFG.7 <sup>(2)(4)</sup>                        | maskable                                             | 0FFE6h           | 19              |
| I/O Port P1 (eight flags)                                                                              | P1IFG.0 to P1IFG.7 <sup>(2)(4)</sup>                        | maskable                                             | 0FFE4h           | 18              |
|                                                                                                        |                                                             |                                                      | 0FFE2h           | 17              |
|                                                                                                        |                                                             |                                                      | 0FFE0h           | 16              |
| See <sup>(5)</sup>                                                                                     |                                                             |                                                      | 0FFDEh to 0FFC0h | 15 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 ranges.
- (2) Multiple source flags
- (3) (non)-maskable: the individual interrupt-enable bit can disable an interrupt event, but the general interrupt enable cannot.
- (4) Interrupt flags are located in the module.
- (5) The interrupt vectors at addresses 0FFDEh 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.

|               |                                                                                   |                                                         |
|---------------|-----------------------------------------------------------------------------------|---------------------------------------------------------|
| <b>Legend</b> | <b>rw:</b>                                                                        | Bit can be read and written.                            |
|               | <b>rw-0,1:</b>                                                                    | Bit can be read and written. It is reset or set by PUC. |
|               | <b>rw-(0,1):</b>                                                                  | Bit can be read and written. It is reset or set by POR. |
|               |  | SFR bit is not present in device.                       |

**Table 6. Interrupt Enable Register 1 and 2**

| 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

| Address | 7                                                                                 | 6                                                                                 | 5                                                                                 | 4                                                                                 | 3                                                                                  | 2                                                                                   | 1                                                                                   | 0                                                                                   |
|---------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| 01h     |  |  |  |  |  |  |  |  |

**Table 7. Interrupt Flag Register 1 and 2**

| 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<sub>CC</sub> power-on or a reset condition at the RST/NMI pin in reset mode.  
**OFIFG** Flag set on oscillator fault.  
**PORIFG** Power-On Reset interrupt flag. Set on V<sub>CC</sub> power-up.  
**RSTIFG** External reset interrupt flag. Set on a reset condition at RST/NMI pin in reset mode. Reset on V<sub>CC</sub> power-up.  
**NMIIFG** Set via RST/NMI pin

| Address | 7                                                                                   | 6                                                                                   | 5                                                                                   | 4                                                                                   | 3                                                                                    | 2                                                                                     | 1                                                                                     | 0                                                                                     |
|---------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| 03h     |  |  |  |  |  |  |  |  |

## Memory Organization

**Table 8. Memory Organization**

|                                                       |                              | <b>MSP430F200x</b>                          | <b>MSP430F201x</b>                          |
|-------------------------------------------------------|------------------------------|---------------------------------------------|---------------------------------------------|
| Memory<br>Main: interrupt vector<br>Main: code memory | Size<br>Flash<br>Flash       | 1KB Flash<br>0FFFFh-0FFC0h<br>0FFFFh-0FC00h | 2KB Flash<br>0FFFFh-0FFC0h<br>0FFFFh-0F800h |
| Information memory                                    | Size<br>Flash                | 256 Byte<br>010FFh - 01000h                 | 256 Byte<br>010FFh - 01000h                 |
| RAM                                                   | Size                         | 128 Byte<br>027Fh - 0200h                   | 128 Byte<br>027Fh - 0200h                   |
| Peripherals                                           | 16-bit<br>8-bit<br>8-bit SFR | 01FFh - 0100h<br>0FFh - 010h<br>0Fh - 00h   | 01FFh - 0100h<br>0FFh - 010h<br>0Fh - 00h   |

## Flash Memory

The flash memory can be programmed via the Spy-Bi-Wire/JTAG port, 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 busses and can be handled using all instructions. For complete module descriptions, refer to the *MSP430F2xx Family User's Guide*.

### 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 and an internal digitally-controlled oscillator (DCO). 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  $\mu$ s. The basic clock module provides the following clock signals:

- Auxiliary clock (ACLK), sourced either from a 32768-Hz watch crystal or the internal 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 9. 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 is one 8-bit I/O port implemented—port P1—and two bits of I/O port P2:

- 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 the eight bits of port P1 and the two bits of port P2.
- Read/write access to port-control registers is supported by all instructions.
- Each I/O has an individually programmable pullup/pulldown resistor.

### Watchdog Timer (WDT+)

The primary function of the watchdog timer (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\_A2

Timer\_A2 is a 16-bit timer/counter with two capture/compare registers. Timer\_A2 can support multiple capture/compares, PWM outputs, and interval timing. Timer\_A2 also has extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each of the capture/compare registers.

**Table 10. Timer\_A2 Signal Connections**

| INPUT PIN NUMBER |          | DEVICE INPUT SIGNAL | MODULE INPUT NAME | MODULE BLOCK | MODULE OUTPUT SIGNAL | OUTPUT PIN NUMBER |           |
|------------------|----------|---------------------|-------------------|--------------|----------------------|-------------------|-----------|
| PW, N            | RSA      |                     |                   |              |                      | PW, N             | RSA       |
| 2 - P1.0         | 1 - P1.0 | TACLK               | TACLK             | Timer        | NA                   |                   |           |
|                  |          | ACLK                | ACLK              |              |                      |                   |           |
|                  |          | SMCLK               | SMCLK             |              |                      |                   |           |
| 2 - P1.0         | 1 - P1.0 | TACLK               | INCLK             |              |                      |                   |           |
| 3 - P1.1         | 2 - P1.1 | TA0                 | CCI0A             | CCR0         | TA0                  | 3 - P1.1          | 2 - P1.1  |
| 7 - P1.5         | 6 - P1.5 | ACLK (internal)     | CCI0B             |              |                      | 7 - P1.5          | 6 - P1.5  |
|                  |          | V <sub>SS</sub>     | GND               |              |                      |                   |           |
|                  |          | V <sub>CC</sub>     | V <sub>CC</sub>   |              |                      |                   |           |
| 4 - P1.2         | 3 - P1.2 | TA1                 | CCI1A             | CCR1         | TA1                  | 4 - P1.2          | 3 - P1.2  |
| 8 - P1.6         | 7 - P1.6 | TA1                 | CCI1B             |              |                      | 8 - P1.6          | 7 - P1.6  |
|                  |          | V <sub>SS</sub>     | GND               |              |                      | 13 - P2.6         | 12 - P2.6 |
|                  |          | V <sub>CC</sub>     | V <sub>CC</sub>   |              |                      |                   |           |

## USI

The universal serial interface (USI) module is used for serial data communication and provides the basic hardware for synchronous communication protocols like SPI and I2C.

## SD16\_A

The SD16\_A module supports 16-bit analog-to-digital conversions. The module implements a 16-bit sigma-delta core and reference generator. In addition to external analog inputs, internal  $V_{CC}$  sense and temperature sensors are also available.

## Peripheral File Map

**Table 11. Peripherals With Word Access**

|                        |                                                                                                                                                                               |                                                                |                                                             |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|-------------------------------------------------------------|
| <b>SD16_A</b>          | General Control<br>Channel 0 Control<br>Interrupt vector word register<br>Channel 0 conversion memory                                                                         | SD16CTL<br>SD16CCTL0<br>SD16IV<br>SD16MEM0                     | 0100h<br>0102h<br>0110h<br>0112h                            |
| <b>Timer_A</b>         | Capture/compare register<br>Capture/compare register<br>Timer_A register<br>Capture/compare control<br>Capture/compare control<br>Timer_A control<br>Timer_A interrupt vector | TACCR1<br>TACCR0<br>TAR<br>TACCTL1<br>TACCTL0<br>TACTL<br>TAIV | 0174h<br>0172h<br>0170h<br>0164h<br>0162h<br>0160h<br>012Eh |
| <b>Flash Memory</b>    | Flash control 3<br>Flash control 2<br>Flash control 1                                                                                                                         | FCTL3<br>FCTL2<br>FCTL1                                        | 012Ch<br>012Ah<br>0128h                                     |
| <b>Watchdog Timer+</b> | Watchdog/timer control                                                                                                                                                        | WDTCTL                                                         | 0120h                                                       |

**Table 12. Peripherals With Byte Access**

|                            |                                                                                                                                                                                             |                                                                    |                                                              |
|----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------|
| <b>SD16_A</b>              | Channel 0 Input Control<br>Analog Enable                                                                                                                                                    | SD16INCTL0<br>SD16AE                                               | 0B0h<br>0B7h                                                 |
| <b>USI</b>                 | USI control 0<br>USI control 1<br>USI clock control<br>USI bit counter<br>USI shift register                                                                                                | USICTL0<br>USICTL1<br>USICKCTL<br>USICNT<br>USISR                  | 078h<br>079h<br>07Ah<br>07Bh<br>07Ch                         |
| <b>Basic Clock System+</b> | Basic clock system control 3<br>Basic clock system control 2<br>Basic clock system control 1<br>DCO clock frequency control                                                                 | BCSCTL3<br>BCSCTL2<br>BCSCTL1<br>DCOCTL                            | 053h<br>058h<br>057h<br>056h                                 |
| <b>Port P2</b>             | Port P2 resistor enable<br>Port P2 selection<br>Port P2 interrupt enable<br>Port P2 interrupt edge select<br>Port P2 interrupt flag<br>Port P2 direction<br>Port P2 output<br>Port P2 input | P2REN<br>P2SEL<br>P2IE<br>P2IES<br>P2IFG<br>P2DIR<br>P2OUT<br>P2IN | 02Fh<br>02Eh<br>02Dh<br>02Ch<br>02Bh<br>02Ah<br>029h<br>028h |
| <b>Port P1</b>             | Port P1 resistor enable<br>Port P1 selection<br>Port P1 interrupt enable<br>Port P1 interrupt edge select<br>Port P1 interrupt flag<br>Port P1 direction<br>Port P1 output<br>Port P1 input | P1REN<br>P1SEL<br>P1IE<br>P1IES<br>P1IFG<br>P1DIR<br>P1OUT<br>P1IN | 027h<br>026h<br>025h<br>024h<br>023h<br>022h<br>021h<br>020h |
| <b>Special Function</b>    | SFR interrupt flag 2<br>SFR interrupt flag 1<br>SFR interrupt enable 2<br>SFR interrupt enable 1                                                                                            | IFG2<br>IFG1<br>IE2<br>IE1                                         | 003h<br>002h<br>001h<br>000h                                 |

## Absolute Maximum Ratings<sup>(1)</sup>

|                                                       |                                    |                     |                                   |
|-------------------------------------------------------|------------------------------------|---------------------|-----------------------------------|
| Voltage applied at V <sub>CC</sub> to V <sub>SS</sub> |                                    |                     | -0.3 V to 4.1 V                   |
| Voltage applied to any pin <sup>(2)</sup>             |                                    |                     | -0.3 V to V <sub>CC</sub> + 0.3 V |
| Diode current at any device terminal                  |                                    |                     | ±2 mA                             |
| T <sub>stg</sub>                                      | Storage temperature <sup>(3)</sup> | Unprogrammed device | -55°C to 150°C                    |
|                                                       |                                    | Programmed device   | -40°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 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.

## THERMAL INFORMATION

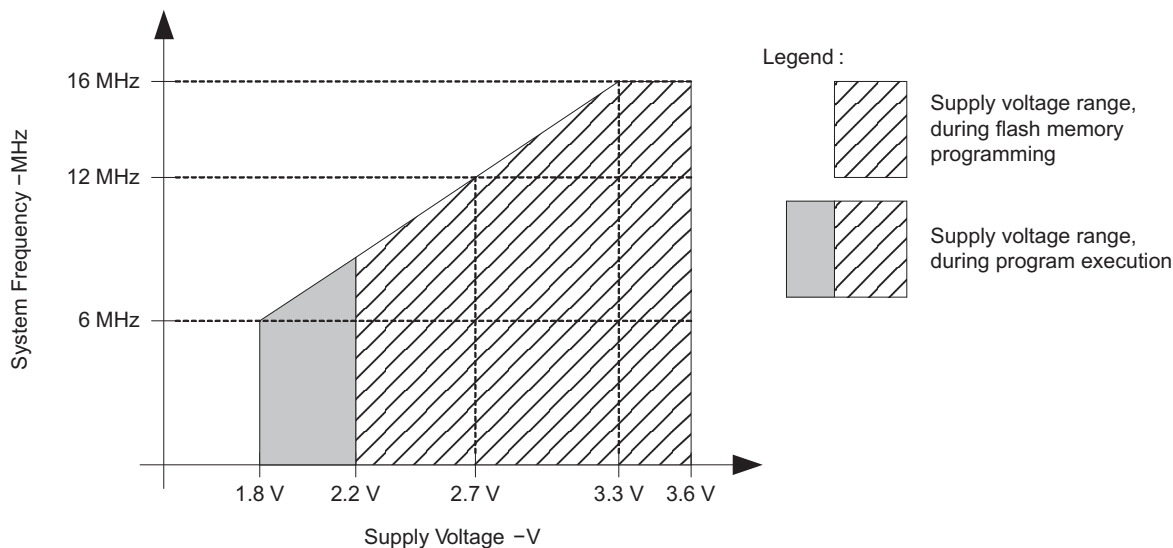
| THERMAL METRIC <sup>(1)</sup> |                                                             | MSP430F2013-EP | UNITS |
|-------------------------------|-------------------------------------------------------------|----------------|-------|
|                               |                                                             | RSA            |       |
|                               |                                                             | 16 PINS        |       |
| $\theta_{JA}$                 | Junction-to-ambient thermal resistance <sup>(2)</sup>       | 38.1           | °C/W  |
| $\theta_{JCTop}$              | Junction-to-case (top) thermal resistance <sup>(3)</sup>    | 26             |       |
| $\theta_{JB}$                 | Junction-to-board thermal resistance <sup>(4)</sup>         | 7.5            |       |
| $\psi_{JT}$                   | Junction-to-top characterization parameter <sup>(5)</sup>   | 0.3            |       |
| $\psi_{JB}$                   | Junction-to-board characterization parameter <sup>(6)</sup> | 5.7            |       |
| $\theta_{JCbott}$             | Junction-to-case (bottom) thermal resistance <sup>(7)</sup> | 1.9            |       |

- (1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](#).
- (2) The junction-to-ambient thermal resistance under natural convection is obtained in a simulation on a JEDEC-standard, high-K board, as specified in JESD51-7, in an environment described in JESD51-2a.
- (3) The junction-to-case (top) thermal resistance is obtained by simulating a cold plate test on the package top. No specific JEDEC-standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.
- (4) The junction-to-board thermal resistance is obtained by simulating in an environment with a ring cold plate fixture to control the PCB temperature, as described in JESD51-8.
- (5) The junction-to-top characterization parameter,  $\psi_{JT}$ , estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining  $\theta_{JA}$ , using a procedure described in JESD51-2a (sections 6 and 7).
- (6) The junction-to-board characterization parameter,  $\psi_{JB}$ , estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining  $\theta_{JA}$ , using a procedure described in JESD51-2a (sections 6 and 7).
- (7) The junction-to-case (bottom) thermal resistance is obtained by simulating a cold plate test on the exposed (power) pad. No specific JEDEC standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.

## Recommended Operating Conditions

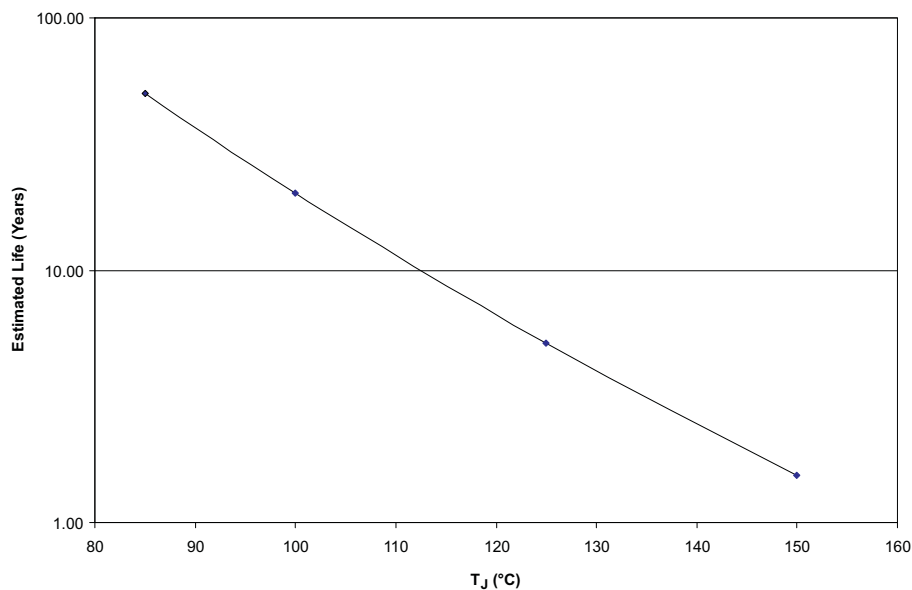
|                     |                                                                | MIN                                                | NOM | MAX | UNIT |     |
|---------------------|----------------------------------------------------------------|----------------------------------------------------|-----|-----|------|-----|
| V <sub>CC</sub>     | Supply voltage                                                 | During program execution                           |     | 1.8 | 3.6  | V   |
|                     |                                                                | During flash program/erase                         |     | 2.2 | 3.6  |     |
| V <sub>SS</sub>     | Supply voltage                                                 | 0                                                  |     |     | V    |     |
| T <sub>A</sub>      | Operating free-air temperature                                 | -40                                                |     |     | 125  | °C  |
| f <sub>SYSTEM</sub> | Processor frequency (maximum MCLK frequency) <sup>(1)(2)</sup> | V <sub>CC</sub> = 1.8 V,<br>Duty cycle = 50% ± 10% |     | dc  | 6    | MHz |
|                     |                                                                | V <sub>CC</sub> = 2.7 V,<br>Duty cycle = 50% ± 10% |     | dc  | 12   |     |
|                     |                                                                | V <sub>CC</sub> ≥ 3.3 V,<br>Duty cycle = 50% ± 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. Safe Operating Area**



- (1) See data sheet for absolute maximum and minimum recommended operating conditions.
- (2) Silicon operating life design goal is 10 years at 110°C junction temperature (does not include package interconnect life).
- (3) The predicted operating lifetime vs. junction temperature is based on reliability modeling using electromigration as the dominant failure mechanism affecting device wearout for the specific device process and design characteristics.

**Figure 2. Operating Life Derating Chart**

## Electrical Characteristics

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

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

| PARAMETER                                          | TEST CONDITIONS                                                                                                                                                                                                                              | $T_A$         | $V_{CC}$ | MIN | TYP | MAX | UNIT          |
|----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----------|-----|-----|-----|---------------|
| $I_{AM,1MHz}$ Active mode (AM) current (1 MHz)     | $f_{DCO} = f_{MCLK} = f_{SMCLK} = 1\text{ MHz}$ ,<br>$f_{ACLK} = 32768\text{ Hz}$ ,<br>Program executes in flash,<br>BCSCTL1 = CALBC1_1MHZ,<br>DCOCTL = CALDCO_1MHZ,<br>CPUOFF = 0, SCG0 = 0,<br>SCG1 = 0, OSCOFF = 0                        |               | 2.2 V    |     | 220 | 280 | $\mu\text{A}$ |
|                                                    |                                                                                                                                                                                                                                              |               | 3 V      |     | 310 | 380 |               |
| $I_{AM,1MHz}$ Active mode (AM) current (1 MHz)     | $f_{DCO} = f_{MCLK} = f_{SMCLK} = 1\text{ MHz}$ ,<br>$f_{ACLK} = 32768\text{ Hz}$ ,<br>Program executes in RAM,<br>BCSCTL1 = CALBC1_1MHZ,<br>DCOCTL = CALDCO_1MHZ,<br>CPUOFF = 0, SCG0 = 0,<br>SCG1 = 0, OSCOFF = 0                          |               | 2.2 V    |     | 190 |     | $\mu\text{A}$ |
|                                                    |                                                                                                                                                                                                                                              |               | 3 V      |     | 265 |     |               |
| $I_{AM,4kHz}$ Active mode (AM) current (4 kHz)     | $f_{MCLK} = f_{SMCLK} = f_{ACLK} = 32768\text{ Hz}/8 = 4096\text{ Hz}$ ,<br>$f_{DCO} = 0\text{ Hz}$ ,<br>Program executes in flash,<br>SELMx = 11, SELS = 1,<br>DIVMx = DIVSx = DIVAx = 11,<br>CPUOFF = 0, SCG0 = 1,<br>SCG1 = 0, OSCOFF = 0 | -40°C to 85°C | 2.2 V    |     | 1.2 | 3   | $\mu\text{A}$ |
|                                                    |                                                                                                                                                                                                                                              | 125°C         | 2.2 V    |     |     | 6   |               |
|                                                    |                                                                                                                                                                                                                                              | -40°C to 85°C | 3 V      |     | 1.6 | 4   |               |
|                                                    |                                                                                                                                                                                                                                              | 125°C         | 3 V      |     |     | 7   |               |
| $I_{AM,100kHz}$ Active mode (AM) current (100 kHz) | $f_{MCLK} = f_{SMCLK} = f_{DCO}(0, 0) \approx 100\text{ kHz}$ ,<br>$f_{ACLK} = 0\text{ Hz}$ ,<br>Program executes in flash,<br>RSELx = 0, DCOx = 0,<br>CPUOFF = 0, SCG0 = 0,<br>SCG1 = 0, OSCOFF = 1                                         | -40°C to 85°C | 2.2 V    |     | 37  | 50  | $\mu\text{A}$ |
|                                                    |                                                                                                                                                                                                                                              | 125°C         | 2.2 V    |     |     | 65  |               |
|                                                    |                                                                                                                                                                                                                                              | -40°C to 85°C | 3 V      |     | 40  | 55  |               |
|                                                    |                                                                                                                                                                                                                                              | 125°C         | 3 V      |     |     | 70  |               |

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

(2) External crystal not used. The currents are characterized with a clock derived from alternate external clock source.

