

MSP430FR263x、MSP430FR253x 电容式触控感应混合信号微控制器

1 器件概述

1.1 特性

- **CapTIvate 技术** – 电容式触控
 - 性能
 - 四路同步快速电极扫描
 - 支持点数超过 1024 的高分辨率滑块
 - 30cm 接近度感测
 - 可靠性
 - 提高了针对电力线、射频 (RF) 及其他环境噪声的抗扰度
 - 内置扩展频谱、自动调整、噪声滤除和消抖算法
 - 提供**可靠的触控解决方案**，具有 10V 均方根 (RMS) 共模噪声、4kV 电快速瞬变以及 15kV 静电放电，符合 IEC-61000-4-6、IEC-61000-4-4 和 IEC-61000-4-2 标准
 - 通过降低 RF 辐射简化电气设计
 - 支持金属触控和防水设计
 - 灵活性
 - 多达 16 个自电容式电极和 64 个互电容式电极
 - 在同一设计中混合使用**自电容式电极和互电容式电极**
 - 支持多点触控功能
 - 宽电容检测范围：0 至 300pF 宽电极范围
 - 低功耗
 - 触摸唤醒模式下的电流 < 0.9μA/按钮，其中电容测量和触控检测由硬件状态机完成，同时 CPU 处于休眠状态
 - 触摸唤醒状态机支持在 CPU 休眠过程中进行电极扫描
 - 用于环境补偿、滤波和阈值检测的硬件加速
 - 易于使用
 - **CapTIvate 设计中心** PC GUI 允许工程师对电容按钮进行实时设计和调试，无需编写代码
 - 存储于 ROM 中的 CapTIvate 软件库为客户应用提供充足的 FRAM
- 嵌入式微控制器
 - 16 位精简指令集 (RISC) 架构
 - 支持的时钟频率最高可达 16MHz
 - 宽电源电压范围：1.8V 至 3.6V ⁽¹⁾
- 优化的超低功耗模式
 - 激活模式：126μA/MHz（典型值）
 - 待机电流
 - 平均电流为 1.7μA/按钮（典型值）（16 个自电容式按钮，8Hz 扫描）
 - 平均电流为 1.7μA/按钮（典型值）（64 个互电容式按钮，8Hz 扫描）
 - 采用 32768Hz 晶振的 LPM3.5 实时时钟 (RTC) 计数器：730nA（典型值）
 - 关断电流 (LPM4.5)：16nA（典型值）
- 超低功耗铁电 RAM (FRAM)
 - 高达 15.5KB 的非易失性存储器
 - 内置错误修正码 (ECC)
 - 可配置的写保护
 - 对程序和常量数据统一进行存储
 - 10¹⁵ 写入周期持久性
 - 抗辐射和非磁性
 - 铁电随机存取存储器 (FRAM) 与静态随机存取存储器 (SRAM) 之比高达 4: 1
- 智能数字外设
 - 4 个 16 位定时器
 - 两个定时器，每个定时器具有三个捕捉/比较寄存器 (Timer_A3)
 - 两个定时器，每个定时器具有两个捕捉/比较寄存器 (Timer_A2)
 - 一个与 CapTIvate™ 技术相关的 16 位定时器
 - 一个仅用作计数器的 16 位 RTC
 - 16 位循环冗余校验 (CRC)
- 增强型串行通信
 - 两个增强型通用串行通信接口 (eUSCI_A) 支持通用异步收发器 (UART)、红外数据通信 (IrDA) 和串行外设接口 (SPI)
 - 一个 eUSCI (eUSCI_B) 支持 SPI 和 I²C
- 高性能模拟
 - 8 通道 10 位模数转换器 (ADC)
 - 1.5V 内部基准电压
 - 采样与保持 200ksps

(1) 最低电源电压受限于 SVS 电平（请参阅 [PMM](#)、[SVS](#) 和 [BOR](#) 中的 V_{SVSH-} 和 V_{SVSH+}）。



- 时钟系统 (CS)
 - 片上 32kHz RC 振荡器 (REFO)
 - 带有锁频环 (FLL) 的片上 16MHz 数字控制振荡器 (DCO)
 - 室温下的精度为 $\pm 1\%$ (具有片上基准)
 - 片上超低频 10kHz 振荡器 (VLO)
 - 片上高频调制振荡器 (MODOSC)
 - 32kHz 外部晶振 (LFXT)
 - 可编程 MCLK 预分频器 (1 至 128)
 - 通过可编程预分频器 (1、2、4 或 8) 从 MCLK 获得的 SMCLK
- 通用输入/输出和引脚功能
 - 共计 19 个 I/O (采用 TSSOP-32 封装)
 - 16 个中断引脚 (P1 和 P2) 可以将 MCU 从低功耗模式下唤醒
- 开发工具和软件
 - 易于使用的生态系统
 - CapTIvate 设计中心 – 代码生成、GUI 定制、实时调试
 - 自由的专业开发环境
- 12KB ROM 库包含 CapTIvate 触控程序库和驱动程序库
- 系列成员 (另请参阅 [器件比较](#))
 - MSP430FR2633: 15KB 程序 FRAM + 512B 信息 FRAM + 4KB RAM
多达 16 个自电容式传感器或 64 个互电容式传感器
 - MSP430FR2533: 15KB 程序 FRAM + 512B 信息 FRAM + 2KB RAM
多达 16 个自电容式传感器和 16 个互电容式传感器
 - MSP430FR2632: 8KB 程序 FRAM + 512B 信息 FRAM + 2KB RAM
多达 8 个自电容式传感器和 16 个互电容式传感器
 - MSP430FR2532: 8KB 程序 FRAM + 512B 信息 FRAM + 1KB RAM
多达 8 个自电容式传感器和 8 个互电容式传感器
- 封装选项
 - 32 引脚: 超薄型四方扁平无引线 (VQFN) 封装 (RHB)
 - 32 引脚: 薄型小外形尺寸 (TSSOP) 封装 (DA)
 - 24 引脚: (VQFN) 封装 (RGE)
 - 24 引脚: DSBGA (YQW)
- 有关完整模块说明, 请参见 [《MSP430FR4xx 和 MSP430FR2xx 系列器件用户指南》](#)

1.2 应用

- 电子智能锁、门键盘和读取器
- 车库门系统
- 入侵 HMI 键盘和控制面板
- 电动百叶窗
- 遥控
- 个人电子产品
- 无线扬声器和耳机
- 手持式视频游戏控制器
- A/V 接收器
- 白色家电
- 小型家用电器
- 园艺和电动工具

1.3 说明

MSP430FR263x 和 MSP430FR253x 是用于电容式触控感应的超低功耗 MSP430™ 微控制器, 采用 [CapTIvate 触控技术](#), 适用于按钮、滑块、滚轮及接近性应用。采用 CapTIvate 技术的 MSP430 MCU 提供市面上最高集成度和自主性的电容式触控解决方案, 具有高可靠性和抗噪能力以及最低功耗。TI 的电容式触控技术支持在同一设计方案中同时使用自电容式和互电容式电极, 最大限度地提高了灵活性。采用 CapTIvate 技术的 MSP430 MCU 可以穿透厚玻璃、塑料外壳、金属和木材, 在恶劣的环境 (包括潮湿、油腻和脏污环境) 中工作。

TI 电容式触控感应 MSP430 MCU 由一套全面的硬件和软件生态系统进行支持, 并配套提供参考设计和代码示例, 协助用户快速开展设计。开发套件包括 [MSP-CAPT-FR2633 CapTIvate 技术开发套件](#)。TI 还提供免费的软件, 如 [CapTIvate 设计中心](#), 工程师可以在其中借助方便易用的 GUI 和 [MSP430Ware™ 软件](#) 以及包括 [CapTIvate 技术指南](#) 在内的全面文档快速进行应用开发。

TI 的 MSP430 超低功耗 (ULP) FRAM 微控制器平台将独特的嵌入式 FRAM 和全面的超低功耗系统架构相结合, 从而使系统设计人员能够在降低能耗的同时提升性能。FRAM 技术将 RAM 的低能耗快速写入、灵活性和耐用性与闪存的非易失性相结合。

器件信息⁽¹⁾

器件型号	封装	封装尺寸 ⁽²⁾
MSP430FR2633IRHB	VQFN (32)	5mm x 5mm
MSP430FR2533IRHB	VQFN (32)	5mm x 5mm
MSP430FR2633IDA	TSSOP (32)	11mm x 6.2mm
MSP430FR2533IDA	TSSOP (32)	11mm x 6.2mm
MSP430FR2632IRGE	超薄四方扁平无引线 (VQFN) (24)	4mm x 4mm
MSP430FR2532IRGE	超薄四方扁平无引线 (VQFN) (24)	4mm x 4mm
MSP430FR2633IYQW	DSBGA (24)	2.29mm x 2.34mm
MSP430FR2632IYQW	DSBGA (24)	2.29mm x 2.34mm

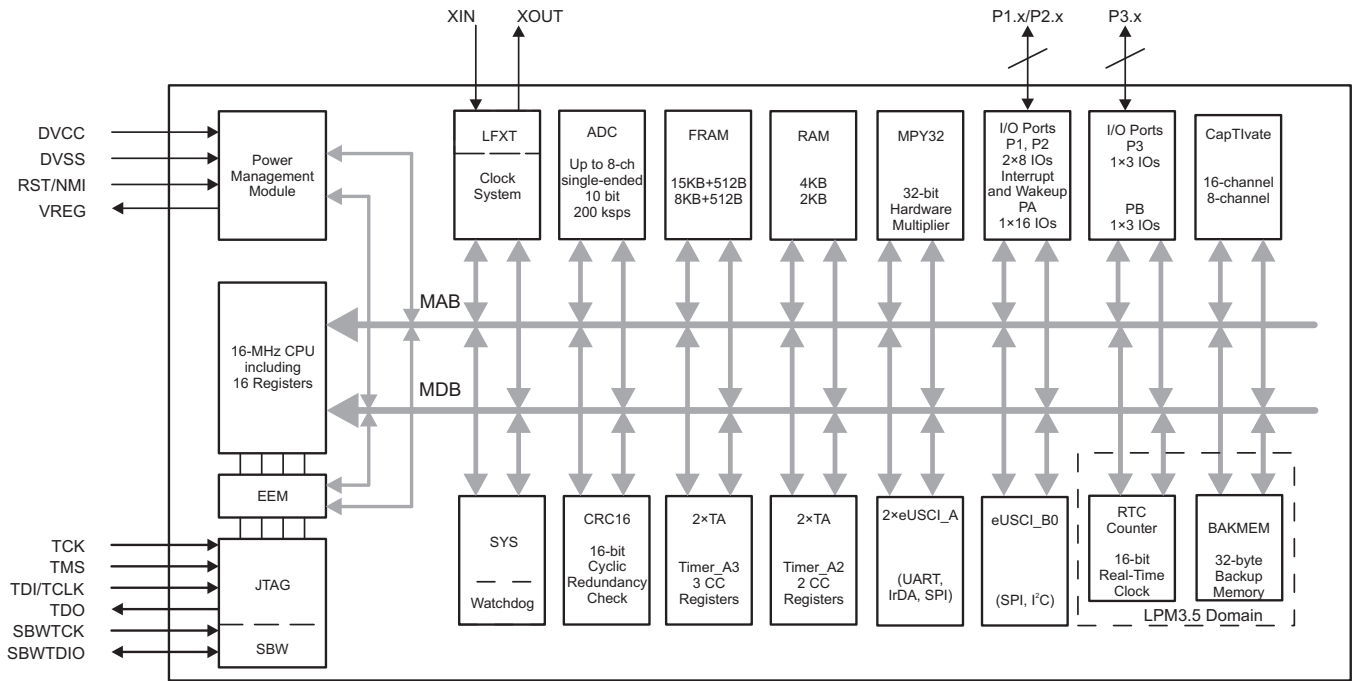
- (1) 要获得最新的产品、封装和订购信息，请参见封装选项附录（节 9），或者访问德州仪器 (TI) 网站 www.ti.com.cn。
- (2) 这里显示的尺寸为近似值。要获得包含误差值的封装尺寸，请参见机械数据（节 9中）。

CAUTION

系统级静电放电 (ESD) 保护必须符合器件级 ESD 规范，以防发生电气过载或对数据或代码存储器造成干扰。有关更多信息，请参阅《MSP430 系统级 ESD 注意事项》。