### Typical Characteristics - Active Mode Supply Current (Into $V_{CC}$ )

#### ACTIVE MODE CURRENT

vs

 $V_{CC}$ 

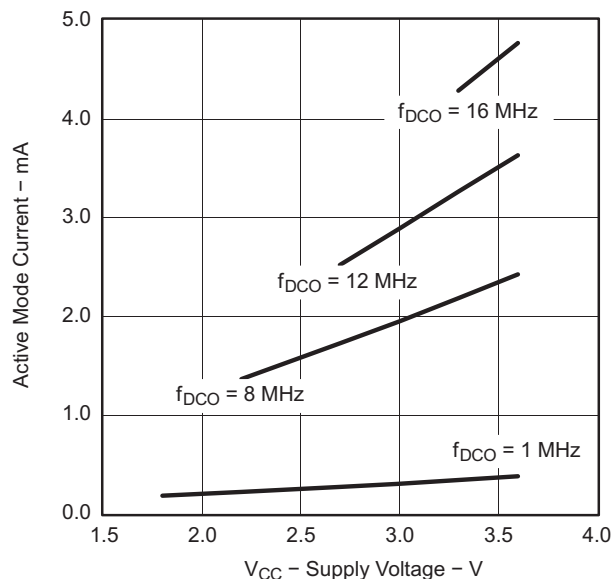
( $T_A = 25^\circ\text{C}$ )


Figure 3.

#### ACTIVE MODE CURRENT

vs

DCO FREQUENCY

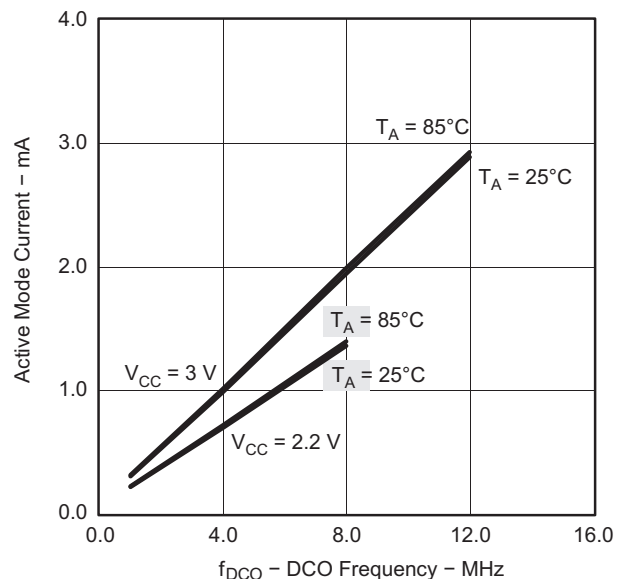


Figure 4.

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

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

| PARAMETER                                                        | TEST CONDITIONS                                                                                                                                                                      | $T_A$         | $V_{CC}$  | MIN | TYP | MAX | UNIT    |
|------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|-----------|-----|-----|-----|---------|
| $I_{LPM0,1MHz}$ Low-power mode 0 (LPM0) current <sup>(3)</sup>   | $f_{MCLK} = 0$ MHz,<br>$f_{SMCLK} = f_{DCO} = 1$ MHz,<br>$f_{ACLK} = 32,768$ Hz,<br>BCSCTL1 = CALBC1_1MHZ,<br>DCOCTL = CALDCO_1MHZ,<br>CPUOFF = 1, SCG0 = 0,<br>SCG1 = 0, OSCOFF = 0 |               | 2.2 V     | 65  |     | 86  | $\mu A$ |
|                                                                  |                                                                                                                                                                                      |               | 3 V       |     | 85  | 108 |         |
| $I_{LPM0,100kHz}$ Low-power mode 0 (LPM0) current <sup>(3)</sup> | $f_{MCLK} = 0$ MHz,<br>$f_{SMCLK} = f_{DCO(0, 0)} \approx 100$ kHz,<br>$f_{ACLK} = 0$ Hz,<br>RSELx = 0, DCOx = 0,<br>CPUOFF = 1, SCG0 = 0,<br>SCG1 = 0, OSCOFF = 1                   |               | 2.2 V     |     | 37  | 52  | $\mu A$ |
|                                                                  |                                                                                                                                                                                      |               | 3 V       |     | 41  | 56  |         |
| $I_{LPM2}$ Low-power mode 2 (LPM2) current <sup>(4)</sup>        | $f_{MCLK} = f_{SMCLK} = 0$ MHz,<br>$f_{DCO} = 1$ MHz,<br>$f_{ACLK} = 32,768$ Hz,<br>BCSCTL1 = CALBC1_1MHZ,<br>DCOCTL = CALDCO_1MHZ,<br>CPUOFF = 1, SCG0 = 0,<br>SCG1 = 1, OSCOFF = 0 | -40°C to 85°C | 2.2 V     |     | 22  | 29  | $\mu A$ |
|                                                                  |                                                                                                                                                                                      | 125°C         |           |     |     | 34  |         |
|                                                                  |                                                                                                                                                                                      | -40°C to 85°C | 3 V       |     | 25  | 32  |         |
|                                                                  |                                                                                                                                                                                      | 125°C         |           |     |     | 37  |         |
| $I_{LPM3,LFXT1}$ Low-power mode 3 (LPM3) current <sup>(3)</sup>  | $f_{DCO} = f_{MCLK} = f_{SMCLK} = 0$ MHz,<br>$f_{ACLK} = 32,768$ Hz,<br>CPUOFF = 1, SCG0 = 1,<br>SCG1 = 1, OSCOFF = 0                                                                | -40°C         | 2.2 V     |     | 0.7 | 1.2 | $\mu A$ |
|                                                                  |                                                                                                                                                                                      | 25°C          |           |     | 0.7 | 1   |         |
|                                                                  |                                                                                                                                                                                      | 85°C          |           |     | 1.4 | 2.3 |         |
|                                                                  |                                                                                                                                                                                      | 125°C         |           |     | 3   | 6.5 |         |
|                                                                  |                                                                                                                                                                                      | -40°C         | 3 V       |     | 0.9 | 1.2 |         |
|                                                                  |                                                                                                                                                                                      | 25°C          |           |     | 0.9 | 1.2 |         |
|                                                                  |                                                                                                                                                                                      | 85°C          |           |     | 1.6 | 2.8 |         |
|                                                                  |                                                                                                                                                                                      | 125°C         |           |     | 3   | 7.6 |         |
| $I_{LPM3,VLO}$ Low-power mode 3 (LPM3) current <sup>(4)</sup>    | $f_{DCO} = f_{MCLK} = f_{SMCLK} = 0$ MHz,<br>$f_{ACLK}$ from internal LF oscillator (VLO),<br>CPUOFF = 1, SCG0 = 1,<br>SCG1 = 1, OSCOFF = 0                                          | -40°C         | 2.2 V     |     | 0.4 | 0.7 | $\mu A$ |
|                                                                  |                                                                                                                                                                                      | 25°C          |           |     | 0.5 | 0.7 |         |
|                                                                  |                                                                                                                                                                                      | 85°C          |           |     | 1   | 1.6 |         |
|                                                                  |                                                                                                                                                                                      | 125°C         |           |     | 2   | 5.5 |         |
|                                                                  |                                                                                                                                                                                      | -40°C         | 3 V       |     | 0.5 | 0.9 |         |
|                                                                  |                                                                                                                                                                                      | 25°C          |           |     | 0.6 | 0.9 |         |
|                                                                  |                                                                                                                                                                                      | 85°C          |           |     | 1.3 | 1.8 |         |
|                                                                  |                                                                                                                                                                                      | 125°C         |           |     | 2.5 | 6.5 |         |
| $I_{LPM4}$ Low-power mode 4 (LPM4) current <sup>(5)</sup>        | $f_{DCO} = f_{MCLK} = f_{SMCLK} = 0$ MHz,<br>$f_{ACLK} = 0$ Hz,<br>CPUOFF = 1, SCG0 = 1,<br>SCG1 = 1, OSCOFF = 1                                                                     | -40°C         | 2.2 V/3 V |     | 0.1 | 0.5 | $\mu A$ |
|                                                                  |                                                                                                                                                                                      | 25°C          |           |     | 0.1 | 0.5 |         |
|                                                                  |                                                                                                                                                                                      | 85°C          |           |     | 0.8 | 1.5 |         |
|                                                                  |                                                                                                                                                                                      | 125°C         |           |     | 2   | 4.4 |         |

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

(2) External crystal not used. The currents are characterized with a clock derived from alternate external clock source.

(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 and P2)

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

| PARAMETER                                                                        | TEST CONDITIONS                                                                                    | V <sub>CC</sub> | MIN                  | TYP | MAX                  | UNIT |
|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-----------------|----------------------|-----|----------------------|------|
| V <sub>IT+</sub> Positive-going input threshold voltage                          |                                                                                                    |                 | 0.45 V <sub>CC</sub> |     | 0.75 V <sub>CC</sub> | V    |
|                                                                                  |                                                                                                    | 2.2 V           | 1.00                 |     | 1.65                 |      |
|                                                                                  |                                                                                                    | 3 V             | 1.35                 |     | 2.25                 |      |
| V <sub>IT-</sub> Negative-going input threshold voltage                          |                                                                                                    |                 | 0.25 V <sub>CC</sub> |     | 0.55 V <sub>CC</sub> | V    |
|                                                                                  |                                                                                                    | 2.2 V           | 0.55                 |     | 1.20                 |      |
|                                                                                  |                                                                                                    | 3 V             | 0.75                 |     | 1.65                 |      |
| V <sub>hys</sub> Input voltage hysteresis (V <sub>IT+</sub> - V <sub>IT-</sub> ) |                                                                                                    | 2.2 V           | 0.2                  |     | 1.0                  | V    |
|                                                                                  |                                                                                                    | 3 V             | 0.3                  |     | 1.0                  |      |
| R <sub>Pull</sub> Pullup/pulldown resistor                                       | For pullup: V <sub>IN</sub> = V <sub>SS</sub> ,<br>For pulldown: V <sub>IN</sub> = V <sub>CC</sub> |                 | 20                   | 35  | 50                   | kΩ   |
| C <sub>I</sub> Input capacitance                                                 | V <sub>IN</sub> = V <sub>SS</sub> or V <sub>CC</sub>                                               |                 |                      | 5   |                      | pF   |

## Inputs (Ports P1 and P2)

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

| PARAMETER                                    | TEST CONDITIONS                                                                              | V <sub>CC</sub> | MIN | TYP | MAX | UNIT |
|----------------------------------------------|----------------------------------------------------------------------------------------------|-----------------|-----|-----|-----|------|
| t <sub>(int)</sub> External interrupt timing | Port P1, P2: P1.x to P2.x, External trigger pulse width to set interrupt flag <sup>(1)</sup> | 2.2 V/3 V       | 25  |     |     | ns   |

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

## Leakage Current (Ports P1 and P2)

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

| PARAMETER                                             | TEST CONDITIONS                       | V <sub>CC</sub> | MIN | MAX | UNIT |
|-------------------------------------------------------|---------------------------------------|-----------------|-----|-----|------|
| I <sub>lkg(Px.y)</sub> High-impedance leakage current | See <sup>(1)</sup> and <sup>(2)</sup> | 2.2 V/3 V       |     | ±50 | nA   |

- (1) The leakage current is measured with V<sub>SS</sub> or V<sub>CC</sub> applied to the corresponding pin(s), unless otherwise noted.  
(2) The leakage of the digital port pins is measured individually. The port pin is selected for input and the pullup/pulldown resistor is disabled.

## Outputs (Ports P1 and P2)

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

| PARAMETER                                 | TEST CONDITIONS                               | V <sub>CC</sub> | MIN                    | TYP | MAX                    | UNIT |
|-------------------------------------------|-----------------------------------------------|-----------------|------------------------|-----|------------------------|------|
| V <sub>OH</sub> High-level output voltage | I <sub>(OHmax)</sub> = -1.5 mA <sup>(1)</sup> | 2.2 V           | V <sub>CC</sub> - 0.25 |     | V <sub>CC</sub>        | V    |
|                                           | I <sub>(OHmax)</sub> = -6 mA <sup>(2)</sup>   | 2.2 V           | V <sub>CC</sub> - 0.6  |     | V <sub>CC</sub>        |      |
|                                           | I <sub>(OHmax)</sub> = -1.5 mA <sup>(1)</sup> | 3 V             | V <sub>CC</sub> - 0.25 |     | V <sub>CC</sub>        |      |
|                                           | I <sub>(OHmax)</sub> = -6 mA <sup>(2)</sup>   | 3 V             | V <sub>CC</sub> - 0.6  |     | V <sub>CC</sub>        |      |
| V <sub>OL</sub> Low-level output voltage  | I <sub>(OLmax)</sub> = 1.5 mA <sup>(1)</sup>  | 2.2 V           | V <sub>SS</sub>        |     | V <sub>SS</sub> + 0.25 | V    |
|                                           | I <sub>(OLmax)</sub> = 6 mA <sup>(2)</sup>    | 2.2 V           | V <sub>SS</sub>        |     | V <sub>SS</sub> + 0.6  |      |
|                                           | I <sub>(OLmax)</sub> = 1.5 mA <sup>(1)</sup>  | 3 V             | V <sub>SS</sub>        |     | V <sub>SS</sub> + 0.25 |      |
|                                           | I <sub>(OLmax)</sub> = 6 mA <sup>(2)</sup>    | 3 V             | V <sub>SS</sub>        |     | V <sub>SS</sub> + 0.6  |      |

- (1) The maximum total current, I<sub>(OHmax)</sub> and I<sub>(OLmax)</sub>, for all outputs combined should not exceed ±12 mA to hold the maximum voltage drop specified.
- (2) The maximum total current, I<sub>(OHmax)</sub> and I<sub>(OLmax)</sub>, for all outputs combined should not exceed ±48 mA to hold the maximum voltage drop specified.

## Output Frequency (Ports P1 and P2)

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

| PARAMETER                                           | TEST CONDITIONS                                                              | V <sub>CC</sub> | MIN | TYP | MAX | UNIT |
|-----------------------------------------------------|------------------------------------------------------------------------------|-----------------|-----|-----|-----|------|
| f <sub>Px,y</sub> Port output frequency (with load) | P1.4/SMCLK, C <sub>L</sub> = 20 pF, R <sub>L</sub> = 1 kΩ <sup>(1) (2)</sup> | 2.2 V           |     |     | 10  | MHz  |
|                                                     |                                                                              | 3 V             |     |     | 12  |      |
| f <sub>Port*CLK</sub> Clock output frequency        | P2.0/ACLK, P1.4/SMCLK, C <sub>L</sub> = 20 pF <sup>(2)</sup>                 | 2.2 V           |     |     | 12  | MHz  |
|                                                     |                                                                              | 3 V             |     |     | 16  |      |

- (1) A resistive divider with 2 × 0.5 kΩ between V<sub>CC</sub> and V<sub>SS</sub> is used as load. The output is connected to the center tap of the divider.
- (2) The output voltage reaches at least 10% and 90% V<sub>CC</sub> at the specified toggle frequency.

## Typical Characteristics - Outputs

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

**LOW-LEVEL OUTPUT CURRENT  
vs  
LOW-LEVEL OUTPUT VOLTAGE**

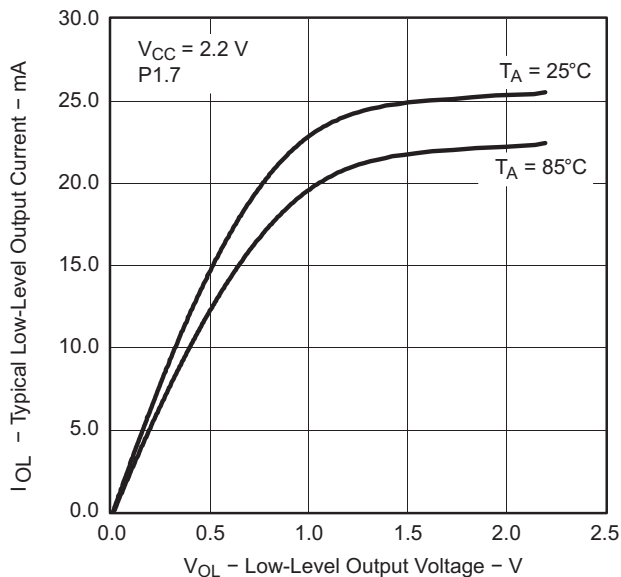


Figure 5.

**LOW-LEVEL OUTPUT CURRENT  
vs  
LOW-LEVEL OUTPUT VOLTAGE**

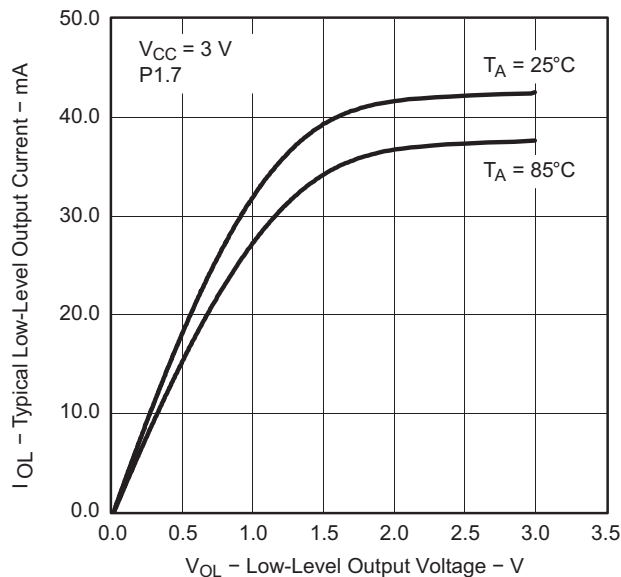


Figure 6.

**HIGH-LEVEL OUTPUT CURRENT  
vs  
HIGH-LEVEL OUTPUT VOLTAGE**

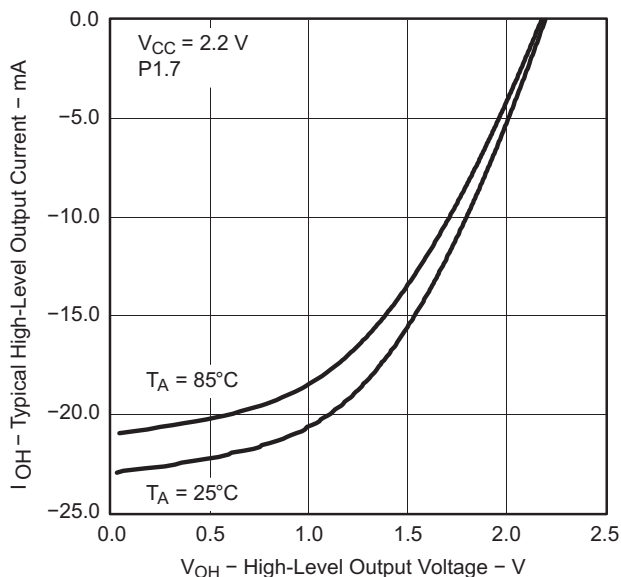


Figure 7.

**HIGH-LEVEL OUTPUT CURRENT  
vs  
HIGH-LEVEL OUTPUT VOLTAGE**

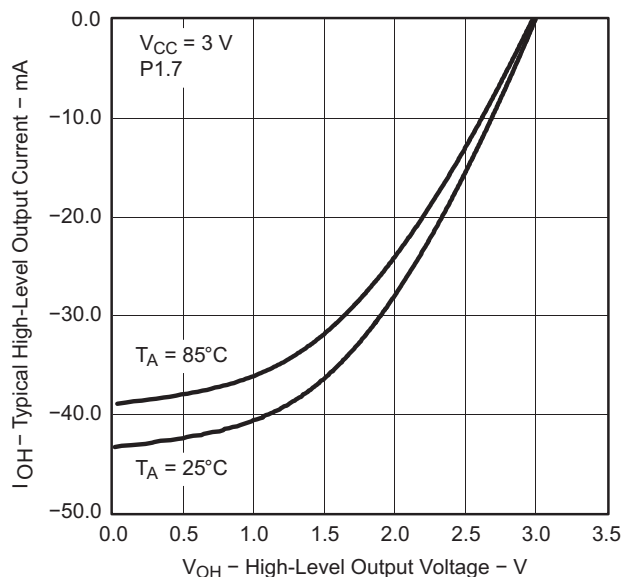


Figure 8.

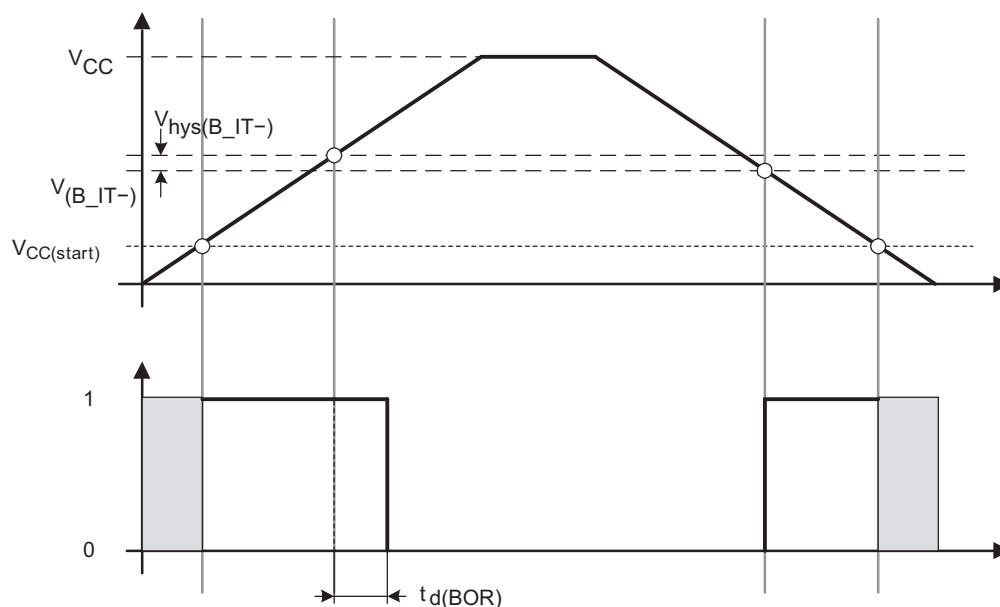
## POR/Brownout Reset (BOR)<sup>(1)</sup>

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

| PARAMETER               | TEST CONDITIONS                                                                                           | V <sub>CC</sub>              | MIN | TYP                        | MAX  | UNIT |
|-------------------------|-----------------------------------------------------------------------------------------------------------|------------------------------|-----|----------------------------|------|------|
| V <sub>CC(start)</sub>  | See Figure 9                                                                                              | dV <sub>CC</sub> /dt ≤ 3 V/s |     | 0.7 × V <sub>(B_IT-)</sub> |      | V    |
| V <sub>(B_IT-)</sub>    | See Figure 9 through Figure 11                                                                            | dV <sub>CC</sub> /dt ≤ 3 V/s |     |                            | 1.71 | V    |
| V <sub>hys(B_IT-)</sub> | See Figure 9                                                                                              | dV <sub>CC</sub> /dt ≤ 3 V/s | 70  | 155                        | 210  | mV   |
| t <sub>d(BOR)</sub>     | See Figure 9 <sup>(2)</sup>                                                                               |                              |     |                            | 2000 | μs   |
| t <sub>(reset)</sub>    | Pulse length needed at $\overline{\text{RST}}/\text{NMI}$ pin to accepted reset internally <sup>(2)</sup> | 2.2 V/3 V                    | 2   |                            |      | μs   |

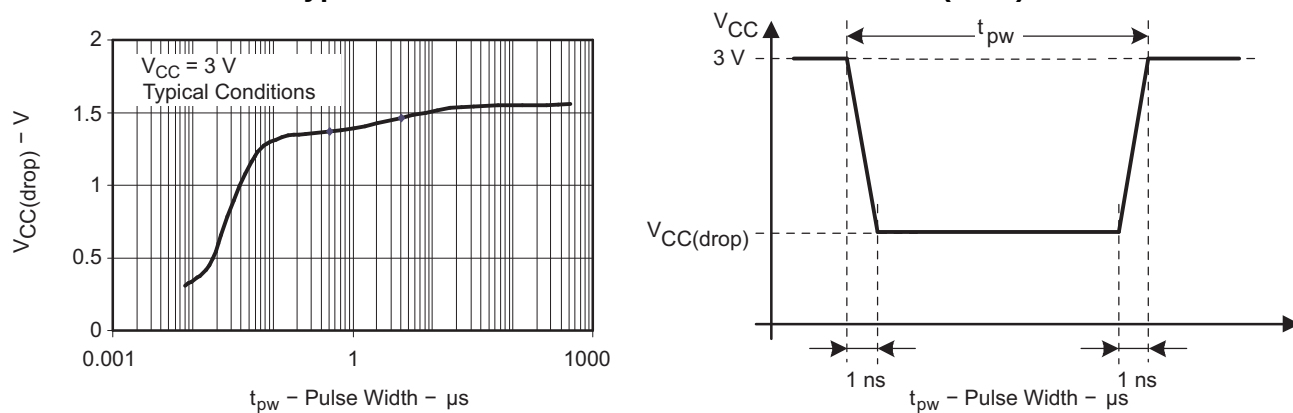
(1) The current consumption of the brownout module is already included in the I<sub>CC</sub> current consumption data. The voltage level V<sub>(B\_IT-)</sub> + V<sub>hys(B\_IT-)</sub> is ≤ 1.8 V.

(2) Minimum and maximum parameters are characterized up to T<sub>A</sub> = 105°C unless otherwise noted.

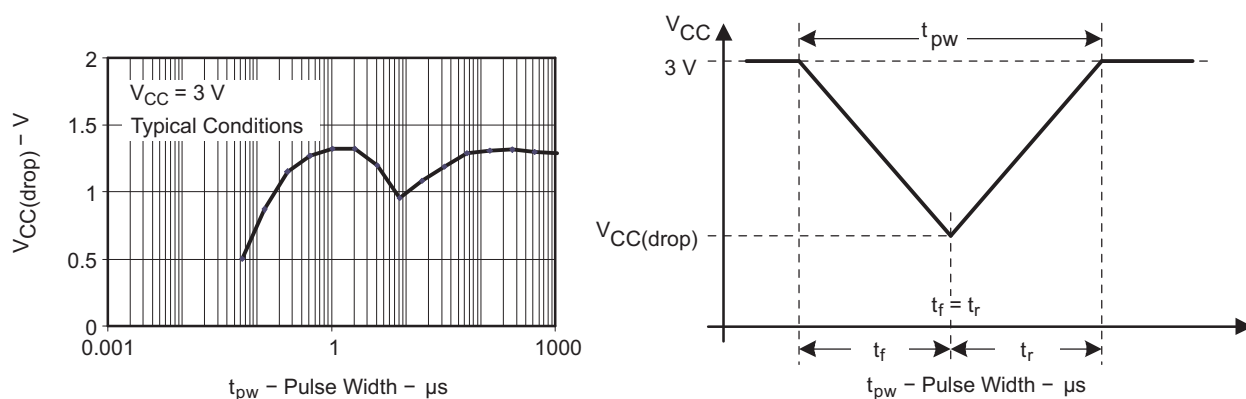


**Figure 9. POR/Brownout Reset (BOR) vs Supply Voltage**

### Typical Characteristics - POR/Brownout Reset (BOR)



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



**Figure 11.  $V_{CC(drop)}$  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<sub>DCO</sub>.
- Modulation control bits MODx select how often f<sub>DCO(RSEL,DCO+1)</sub> is used within the period of 32 DCOCLK cycles. The frequency f<sub>DCO(RSEL,DCO)</sub> 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 <sub>CC</sub> | MIN  | TYP  | MAX  | UNIT  |
|------------------------|----------------------------------------------|------------------------------------------------------------------------------|-----------------|------|------|------|-------|
| V <sub>CC</sub>        | Supply voltage                               | RSELx < 14                                                                   |                 | 1.8  |      | 3.6  | V     |
|                        |                                              | RSELx = 14                                                                   |                 | 2.2  |      | 3.6  |       |
|                        |                                              | RSELx = 15                                                                   |                 | 3.0  |      | 3.6  |       |
| f <sub>DCO(0,0)</sub>  | DCO frequency (0, 0)                         | RSELx = 0, DCOx = 0, MODx = 0                                                | 2.2 V/3 V       | 0.06 |      | 0.14 | MHz   |
| f <sub>DCO(0,3)</sub>  | DCO frequency (0, 3)                         | RSELx = 0, DCOx = 3, MODx = 0                                                | 2.2 V/3 V       | 0.07 |      | 0.17 | MHz   |
| f <sub>DCO(1,3)</sub>  | DCO frequency (1, 3)                         | RSELx = 1, DCOx = 3, MODx = 0                                                | 2.2 V/3 V       | 0.10 |      | 0.20 | MHz   |
| f <sub>DCO(2,3)</sub>  | DCO frequency (2, 3)                         | RSELx = 2, DCOx = 3, MODx = 0                                                | 2.2 V/3 V       | 0.14 |      | 0.28 | MHz   |
| f <sub>DCO(3,3)</sub>  | DCO frequency (3, 3)                         | RSELx = 3, DCOx = 3, MODx = 0                                                | 2.2 V/3 V       | 0.20 |      | 0.40 | MHz   |
| f <sub>DCO(4,3)</sub>  | DCO frequency (4, 3)                         | RSELx = 4, DCOx = 3, MODx = 0                                                | 2.2 V/3 V       | 0.28 |      | 0.54 | MHz   |
| f <sub>DCO(5,3)</sub>  | DCO frequency (5, 3)                         | RSELx = 5, DCOx = 3, MODx = 0                                                | 2.2 V/3 V       | 0.39 |      | 0.77 | MHz   |
| f <sub>DCO(6,3)</sub>  | DCO frequency (6, 3)                         | RSELx = 6, DCOx = 3, MODx = 0                                                | 2.2 V/3 V       | 0.54 |      | 1.06 | MHz   |
| f <sub>DCO(7,3)</sub>  | DCO frequency (7, 3)                         | RSELx = 7, DCOx = 3, MODx = 0                                                | 2.2 V/3 V       | 0.80 |      | 1.50 | MHz   |
| f <sub>DCO(8,3)</sub>  | DCO frequency (8, 3)                         | RSELx = 8, DCOx = 3, MODx = 0                                                | 2.2 V/3 V       | 1.10 |      | 2.10 | MHz   |
| f <sub>DCO(9,3)</sub>  | DCO frequency (9, 3)                         | RSELx = 9, DCOx = 3, MODx = 0                                                | 2.2 V/3 V       | 1.60 |      | 3.00 | MHz   |
| f <sub>DCO(10,3)</sub> | DCO frequency (10, 3)                        | RSELx = 10, DCOx = 3, MODx = 0                                               | 2.2 V/3 V       | 2.50 |      | 4.30 | MHz   |
| f <sub>DCO(11,3)</sub> | DCO frequency (11, 3)                        | RSELx = 11, DCOx = 3, MODx = 0                                               | 2.2 V/3 V       | 3.00 |      | 5.50 | MHz   |
| f <sub>DCO(12,3)</sub> | DCO frequency (12, 3)                        | RSELx = 12, DCOx = 3, MODx = 0                                               | 2.2 V/3 V       | 4.30 |      | 7.30 | MHz   |
| f <sub>DCO(13,3)</sub> | DCO frequency (13, 3)                        | RSELx = 13, DCOx = 3, MODx = 0                                               | 2.2 V/3 V       | 6.00 |      | 9.60 | MHz   |
| f <sub>DCO(14,3)</sub> | DCO frequency (14, 3)                        | RSELx = 14, DCOx = 3, MODx = 0                                               | 2.2 V/3 V       | 8.60 |      | 13.9 | MHz   |
| f <sub>DCO(15,3)</sub> | DCO frequency (15, 3)                        | RSELx = 15, DCOx = 3, MODx = 0                                               | 3 V             | 12.0 |      | 18.5 | MHz   |
| f <sub>DCO(15,7)</sub> | DCO frequency (15, 7)                        | RSELx = 15, DCOx = 7, MODx = 0                                               | 3 V             | 16.0 |      | 26.0 | MHz   |
| S <sub>RSEL</sub>      | Frequency step between range RSEL and RSEL+1 | S <sub>RSEL</sub> = f <sub>DCO(RSEL+1,DCO)</sub> /f <sub>DCO(RSEL,DCO)</sub> | 2.2 V/3 V       |      |      | 1.55 | ratio |
| S <sub>DCO</sub>       | Frequency step between tap DCO and DCO+1     | S <sub>DCO</sub> = f <sub>DCO(RSEL,DCO+1)</sub> /f <sub>DCO(RSEL,DCO)</sub>  | 2.2 V/3 V       | 1.03 | 1.08 | 1.14 |       |
|                        | 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 <sub>A</sub> | V <sub>CC</sub> | MIN   | TYP  | MAX   | UNIT |
|------------------------------------|--------------------------|------------------------------------------------------------------------|----------------|-----------------|-------|------|-------|------|
| Frequency tolerance at calibration |                          |                                                                        | 25°C           | 3 V             | -1    | ±0.2 | +1    | %    |
| f <sub>CAL(1MHz)</sub>             | 1-MHz calibration value  | BCSCTL1 = CALBC1_1MHZ,<br>DCOCTL = CALDCO_1MHZ,<br>Gating time: 5 ms   | 25°C           | 3 V             | 0.990 | 1    | 1.010 | MHz  |
| f <sub>CAL(8MHz)</sub>             | 8-MHz calibration value  | BCSCTL1 = CALBC1_8MHZ,<br>DCOCTL = CALDCO_8MHZ,<br>Gating time: 5 ms   | 25°C           | 3 V             | 7.920 | 8    | 8.080 | MHz  |
| f <sub>CAL(12MHz)</sub>            | 12-MHz calibration value | BCSCTL1 = CALBC1_12MHZ,<br>DCOCTL = CALDCO_12MHZ,<br>Gating time: 5 ms | 25°C           | 3 V             | 11.88 | 12   | 12.12 | MHz  |
| f <sub>CAL(16MHz)</sub>            | 16-MHz calibration value | BCSCTL1 = CALBC1_16MHZ,<br>DCOCTL = CALDCO_16MHZ,<br>Gating time: 2 ms | 25°C           | 3 V             | 15.84 | 16   | 16.16 | MHz  |

## Calibrated DCO Frequencies - Tolerance Over Temperature -40°C to 125°C

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

| PARAMETER                         |                          | TEST CONDITIONS                                                        | T <sub>A</sub> | V <sub>CC</sub> | MIN   | TYP   | MAX   | UNIT |
|-----------------------------------|--------------------------|------------------------------------------------------------------------|----------------|-----------------|-------|-------|-------|------|
| 1-MHz tolerance over temperature  |                          |                                                                        | -40°C to 125°C | 3 V             | -2.5  | ±1.25 | +2.5  | %    |
| 8-MHz tolerance over temperature  |                          |                                                                        | -40°C to 125°C | 3 V             | -5    | ±1.25 | +5    | %    |
| 12-MHz tolerance over temperature |                          |                                                                        | -40°C to 125°C | 3 V             | -5    | ±1.25 | +2.5  | %    |
| 16-MHz tolerance over temperature |                          |                                                                        | -40°C to 125°C | 3 V             | -6.25 | ±2.0  | +3    | %    |
| f <sub>CAL(1MHz)</sub>            | 1-MHz calibration value  | BCSCTL1 = CALBC1_1MHZ,<br>DCOCTL = CALDCO_1MHZ,<br>Gating time: 5 ms   | -40°C to 125°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 <sub>CAL(8MHz)</sub>            | 8-MHz calibration value  | BCSCTL1 = CALBC1_8MHZ,<br>DCOCTL = CALDCO_8MHZ,<br>Gating time: 5 ms   | -40°C to 125°C | 2.2 V           | 7.6   | 8     | 8.4   | MHz  |
|                                   |                          |                                                                        |                | 3 V             | 7.6   | 8     | 8.4   |      |
|                                   |                          |                                                                        |                | 3.6 V           | 7.6   | 8     | 8.4   |      |
| f <sub>CAL(12MHz)</sub>           | 12-MHz calibration value | BCSCTL1 = CALBC1_12MHZ,<br>DCOCTL = CALDCO_12MHZ,<br>Gating time: 5 ms | -40°C to 125°C | 2.2 V           | 11.6  | 12    | 12.3  | MHz  |
|                                   |                          |                                                                        |                | 3 V             | 11.6  | 12    | 12.3  |      |
|                                   |                          |                                                                        |                | 3.6 V           | 11.6  | 12    | 12.3  |      |
| f <sub>CAL(16MHz)</sub>           | 16-MHz calibration value | BCSCTL1 = CALBC1_16MHZ,<br>DCOCTL = CALDCO_16MHZ,<br>Gating time: 2 ms | -40°C to 125°C | 3 V             | 15    | 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)

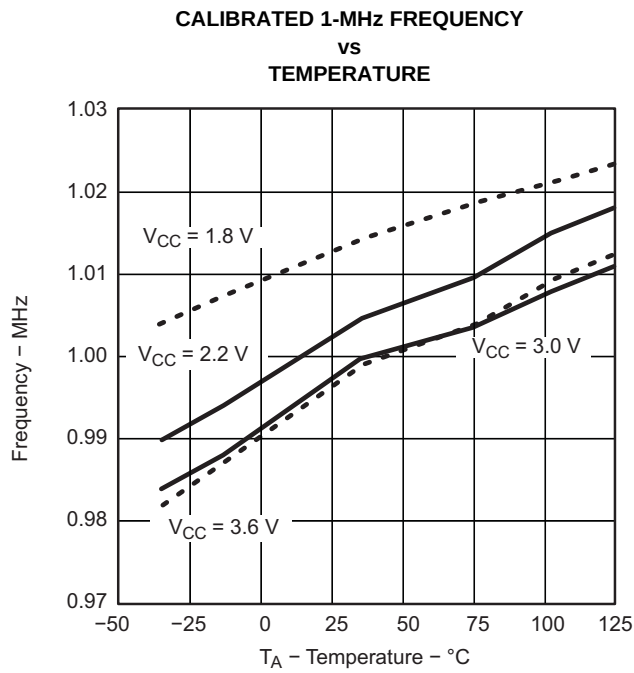
| PARAMETER                                 | TEST CONDITIONS                                                        | $T_A$ | $V_{CC}$       | MIN   | TYP | MAX   | UNIT |
|-------------------------------------------|------------------------------------------------------------------------|-------|----------------|-------|-----|-------|------|
| 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 | -4    | ±2  | +3    | %    |
| 16-MHz tolerance over $V_{CC}$            |                                                                        | 25°C  | 3 V to 3.6 V   | -6.25 | ±2  | +3    | %    |
| $f_{CAL(1MHz)}$ 1-MHz calibration value   | BCSCTL1 = CALBC1_1MHZ,<br>DCOCTL = CALDCO_1MHZ,<br>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,<br>DCOCTL = CALDCO_8MHZ,<br>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,<br>DCOCTL = CALDCO_12MHZ,<br>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,<br>DCOCTL = CALDCO_16MHZ,<br>Gating time: 2 ms | 25°C  | 3 V to 3.6 V   | 15    | 16  | 16.48 | MHz  |