1.4 功能框图

图 1-1 给出了功能框图。



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图 1-1. 功能框图

- MCU 的主电源对 DVCC 和 DVSS 分别为数字模块和模拟模块供电。推荐的旁路电容和去耦电容分别为 4.7μF 至 10μF 和 0.1μF，精度为 ±5%。
- VREG 是 CapTlvate 稳压器的去耦电容。所需去耦电容的建议值为 1μF，最大等效串联电阻 (ESR) ≤ 200mΩ。
- P1 和 P2 特有引脚中断功能，可将 MCU 从所有低功耗模式 (LPM) 唤醒（包括 LPM3.5 和 LPM4）。
- 每个 Timer_A3 具有三个捕捉/比较寄存器。仅 CCR1 和 CCR2 从外部连接。CCR0 寄存器仅用于内部周期时序和生成中断。
- 每个 Timer_A2 具有两个捕捉/比较寄存器。两个寄存器仅用于内部周期时序和生成中断。
- 在 LPM3 模式下，CapTlvate 可在其他外设停止工作的情况下继续工作。

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2 修订历史记录

注：之前版本的页码可能与当前版本有所不同。

Changes from December 10, 2015 to June 8, 2017	Page
• 更改了 特性 列表的组织形式	1
• 在节 1.1“特性”中的“封装选项”列表中添加了 DSBGA (YQW) 封装	2
• 更新了节 1.2“应用”中的列表	2
• 更新节 1.3, 说明.....	2
• 在器件信息表（位于节 1.3“说明”中）中添加了 DSBGA (YQW) 封装选项.....	3
• Added MSP430FR2633IYQW and MSP430FR2632IYQW to Table 3-1, Device Comparison	7
• Added Section 3.1, Related Products	7
• Added DSBGA (YQW) pinout	11
• Added DSBGA (YQW) package to Table 4-1, Pin Attributes	12
• Added DSBGA (YQW) package to Table 4-2, Signal Descriptions	15
• Added row for QFN thermal pad in Table 4-2, Signal Descriptions	17
• Remove FRAM reflow note.	19
• Updated the notes on I_{LPM3} , CapTivate, 16 buttons and I_{LPM3} , CapTivate, 64 buttons in Section 5.7, Low-Power Mode (LPM3 and LPM4) Supply Currents (Into V_{CC}) Excluding External Current	21
• Added DSBGA (YQW) package and changed notes for Section 5.10, Thermal Resistance Characteristics	24
• Removed ADCDIV from the formula for the TYP value in the second row of the $t_{CONVERT}$ parameter in Table 5-21, ADC, 10-Bit Timing Parameters (removed because ADCCLK is after division).....	39
• Add Blank Device detected description	47
• Changed the paragraph that starts "Quickly switching digital signals and ..." in Section 7.2.1.2, Design Requirements	79
• 更新了图 8-1“器件命名规则”	87
• 将先前的开发工具支持 部分替换为节 8.3“工具和软件”	88
• 更新了节 8.4“文档支持”的格式和内容.....	89

3 Device Comparison

Table 3-1 summarizes the features of the available family members.

Table 3-1. Device Comparison⁽¹⁾⁽²⁾

DEVICE	PROGRAM FRAM + INFORMATION FRAM (BYTES)	SRAM (BYTES)	TA0 TO TA3	eUSCI_A		eUSCI_B	10-BIT ADC CHANNELS	CapTIvate™ CHANNELS	GPIOs	PACKAGE TYPE
				UART	SPI					
MSP430FR2633IRHB	15360 + 512	4096	2, 3 × CCR ⁽³⁾ 2, 2 × CCR	up to 2	up to 2	1	8	16 ⁽⁴⁾	19	32 RHB (VQFN)
MSP430FR2533IRHB	15360 + 512	2048	2, 3 × CCR ⁽³⁾ 2, 2 × CCR	up to 2	up to 2	1	8	16 ⁽⁴⁾	19	32 RHB (VQFN)
MSP430FR2633IDA	15360 + 512	4096	2, 3 × CCR ⁽³⁾ 2, 2 × CCR	up to 2	up to 2	1	8	16 ⁽⁴⁾	19	32 DA (TSSOP)
MSP430FR2533IDA	15360 + 512	2048	2, 3 × CCR ⁽³⁾ 2, 2 × CCR	up to 2	up to 2	1	8	16 ⁽⁴⁾	19	32 DA (TSSOP)
MSP430FR2632IRGE	8192 + 512	2048	2, 3 × CCR ⁽³⁾ 2, 2 × CCR	up to 2	1	1	8	8 ⁽⁵⁾	15	24 RGE (VQFN)
MSP430FR2532IRGE	8192 + 512	1024	2, 3 × CCR ⁽³⁾ 2, 2 × CCR	up to 2	1	1	8	8 ⁽⁵⁾	15	24 RGE (VQFN)
MSP430FR2633IYQW	15360 + 512	4096	2, 3 × CCR ⁽³⁾ 2, 2 × CCR	up to 2	1	1	8	8 ⁽⁶⁾	17	24 YQW (DSBGA)
MSP430FR2632IYQW	8192 + 512	2048	2, 3 × CCR ⁽³⁾ 2, 2 × CCR	up to 2	1	1	8	8 ⁽⁶⁾	17	24 YQW (DSBGA)

- (1) For the most current package and ordering information, see the *Package Option Addendum* in [§ 9](#), or see the TI website at www.ti.com
- (2) Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/packaging
- (3) A CCR register is a configurable register that provides internal and external capture or compare inputs, or internal and external PWM outputs.
- (4) Eight dedicated CapTIvate channels are included.
- (5) Four dedicated CapTIvate channels are included.
- (6) Two dedicated CapTIvate channels are included.

3.1 Related Products

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

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

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

Products for MSP430FRxx FRAM Microcontrollers 16-bit microcontrollers for ultra-low-power sensing and system management in building automation, smart grid, and industrial designs.

Companion Products for MSP430FR2633 Review products that are frequently purchased or used with this product.

Reference Designs for MSP430FR2633 The TI Designs Reference Design Library is a robust reference design library that spans analog, embedded processor, and connectivity. Created by TI experts to help you jump start your system design, all TI Designs include schematic or block diagrams, BOMs, and design files to speed your time to market. Search and download designs at ti.com/tidesigns.

4 Terminal Configuration and Functions

4.1 Pin Diagrams

Figure 4-1 shows the pinout for the 32-pin RHB package.

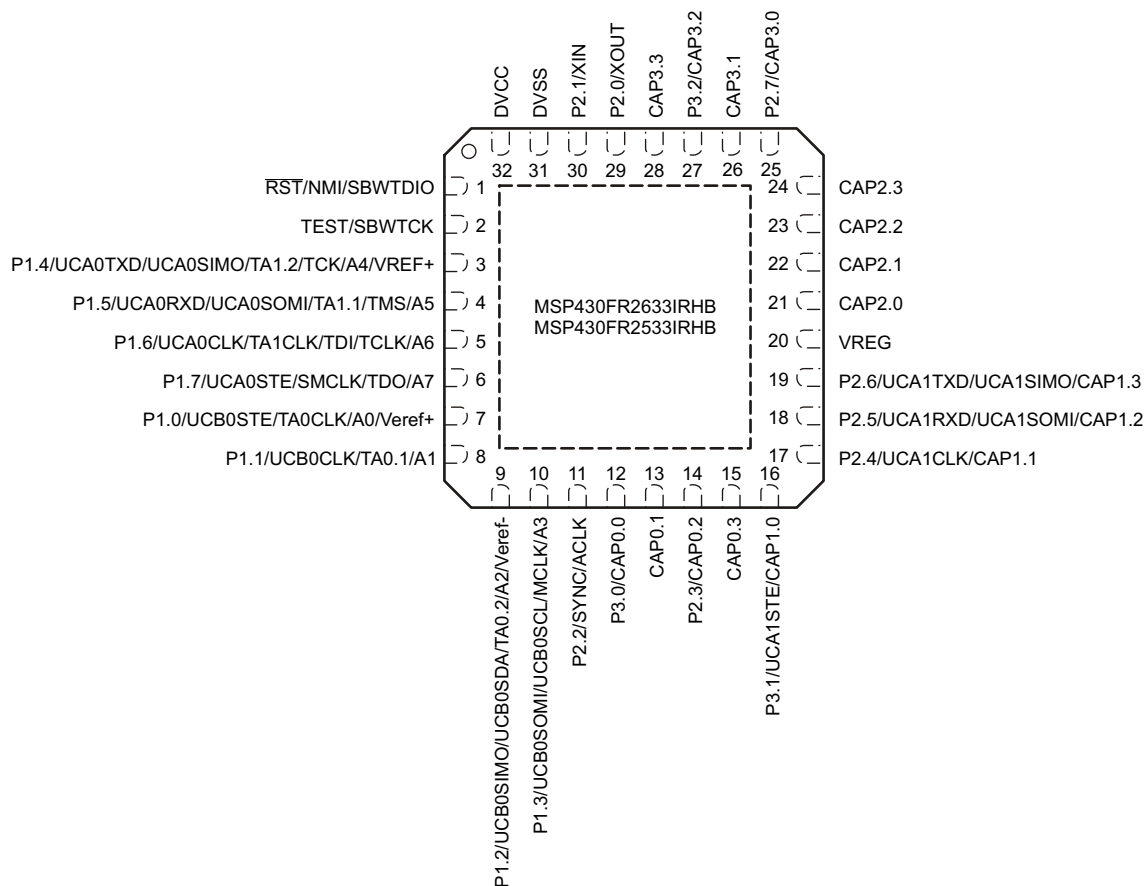


Figure 4-1. 32-Pin RHB Package (Top View)

Figure 4-2 shows the pinout for the 32-pin DA package.

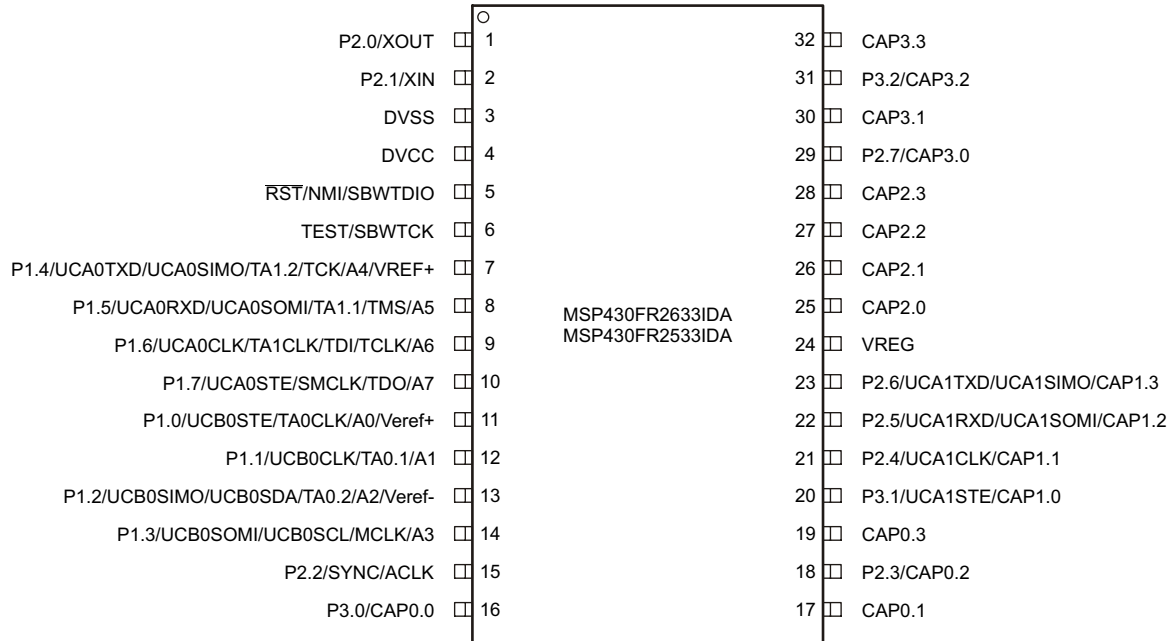


Figure 4-2. 32-Pin DA Package (Top View)

Figure 4-3 shows the pinout for the 24-pin RGE package.

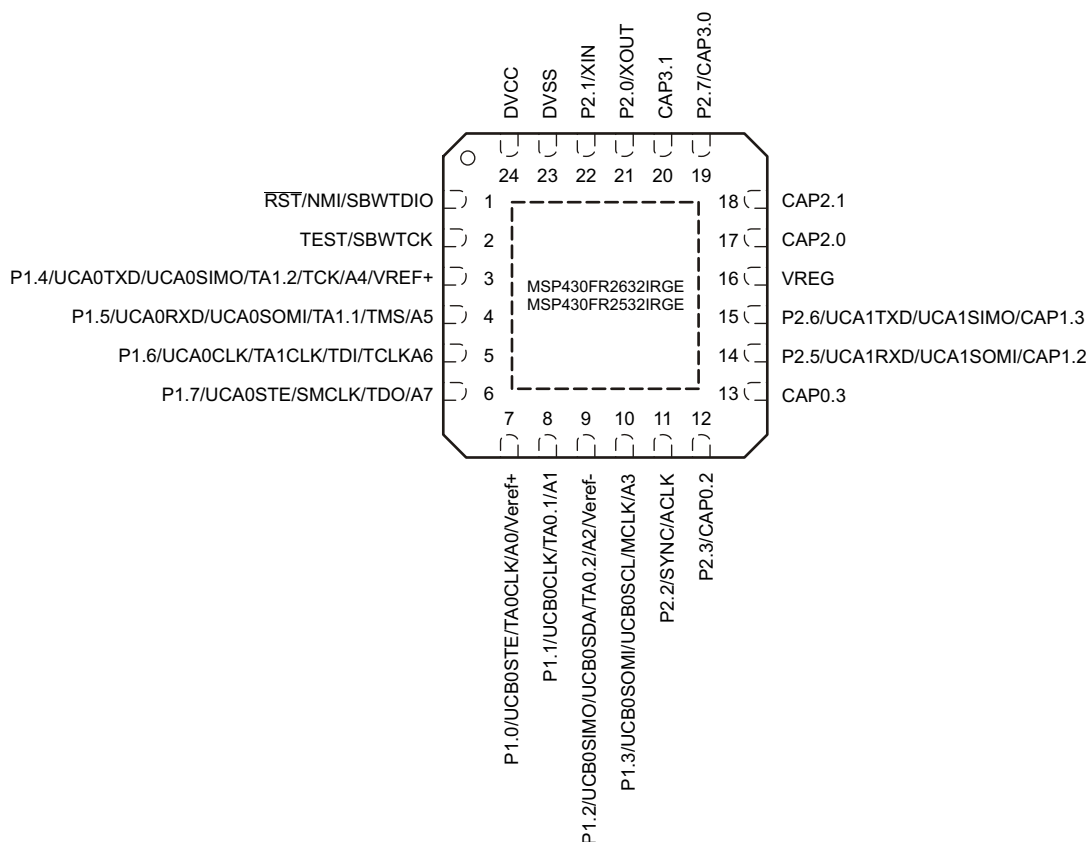


Figure 4-3. 24-Pin RGE Package (Top View)

Figure 4-4 shows the top view of the YQW package, and Figure 4-5 shows the bottom (ball-side) view.

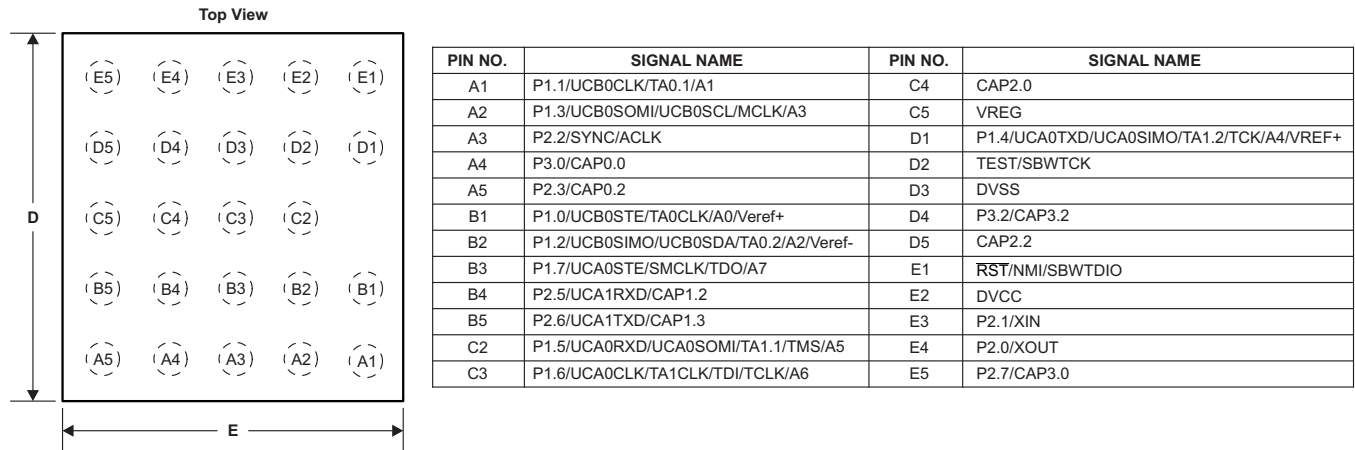


Figure 4-4. 24-Pin YQW Package (Top View)

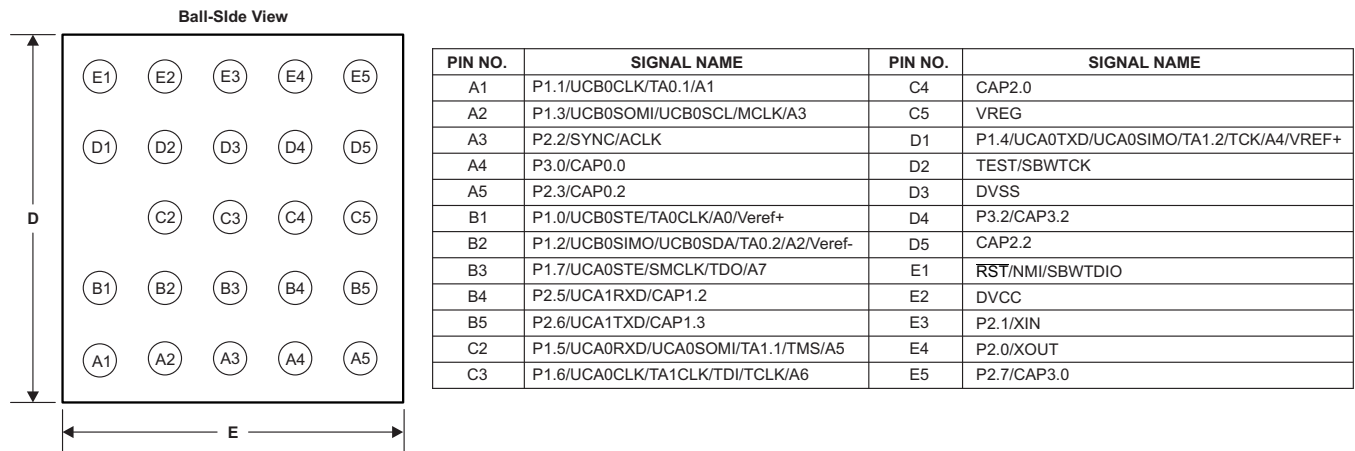


Figure 4-5. 24-Pin YQW Package (Bottom View)

4.2 Pin Attributes

Table 4-1 lists the attributes of all pins.

Table 4-1. Pin Attributes

PIN NUMBER				SIGNAL NAME ⁽¹⁾ (2)	SIGNAL TYPE ⁽³⁾	BUFFER TYPE ⁽⁴⁾	POWER SOURCE ⁽⁵⁾	RESET STATE AFTER BOR ⁽⁶⁾
RHB	DA	RGE	YQW					
1	5	1	E1	RST (RD)	I	LVC MOS	DVCC	OFF
				NMI	I	LVC MOS	DVCC	–
				SBWTDIO	I/O	LVC MOS	DVCC	–
2	6	2	D2	TEST (RD)	I	LVC MOS	DVCC	OFF
				SBWTCK	I	LVC MOS	DVCC	–
3	7	3	D1	P1.4 (RD)	I/O	LVC MOS	DVCC	OFF
				UCA0TXD	O	LVC MOS	DVCC	–
				UCA0SIMO	I/O	LVC MOS	DVCC	–
				TA1.2	I/O	LVC MOS	DVCC	–
				TCK	I	LVC MOS	DVCC	–
				A4	I	Analog	DVCC	–
				VREF+	O	Power	DVCC	–
4	8	4	C2	P1.5 (RD)	I/O	LVC MOS	DVCC	OFF
				UCA0RXD	I	LVC MOS	DVCC	–
				UCA0SOMI	I/O	LVC MOS	DVCC	–
				TA1.1	I/O	LVC MOS	DVCC	–
				TMS	I	LVC MOS	DVCC	–
				A5	I	Analog	DVCC	–
5	9	5	C3	P1.6 (RD)	I/O	LVC MOS	DVCC	OFF
				UCA0CLK	I/O	LVC MOS	DVCC	–
				TA1CLK	I	LVC MOS	DVCC	–
				TDI	I	LVC MOS	DVCC	–
				TCLK	I	LVC MOS	DVCC	–
				A6	I	Analog	DVCC	–
6	10	6	B3	P1.7 (RD)	I/O	LVC MOS	DVCC	OFF
				UCA0STE	I/O	LVC MOS	DVCC	–
				SMCLK	O	LVC MOS	DVCC	–
				TDO	O	LVC MOS	DVCC	–
				A7	I	Analog	DVCC	–
7	11	7	B1	P1.0 (RD)	I/O	LVC MOS	DVCC	OFF
				UCB0STE	I/O	LVC MOS	DVCC	–
				TA0CLK	I	LVC MOS	DVCC	–
				A0	I	Analog	DVCC	–
				Veref+	I	Power	DVCC	–

(1) Signals names with (RD) denote the reset default pin name.

(2) To determine the pin mux encodings for each pin, see [Section 6.11, Input/Output Diagrams](#).

(3) Signal Types: I = Input, O = Output, I/O = Input or Output

(4) Buffer Types: LVC MOS, Analog, or Power (see [Table 4-3](#))

(5) The power source shown in this table is the I/O power source, which may differ from the module power source.

(6) Reset States:

OFF = High-impedance with Schmitt trigger and pullup or pulldown (if available) disabled

N/A = Not applicable

Table 4-1. Pin Attributes (continued)

PIN NUMBER				SIGNAL NAME ⁽¹⁾ (2)	SIGNAL TYPE ⁽³⁾	BUFFER TYPE ⁽⁴⁾	POWER SOURCE ⁽⁵⁾	RESET STATE AFTER BOR ⁽⁶⁾
RHB	DA	RGE	YQW					
8	12	8	A1	P1.1 (RD)	I/O	LVC MOS	DVCC	OFF
				UCB0CLK	I/O	LVC MOS	DVCC	–
				TA0.1	I/O	LVC MOS	DVCC	–
				A1	I	Analog	DVCC	–
9	13	9	B2	P1.2 (RD)	I/O	LVC MOS	DVCC	OFF
				UCB0SIMO	I/O	LVC MOS	DVCC	–
				UCB0SDA	I/O	LVC MOS	DVCC	–
				TA0.2	I/O	LVC MOS	DVCC	–
				A2	I	Analog	DVCC	–
				Veref-	I	Power	DVCC	–
10	14	10	A2	P1.3 (RD)	I/O	LVC MOS	DVCC	OFF
				UCB0SOMI	I/O	LVC MOS	DVCC	–
				UCB0SCL	I/O	LVC MOS	DVCC	–
				MCLK	O	LVC MOS	DVCC	–
				A3	I	Analog	DVCC	–
11	15	11	A3	P2.2 (RD)	I/O	LVC MOS	DVCC	OFF
				SYNC	I	LVC MOS	DVCC	–
				ACLK	O	LVC MOS	DVCC	–
12	16	–	A4	P3.0 (RD)	I/O	LVC MOS	DVCC	OFF
				CAP0.0	I/O	Analog	V _{REG}	–
13	17	–	–	CAP0.1	I/O	Analog	V _{REG}	OFF
14	18	12	A5	P2.3 (RD)	I/O	LVC MOS	DVCC	OFF
				CAP0.2	I/O	Analog	V _{REG}	–
15	19	13	–	CAP0.3	I/O	Analog	V _{REG}	OFF
16	20	–	–	P3.1 (RD)	I/O	LVC MOS	DVCC	OFF
				UCA1STE	I/O	LVC MOS	DVCC	–
				CAP1.0	I/O	Analog	V _{REG}	–
17	21	–	–	P2.4 (RD)	I/O	LVC MOS	DVCC	OFF
				UCA1CLK	I/O	LVC MOS	DVCC	–
				CAP1.1	I/O	Analog	V _{REG}	–
18	22	14	B4	P2.5 (RD)	I/O	LVC MOS	DVCC	OFF
				UCA1RXD	I	LVC MOS	DVCC	–
				UCA1SOMI	I/O	LVC MOS	DVCC	–
				CAP1.2	I/O	Analog	V _{REG}	–
19	23	15	B5	P2.6 (RD)	I/O	LVC MOS	DVCC	OFF
				UCA1TXD	O	LVC MOS	DVCC	–
				UCA1SIMO	I/O	LVC MOS	DVCC	–
				CAP1.3	I/O	Analog	V _{REG}	–
20	24	16	C5	VREG	P	Power	V _{REG}	N/A
21	25	17	C4	CAP2.0	I/O	Analog	V _{REG}	OFF
22	26	18	–	CAP2.1	I/O	Analog	V _{REG}	OFF
23	27	–	D5	CAP2.2	I/O	Analog	V _{REG}	OFF
24	28	–	–	CAP2.3	I/O	Analog	V _{REG}	OFF
25	29	19	E5	P2.7 (RD)	I/O	LVC MOS	DVCC	OFF
				CAP3.0	I/O	Analog	V _{REG}	–
26	30	20	–	CAP3.1	I/O	Analog	V _{REG}	OFF