## Calibrated DCO Frequencies - Overall Tolerance

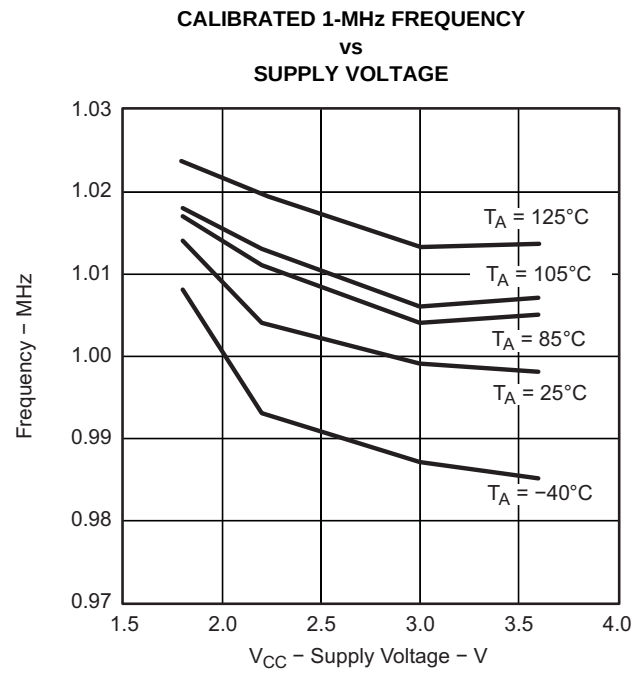
over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

| PARAMETER                                 | TEST CONDITIONS                                                        | $V_{CC}$       | MIN   | TYP  | MAX   | UNIT |
|-------------------------------------------|------------------------------------------------------------------------|----------------|-------|------|-------|------|
| 1-MHz tolerance overall                   |                                                                        | 1.8 V to 3.6 V | -5    | ±2.5 | +5    | %    |
| 8-MHz tolerance overall                   |                                                                        | 1.8 V to 3.6 V | -5    | ±2.5 | +5    | %    |
| 12-MHz tolerance overall                  |                                                                        | 2.2 V to 3.6 V | -5    | ±2.5 | +5    | %    |
| 16-MHz tolerance overall                  |                                                                        | 3 V to 3.6 V   | -6.25 | ±3   | +6.25 | %    |
| $f_{CAL(1MHz)}$ 1-MHz calibration value   | BCSCTL1 = CALBC1_1MHZ,<br>DCOCTL = CALDCO_1MHZ,<br>Gating time: 5 ms   | 1.8 V to 3.6 V | 0.95  | 1    | 1.05  | MHz  |
| $f_{CAL(8MHz)}$ 8-MHz calibration value   | BCSCTL1 = CALBC1_8MHZ,<br>DCOCTL = CALDCO_8MHZ,<br>Gating time: 5 ms   | 1.8 V to 3.6 V | 7.6   | 8    | 8.4   | MHz  |
| $f_{CAL(12MHz)}$ 12-MHz calibration value | BCSCTL1 = CALBC1_12MHZ,<br>DCOCTL = CALDCO_12MHZ,<br>Gating time: 5 ms | 2.2 V to 3.6 V | 11.4  | 12   | 12.6  | MHz  |
| $f_{CAL(16MHz)}$ 16-MHz calibration value | BCSCTL1 = CALBC1_16MHZ,<br>DCOCTL = CALDCO_16MHZ,<br>Gating time: 2 ms | 3 V to 3.6 V   | 15    | 16   | 17    | MHz  |

# **Typical Characteristics - Calibrated 1-MHz DCO Frequency**



**Figure 12.**



**Figure 13.**

## Wake-Up From Lower-Power Modes (LPM3/4)<sup>(1)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$

| PARAMETER                                                                 | TEST CONDITIONS                                  | $V_{CC}$  | MIN | TYP                                             | MAX | UNIT          |
|---------------------------------------------------------------------------|--------------------------------------------------|-----------|-----|-------------------------------------------------|-----|---------------|
| $t_{\text{DCO,LPM3/4}}$ DCO clock wake-up time from LPM3/4 <sup>(2)</sup> | BCSCTL1 = CALBC1_1MHZ,<br>DCOCTL = CALDCO_1MHZ   | 2.2 V/3 V |     |                                                 | 2   | $\mu\text{s}$ |
|                                                                           | BCSCTL1 = CALBC1_8MHZ,<br>DCOCTL = CALDCO_8MHZ   |           |     |                                                 | 1.5 |               |
|                                                                           | BCSCTL1 = CALBC1_12MHZ,<br>DCOCTL = CALDCO_12MHZ |           |     |                                                 | 1   |               |
|                                                                           | BCSCTL1 = CALBC1_16MHZ,<br>DCOCTL = CALDCO_16MHZ | 3 V       |     |                                                 | 1   |               |
| $t_{\text{CPU,LPM3/4}}$ CPU wake-up time from LPM3/4 <sup>(3)</sup>       |                                                  |           |     | $1 / f_{\text{MCLK}} + t_{\text{Clock,LPM3/4}}$ |     |               |

- (1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.  
 (2) The DCO clock wake-up time is measured from the edge of an external wake-up signal (for example, port interrupt) to the first clock edge observable externally on a clock pin (MCLK or SMCLK).  
 (3) Parameter applicable only if DCOCLK is used for MCLK.

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

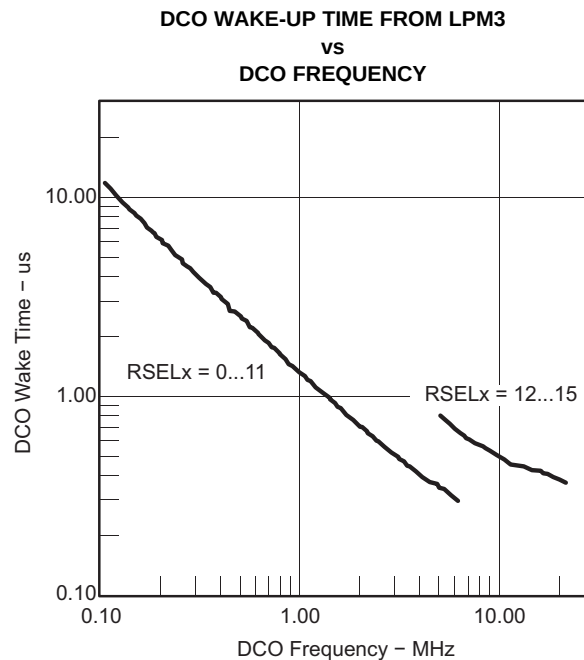


Figure 14.

## Crystal Oscillator, XT1, Low-Frequency Mode<sup>(1)(2)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$

| PARAMETER                   | TEST CONDITIONS                                                   | V <sub>CC</sub>                                                                    | MIN       | TYP   | MAX   | UNIT |    |
|-----------------------------|-------------------------------------------------------------------|------------------------------------------------------------------------------------|-----------|-------|-------|------|----|
| f <sub>LFXT1,LF</sub>       | LFXT1 oscillator crystal frequency, LF mode 0, 1                  | 1.8 V to 3.6 V                                                                     | 32768     |       |       | Hz   |    |
| f <sub>LFXT1,LF,logic</sub> | LFXT1 oscillator logic level square wave input frequency, LF mode | 1.8 V to 3.6 V                                                                     | 10000     | 32768 | 50000 | Hz   |    |
| OA <sub>LF</sub>            | Oscillation allowance for LF crystals                             | XTS = 0, LFXT1Sx = 0, f <sub>LFXT1,LF</sub> = 32768 Hz, C <sub>L,eff</sub> = 6 pF  | 500       |       |       | kΩ   |    |
|                             |                                                                   | XTS = 0, LFXT1Sx = 0, f <sub>LFXT1,LF</sub> = 32768 Hz, C <sub>L,eff</sub> = 12 pF | 200       |       |       |      |    |
| C <sub>L,eff</sub>          | Integrated effective load capacitance, LF mode <sup>(3)</sup>     | 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 P1.0/ACLK, f <sub>LFXT1,LF</sub> = 32768 Hz                   | 2.2 V/3 V | 30    | 50    | 70   | %  |
| f <sub>Fault,LF</sub>       | Oscillator fault frequency, LF mode <sup>(4)</sup>                | XTS = 0, LFXT1Sx = 3 <sup>(5)</sup>                                                | 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/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) Crystal oscillator cannot be operated beyond  $105^\circ\text{C}$ . Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.
- (3) Includes parasitic bond and package capacitance (approximately 2 pF per pin).  
Since 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.
- (4) 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.
- (5) 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 |
|--------------------|---------------------------------------------------|----------------|----------------|------|-----|------|
| $f_{VLO}$          | -40°C to 85°C                                     | 2.2 V/3 V      | 4              | 12   | 20  | kHz  |
|                    | 125°C                                             |                |                |      | 22  |      |
| $df_{VLO}/dT$      | VLO frequency temperature drift <sup>(1)</sup>    | -40°C to 125°C | 2.2 V/3 V      | 0.68 |     | %/°C |
| $df_{VLO}/dV_{CC}$ | VLO frequency supply voltage drift <sup>(2)</sup> | 25°C           | 1.8 V to 3.6 V | 4    |     | %/V  |

- (1) Calculated using the box method:  
(MAX(-40 to 125°C) - MIN(-40 to 125°C)) / MIN(-40 to 125°C) / (125°C - (-40°C))
- (2) Calculated using the box method: (MAX(1.8 to 3.6 V) - MIN(1.8 to 3.6 V)) / MIN(1.8 to 3.6 V) / (3.6 V - 1.8 V)

## Timer\_A

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$

| PARAMETER    | TEST CONDITIONS                                                               | $V_{CC}$ | MIN       | TYP | MAX | UNIT |
|--------------|-------------------------------------------------------------------------------|----------|-----------|-----|-----|------|
| $f_{TA}$     | Internal: SMCLK, ACLK<br>External: TACLK, INCLK<br>Duty cycle = 50% $\pm$ 10% | 2.2 V    |           |     | 10  | MHz  |
|              |                                                                               | 3 V      |           |     | 16  |      |
| $t_{TA,cap}$ | Timer_A capture timing <sup>(1)</sup>                                         | TA0, TA1 | 2.2 V/3 V | 20  |     | ns   |

- (1) Parameter characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

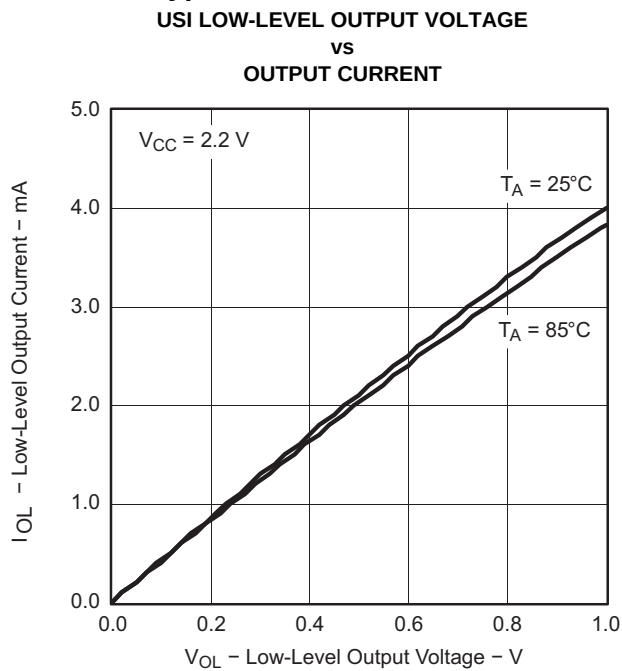
## USI, Universal Serial Interface<sup>(1)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$

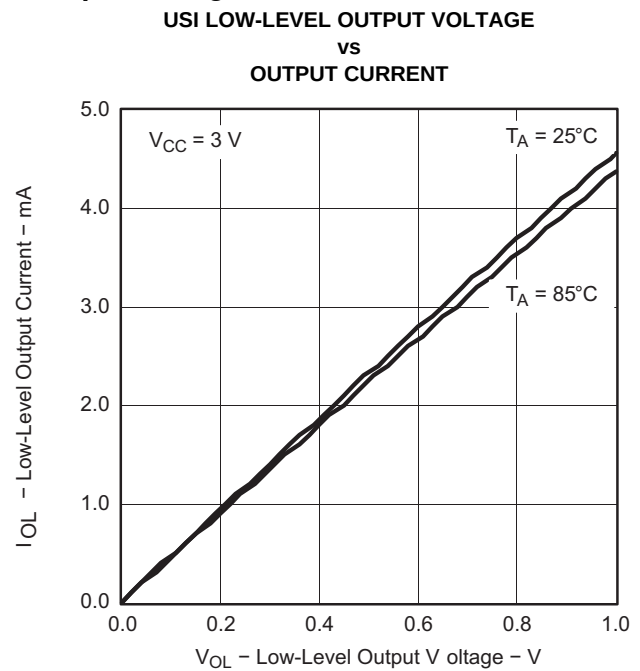
| PARAMETER                                            | TEST CONDITIONS                                                  | $V_{CC}$  | MIN      | TYP | MAX            | UNIT |
|------------------------------------------------------|------------------------------------------------------------------|-----------|----------|-----|----------------|------|
| $f_{USI}$ USI clock frequency                        | External: SCLK,<br>Duty cycle = 50% $\pm$ 10%,<br>SPI slave mode | 2.2 V     |          |     | 10             | MHz  |
|                                                      |                                                                  | 3 V       |          |     | 16             |      |
| $V_{OL,I2C}$ Low-level output voltage on SDA and SCL | USI module in I2C mode,<br>$I_{OL(max)} = 1.5\text{ mA}$         | 2.2 V/3 V | $V_{SS}$ |     | $V_{SS} + 0.4$ | V    |

(1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

### Typical Characteristics, USI Low-Level Output Voltage on SDA and SCL



**Figure 15.**



**Figure 16.**

## SD16\_A, Power Supply and Recommended Operating Conditions<sup>(1)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$ 

| PARAMETER         |                                                    | TEST CONDITIONS                                                                                                        |              | T <sub>A</sub> | V <sub>CC</sub> | MIN  | TYP | MAX  | UNIT |
|-------------------|----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|--------------|----------------|-----------------|------|-----|------|------|
| AV <sub>CC</sub>  | Analog supply voltage range                        | AV <sub>CC</sub> = DV <sub>CC</sub> = V <sub>CC</sub> ,<br>AV <sub>SS</sub> = DV <sub>SS</sub> = V <sub>SS</sub> = 0 V |              |                |                 | 2.5  |     | 3.6  | V    |
| I <sub>SD16</sub> | Analog supply current including internal reference | SD16LP = 0,<br>f <sub>SD16</sub> = 1 MHz,<br>SD16OSR = 256                                                             | GAIN: 1,2    | -40°C to 85°C  | 3 V             | 730  |     | 1050 | μA   |
|                   |                                                    |                                                                                                                        |              | 105°C          |                 | 1170 |     |      |      |
|                   |                                                    |                                                                                                                        | GAIN: 4,8,16 | -40°C to 85°C  |                 | 810  |     | 1150 |      |
|                   |                                                    |                                                                                                                        |              | 105°C          |                 | 1300 |     |      |      |
|                   |                                                    |                                                                                                                        | GAIN: 32     | -40°C to 85°C  |                 | 1160 |     | 1700 |      |
|                   |                                                    |                                                                                                                        |              | 105°C          |                 | 1850 |     |      |      |
|                   |                                                    | SD16LP = 1,<br>f <sub>SD16</sub> = 0.5 MHz,<br>SD16OSR = 256                                                           | GAIN: 1      | -40°C to 85°C  |                 | 720  |     | 1030 |      |
|                   |                                                    |                                                                                                                        |              | 105°C          |                 | 1160 |     |      |      |
|                   |                                                    |                                                                                                                        | GAIN: 32     | -40°C to 85°C  |                 | 810  |     | 1150 |      |
|                   |                                                    |                                                                                                                        |              | 105°C          |                 | 1300 |     |      |      |
| f <sub>SD16</sub> | SD16 input clock frequency                         | SD16LP = 0<br>(Low power mode disabled)                                                                                |              | 3 V            | 0.03            | 1    | 1.1 | MHz  |      |
|                   |                                                    | SD16LP = 1<br>(Low power mode enabled)                                                                                 |              |                | 0.03            | 0.5  |     |      |      |

(1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

## SD16\_A, Input Range<sup>(1)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$ 

| PARAMETER           |                                                                           | TEST CONDITIONS            |                | V <sub>CC</sub> | MIN                         | TYP | MAX                         | UNIT |
|---------------------|---------------------------------------------------------------------------|----------------------------|----------------|-----------------|-----------------------------|-----|-----------------------------|------|
| V <sub>ID,FSR</sub> | Differential full scale input voltage range <sup>(2)</sup>                | Bipolar mode, SD16UNI = 0  |                |                 | -(V <sub>REF</sub> /2)/GAIN |     | +(V <sub>REF</sub> /2)/GAIN | mV   |
|                     |                                                                           | Unipolar mode, SD16UNI = 1 |                |                 | 0                           |     | +(V <sub>REF</sub> /2)/GAIN |      |
| V <sub>ID</sub>     | Differential input voltage range for specified performance <sup>(2)</sup> | SD16REFON = 1              | SD16GAINx = 1  |                 | ±500                        |     | mV                          |      |
|                     |                                                                           |                            | SD16GAINx = 2  |                 | ±250                        |     |                             |      |
|                     |                                                                           |                            | SD16GAINx = 4  |                 | ±125                        |     |                             |      |
|                     |                                                                           |                            | SD16GAINx = 8  |                 | ±62                         |     |                             |      |
|                     |                                                                           |                            | SD16GAINx = 16 |                 | ±31                         |     |                             |      |
|                     |                                                                           |                            | SD16GAINx = 32 |                 | ±15                         |     |                             |      |
| Z <sub>I</sub>      | Input impedance (one input pin to AV <sub>SS</sub> )                      | f <sub>SD16</sub> = 1 MHz  | SD16GAINx = 1  | 3 V             | 200                         |     | kΩ                          |      |
|                     |                                                                           |                            | SD16GAINx = 32 |                 | 75                          |     |                             |      |
| Z <sub>ID</sub>     | Differential input impedance (IN+ to IN-)                                 | f <sub>SD16</sub> = 1 MHz  | SD16GAINx = 1  | 3 V             | 300                         | 400 | kΩ                          |      |
|                     |                                                                           |                            | SD16GAINx = 32 |                 | 100                         | 150 |                             |      |
| V <sub>I</sub>      | Absolute input voltage range                                              |                            |                |                 | AV <sub>SS</sub> - 0.1      |     | AV <sub>CC</sub>            | V    |
| V <sub>IC</sub>     | Common-mode input voltage range                                           |                            |                |                 | AV <sub>SS</sub> - 0.1      |     | AV <sub>CC</sub>            | V    |

(1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

(2) The analog input range depends on the reference voltage applied to  $V_{REF}$ . If  $V_{REF}$  is sourced externally, the full-scale range is defined by  $V_{FSR+} = +(V_{REF}/2)/\text{GAIN}$  and  $V_{FSR-} = -(V_{REF}/2)/\text{GAIN}$ . The analog input range should not exceed 80% of  $V_{FSR+}$  or  $V_{FSR-}$ .