Table 4-1. Pin Attributes (continued)

PIN NUMBER				SIGNAL NAME ⁽¹⁾ (2)	SIGNAL TYPE ⁽³⁾	BUFFER TYPE ⁽⁴⁾	POWER SOURCE ⁽⁵⁾	RESET STATE AFTER BOR ⁽⁶⁾
RHB	DA	RGE	YQW					
27	31	–	D4	P3.2 (RD)	I/O	LVC MOS	DVCC	OFF
				CAP3.2	I/O	Analog	V _{REG}	–
28	32	–	–	CAP3.3	I/O	Analog	V _{REG}	OFF
29	1	21	E4	P2.0 (RD)	I/O	LVC MOS	DVCC	OFF
				XOUT	O	LVC MOS	DVCC	–
30	2	22	E3	P2.1 (RD)	I/O	LVC MOS	DVCC	OFF
				XIN	I	LVC MOS	DVCC	–
31	3	23	D3	DVSS	P	Power	DVCC	N/A
32	4	24	E2	DVCC	P	Power	DVCC	N/A

4.3 Signal Descriptions

Table 4-2 describes the signals for all device variants and package options.

Table 4-2. Signal Descriptions

FUNCTION	SIGNAL NAME	PIN NUMBER				PIN TYPE ⁽¹⁾	DESCRIPTION
		RHB	DA	RGE	YQW		
ADC	A0	7	11	7	B1	I	Analog input A0
	A1	8	12	8	A1	I	Analog input A1
	A2	9	13	9	B2	I	Analog input A2
	A3	10	14	10	A2	I	Analog input A3
	A4	3	7	3	D1	I	Analog input A4
	A5	4	8	4	C2	I	Analog input A5
	A6	5	9	5	C3	I	Analog input A6
	A7	6	10	6	B3	I	Analog input A7
	Veref+	7	11	7	B1	I	ADC positive reference
	Veref-	9	13	9	B2	I	ADC negative reference
CapTlvate	CAP0.0	12	16	–	A4	I/O	CapTlvate channel
	CAP0.1	13	17	–	–	I/O	CapTlvate channel
	CAP0.2	14	18	12	A5	I/O	CapTlvate channel
	CAP0.3	15	19	13	–	I/O	CapTlvate channel
	CAP1.0	16	20	–	–	I/O	CapTlvate channel
	CAP1.1	17	21	–	–	I/O	CapTlvate channel
	CAP1.2	18	22	14	B4	I/O	CapTlvate channel
	CAP1.3	19	23	15	B5	I/O	CapTlvate channel
	CAP2.0	21	25	17	C4	I/O	CapTlvate channel
	CAP2.1	22	26	18	–	I/O	CapTlvate channel
	CAP2.2	23	27	–	D5	I/O	CapTlvate channel
	CAP2.3	24	28	–	–	I/O	CapTlvate channel
	CAP3.0	25	29	19	E5	I/O	CapTlvate channel
	CAP3.1	26	30	20	–	I/O	CapTlvate channel
	CAP3.2	27	31	–	D4	I/O	CapTlvate channel
	CAP3.3	28	32	–	–	I/O	CapTlvate channel
	SYNC	11	15	11	A3	I	CapTlvate synchronous trigger input for processing and conversion
Clock	ACLK	11	15	11	A3	O	ACLK output
	MCLK	10	14	10	A2	O	MCLK output
	SMCLK	6	10	6	B3	O	SMCLK output
	XIN	30	2	22	E3	I	Input terminal for crystal oscillator
	XOUT	29	1	21	E4	O	Output terminal for crystal oscillator
Debug	SBWTCK	2	6	2	D2	I	Spy-Bi-Wire input clock
	SBWTDIO	1	5	1	E1	I/O	Spy-Bi-Wire data input/output
	TCK	3	7	3	D1	I	Test clock
	TCLK	5	9	5	C3	I	Test clock input
	TDI	5	9	5	C3	I	Test data input
	TDO	6	10	6	B3	O	Test data output
	TEST	2	6	2	D2	I	Test Mode pin – selected digital I/O on JTAG pins
	TMS	4	8	4	C2	I	Test mode select

(1) Pin Types: I = Input, O = Output, I/O = Input or Output, P = Power

Table 4-2. Signal Descriptions (continued)

FUNCTION	SIGNAL NAME	PIN NUMBER				PIN TYPE ⁽¹⁾	DESCRIPTION
		RHB	DA	RGE	YQW		
GPIO	P1.0	7	11	7	B1	I/O	General-purpose I/O
	P1.1	8	12	8	A1	I/O	General-purpose I/O
	P1.2	9	13	9	B2	I/O	General-purpose I/O
	P1.3	10	14	10	A2	I/O	General-purpose I/O
	P1.4	3	7	3	D1	I/O	General-purpose I/O ⁽²⁾
	P1.5	4	8	4	C2	I/O	General-purpose I/O ⁽²⁾
	P1.6	5	9	5	C3	I/O	General-purpose I/O ⁽²⁾
	P1.7	6	10	6	B3	I/O	General-purpose I/O ⁽²⁾
	P2.0	29	1	21	E4	I/O	General-purpose I/O
	P2.1	30	2	22	E3	I/O	General-purpose I/O
	P2.2	11	15	11	A3	I/O	General-purpose I/O
	P2.3	14	18	12	A5	I/O	General-purpose I/O
	P2.4	17	21	–	–	I/O	General-purpose I/O
	P2.5	18	22	14	B4	I/O	General-purpose I/O
	P2.6	19	23	15	B5	I/O	General-purpose I/O
	P2.7	25	29	19	E5	I/O	General-purpose I/O
	P3.0	12	16	–	A4	I/O	General-purpose I/O
	P3.1	16	20	–	–	I/O	General-purpose I/O
	P3.2	27	31	–	D4	I/O	General-purpose I/O
I ² C	UCB0SCL	10	14	10	A2	I/O	eUSCI_B0 I ² C clock
	UCB0SDA	9	13	9	B2	I/O	eUSCI_B0 I ² C data
Power	DVCC	32	4	24	E2	P	Power supply
	DVSS	31	3	23	D3	P	Power ground
	VREF+	3	7	3	D1	P	Output of positive reference voltage with ground as reference
	VREG	20	24	16	C5	O	CapTivate regulator external decoupling capacitor
SPI	UCA0CLK	5	9	5	C3	I/O	eUSCI_A0 SPI clock input/output
	UCA0SIMO	3	7	3	D1	I/O	eUSCI_A0 SPI slave in/master out
	UCA0SOMI	4	8	4	C2	I/O	eUSCI_A0 SPI slave out/master in
	UCA0STE	6	10	6	B3	I/O	eUSCI_A0 SPI slave transmit enable
	UCA1CLK	17	21	–	–	I/O	eUSCI_A1 SPI clock input/output
	UCA1SIMO	19	23	15	B5	I/O	eUSCI_A1 SPI slave in/master out
	UCA1SOMI	18	22	14	B4	I/O	eUSCI_A1 SPI slave out/master in
	UCA1STE	16	20	–	–	I/O	eUSCI_A1 SPI slave transmit enable
	UCB0CLK	8	12	8	A1	I/O	eUSCI_B0 clock input/output
	UCB0SIMO	9	13	9	B2	I/O	eUSCI_B0 SPI slave in/master out
	UCB0SOMI	10	14	10	A2	I/O	eUSCI_B0 SPI slave out/master in
	UCB0STE	7	11	7	B1	I/O	eUSCI_B0 slave transmit enable
System	NMI	1	5	1	E1	I	Nonmaskable interrupt input
	$\overline{\text{RST}}$	1	5	1	E1	I	Active-low reset input

(2) Because this pin is multiplexed with the JTAG function, TI recommends disabling the pin interrupt function while in JTAG debug to prevent collisions.

Table 4-2. Signal Descriptions (continued)

FUNCTION	SIGNAL NAME	PIN NUMBER				PIN TYPE ⁽¹⁾	DESCRIPTION
		RHB	DA	RGE	YQW		
Timer_A	TA0.1	8	12	8	A1	I/O	Timer TA0 CCR1 capture: CCI1A input, compare: Out1 outputs
	TA0.2	9	13	9	B2	I/O	Timer TA0 CCR2 capture: CCI2A input, compare: Out2 outputs
	TA0CLK	7	11	7	B1	I	Timer clock input TACLK for TA0
	TA1.1	4	8	4	C2	I/O	Timer TA1 CCR1 capture: CCI1A input, compare: Out1 outputs
	TA1.2	3	7	3	D1	I/O	Timer TA1 CCR2 capture: CCI2A input, compare: Out2 outputs
	TA1CLK	5	9	5	C3	I	Timer clock input TACLK for TA1
UART	UCA0RXD	4	8	4	C2	I	eUSCI_A0 UART receive data
	UCA0TXD	3	7	3	D1	O	eUSCI_A0 UART transmit data
	UCA1RXD	18	22	14	B4	I	eUSCI_A1 UART receive data
	UCA1TXD	19	23	15	B5	O	eUSCI_A1 UART transmit data
QFN Pad	QFN thermal pad	Pad	N/A	Pad	N/A		QFN package exposed thermal pad. TI recommends connecting to V _{SS} .

4.4 Pin Multiplexing

Pin multiplexing for these MCUs is controlled by both register settings and operating modes (for example, if the MCU is in test mode). For details of the settings for each pin and schematics of the multiplexed ports, see [Section 6.11](#).

4.5 Buffer Types

[Table 4-3](#) defines the pin buffer types that are listed in [Table 4-1](#).

Table 4-3. Buffer Types

BUFFER TYPE (STANDARD)	NOMINAL VOLTAGE	HYSTERESIS	PU OR PD	NOMINAL PU OR PD STRENGTH (μ A)	OUTPUT DRIVE STRENGTH (mA)	OTHER CHARACTERISTICS
LVC MOS	3.0 V	$\gamma^{(1)}$	Programmable	See Section 5.11.4	See Section 5.11.4	
Analog	3.0 V	N	N/A	N/A	N/A	See analog modules in Section 5 for details.
Power (DVCC)	3.0 V	N	N/A	N/A	N/A	SVS enables hysteresis on DVCC.
Power (AVCC)	3.0 V	N	N/A	N/A	N/A	

(1) Only for input pins.

4.6 Connection of Unused Pins

[Table 4-4](#) lists the correct termination of unused pins.

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

PIN	POTENTIAL	COMMENT
Px.0 to Px.7	Open	Switched to port function, output direction (PxDIR.n = 1)
$\overline{\text{RST}}/\text{NMI}$	DV _{CC}	47-k Ω pullup or internal pullup selected with 10-nF (or 1.1-nF) pulldown ⁽²⁾
TEST	Open	This pin always has an internal pulldown enabled.
CAP2.x, CAPx.1, CAPx.3	Open	These pins have internal pullup and pulldown resistors, and high impedance is their default setting.

(1) Any unused pin with a secondary function that is shared with general-purpose I/O should follow the Px.0 to Px.7 unused pin connection guidelines.

(2) The pulldown capacitor should not exceed 1.1 nF when using MCUs with Spy-Bi-Wire interface in Spy-Bi-Wire mode with TI tools like FET interfaces or GANG programmers.

5 Specifications

5.1 Absolute Maximum Ratings⁽¹⁾

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

	MIN	MAX	UNIT
Voltage applied at DVCC pin to V _{SS}	−0.3	4.1	V
Voltage applied to any dedicated CapTivate pin or pin in CapTivate mode ⁽²⁾	−0.3	V _{REG}	V
Voltage applied to any other pin ⁽³⁾	−0.3	V _{CC} + 0.3 (4.1 V Max)	V
Diode current at any device pin		±2	mA
Maximum junction temperature, T _J		85	°C
Storage temperature, T _{stg} ⁽⁴⁾	−40	125	°C

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) This applies to dedicated CapTivate I/Os only or I/Os worked in CapTivate mode.
- (3) All voltages referenced to V_{SS}.
- (4) Higher temperature may be applied during board soldering according to the current JEDEC J-STD-020 specification with peak reflow temperatures not higher than classified on the device label on the shipping boxes or reels.

5.2 ESD Ratings

	VALUE	UNIT
V _(ESD) Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 ⁽¹⁾	±2000
	Charged-device model (CDM), per JEDEC specification JESD22-C101 ⁽²⁾	±500

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process. Pins listed as ±2000 V may actually have higher performance.
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process. Pins listed as ±500 V may actually have higher performance.

5.3 Recommended Operating Conditions

		MIN	NOM	MAX	UNIT
V _{CC}	Supply voltage applied at DVCC pin ⁽¹⁾⁽²⁾⁽³⁾	1.8		3.6	V
V _{SS}	Supply voltage applied at DVSS pin		0		V
T _A	Operating free-air temperature	−40		85	°C
T _J	Operating junction temperature	−40		85	°C
C _{DVCC}	Recommended capacitor at DVCC ⁽⁴⁾	4.7	10		μF
C _{REG}	External buffer capacitor, ESR ≤ 200 mΩ	0.8	1	1.2	μF
C _{ELECTRODE}	Maximum capacitance of all external electrodes on all CapTivate blocks			300	pF
f _{SYSTEM}	Processor frequency (maximum MCLK frequency) ⁽³⁾⁽⁵⁾	No FRAM wait states (NWAITSx = 0)	0	8	MHz
		With FRAM wait states (NWAITSx = 1) ⁽⁶⁾	0	16 ⁽⁷⁾	
f _{ACLK}	Maximum ACLK frequency			40	kHz
f _{SMCLK}	Maximum SMCLK frequency			16 ⁽⁷⁾	MHz

- (1) Supply voltage changes faster than 0.2 V/μs can trigger a BOR reset even within the recommended supply voltage range.
- (2) Modules may have a different supply voltage range specification. See the specification of the respective module in this data sheet.
- (3) The minimum supply voltage is defined by the SVS levels. See the SVS threshold parameters in [Table 5-2](#).
- (4) A capacitor tolerance of ±20% or better is required.
- (5) Modules may have a different maximum input clock specification. See the specification of the respective module in this data sheet.
- (6) Wait states only occur on actual FRAM accesses (that is, on FRAM cache misses). RAM and peripheral accesses are always executed without wait states.
- (7) If clock sources such as HF crystals or the DCO with frequencies >16 MHz are used, the clock must be divided in the clock system to comply with this operating condition.

5.4 Active Mode Supply Current Into V_{CC} Excluding External Current⁽¹⁾

$V_{CC} = 3\text{ V}$, $T_A = 25^\circ\text{C}$ (unless otherwise noted)

PARAMETER	EXECUTION MEMORY	TEST CONDITION	FREQUENCY (f _{MCLK} = f _{SMCLK})						UNIT
			1 MHz 0 WAIT STATES (NWAITS _x = 0)		8 MHz 0 WAIT STATES (NWAITS _x = 0)		16 MHz 1 WAIT STATE (NWAITS _x = 1)		
			TYP	MAX	TYP	MAX	TYP	MAX	
I _{AM, FRAM} (0%)	FRAM 0% cache hit ratio	3 V, 25°C	504		2772		3047	3480	µA
		3 V, 85°C	516		2491		2871		
I _{AM, FRAM} (100%)	FRAM 100% cache hit ratio	3 V, 25°C	203		625		1000	1215	µA
		3 V, 85°C	212		639		1016		
I _{AM, RAM} ⁽²⁾	RAM	3 V, 25°C	229		818		1377		µA

(1) All inputs are tied to 0 V or to V_{CC} . Outputs do not source or sink any current. Characterized with program executing typical data processing.

$f_{ACLK} = 32768\text{ Hz}$, $f_{MCLK} = f_{SMCLK} = f_{DCO}$ at specified frequency

Program and data entirely reside in FRAM. All execution is from FRAM.

(2) Program and data reside entirely in RAM. All execution is from RAM. No access to FRAM.

5.5 Active Mode Supply Current Per MHz

$V_{CC} = 3\text{ V}$, $T_A = 25^\circ\text{C}$ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	TYP	UNIT
$dI_{AM,FRAM}/df$	Active mode current consumption per MHz, execution from FRAM, no wait states [I_{AM} (75% cache hit rate) at 8 MHz – I_{AM} (75% cache hit rate) at 1 MHz] / 7 MHz	126	$\mu\text{A}/\text{MHz}$

5.6 Low-Power Mode LPM0 Supply Currents Into V_{CC} Excluding External Current

$V_{CC} = 3\text{ V}$, $T_A = 25^\circ\text{C}$ (unless otherwise noted)⁽¹⁾⁽²⁾

PARAMETER	V _{CC}	FREQUENCY (f _{SMCLK})						UNIT
		1 MHz		8 MHz		16 MHz		
		TYP	MAX	TYP	MAX	TYP	MAX	
I _{LPM0}	2 V	156		328		420		μA
	3 V	166		342		433		

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

(2) Current for watchdog timer clocked by SMCLK included.

$f_{ACLK} = 32768\text{ Hz}$, $f_{MCLK} = 0\text{ MHz}$, f_{SMCLK} at specified frequency.

5.7 Low-Power Mode (LPM3 and LPM4) Supply Currents (Into V_{CC}) Excluding External Current

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

PARAMETER		V_{CC}	–40°C		25°C		85°C		UNIT
			TYP	MAX	TYP	MAX	TYP	MAX	
$I_{LPM3,XT1}$	Low-power mode 3, 12.5-pF crystal, includes SVS ⁽²⁾⁽³⁾⁽⁴⁾	3 V	0.98		1.18	1.65	3.24		μA
		2 V	0.96		1.16		3.21		
$I_{LPM3,VLO}$	Low-power mode 3, VLO, excludes SVS ⁽⁵⁾	3 V	0.78		0.98	1.40	3.04		μA
		2 V	0.76		0.96		3.01		
$I_{LPM3,RTC}$	Low-power mode 3, RTC, excludes SVS ⁽⁶⁾ (see Figure 5-1)	3 V	0.93		1.13		3.19		μA
$I_{LPM3,CapTivate,1}$ proximity, wake on touch	Low-power mode 3, CapTivate, excludes SVS ⁽⁷⁾	3.3 V			5				μA
$I_{LPM3,CapTivate,1}$ button, wake on touch	Low-power mode 3, CapTivate, excludes SVS ⁽⁸⁾	3.3 V			3.4				μA
$I_{LPM3,CapTivate,4}$ buttons, wake on touch	Low-power mode 3, CapTivate, excludes SVS ⁽⁹⁾	3.3 V			3.6				μA
$I_{LPM3,CapTivate,16}$ buttons	Low-power mode 3, CapTivate, excludes SVS ⁽¹⁰⁾	3.3 V			27.2				μA
$I_{LPM3,CapTivate,64}$ buttons	Low-power mode 3, CapTivate, excludes SVS ⁽¹¹⁾	3.3 V			109.2				μA
$I_{LPM4,SVS}$	Low-power mode 4, includes SVS	3 V	0.51		0.65		2.65		μA
		2 V	0.49		0.64		2.63		
I_{LPM4}	Low-power mode 4, excludes SVS	3 V	0.35		0.49		2.49		μA
		2 V	0.34		0.48		2.46		
$I_{LPM4,CapTivate,1}$ proximity, wake on touch	Low-power mode 4, CapTivate, excludes SVS ⁽¹²⁾	3 V			4.4				μA

- (1) All inputs are tied to 0 V or to V_{CC} . Outputs do not source or sink any current.
- (2) Not applicable for MCUs with HF crystal oscillator only.
- (3) Characterized with a Micro Crystal MS1V-T1K crystal with a load capacitance of 12.5 pF. The internal and external load capacitance are chosen to closely match the required 12.5-pF load.
- (4) Low-power mode 3, 12.5-pF crystal, includes SVS test conditions:
Current for watchdog timer clocked by ACLK and RTC clocked by XT1 included. Current for brownout and SVS included (SVSHE = 1).
CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 0 (LPM3),
 f_{XT1} = 32768 Hz, f_{ACLK} = f_{XT1} , f_{MCLK} = f_{SMCLK} = 0 MHz
- (5) Low-power mode 3, VLO, excludes SVS test conditions:
Current for watchdog timer clocked by VLO included. RTC disabled. Current for brownout included. SVS disabled (SVSHE = 0).
CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 0 (LPM3)
 f_{XT1} = 32768 Hz, f_{ACLK} = f_{MCLK} = f_{SMCLK} = 0 MHz
- (6) RTC periodically wakes up every second with external 32768-Hz input as source.
- (7) CapTivate technology works in LPM3 with one proximity sensor for wake on touch. CapTivate BSWP demo panel with 1.5-mm overlay. Current for brownout included. SVS disabled (SVSHE = 0).
 f_{SCAN} = 8 Hz, f_{CONVER} = 2 MHz, COUNTS = 800
- (8) CapTivate technology works in LPM3 with one button, wake on touch. CapTivate BSWP demo panel with 1.5-mm overlay. Current for brownout included. SVS disabled (SVSHE = 0).
 f_{SCAN} = 8 Hz, f_{CONVER} = 2 MHz, COUNTS = 250
- (9) CapTivate technology works in LPM3 with four self-capacitance buttons, wake on touch. CapTivate BSWP demo panel with 1.5-mm overlay. Current for brownout included. SVS disabled (SVSHE = 0).
 f_{SCAN} = 8 Hz, f_{CONVER} = 2 MHz, COUNTS = 250
- (10) CapTivate technology works in LPM3 with 16 self-capacitance buttons. The CPU enters active mode between time cycles to configure the conversions and read the results. CapTivate BSWP demo panel with 1.5-mm overlay. Current for brownout included. SVS disabled (SVSHE = 0).
 f_{SCAN} = 8 Hz, f_{CONVER} = 2 MHz, COUNTS = 250
- (11) CapTivate technology works in LPM3 with 64 mutual-capacitance buttons. The CPU enters active mode between time cycles to configure the conversions and read the results. TIDM-CAPTIVATE-64-BUTTON 64-Button Capacitive Touch Panel. Current for brownout included. SVS disabled (SVSHE = 0).
 f_{SCAN} = 8 Hz, f_{CONVER} = 2 MHz, COUNTS = 250
- (12) CapTivate technology works in LPM4 with one proximity sensor for wake on touch. CapTivate BSWP demo panel with 1.5-mm overlay. Current for brownout included. SVS disabled (SVSHE = 0). VLO (10 kHz) sources to CapTivate timer, no external crystal.
 f_{SCAN} = 8 Hz, f_{CONVER} = 2 MHz, COUNTS = 800

Low-Power Mode (LPM3 and LPM4) Supply Currents (Into V_{CC}) Excluding External Current (continued)

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

PARAMETER	V_{CC}	–40°C		25°C		85°C		UNIT
		TYP	MAX	TYP	MAX	TYP	MAX	
I_{LPM4} , CapTivate, 1 button, wake on touch Low-power mode 4, CapTivate, excludes SVS ⁽¹³⁾	3 V			2.7				μA
I_{LPM4} , CapTivate, 4 buttons, wake on touch Low-power mode 4, CapTivate, excludes SVS ⁽¹⁴⁾	3 V			3.0				μA

(13) CapTivate technology works in LPM4 with one button, wake on touch. CapTivate BSWP demo panel with 1.5-mm overlay. Current for brownout included. SVS disabled (SVSHE = 0). VLO (10 kHz) sources to CapTivate timer, no external crystal.