**SD16\_A, SINAD Performance ( $f_{SD16} = 1$  MHz, SD16OSRx = 1024, SD16REFON = 1)<sup>(1)</sup>**

 over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$ 

| PARAMETER                                                             | TEST CONDITIONS                                                                               | $V_{CC}$ | MIN | TYP | UNIT |
|-----------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|----------|-----|-----|------|
| SINAD <sub>1024</sub> Signal-to-noise + distortion ratio (OSR = 1024) | SD16GAINx = 1,<br>Signal amplitude: $V_{IN} = 500$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz | 3 V      | 86  | 87  | dB   |
|                                                                       | SD16GAINx = 2,<br>Signal amplitude: $V_{IN} = 250$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz |          | 82  | 83  |      |
|                                                                       | SD16GAINx = 4,<br>Signal amplitude: $V_{IN} = 125$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz |          | 78  | 79  |      |
|                                                                       | SD16GAINx = 8,<br>Signal amplitude: $V_{IN} = 62$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz  |          | 73  | 74  |      |
|                                                                       | SD16GAINx = 16,<br>Signal amplitude: $V_{IN} = 31$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz |          | 68  | 69  |      |
|                                                                       | SD16GAINx = 32,<br>Signal amplitude: $V_{IN} = 15$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz |          | 62  | 63  |      |

 (1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

**SD16\_A, SINAD Performance ( $f_{SD16} = 1$  MHz, SD16OSRx = 256, SD16REFON = 1)<sup>(1)</sup>**

 over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$ 

| PARAMETER                                                           | TEST CONDITIONS                                                                               | $V_{CC}$ | MIN | TYP | UNIT |
|---------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|----------|-----|-----|------|
| SINAD <sub>256</sub> Signal-to-noise + distortion ratio (OSR = 256) | SD16GAINx = 1,<br>Signal amplitude: $V_{IN} = 500$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz | 3 V      | 82  | 83  | dB   |
|                                                                     | SD16GAINx = 2,<br>Signal amplitude: $V_{IN} = 250$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz |          | 76  | 77  |      |
|                                                                     | SD16GAINx = 4,<br>Signal amplitude: $V_{IN} = 125$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz |          | 71  | 72  |      |
|                                                                     | SD16GAINx = 8,<br>Signal amplitude: $V_{IN} = 62$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz  |          | 67  | 68  |      |
|                                                                     | SD16GAINx = 16,<br>Signal amplitude: $V_{IN} = 31$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz |          | 63  | 64  |      |
|                                                                     | SD16GAINx = 32,<br>Signal amplitude: $V_{IN} = 15$ mV,<br>Signal frequency: $f_{IN} = 100$ Hz |          | 57  | 58  |      |

 (1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

## Typical Characteristics, SD16\_A SINAD Performance Over OSR

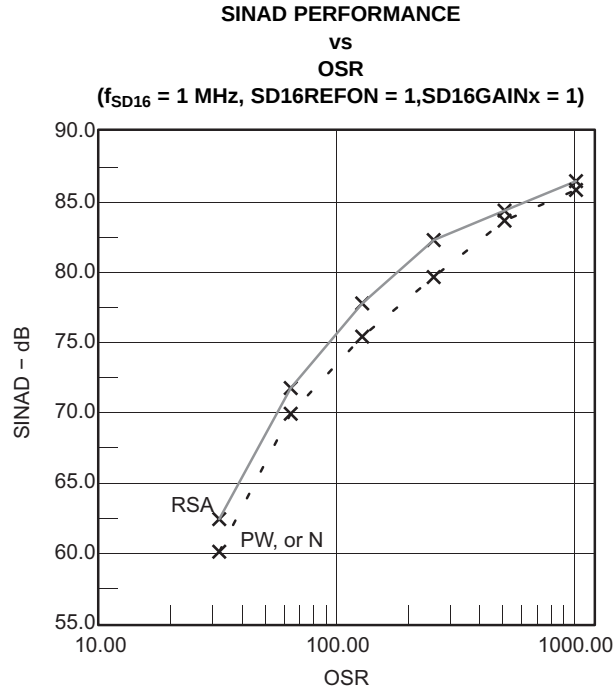


Figure 17.

### SD16\_A, Performance ( $f_{SD16} = 1 \text{ MHz}$ , $SD16OSRx = 256$ , $SD16REFON = 1$ )<sup>(1)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$

| PARAMETER            |                                      | TEST CONDITIONS                                                                                          | V <sub>CC</sub> | MIN           | TYP   | MAX   | UNIT       |
|----------------------|--------------------------------------|----------------------------------------------------------------------------------------------------------|-----------------|---------------|-------|-------|------------|
| G                    | Nominal gain                         | SD16GAINx = 1                                                                                            | 3 V             | 0.97          | 1.00  | 1.02  |            |
|                      |                                      | SD16GAINx = 2                                                                                            |                 | 1.90          | 1.96  | 2.02  |            |
|                      |                                      | SD16GAINx = 4                                                                                            |                 | 3.76          | 3.86  | 3.96  |            |
|                      |                                      | SD16GAINx = 8                                                                                            |                 | 7.36          | 7.62  | 7.84  |            |
|                      |                                      | SD16GAINx = 16                                                                                           |                 | 14.56         | 15.04 | 15.52 |            |
|                      |                                      | SD16GAINx = 32                                                                                           |                 | 27.20         | 28.35 | 29.76 |            |
| ΔG/ΔT                | Gain temperature drift               | SD16GAINx = 1 <sup>(2)</sup>                                                                             | 3 V             | 15            |       |       | ppm/°C     |
| E <sub>OS</sub>      | Offset error                         | SD16GAINx = 1                                                                                            | 3 V             | ±0.2          |       |       | %FSR       |
|                      |                                      | SD16GAINx = 32                                                                                           |                 | ±1.5          |       |       |            |
| ΔE <sub>OS</sub> /ΔT | Offset error temperature coefficient | SD16GAINx = 1                                                                                            | 3 V             | ±4      ±20   |       |       | ppm FSR/°C |
|                      |                                      | SD16GAINx = 32                                                                                           |                 | ±20      ±100 |       |       |            |
| CMRR                 | Common-mode rejection ratio          | SD16GAINx = 1,<br>Common-mode input signal:<br>V <sub>ID</sub> = 500 mV, f <sub>IN</sub> = 50 Hz, 100 Hz | 3 V             | >90           |       |       | dB         |
|                      |                                      | SD16GAINx = 32,<br>Common-mode input signal:<br>V <sub>ID</sub> = 16 mV, f <sub>IN</sub> = 50 Hz, 100 Hz |                 | >75           |       |       |            |
| DC PSR               | DC power supply rejection            | SD16GAINx = 1, V <sub>IN</sub> = 500 mV,<br>V <sub>CC</sub> = 2.5 V to 3.6 V <sup>(3)</sup>              | 2.5 V to 3.6 V  | 0.35          |       |       | %/V        |
| AC PSRR              | AC power supply rejection ratio      | SD16GAINx = 1,<br>V <sub>CC</sub> = 3 V ± 100 mV, f <sub>IN</sub> = 50 Hz                                | 3 V             | >80           |       |       | dB         |

(1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

(2) Calculated using the box method:  $(\text{MAX}(-40^\circ\text{C to } 85^\circ\text{C}) - \text{MIN}(-40^\circ\text{C to } 85^\circ\text{C})) / \text{MIN}(-40^\circ\text{C to } 85^\circ\text{C}) / (85^\circ\text{C} - (-40^\circ\text{C}))$

(3) Calculated using the ADC output code and the box method:

$(\text{MAX-code}(2.5 \text{ V to } 3.6 \text{ V}) - \text{MIN-code}(2.5 \text{ V to } 3.6 \text{ V})) / \text{MIN-code}(2.5 \text{ V to } 3.6 \text{ V}) / (3.6 \text{ V} - 2.5 \text{ V})$

### SD16\_A, Built-In Voltage Reference<sup>(1)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$

| PARAMETER                                                          | TEST CONDITIONS                                                | $T_A$         | $V_{CC}$       | MIN  | TYP  | MAX  | UNIT            |
|--------------------------------------------------------------------|----------------------------------------------------------------|---------------|----------------|------|------|------|-----------------|
| $V_{REF}$ Internal reference voltage                               | SD16REFON = 1,<br>SD16VMIDON = 0                               |               | 3 V            | 1.14 | 1.20 | 1.26 | V               |
| $I_{REF}$ Reference supply current                                 | SD16REFON = 1,<br>SD16VMIDON = 0                               | -40°C to 85°C | 3 V            |      | 190  | 280  | $\mu\text{A}$   |
|                                                                    |                                                                | 105°C         | 3 V            |      |      | 295  |                 |
| TC Temperature coefficient                                         | SD16REFON = 1,<br>SD16VMIDON = 0                               |               | 3 V            |      | 18   | 50   | ppm/°C          |
| $C_{REF}$ $V_{REF}$ load capacitance                               | SD16REFON = 1,<br>SD16VMIDON = 0 <sup>(2)</sup>                |               |                |      | 100  |      | nF              |
| $I_{LOAD}$ $V_{REF(I)}$ maximum load current                       | SD16REFON = 1,<br>SD16VMIDON = 0                               |               | 3 V            |      |      | ±200 | nA              |
| $t_{ON}$ Turn-on time                                              | SD16REFON = 0 → 1,<br>SD16VMIDON = 0,<br>$C_{REF} = 100$ nF    |               | 3 V            |      | 5    |      | ms              |
| DC PSR DC power supply rejection<br>$\Delta V_{REF}/\Delta V_{CC}$ | SD16REFON = 1,<br>SD16VMIDON = 0,<br>$V_{CC} = 2.5$ V to 3.6 V |               | 2.5 V to 3.6 V |      | 100  |      | $\mu\text{V/V}$ |

(1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

(2) There is no capacitance required on  $V_{REF}$ . However, a capacitance of at least 100 nF is recommended to reduce any reference voltage noise.

### SD16\_A, Reference Output Buffer<sup>(1)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$

| PARAMETER                                                                  | TEST CONDITIONS                                             | $T_A$         | $V_{CC}$ | MIN | TYP | MAX | UNIT          |
|----------------------------------------------------------------------------|-------------------------------------------------------------|---------------|----------|-----|-----|-----|---------------|
| $V_{REF,BUF}$ Reference buffer output voltage                              | SD16REFON = 1,<br>SD16VMIDON = 1                            |               | 3 V      |     | 1.2 |     | V             |
| $I_{REF,BUF}$ Reference supply + reference output buffer quiescent current | SD16REFON = 1,<br>SD16VMIDON = 1                            | -40°C to 85°C | 3 V      |     | 385 | 600 | $\mu\text{A}$ |
|                                                                            |                                                             | 105°C         |          |     |     | 660 |               |
| $C_{REF(O)}$ Required load capacitance on $V_{REF}$                        | SD16REFON = 1,<br>SD16VMIDON = 1                            |               |          | 470 |     |     | nF            |
| $I_{LOAD,Max}$ Maximum load current on $V_{REF}$                           | SD16REFON = 1,<br>SD16VMIDON = 1                            |               | 3 V      |     |     | ±1  | mA            |
| Maximum voltage variation vs load current                                  | $ I_{LOAD}  = 0$ to 1 mA                                    |               | 3 V      | -15 |     | +15 | mV            |
| $t_{ON}$ Turn on time                                                      | SD16REFON = 0 → 1,<br>SD16VMIDON = 1,<br>$C_{REF} = 470$ nF |               | 3 V      |     | 100 |     | $\mu\text{s}$ |

(1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

### SD16\_A, External Reference Input<sup>(1)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$

| PARAMETER                        | TEST CONDITIONS | $V_{CC}$ | MIN | TYP  | MAX | UNIT |
|----------------------------------|-----------------|----------|-----|------|-----|------|
| $V_{REF(I)}$ Input voltage range | SD16REFON = 0   | 3 V      | 1   | 1.25 | 1.5 | V    |
| $I_{REF(I)}$ Input current       | SD16REFON = 0   | 3 V      |     |      | 50  | nA   |

(1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

## SD16\_A, Temperature Sensor<sup>(1)(2)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$

| PARAMETER                                                | TEST CONDITIONS                                        | $V_{CC}$ | MIN  | TYP  | MAX  | UNIT                 |
|----------------------------------------------------------|--------------------------------------------------------|----------|------|------|------|----------------------|
| $TC_{\text{Sensor}}$ Sensor temperature coefficient      |                                                        |          | 1.18 | 1.32 | 1.46 | mV/ $^\circ\text{C}$ |
| $V_{\text{Offset, Sensor}}$ Sensor offset voltage        |                                                        |          | -100 |      | 100  | mV                   |
| $V_{\text{Sensor}}$ Sensor output voltage <sup>(3)</sup> | Temperature sensor voltage at $T_A = 85^\circ\text{C}$ | 3 V      | 435  | 475  | 515  | mV                   |
|                                                          | Temperature sensor voltage at $T_A = 25^\circ\text{C}$ |          | 355  | 395  | 435  |                      |
|                                                          | Temperature sensor voltage at $T_A = 0^\circ\text{C}$  |          | 320  | 360  | 400  |                      |

(1) Values are not based on calculations using  $TC_{\text{Sensor}}$  or  $V_{\text{Offset, sensor}}$  but on measurements.

(2) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

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

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

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

## Flash Memory<sup>(1)(2)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$

| PARAMETER                                                                    | TEST CONDITIONS                                     | $V_{CC}$    | MIN    | TYP    | MAX | UNIT             |
|------------------------------------------------------------------------------|-----------------------------------------------------|-------------|--------|--------|-----|------------------|
| $V_{CC(\text{PGM/ERASE})}$ Program and erase supply voltage                  |                                                     |             | 2.2    |        | 3.6 | V                |
| $f_{\text{FTG}}$ Flash timing generator frequency                            |                                                     |             | 257    |        | 476 | kHz              |
| $I_{\text{PGM}}$ Supply current from $V_{CC}$ during program                 |                                                     | 2.2 V/3.6 V |        | 1      | 5   | mA               |
| $I_{\text{ERASE}}$ Supply current from $V_{CC}$ during erase                 |                                                     | 2.2 V/3.6 V |        | 1      | 7   | mA               |
| $t_{\text{CPT}}$ Cumulative program time <sup>(3)</sup>                      |                                                     | 2.2 V/3.6 V |        |        | 10  | ms               |
| $t_{\text{CMERASE}}$ Cumulative mass erase time                              |                                                     | 2.2 V/3.6 V | 20     |        |     | ms               |
| Program/erase endurance                                                      | $-40^\circ\text{C} \leq T_J \leq 105^\circ\text{C}$ |             | $10^4$ | $10^5$ |     | cycles           |
| $t_{\text{Retention}}$ Data retention duration                               | $T_J = 25^\circ\text{C}$                            |             | 100    |        |     | years            |
| $t_{\text{Word}}$ Word or byte program time                                  | See <sup>(4)</sup>                                  |             |        | 30     |     | $t_{\text{FTG}}$ |
| $t_{\text{Block, 0}}$ Block program time for first byte or word              | See <sup>(4)</sup>                                  |             |        | 25     |     | $t_{\text{FTG}}$ |
| $t_{\text{Block, 1-63}}$ Block program time for each additional byte or word | See <sup>(4)</sup>                                  |             |        | 18     |     | $t_{\text{FTG}}$ |
| $t_{\text{Block, End}}$ Block program end-sequence wait time                 | See <sup>(4)</sup>                                  |             |        | 6      |     | $t_{\text{FTG}}$ |
| $t_{\text{Mass Erase}}$ Mass erase time                                      | See <sup>(4)</sup>                                  |             |        | 10593  |     | $t_{\text{FTG}}$ |
| $t_{\text{Seg Erase}}$ Segment erase time                                    | See <sup>(4)</sup>                                  |             |        | 4819   |     | $t_{\text{FTG}}$ |

(1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

(2) Additional flash retention documentation located in application report (SLAA392).

(3) 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.

(4) These values are hardwired into the Flash Controller's state machine ( $t_{\text{FTG}} = 1/f_{\text{FTG}}$ ).

## RAM<sup>(1)</sup>

over recommended ranges of supply voltage and up to operating free-air temperature  $T_A = 105^\circ\text{C}$

| PARAMETER                                                       | TEST CONDITIONS | MIN | MAX | UNIT |
|-----------------------------------------------------------------|-----------------|-----|-----|------|
| $V_{(\text{RAMh})}$ RAM retention supply voltage <sup>(2)</sup> | CPU halted      | 1.6 |     | V    |

(1) Parameters are characterized up to  $T_A = 105^\circ\text{C}$  unless otherwise noted.

(2) 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             |                                                                                       | V <sub>CC</sub> | MIN   | TYP | MAX | UNIT |
|-----------------------|---------------------------------------------------------------------------------------|-----------------|-------|-----|-----|------|
| f <sub>SBW</sub>      | Spy-Bi-Wire input frequency                                                           | 2.2 V/3 V       | 0     |     | 20  | MHz  |
| t <sub>SBW,Low</sub>  | Spy-Bi-Wire low clock pulse length <sup>(1)</sup>                                     | 2.2 V/3 V       | 0.025 |     | 15  | μs   |
| t <sub>SBW,En</sub>   | Spy-Bi-Wire enable time (TEST high to acceptance of first clock edge <sup>(2)</sup> ) | 2.2 V/3 V       |       |     | 1   | μs   |
| t <sub>SBW,Ret</sub>  | Spy-Bi-Wire return to normal operation time                                           | 2.2 V/3 V       | 15    |     | 100 | μs   |
| f <sub>TCK</sub>      | TCK input frequency <sup>(3)</sup>                                                    | 2.2 V           | 0     |     | 5   | MHz  |
|                       |                                                                                       | 3 V             | 0     |     | 10  | MHz  |
| R <sub>Internal</sub> | Internal pulldown resistance on TEST                                                  | 2.2 V/3 V       | 25    | 60  | 90  | kΩ   |

(1) Parameters are characterized up to T<sub>A</sub> = 105°C unless otherwise noted.

(2) Tools accessing the Spy-Bi-Wire interface need to wait for the maximum t<sub>SBW,En</sub> time after pulling the TEST/SBWCLK pin high before applying the first SBWCLK clock edge.

(3) f<sub>TCK</sub> may be restricted to meet the timing requirements of the module selected.

## JTAG Fuse<sup>(1)</sup>

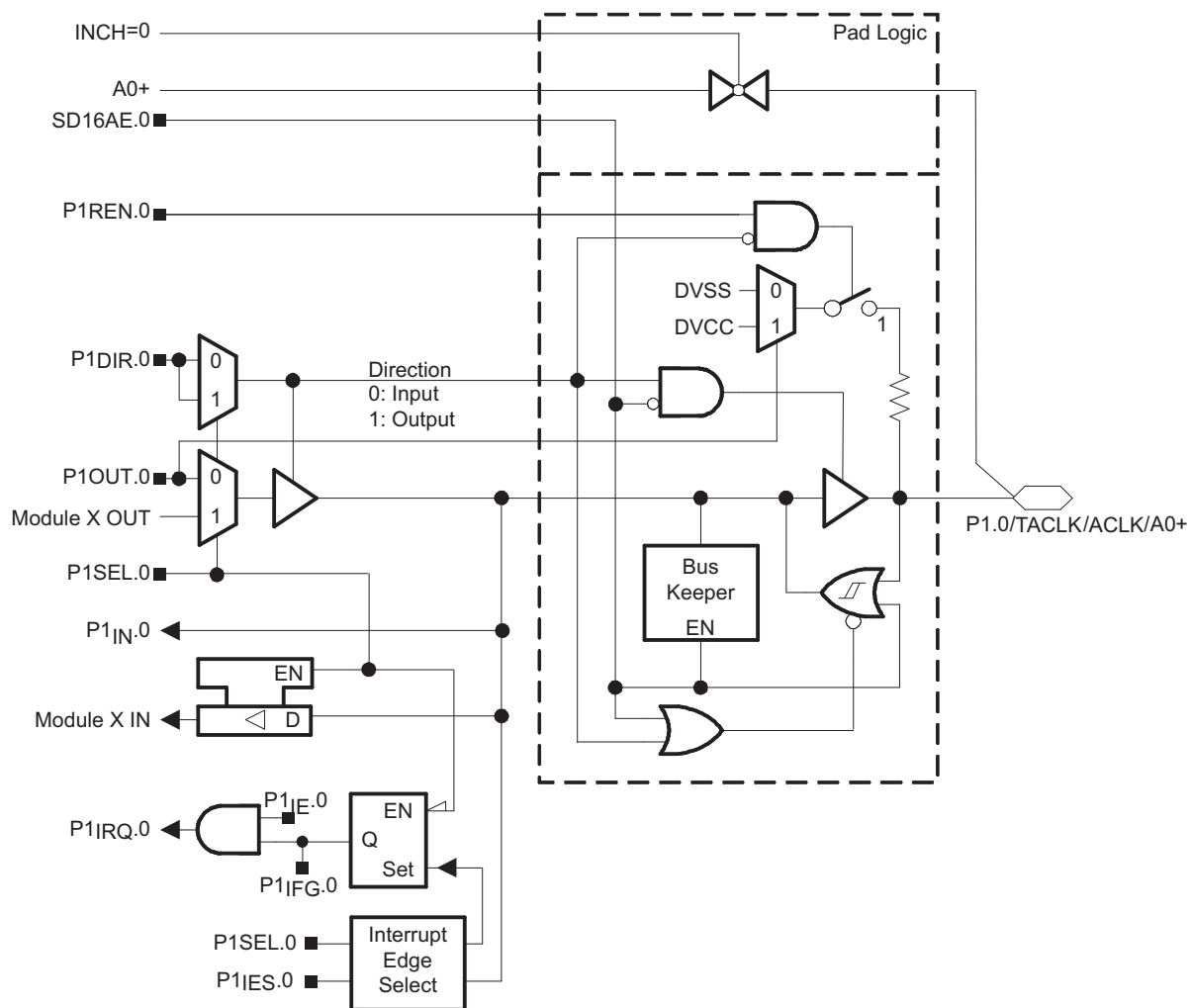
over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

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

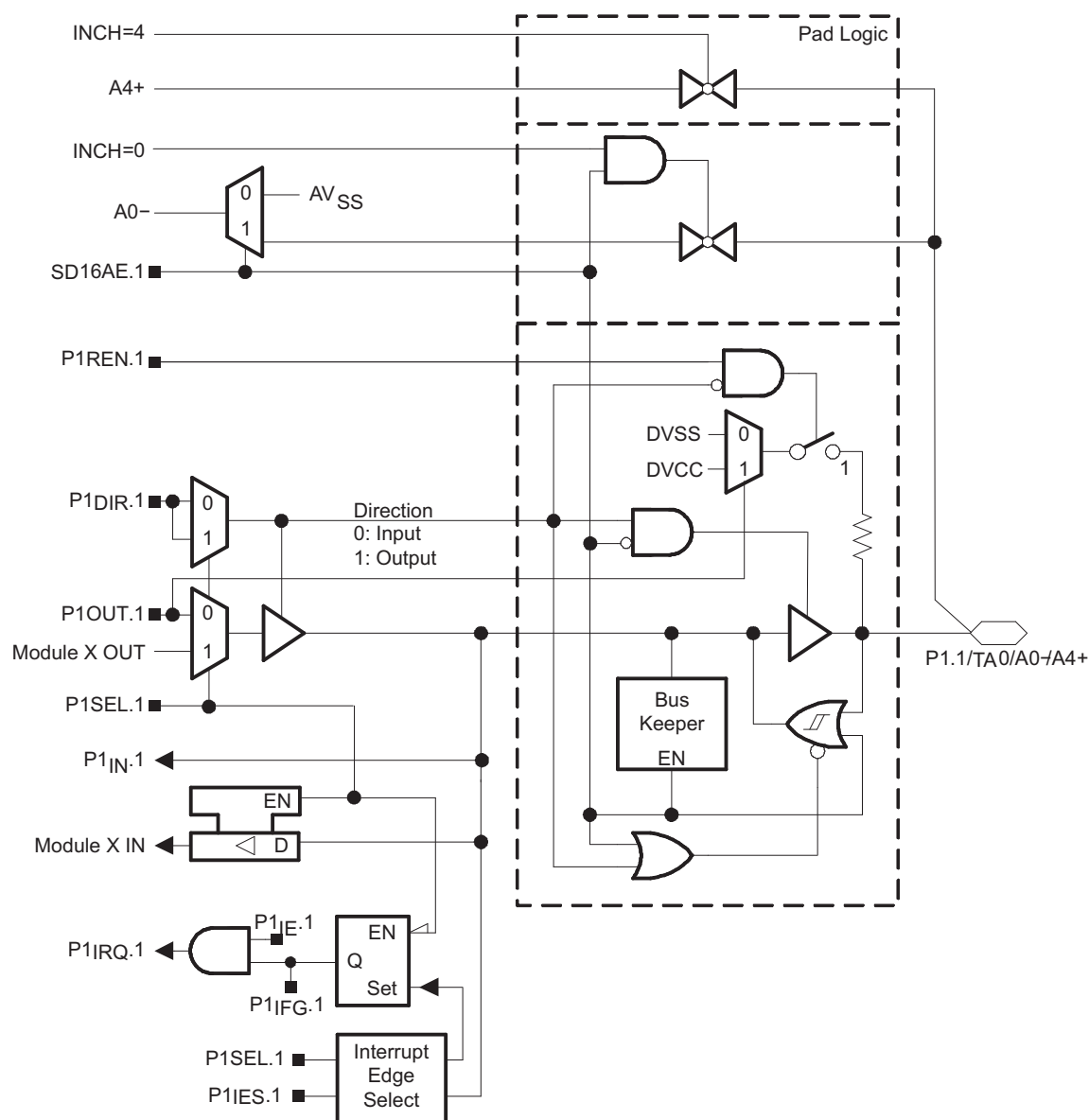
(1) Once the fuse is blown, no further access to the JTAG/Test, Spy-Bi-Wire, and emulation feature is possible, and JTAG is switched to bypass mode.

## APPLICATION INFORMATION

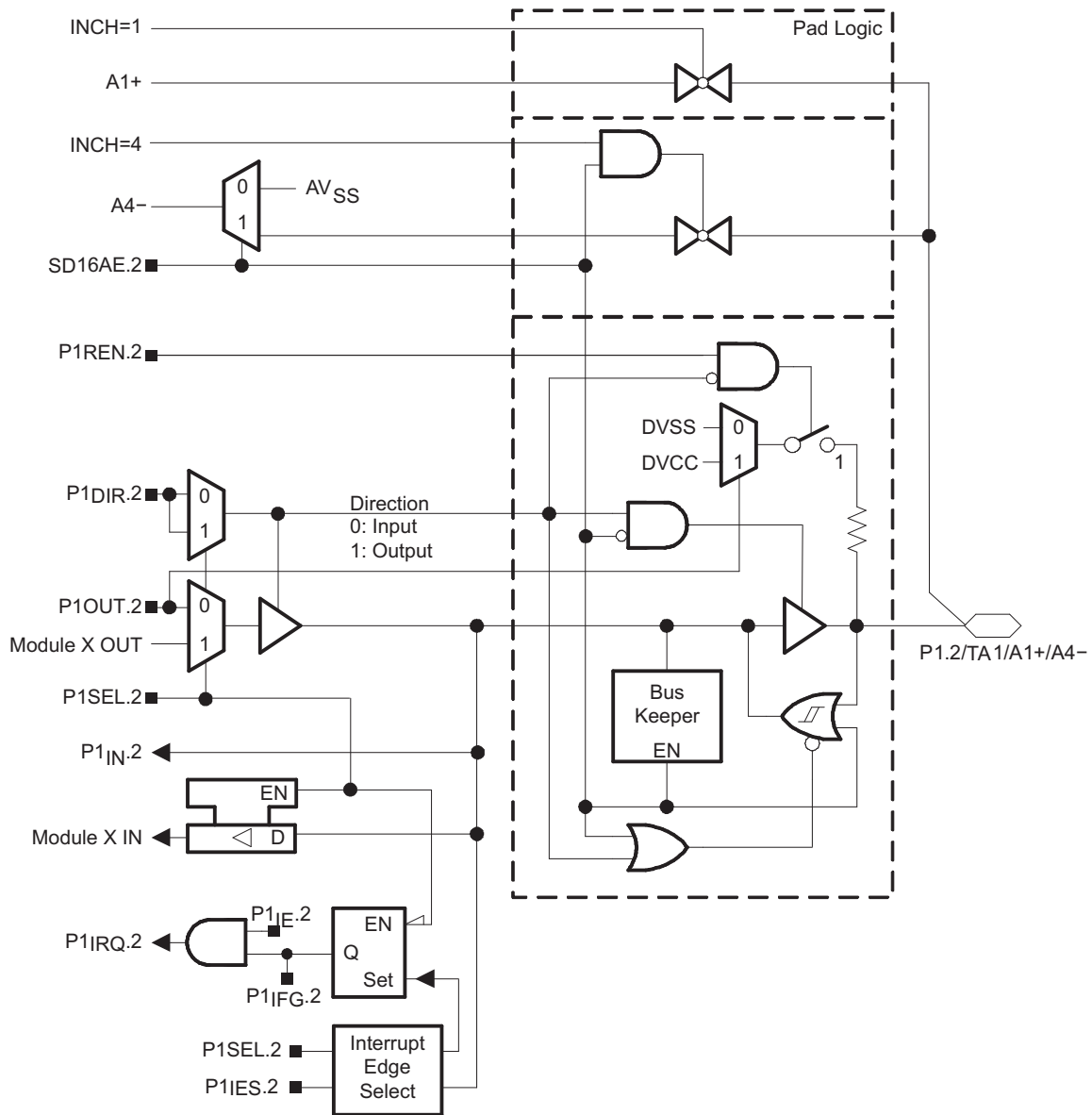
### Port P1 (P1.0) Pin Schematics



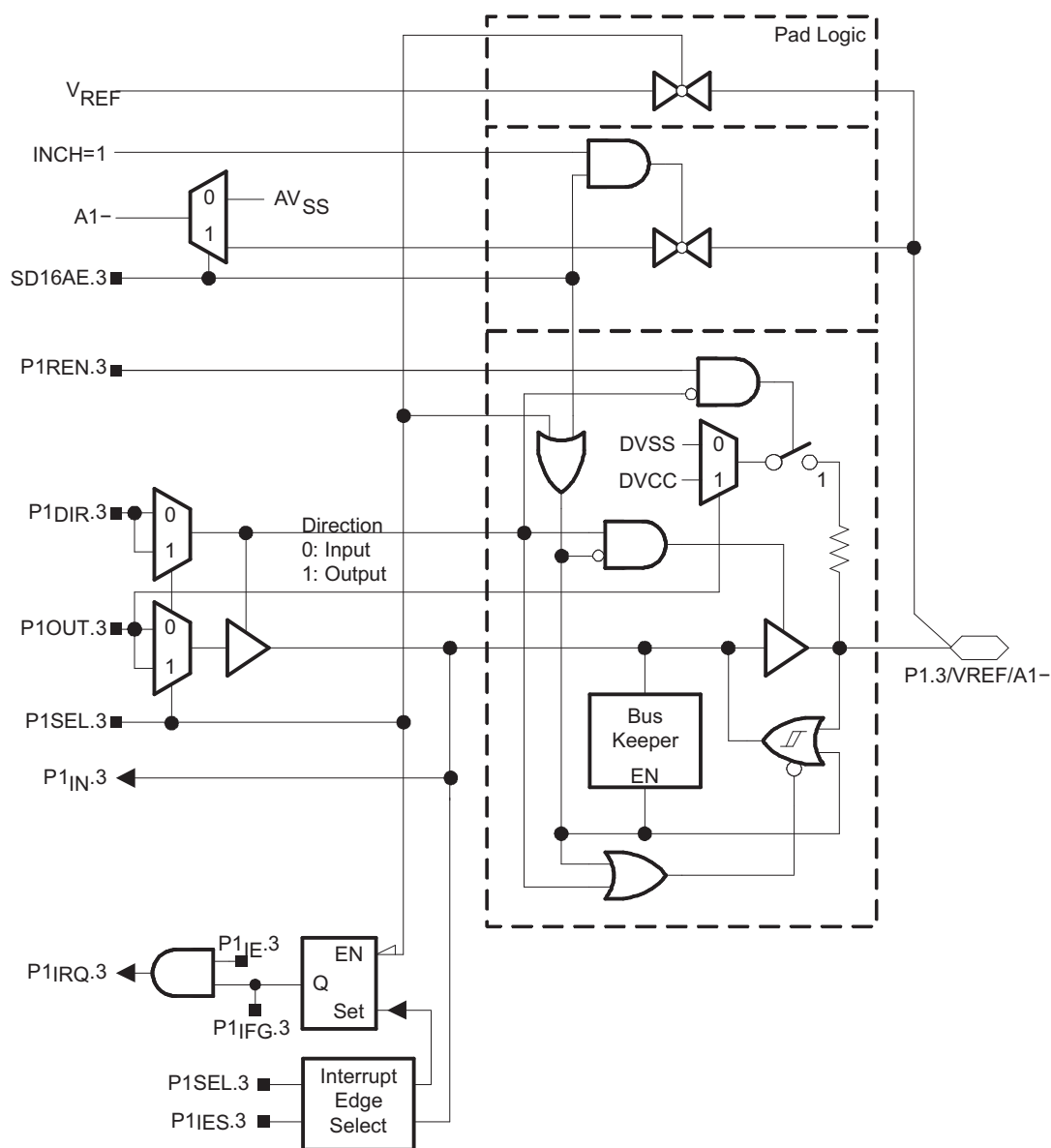
## Port P1 (P1.1) Pin Schematics



## Port P1 (P1.2) Pin Schematics



## Port P1 (P1.3) Pin Schematics



**Table 13. Port P1 (P1.0 to P1.3) Pin Functions**

| PIN NAME (P1.x)     | x | FUNCTION                         | CONTROL BITS / SIGNALS <sup>(1)(2)</sup> |         |          |       |
|---------------------|---|----------------------------------|------------------------------------------|---------|----------|-------|
|                     |   |                                  | P1DIR.x                                  | P1SEL.x | SD16AE.x | INCHx |
| P1.0/TACLK/ACLK/A0+ | 0 | P1.0 <sup>(3)</sup> input/output | 0/1                                      | 0       | 0        | N/A   |
|                     |   | Timer_A2.TACLK/INCLK             | 0                                        | 1       | 0        | N/A   |
|                     |   | ACLK                             | 1                                        | 1       | 0        | N/A   |
|                     |   | A0+ <sup>(4)</sup>               | X                                        | X       | 1        | 0     |
| P1.1/TA0/A0-/A4+    | 1 | P1.1 <sup>(3)</sup> input/output | 0/1                                      | 0       | 0        | N/A   |
|                     |   | Timer_A2.CCI0A                   | 0                                        | 1       | 0        | N/A   |
|                     |   | Timer_A2.TA0                     | 1                                        | 1       | 0        | N/A   |
|                     |   | A0- <sup>(4)(5)</sup>            | X                                        | X       | 1        | 0     |
|                     |   | A4+ <sup>(4)</sup>               | X                                        | X       | 1        | 4     |
| P1.2/TA1/A1+/A4-    | 2 | P1.2 <sup>(3)</sup> input/output | 0/1                                      | 0       | 0        | N/A   |
|                     |   | Timer_A2.CCI1A                   | 0                                        | 1       | 0        | N/A   |
|                     |   | Timer_A2.TA1                     | 1                                        | 1       | 0        | N/A   |
|                     |   | A1+ <sup>(4)</sup>               | X                                        | X       | 1        | 1     |
|                     |   | A4- <sup>(4)(5)</sup>            | X                                        | X       | 1        | 4     |
| P1.3/VREF/A1-       | 3 | P1.3 <sup>(3)</sup> input/output | 0/1                                      | 0       | 0        | N/A   |
|                     |   | VREF                             | X                                        | 1       | 0        | N/A   |
|                     |   | A1- <sup>(4)(5)</sup>            | X                                        | X       | 1        | 1     |

(1) X = Don't care

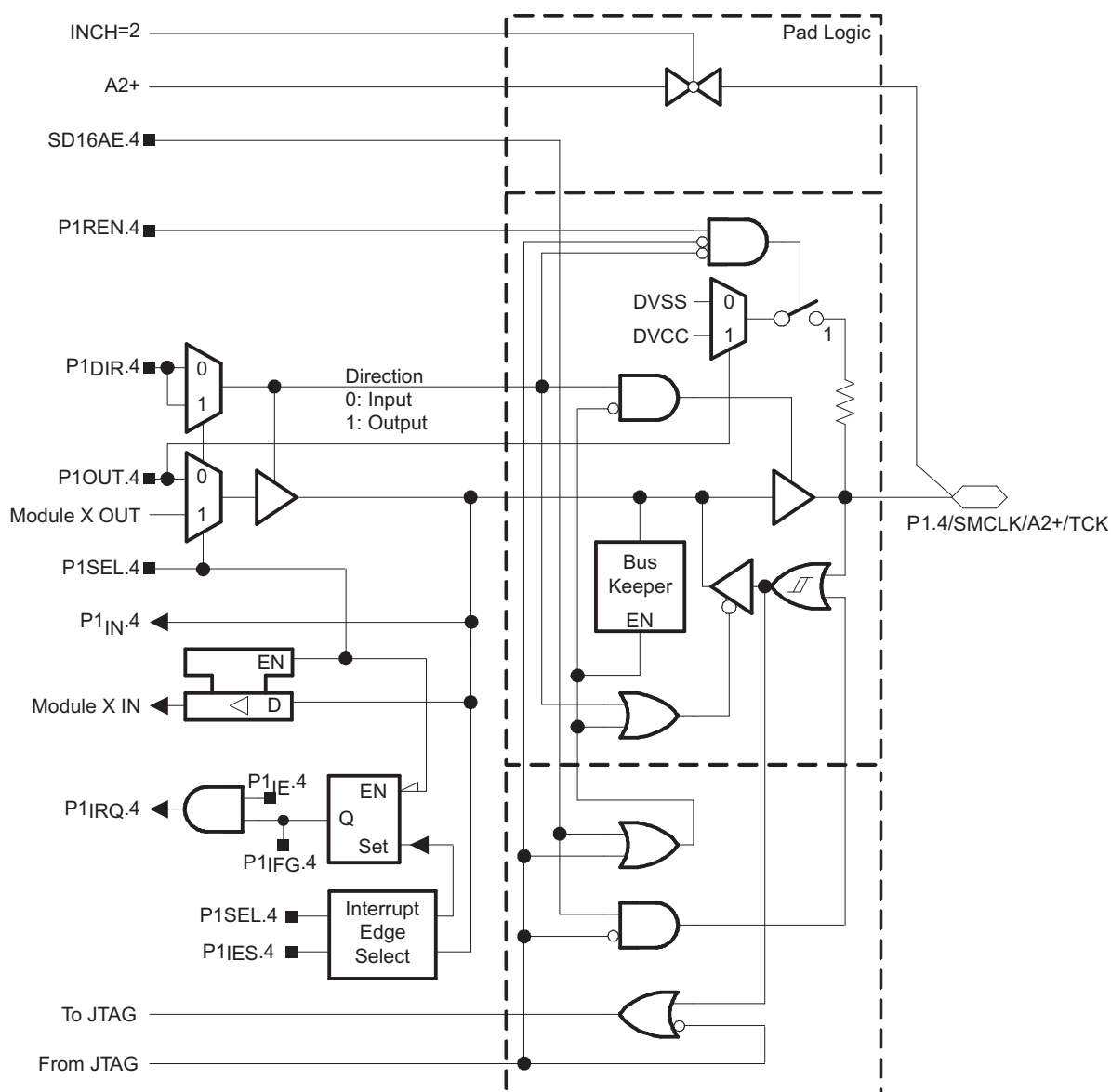
(2) N/A = Not available or not applicable