$f_{SCAN} = 8$ Hz, $f_{CONVER} = 2$ MHz, COUNTS = 250

(14) CapTivate technology works in LPM4 with four self-capacitance buttons, wake on touch. CapTivate BSWP demo panel with 1.5-mm overlay. Current for brownout included. SVS disabled (SVSHE = 0). VLO (10 kHz) sources to CapTivate timer, no external crystal.

$f_{SCAN} = 8$ Hz, $f_{CONVER} = 2$ MHz, COUNTS = 250

5.8 Low-Power Mode LPMx.5 Supply Currents (Into V_{CC}) Excluding External Current

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

PARAMETER	V_{CC}	–40°C		25°C		85°C		UNIT
		TYP	MAX	TYP	MAX	TYP	MAX	
$I_{LPM3.5, XT1}$ Low-power mode 3.5, 12.5-pF crystal, includes SVS ⁽¹⁾⁽²⁾⁽³⁾ (also see Figure 5-2)	3 V	0.65		0.73	0.95	0.99	1.42	μA
	2 V	0.63		0.71		0.87		
$I_{LPM4.5, SVS}$ Low-power mode 4.5, includes SVS ⁽⁴⁾ (see Figure 5-3)	3 V	0.22		0.24	0.31	0.30	0.38	μA
	2 V	0.21		0.23		0.28		
$I_{LPM4.5}$ Low-power mode 4.5, excludes SVS ⁽⁵⁾	3 V	0.012		0.016	0.055	0.061	0.120	μA
	2 V	0.002		0.007		0.044		

(1) Not applicable for MCUs with HF crystal oscillator only.

(2) Characterized with a Micro Crystal MS1V-T1K crystal with a load capacitance of 12.5 pF. The internal and external load capacitance are chosen to closely match the required 12.5-pF load.

(3) Low-power mode 3.5, 12.5-pF crystal, includes SVS test conditions:

Current for RTC clocked by XT1 included. Current for brownout and SVS included (SVSHE = 1). Core regulator disabled.

PMMREGOFF = 1, CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 1 (LPMx.5),

$f_{XT1} = 32768$ Hz, $f_{ACLK} = 0$, $f_{MCLK} = f_{SMCLK} = 0$ MHz

(4) Low-power mode 4.5, includes SVS test conditions:

Current for brownout and SVS included (SVSHE = 1). Core regulator disabled.

PMMREGOFF = 1, CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 1 (LPMx.5),

$f_{XT1} = 0$ Hz, $f_{ACLK} = f_{MCLK} = f_{SMCLK} = 0$ MHz

(5) Low-power mode 4.5, excludes SVS test conditions:

Current for brownout included. SVS disabled (SVSHE = 0). Core regulator disabled.

PMMREGOFF = 1, CPUOFF = 1, SCG0 = 1 SCG1 = 1, OSCOFF = 1 (LPMx.5),

$f_{XT1} = 0$ Hz, $f_{ACLK} = f_{MCLK} = f_{SMCLK} = 0$ MHz

5.9 Typical Characteristics - Low-Power Mode Supply Currents

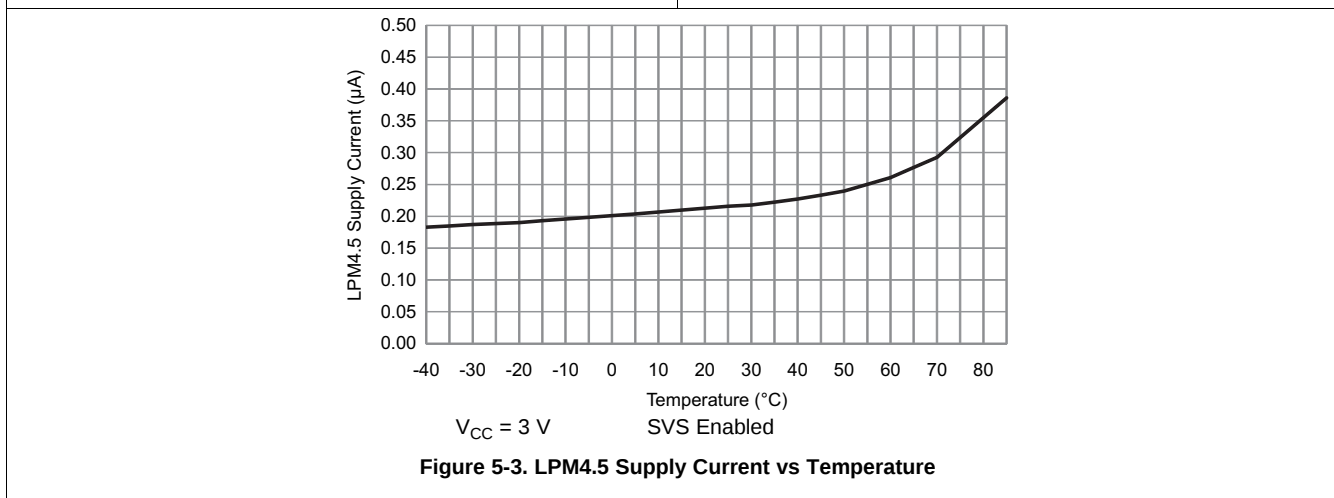
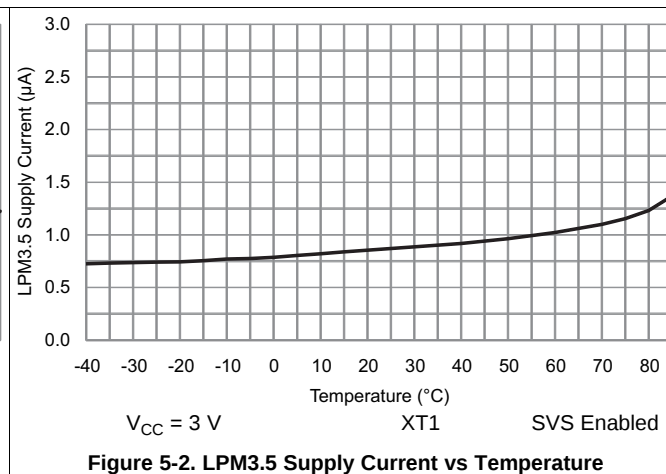
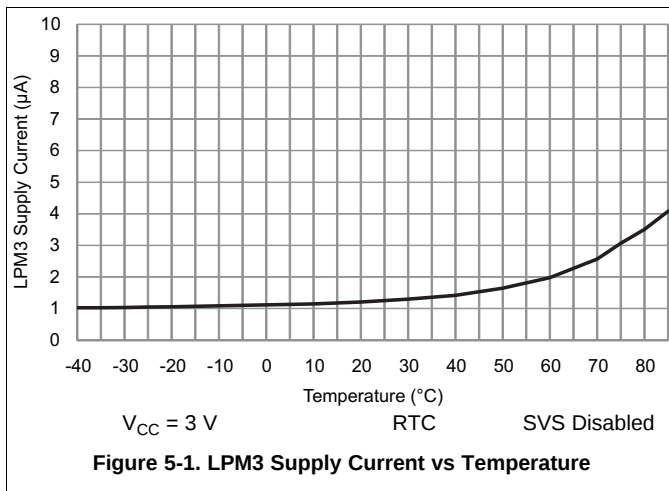


Table 5-1. Typical Characteristics – Current Consumption Per Module

MODULE	TEST CONDITIONS	REFERENCE CLOCK	MIN	TYP	MAX	UNIT
Timer_A		Module input clock		5		µA/MHz
eUSCI_A	UART mode	Module input clock		7		µA/MHz
eUSCI_A	SPI mode	Module input clock		5		µA/MHz
eUSCI_B	SPI mode	Module input clock		5		µA/MHz
eUSCI_B	I ² C mode, 100 kbaud	Module input clock		5		µA/MHz
RTC		32 kHz		85		nA
CRC	From start to end of operation	MCLK		8.5		µA/MHz

5.10 Thermal Resistance Characteristics

THERMAL METRIC ⁽¹⁾		VALUE ⁽²⁾	UNIT
R θ_{JA} Junction-to-ambient thermal resistance, still air	VQFN 32 pin (RHB)	33.5	°C/W
	TSSOP 32 pin (DA)	69.4	
	VQFN 24 pin (RGE)	32.6	
	DSBGA 24 pin (YQW)	63.7	
R $\theta_{JC(top)}$ Junction-to-case (top) thermal resistance	VQFN 32 pin (RHB)	25.7	°C/W
	TSSOP 32 pin (DA)	18.1	
	VQFN 24 pin (RGE)	32.4	
	DSBGA 24 pin (YQW)	0.3	
R θ_{JB} Junction-to-board thermal resistance	VQFN 32 pin (RHB)	7.6	°C/W
	TSSOP 32 pin (DA)	33.1	
	VQFN 24 pin (RGE)	10.1	
	DSBGA 24 pin (YQW)	9.2	

(1) For more information about traditional and new thermal metrics, see [Semiconductor and IC Package Thermal Metrics](#).

(2) These values are based on a JEDEC-defined 2S2P system (with the exception of the Theta JC (R θ_{JC}) value, which is based on a JEDEC-defined 1S0P system) and will change based on environment and application. For more information, see these EIA/JEDEC standards:

- JESD51-2, *Integrated Circuits Thermal Test Method Environmental Conditions - Natural Convection (Still Air)*
- JESD51-3, *Low Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages*
- JESD51-7, *High Effective Thermal Conductivity Test Board for Leaded Surface Mount Packages*
- JESD51-9, *Test Boards for Area Array Surface Mount Package Thermal Measurements*

5.11 Timing and Switching Characteristics

5.11.1 Power Supply Sequencing

Table 5-2 lists the characteristics of the SVS and BOR.

Table 5-2. PMM, SVS and BOR

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Figure 5-4)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_{BOR, \text{ safe}}$	Safe BOR power-down level ⁽¹⁾	0.1			V
$t_{BOR, \text{ safe}}$	Safe BOR reset delay ⁽²⁾	10			ms
$I_{SVSH, AM}$	SVS _H current consumption, active mode			1.5	μA
$I_{SVSH, LPM}$	SVS _H current consumption, low-power modes		240		nA
V_{SVSH-}	SVS _H power-down level	1.71	1.80	1.86	V
V_{SVSH+}	SVS _H power-up level	1.74	1.89	1.99	V
$V_{SVSH, \text{ hys}}$	SVS _H hysteresis		80		mV
$t_{PD, SVSH, AM}$	SVS _H propagation delay, active mode			10	μs
$t_{PD, SVSH, LPM}$	SVS _H propagation delay, low-power modes			100	μs
$V_{REF, 1.2V}$	1.2-V REF voltage ⁽³⁾	1.158	1.20	1.242	V

(1) A safe BOR can be correctly generated only if DVCC drops below this voltage before it rises.

(2) When an BOR occurs, a safe BOR can be correctly generated only if DVCC is kept low longer than this period before it reaches V_{SVSH+} .

(3) This is a characterized result with external 1-mA load to ground from –40°C to 85°C.

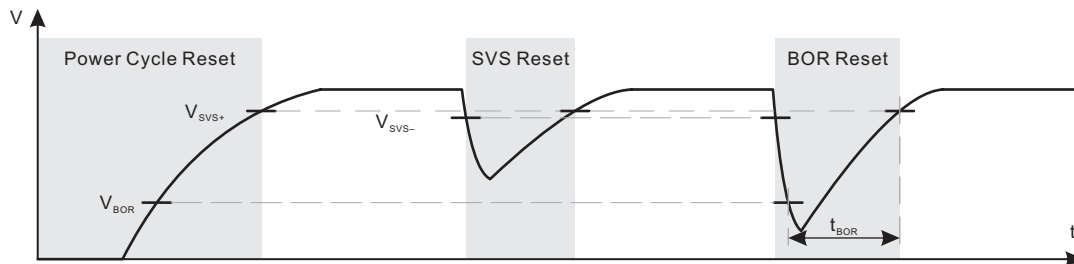


Figure 5-4. Power Cycle, SVS, and BOR Reset Conditions

5.11.2 Reset Timing

Table 5-3 lists the wake-up times.

Table 5-3. Wake-up Times From Low-Power Modes and Reset

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

PARAMETER		TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
t _{WAKE-UP FRAM}	Additional wake-up time to activate the FRAM in AM if previously disabled by the FRAM controller or from a LPM if immediate activation is selected for wakeup ⁽¹⁾		3 V		10		μs
t _{WAKE-UP LPM0}	Wake-up time from LPM0 to active mode ⁽¹⁾		3 V		200 + 2.5 / f _{DCO}		ns
t _{WAKE-UP LPM3}	Wake-up time from LPM3 to active mode ⁽²⁾		3 V		10		μs
t _{WAKE-UP LPM4}	Wake-up time from LPM4 to active mode		3 V		10		μs
t _{WAKE-UP LPM3.5}	Wake-up time from LPM3.5 to active mode ⁽²⁾		3 V		350		μs
t _{WAKE-UP LPM4.5}	Wake-up time from LPM4.5 to active mode ⁽²⁾	SVSHE = 1	3 V		350		μs
		SVSHE = 0			1		ms
t _{WAKE-UP-RESET}	Wake-up time from $\overline{\text{RST}}$ or BOR event to active mode ⁽²⁾		3 V		1		ms
t _{RESET}	Pulse duration required at $\overline{\text{RST}}$ /NMI pin to accept a reset		3 V		2		μs

- (1) The wake-up time is measured from the edge of an external wake-up signal (for example, port interrupt or wake-up event) to the first externally observable MCLK clock edge.
- (2) The wake-up time is measured from the edge of an external wake-up signal (for example, port interrupt or wake-up event) until the first instruction of the user program is executed.

5.11.3 Clock Specifications

Table 5-4 lists the characteristics of XT1.

Table 5-4. XT1 Crystal Oscillator (Low Frequency)

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

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
f _{XT1, LF} XT1 oscillator crystal, low frequency	LFXTBYPASS = 0			32768		Hz
DC _{XT1, LF} XT1 oscillator LF duty cycle	Measured at MCLK, f _{LFXT} = 32768 Hz		30%		70%	
f _{XT1, SW} XT1 oscillator logic-level square-wave input frequency	LFXTBYPASS = 1 ⁽²⁾⁽³⁾			32.768		kHz
DC _{XT1, SW} LFXT oscillator logic-level square-wave input duty cycle	LFXTBYPASS = 1		40%		60%	
OA _{LFXT} Oscillation allowance for LF crystals ⁽⁴⁾	LFXTBYPASS = 0, LFXTDRIVE = {3}, f _{LFXT} = 32768 Hz, C _{L,eff} = 12.5 pF			200		kΩ
C _{L,eff} Integrated effective load capacitance ⁽⁵⁾	See ⁽⁶⁾			1		pF
t _{START, LFXT} Start-up time ⁽⁷⁾	f _{OSC} = 32768 Hz, LFXTBYPASS = 0, LFXTDRIVE = {3}, T _A = 25°C, C _{L,eff} = 12.5 pF			1000		ms
f _{Fault, LFXT} Oscillator fault frequency ⁽⁸⁾	XTS = 0 ⁽⁹⁾		0		3500	Hz

- (1) To improve EMI on the LFXT oscillator, observe the following guidelines:
 - Keep the trace between the device and the crystal as short as possible.
 - Design a good ground plane around the oscillator pins.
 - Prevent crosstalk from other clock or data lines into oscillator pins XIN and XOUT.
 - Avoid running PCB traces underneath or adjacent to the XIN and XOUT pins.
 - Use assembly materials and processes that avoid any parasitic load on the oscillator XIN and XOUT pins.
 - If conformal coating is used, make sure that it does not induce capacitive or resistive leakage between the oscillator pins.
- (2) When LFXTBYPASS is set, LFXT circuits are automatically powered down. Input signal is a digital square wave with parametrics defined in the Schmitt-trigger inputs section of this data sheet. Duty cycle requirements are defined by DC_{LFXT, SW}.
- (3) Maximum frequency of operation of the entire device cannot be exceeded.
- (4) Oscillation allowance is based on a safety factor of 5 for recommended crystals. The oscillation allowance is a function of the LFXTDRIVE settings and the effective load. In general, comparable oscillator allowance can be achieved based on the following guidelines, but should be evaluated based on the actual crystal selected for the application:
 - For LFXTDRIVE = {0}, C_{L,eff} = 3.7 pF
 - For LFXTDRIVE = {1}, 6 pF ≤ C_{L,eff} ≤ 9 pF
 - For LFXTDRIVE = {2}, 6 pF ≤ C_{L,eff} ≤ 10 pF
 - For LFXTDRIVE = {3}, 6 pF ≤ C_{L,eff} ≤ 12 pF
- (5) Includes parasitic bond and package capacitance (approximately 2 pF per pin).
- (6) Requires external capacitors at both terminals. Values are specified by crystal manufacturers.
- (7) Includes start-up counter of 1024 clock cycles.
- (8) Frequencies above the MAX specification do not set the fault flag. Frequencies between the MIN and MAX specifications might set the flag. A static condition or stuck at fault condition sets the flag.
- (9) Measured with logic-level input frequency but also applies to operation with crystals.

Table 5-5 lists the characteristics of the FLL.

Table 5-5. DCO FLL, Frequency

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

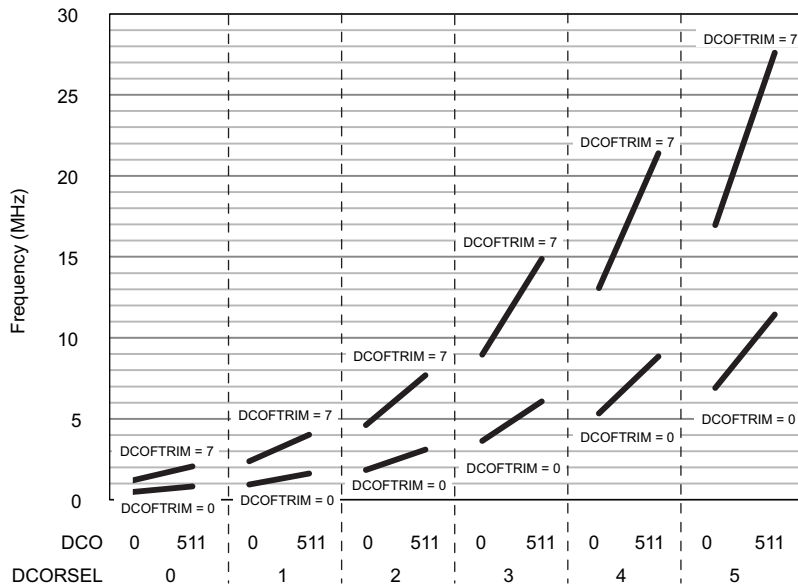
PARAMETER	TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
f _{DCO, FLL}	FLL lock frequency, 16 MHz, 25°C	Measured at MCLK, Internal trimmed REFO as reference	3 V	–1.0%	1.0%	
	FLL lock frequency, 16 MHz, –40°C to 85°C		3 V	–2.0%	2.0%	
	FLL lock frequency, 16 MHz, –40°C to 85°C	Measured at MCLK, XT1 crystal as reference	3 V	–0.5%	0.5%	
f _{DUTY} Duty cycle	Measured at MCLK, XT1 crystal as reference	3 V	40%	50%	60%	
Jitter _{cc} Cycle-to-cycle jitter, 16 MHz		3 V		0.25%		
Jitter _{long} Long term jitter, 16 MHz		3 V		0.022%		
t _{FLL, lock} FLL lock time		3 V		280		ms
t _{start-up} DCO start-up time, 2 MHz	Measured at MCLK	3 V		16		μs

Table 5-6 lists the characteristics of the DCO.

Table 5-6. DCO Frequency

over recommended operating free-air temperature (unless otherwise noted) (also see Figure 5-5)

PARAMETER	TEST CONDITIONS	V _{CC}	TYP	UNIT
f _{DCO, 16MHz} DCO frequency, 16 MHz	DCORSEL = 101b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 0	3 V	7.46	MHz
	DCORSEL = 101b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 511		12.26	
	DCORSEL = 101b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 0		17.93	
	DCORSEL = 101b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 511		29.1	
f _{DCO, 12MHz} DCO frequency, 12 MHz	DCORSEL = 100b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 0	3 V	5.75	MHz
	DCORSEL = 100b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 511		9.5	
	DCORSEL = 100b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 0		13.85	
	DCORSEL = 100b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 511		22.5	
f _{DCO, 8MHz} DCO frequency, 8 MHz	DCORSEL = 011b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 0	3 V	3.91	MHz
	DCORSEL = 011b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 511		6.49	
	DCORSEL = 011b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 0		9.5	
	DCORSEL = 011b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 511		15.6	
f _{DCO, 4MHz} DCO frequency, 4 MHz	DCORSEL = 010b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 0	3 V	2.026	MHz
	DCORSEL = 010b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 511		3.407	
	DCORSEL = 010b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 0		4.95	
	DCORSEL = 010b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 511		8.26	
f _{DCO, 2MHz} DCO frequency, 2 MHz	DCORSEL = 001b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 0	3 V	1.0225	MHz
	DCORSEL = 001b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 511		1.729	
	DCORSEL = 001b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 0		2.525	
	DCORSEL = 001b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 511		4.25	
f _{DCO, 1MHz} DCO frequency, 1 MHz	DCORSEL = 000b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 0	3 V	0.5319	MHz
	DCORSEL = 000b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 000b, DCO = 511		0.9029	
	DCORSEL = 000b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 0		1.307	
	DCORSEL = 000b, DISMOD = 1b, DCOFTRIMEN = 1b, DCOFTRIM = 111b, DCO = 511		2.21	



$V_{CC} = 3\text{ V}$

$T_A = -40^{\circ}\text{C to } 85^{\circ}\text{C}$

Figure 5-5. Typical DCO Frequency

Table 5-7 lists the characteristics of the REFO.

Table 5-7. REFO

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

PARAMETER	TEST CONDITIONS	V_{CC}	MIN	TYP	MAX	UNIT
I_{REFO}	REFO oscillator current consumption	$T_A = 25^{\circ}\text{C}$		15		μA
f_{REFO}	REFO calibrated frequency	Measured at MCLK		32768		Hz
	REFO absolute calibrated tolerance	$-40^{\circ}\text{C to } 85^{\circ}\text{C}$	-3.5%		+3.5%	
df_{REFO}/dT	REFO frequency temperature drift	Measured at MCLK ⁽¹⁾		0.01		$\%/^{\circ}\text{C}$
df_{REFO}/dV_{CC}	REFO frequency supply voltage drift	Measured at MCLK at 25°C ⁽²⁾		1		$\%/V$
f_{DC}	REFO duty cycle	Measured at MCLK	40%	50%	60%	
t_{START}	REFO start-up time	40% to 60% duty cycle		50		μs

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

(2) Calculated using the box method: $(\text{MAX}(1.8\text{ V to } 3.6\text{ V}) - \text{MIN}(1.8\text{ V to } 3.6\text{ V})) / \text{MIN}(1.8\text{ V to } 3.6\text{ V}) / (3.6\text{ V} - 1.8\text{ V})$

Table 5-8 lists the characteristics of the VLO.

NOTE

The VLO clock frequency is reduced by 15% (typical) when the device switches from active mode to LPM3 or LPM4, because the reference changes. This lower frequency is not a violation of the VLO specifications (see Table 5-8).

Table 5-8. Internal Very-Low-Power Low-Frequency Oscillator (VLO)

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

PARAMETER	TEST CONDITIONS	V _{CC}	TYP	UNIT
f _{VLO} VLO frequency	Measured at MCLK	3 V	10	kHz
df _{VLO} /dT VLO frequency temperature drift	Measured at MCLK ⁽¹⁾	3 V	0.5	%/°C
df _{VLO} /dV _{CC} VLO frequency supply voltage drift	Measured at MCLK ⁽²⁾	1.8 V to 3.6 V	4	%/V
f _{VLO,DC} Duty cycle	Measured at MCLK	3 V	50%	

(1) Calculated using the box method: (MAX(–40°C to 85°C) – MIN(–40°C to 85°C)) / MIN(–40°C to 85°C) / (85°C – (–40°C))

(2) Calculated using the box method: (MAX(1.8 V to 3.6 V) – MIN(1.8 V to 3.6 V)) / MIN(1.8 V to 3.6 V) / (3.6 V – 1.8 V)

Table 5-9 lists the characteristics of the MODOSC.