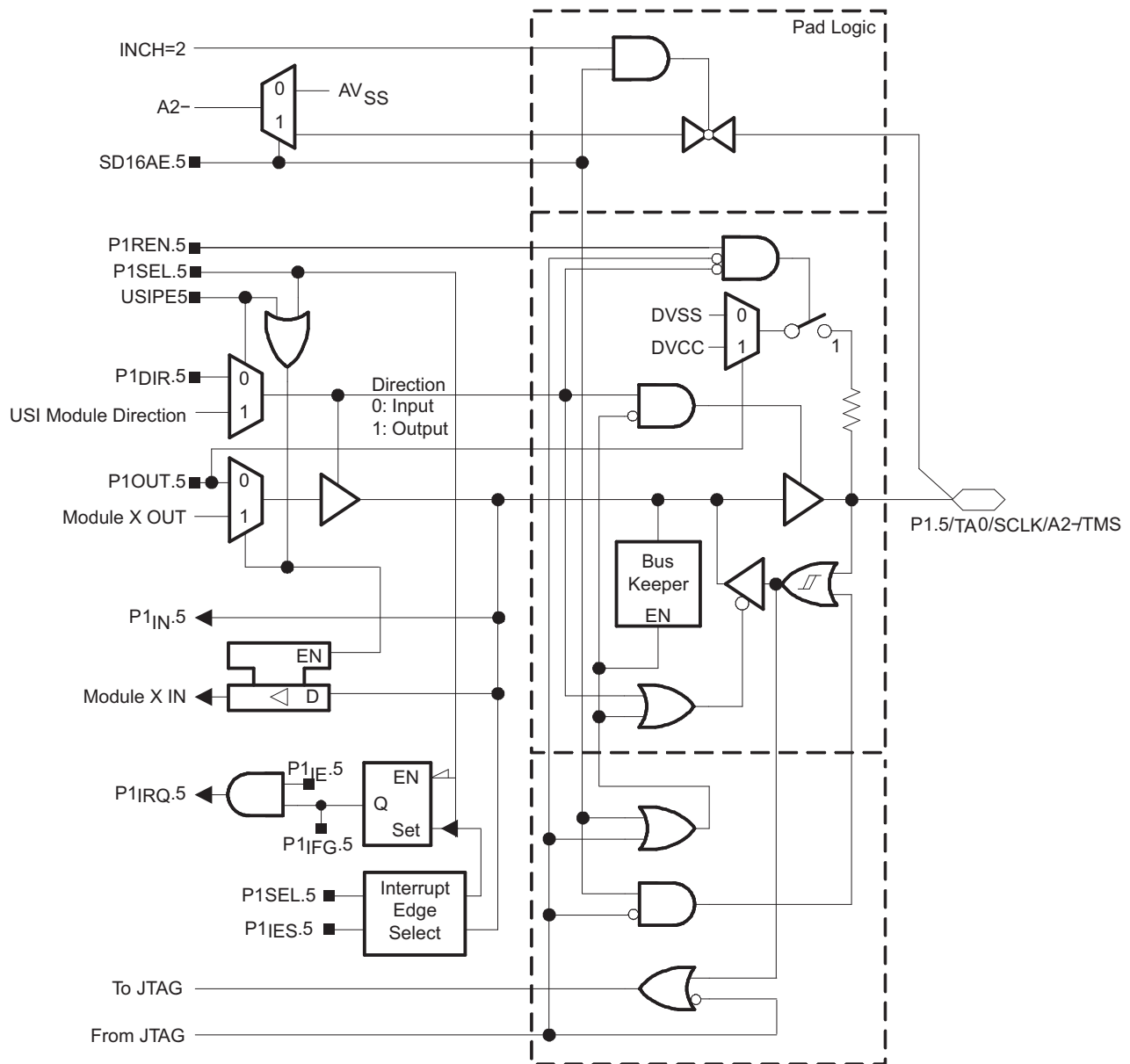
(3) Default after reset (PUC/POR)

(4) Setting the SD16AE.x bit disables the output driver as well as the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

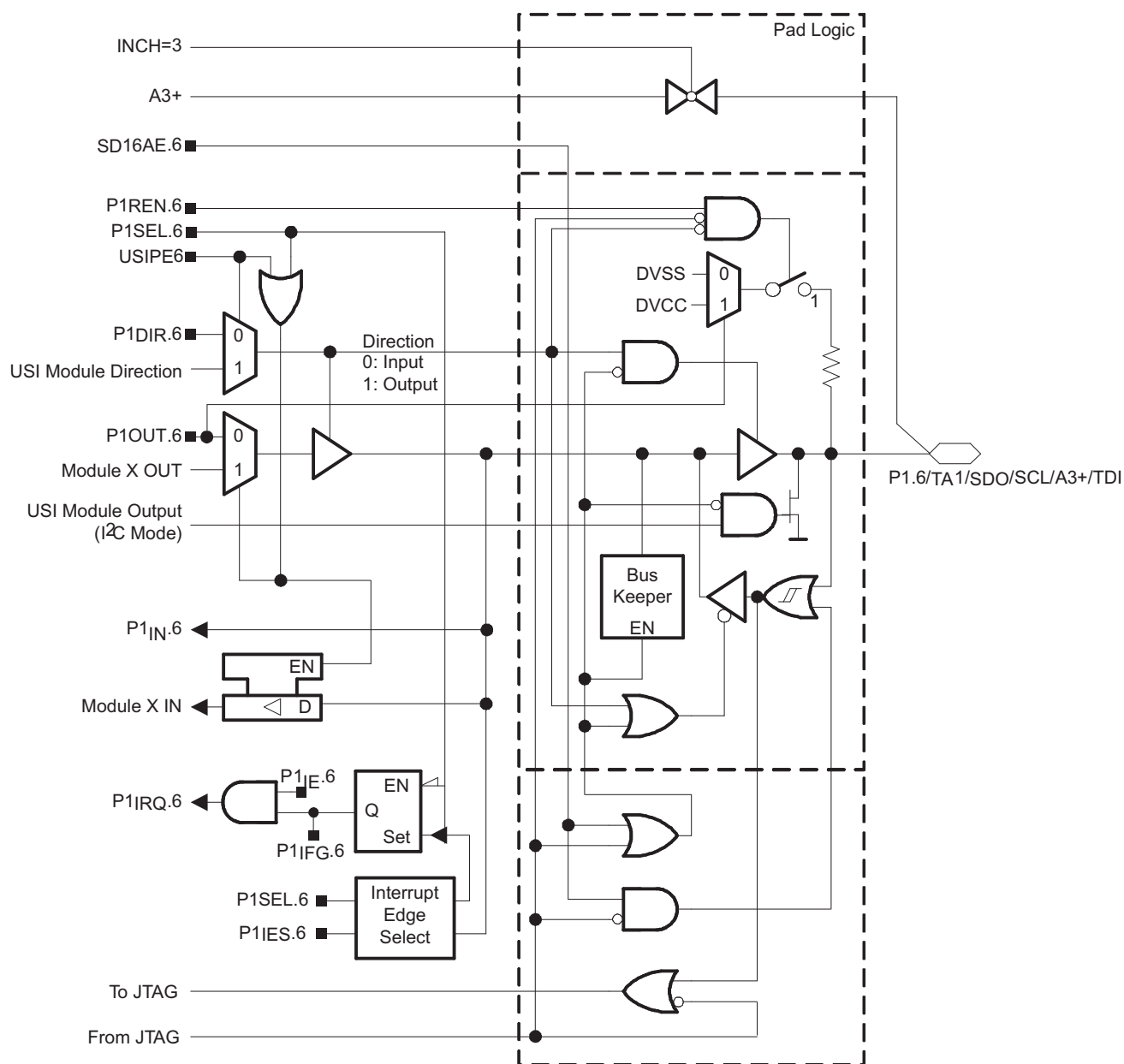
(5) With SD16AE.x = 0 the negative inputs are connected to VSS if the corresponding input is selected.

## Port P1 (P1.4) Pin Schematics

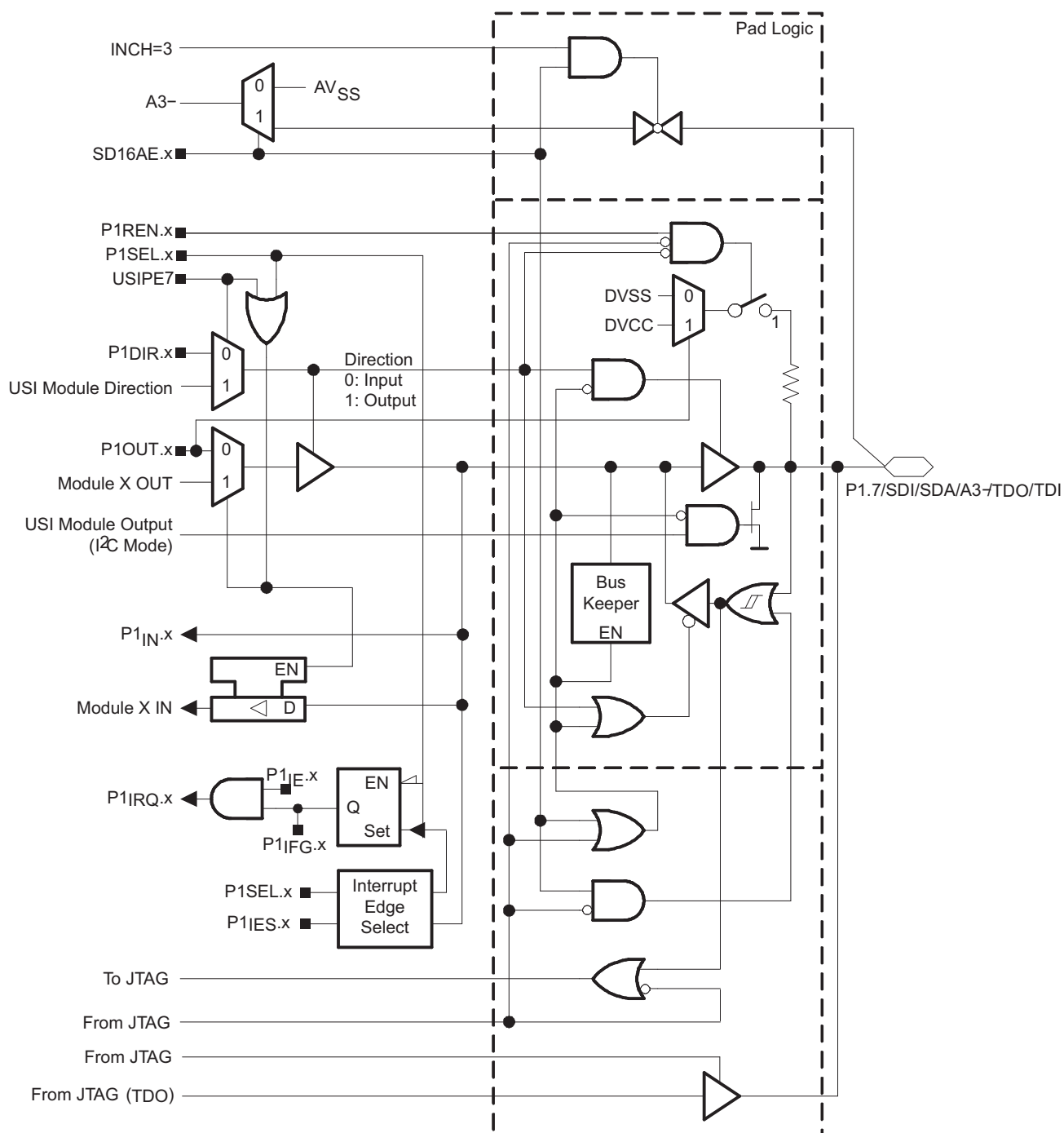




## Port P1 (P1.6) Pin Schematics



## Port P1 (P1.7) Pin Schematics



**Table 14. Port P1 (P1.4 to P1.7) Pin Functions**

| PIN NAME (P1.x)          | x | FUNCTION                         | CONTROL BITS / SIGNALS <sup>(1)(2)</sup> |         |        |          |       |
|--------------------------|---|----------------------------------|------------------------------------------|---------|--------|----------|-------|
|                          |   |                                  | P1DIR.x                                  | P1SEL.x | USIP.x | SD16AE.x | INCHx |
| P1.4/SMCLK/A2+/TCK       | 4 | P1.4 <sup>(3)</sup> input/output | 0/1                                      | 0       | N/A    | 0        | N/A   |
|                          |   | N/A                              | 0                                        | 1       | N/A    | 0        | N/A   |
|                          |   | SMCLK                            | 1                                        | 1       | N/A    | 0        | N/A   |
|                          |   | A2+ <sup>(4)</sup>               | X                                        | X       | N/A    | 1        | 2     |
|                          |   | TCK <sup>(5)</sup>               | X                                        | X       | N/A    | X        | X     |
| P1.5/TA0/SCLK/A2-/TMS    | 5 | P1.5 <sup>(3)</sup> input/output | 0/1                                      | 0       | 0      | 0        | N/A   |
|                          |   | N/A                              | 0                                        | 1       | 0      | 0        | N/A   |
|                          |   | Timer_A2.TA0                     | 1                                        | 1       | 0      | 0        | N/A   |
|                          |   | SCLK                             | X                                        | X       | 1      | 0        | N/A   |
|                          |   | A2- <sup>(4)(6)</sup>            | X                                        | X       | X      | 1        | 2     |
|                          |   | TMS <sup>(5)</sup>               | X                                        | X       | X      | X        | X     |
| P1.6/TA1/SDO/SCL/A3+/TDI | 6 | P1.6 <sup>(3)</sup> input/output | 0/1                                      | 0       | 0      | 0        | N/A   |
|                          |   | Timer_A2.CCI1B                   | 0                                        | 1       | 0      | 0        | N/A   |
|                          |   | Timer_A2.TA1                     | 1                                        | 1       | 0      | 0        | N/A   |
|                          |   | SDO (SPI) / SCL (I2C)            | X                                        | X       | 1      | 0        | N/A   |
|                          |   | A3+ <sup>(4)</sup>               | X                                        | X       | X      | 1        | 3     |
|                          |   | TDI <sup>(5)</sup>               | X                                        | X       | X      | X        | X     |
| P1.7/SDI/SDA/A3-/TDO/TDI | 7 | P1.7 <sup>(3)</sup> input/output | 0/1                                      | 0       | 0      | 0        | N/A   |
|                          |   | N/A                              | 0                                        | 1       | 0      | 0        | N/A   |
|                          |   | DVSS                             | 1                                        | 1       | 0      | 0        | N/A   |
|                          |   | SDI (SPI) / SDA (I2C)            | X                                        | X       | 1      | 0        | N/A   |
|                          |   | A3- <sup>(4)(6)</sup>            | X                                        | X       | X      | 1        | 3     |
|                          |   | TDO/TDI <sup>(5)(7)</sup>        | X                                        | X       | X      | X        | X     |

(1) X = Don't care

(2) N/A = Not available or not applicable

(3) Default after reset (PUC/POR)

(4) Setting the SD16AE.x bit disables the output driver as well as the input Schmitt trigger to prevent parasitic cross currents when applying analog signals.

(5) In JTAG mode the internal pullup/down resistors are disabled.

(6) With SD16AE.x = 0 the negative inputs are connected to VSS if the corresponding input is selected.

(7) Function controlled by JTAG

## Port P2 (P2.6) Pin Schematics

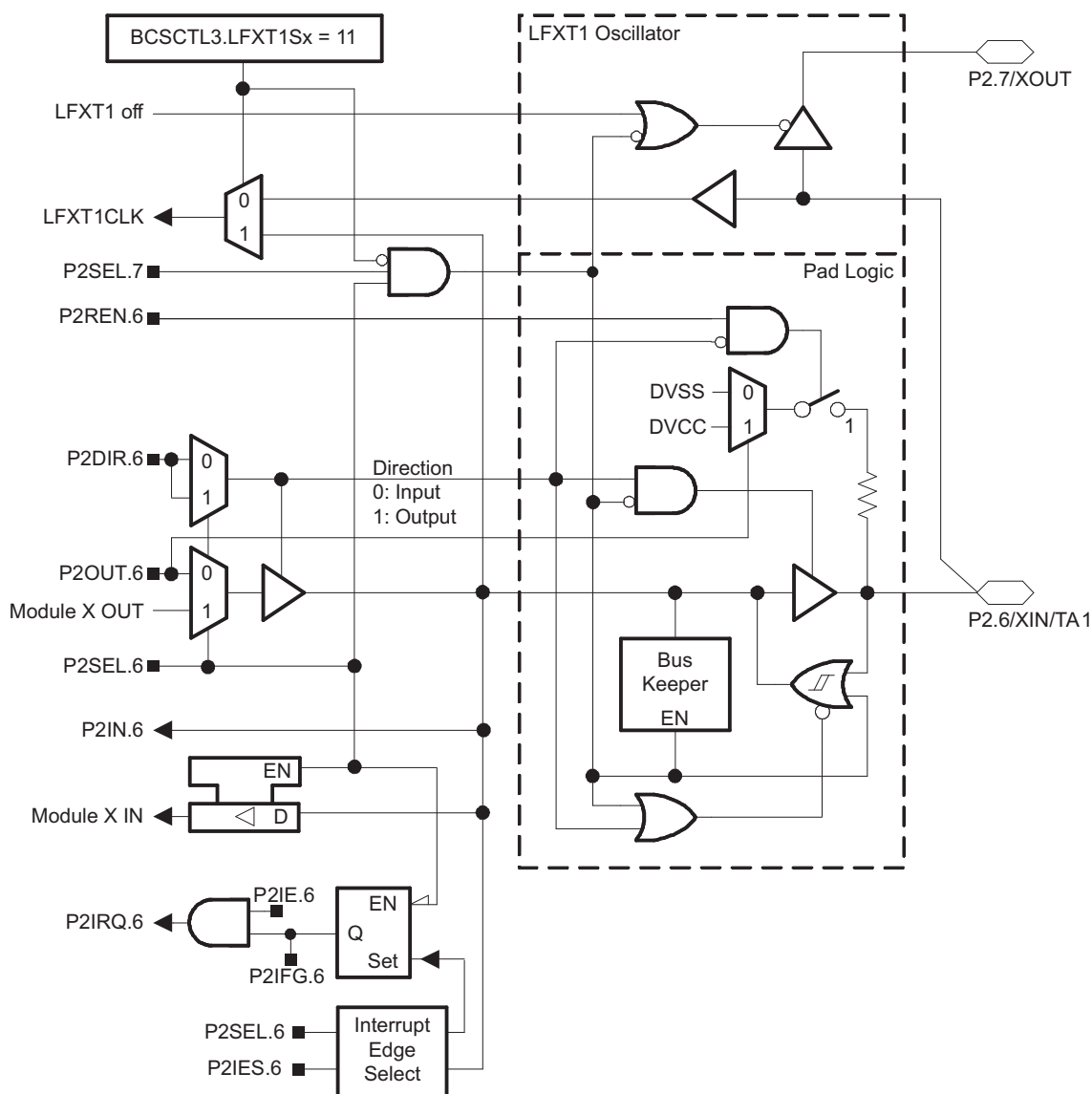


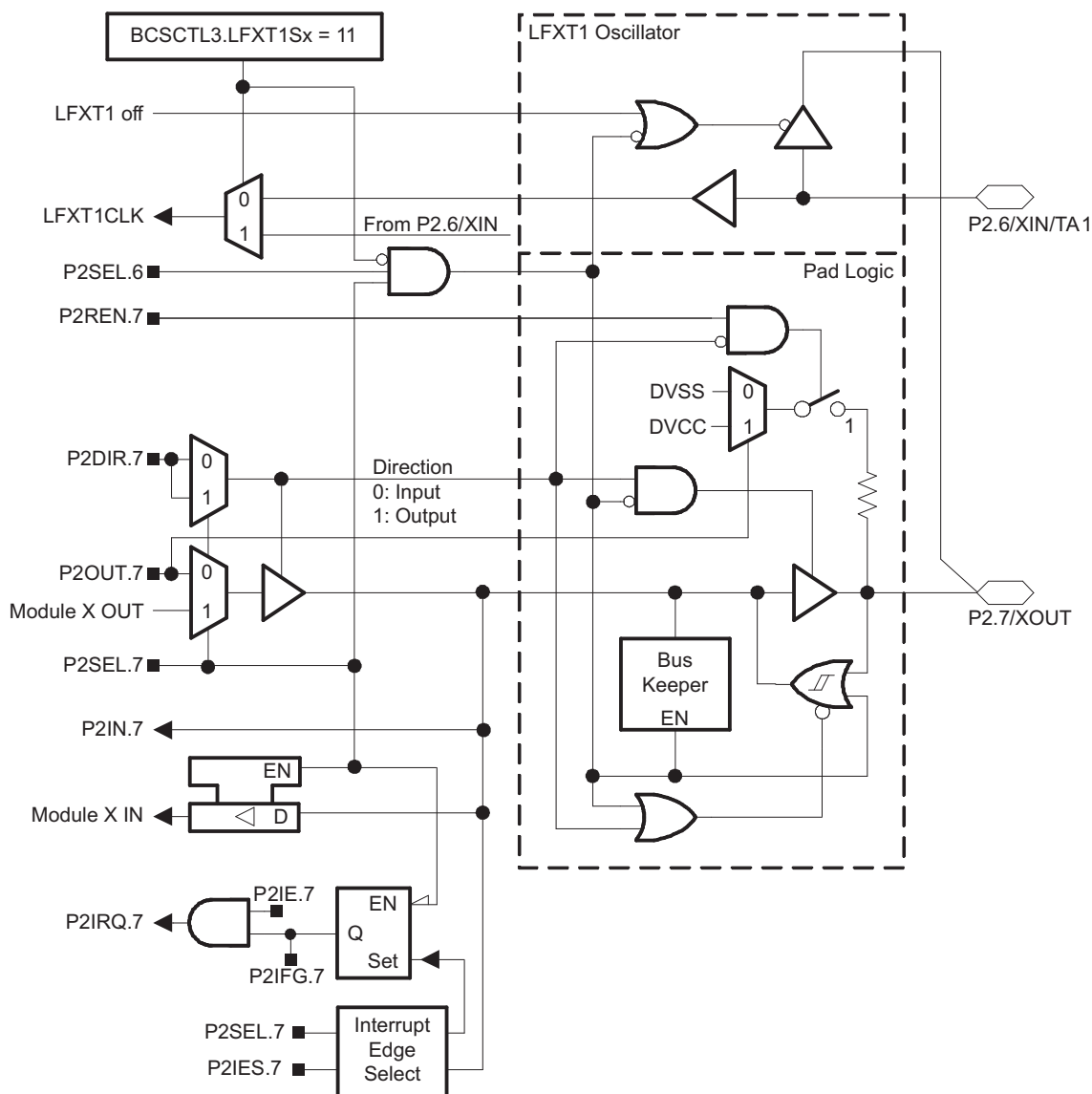
Table 15. Port P2 (P2.6) Pin Functions

| PIN NAME (P2.x) | x | FUNCTION              | CONTROL BITS / SIGNALS |         |
|-----------------|---|-----------------------|------------------------|---------|
|                 |   |                       | P2DIR.x                | P2SEL.x |
| P2.6/XIN/TA1    | 6 | P2.6 input/output     | 0/1                    | 0       |
|                 |   | XIN <sup>(1)(2)</sup> | 0                      | 1       |
|                 |   | Timer_A2.TA1          | 1                      | 1       |

(1) Default after reset (PUC/POR)

(2) XIN is used as digital clock input if the bits LFXT1Sx in register BCSCCTL3 are set to 11.

## Port P2 (P2.7) Pin Schematics



**Table 16. Port P2 (P2.7) Pin Functions**

| PIN NAME (P2.x) | x | FUNCTION               | CONTROL BITS / SIGNALS |         |
|-----------------|---|------------------------|------------------------|---------|
|                 |   |                        | P2DIR.x                | P2SEL.x |
| P2.7/XOUT       | 7 | P2.7 input/output      | 0/1                    | 0       |
|                 |   | DVSS                   | 0                      | 1       |
|                 |   | XOUT <sup>(1)(2)</sup> | 1                      | 1       |

(1) Default after reset (PUC/POR)

(2) If the pin P2.7/XOUT 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.

## PACKAGING INFORMATION

| Orderable part number              | Status<br>(1) | Material type<br>(2) | Package   Pins | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|------------------------------------|---------------|----------------------|----------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">MSP430F2013QRSATEP</a> | Active        | Production           | QFN (RSA)   16 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | M430F<br>2013Q      |
| <a href="#">V62/11613-01XE</a>     | Active        | Production           | QFN (RSA)   16 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | M430F<br>2013Q      |

<sup>(1)</sup> **Status:** For more details on status, see our [product life cycle](#).

<sup>(2)</sup> **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

<sup>(3)</sup> **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

<sup>(4)</sup> **Lead finish/Ball material:** Parts 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.

<sup>(5)</sup> **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "-" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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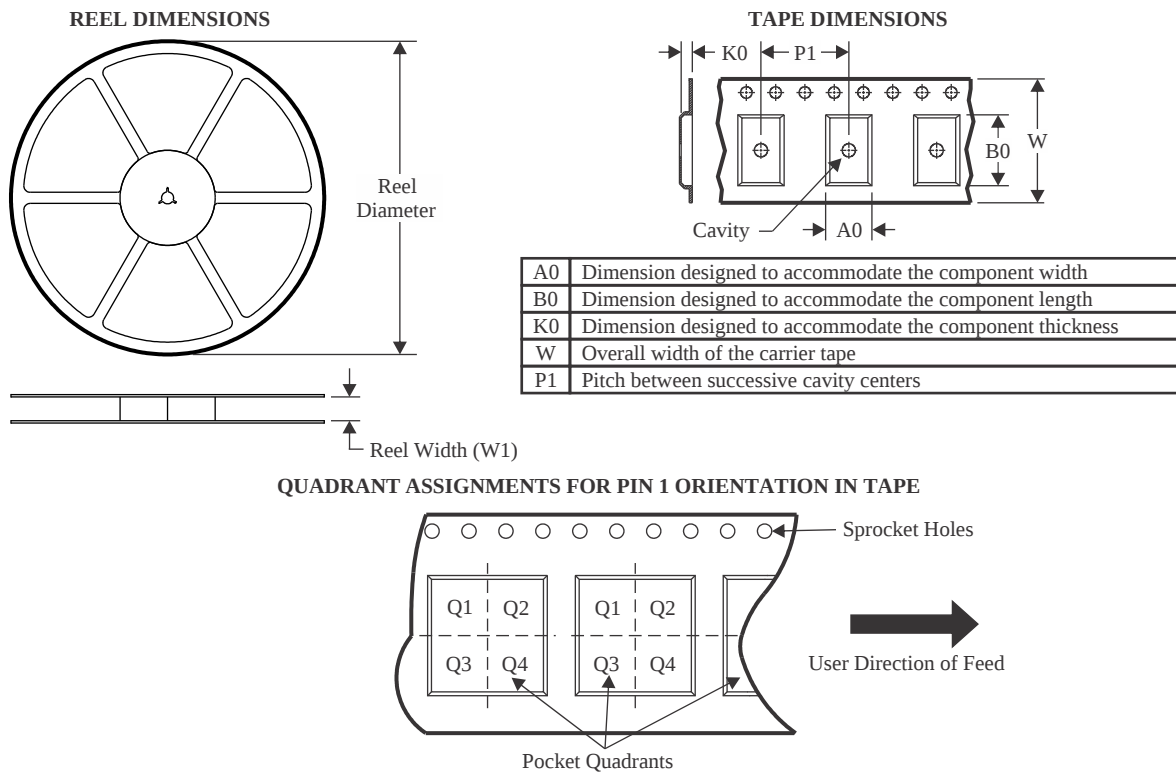
**OTHER QUALIFIED VERSIONS OF MSP430F2013-EP :**

- Catalog : [MSP430F2013](#)

NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product

## TAPE AND REEL INFORMATION



\*All dimensions are nominal

| Device             | Package Type | Package Drawing | Pins | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|--------------------|--------------|-----------------|------|-----|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| MSP430F2013QRSATEP | QFN          | RSA             | 16   | 250 | 180.0              | 12.4               | 4.25    | 4.25    | 1.15    | 8.0     | 12.0   | Q2            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device             | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|--------------------|--------------|-----------------|------|-----|-------------|------------|-------------|
| MSP430F2013QRSATEP | QFN          | RSA             | 16   | 250 | 213.0       | 191.0      | 35.0        |

## GENERIC PACKAGE VIEW

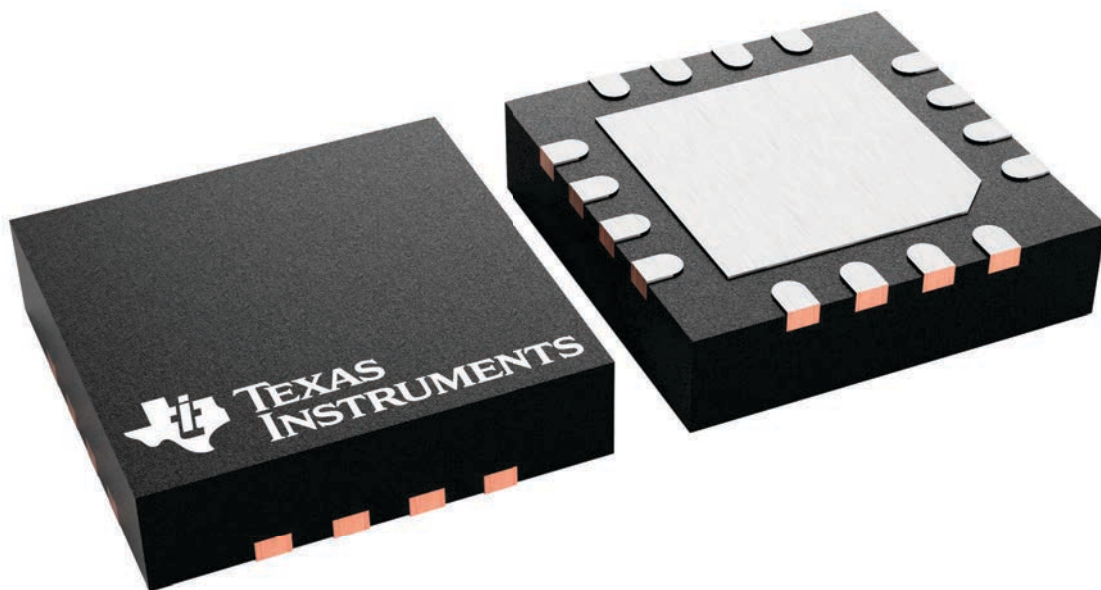
**RSA 16**

**VQFN - 1 mm max height**

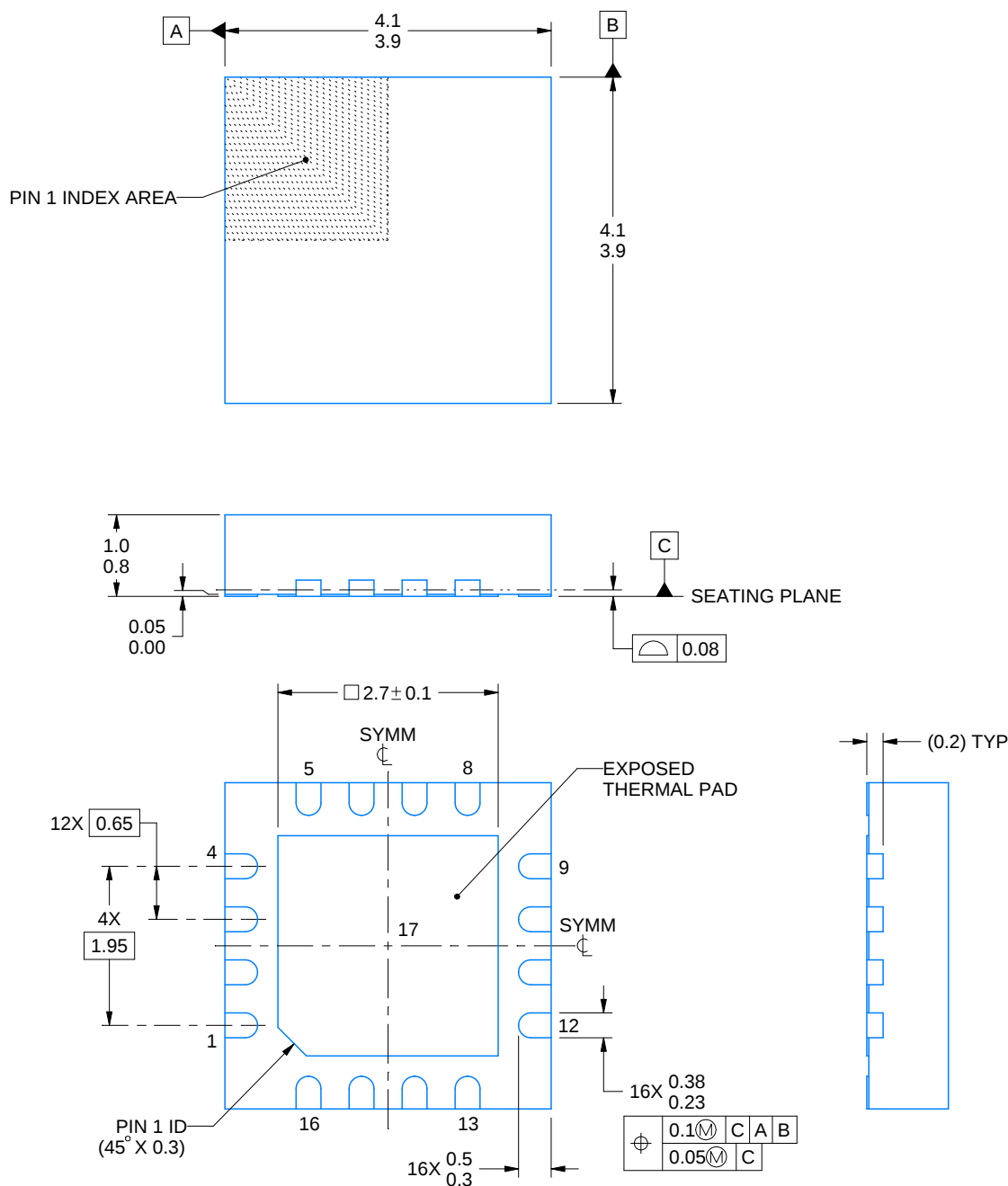
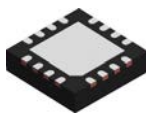
4 x 4, 0.65 mm pitch

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.



4230969/A



4219093/A 08/2021

## NOTES:

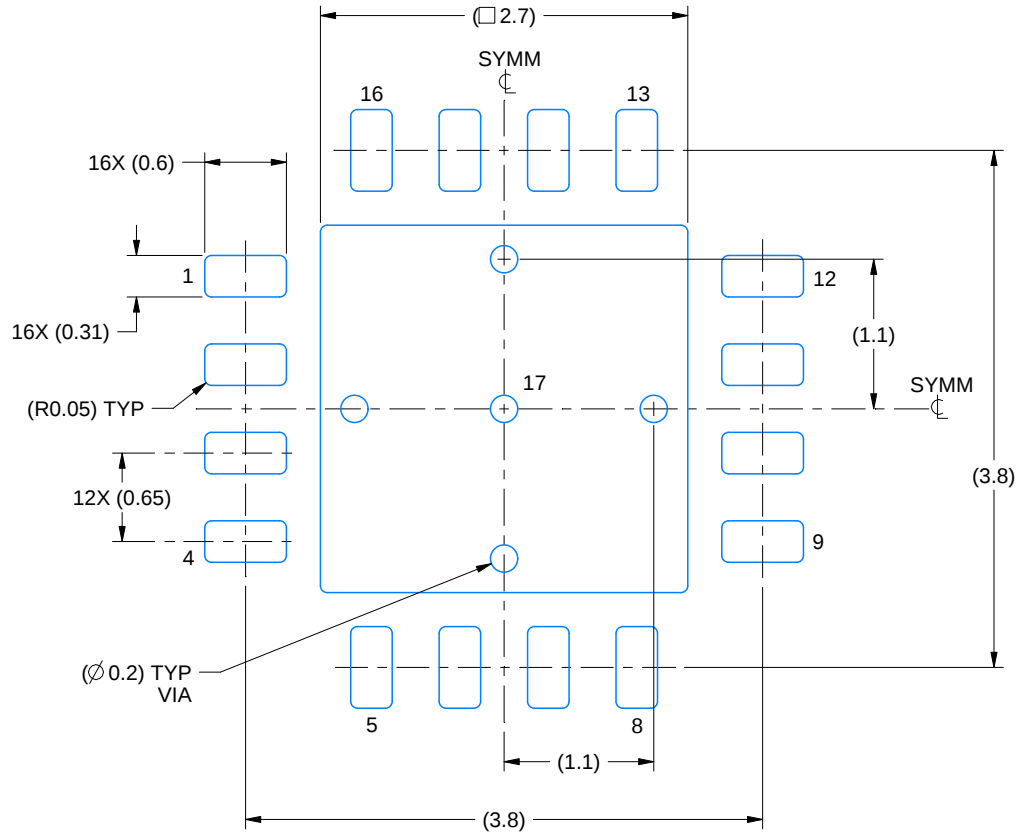
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.
4. Reference JEDEC registration MO-220.

# EXAMPLE BOARD LAYOUT

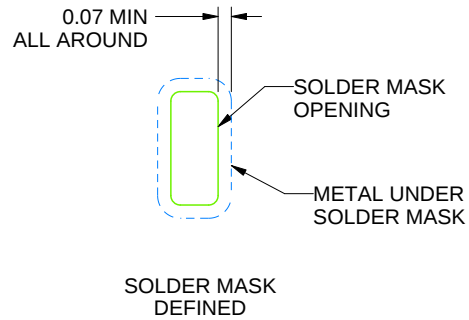
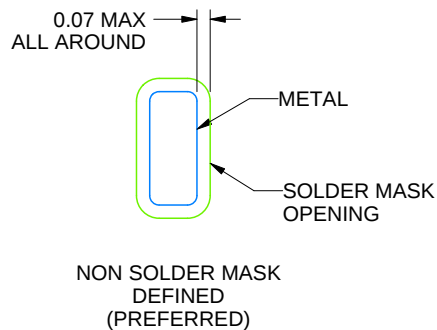
RSA0016B

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:18X



SOLDER MASK DETAILS

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NOTES: (continued)

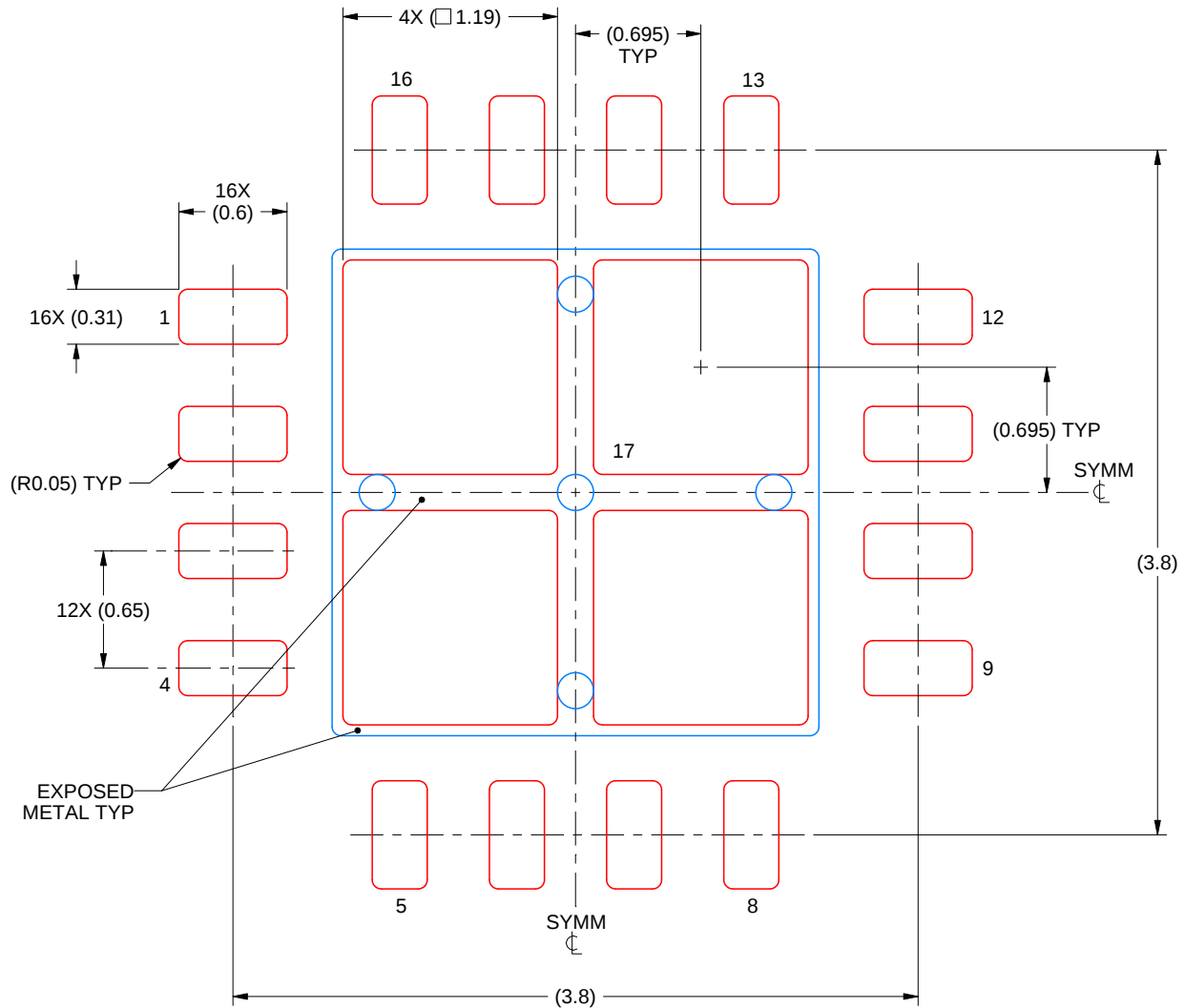
5. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/sluea271](http://www.ti.com/lit/sluea271)).
6. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

# EXAMPLE STENCIL DESIGN

RSA0016B

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



**SOLDER PASTE EXAMPLE**  
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD  
77% PRINTED SOLDER COVERAGE BY AREA  
SCALE:25X

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NOTES: (continued)

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

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