Table 5-9. Module Oscillator (MODOSC)

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

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
f _{MODOSC} MODOSC frequency		3 V	3.8	4.8	5.8	MHz
f _{MODOSC} /dT MODOSC frequency temperature drift		3 V		0.102		%/°C
f _{MODOSC} /dV _{CC} MODOSC frequency supply voltage drift		1.8 V to 3.6 V		1.02		%/V
f _{MODOSC,DC} Duty cycle		3 V	40%	50%	60%	

5.11.4 Digital I/Os

Table 5-10 lists the characteristics of the digital inputs.

Table 5-10. Digital Inputs

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

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
V _{IT+} Positive-going input threshold voltage		2 V	0.90		1.50	V
		3 V	1.35		2.25	
V _{IT-} Negative-going input threshold voltage		2 V	0.50		1.10	V
		3 V	0.75		1.65	
V _{hys} Input voltage hysteresis (V _{IT+} – V _{IT-})		2 V	0.3		0.8	V
		3 V	0.4		1.2	
R _{Pull} Pullup or pulldown resistor	For pullup: V _{IN} = V _{SS} For pulldown: V _{IN} = V _{CC}		20	35	50	kΩ
C _{I,dig} Input capacitance, digital only port pins	V _{IN} = V _{SS} or V _{CC}			3		pF
C _{I,ana} Input capacitance, port pins with shared analog functions	V _{IN} = V _{SS} or V _{CC}			5		pF
I _{lkg(Px,y)} High-impedance leakage current	See ⁽¹⁾ ⁽²⁾	2 V, 3 V	–20		20	nA

(1) The leakage current is measured with V_{SS} or V_{CC} applied to the corresponding pins, unless otherwise noted.

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

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

Table 5-11. Digital Outputs

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (also see Figure 5-6, Figure 5-7, Figure 5-8, and Figure 5-9)

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
V _{OH} High-level output voltage	I _(OHmax) = –3 mA ⁽¹⁾	2 V	1.4		2.0	V
	I _(OHmax) = –5 mA ⁽¹⁾	3 V	2.4		3.0	
V _{OL} Low-level output voltage	I _(OLmax) = 3 mA ⁽¹⁾	2 V	0.0		0.60	V
	I _(OHmax) = 5 mA ⁽¹⁾	3 V	0.0		0.60	
f _{Port_CLK} Clock output frequency	C _L = 20 pF ⁽²⁾	2 V	16			MHz
		3 V	16			
t _{rise,dig} Port output rise time, digital only port pins	C _L = 20 pF	2 V		10		ns
		3 V		7		
t _{fall,dig} Port output fall time, digital only port pins	C _L = 20 pF	2 V		10		ns
		3 V		5		

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

(2) The port can output frequencies at least up to the specified limit and might support higher frequencies.

5.11.4.1 Typical Characteristics – Outputs at 3 V and 2 V

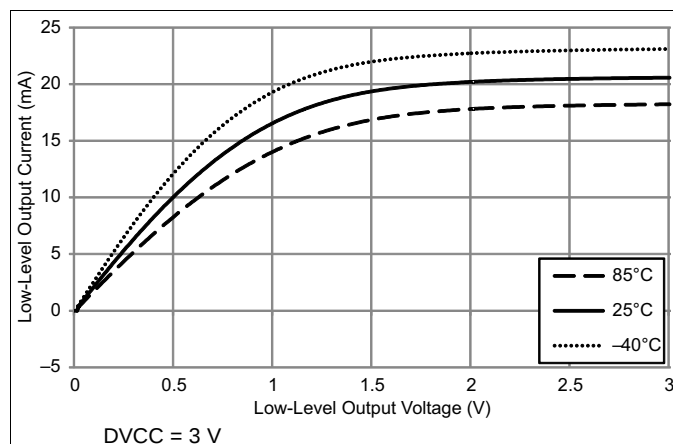


Figure 5-6. Typical Low-Level Output Current vs Low-Level Output Voltage

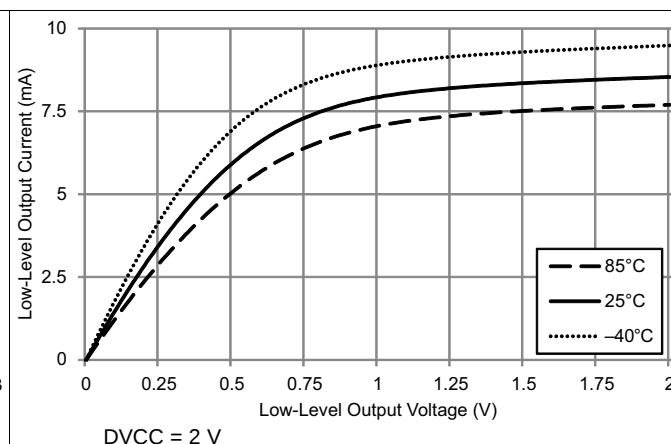


Figure 5-7. Typical Low-Level Output Current vs Low-Level Output Voltage

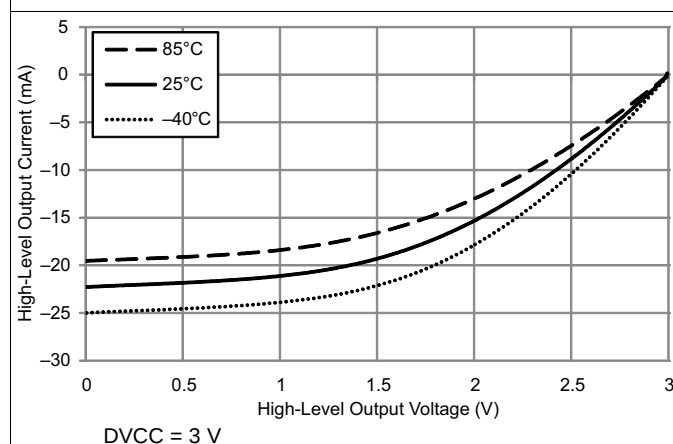


Figure 5-8. Typical High-Level Output Current vs High-Level Output Voltage

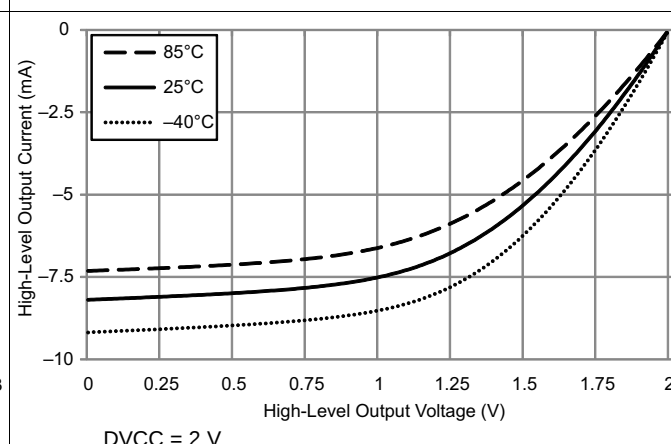


Figure 5-9. Typical High-Level Output Current vs High-Level Output Voltage

5.11.5 VREF+ Built-in Reference

Table 5-12 lists the characteristics of VREF+.

Table 5-12. VREF+

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

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
V _{REF+}	Positive built-in reference voltage	EXTREFEN = 1 with 1-mA load current	2 V, 3 V	1.15	1.19	1.23 V
TC _{REF+}	Temperature coefficient of built-in reference voltage			30		μV/°C

5.11.6 Timer_A

Table 5-13 lists the characteristics of Timer_A.

Table 5-13. Timer_A

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

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
f _{TA}	Timer_A input clock frequency	Internal: SMCLK or ACLK, External: TACLK, Duty cycle = 50% ±10%	2 V, 3 V		16	MHz

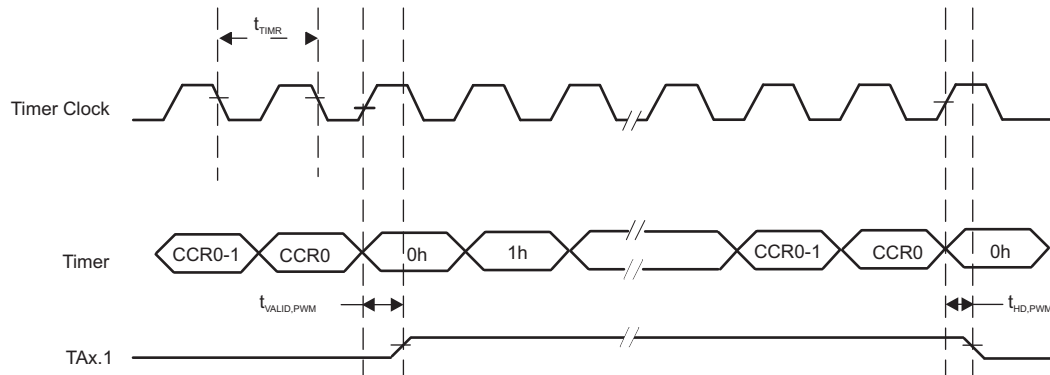


Figure 5-10. Timer PWM Mode

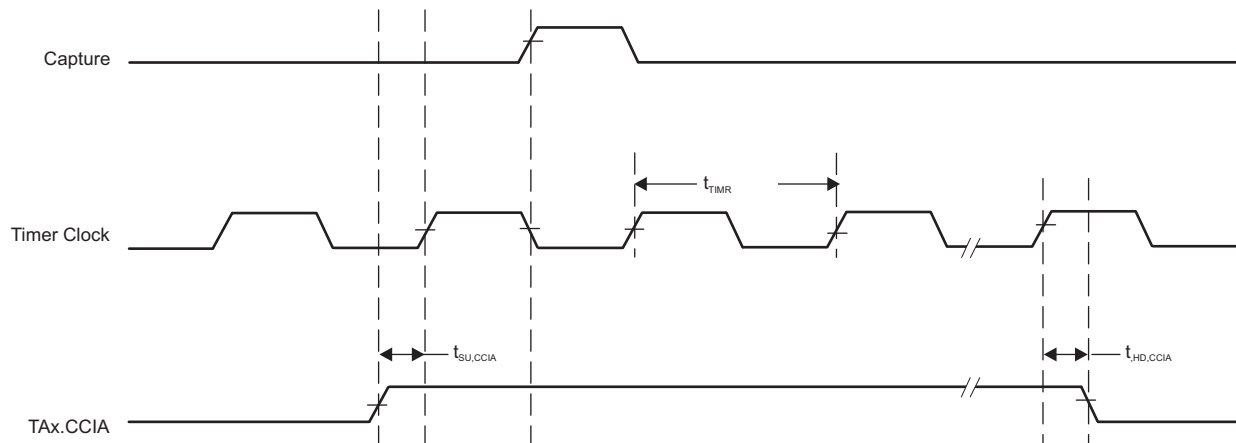


Figure 5-11. Timer Capture Mode

5.11.7 eUSCI

Table 5-14 lists the supported frequencies of the eUSCI in UART mode.

Table 5-14. eUSCI (UART Mode) Clock Frequency

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

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	MAX	UNIT
f _{eUSCI} eUSCI input clock frequency	Internal: SMCLK or MODCLK, External: UCLK, Duty cycle = 50% ±10%	2 V, 3 V		16	MHz
f _{BITCLK} BITCLK clock frequency (equals baud rate in Mbaud)		2 V, 3 V		5	MHz

Table 5-15 lists the characteristics of the eUSCI in UART mode.

Table 5-15. eUSCI (UART Mode)

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

PARAMETER	TEST CONDITIONS	V _{CC}	TYP	UNIT
t _t UART receive deglitch time ⁽¹⁾	UCGLITx = 0	2 V, 3 V	12	ns
	UCGLITx = 1		40	
	UCGLITx = 2		68	
	UCGLITx = 3		110	

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

Table 5-16 lists the supported frequencies of the eUSCI in SPI master mode.

Table 5-16. eUSCI (SPI Master Mode) Clock Frequency

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

PARAMETER	TEST CONDITIONS	MIN	MAX	UNIT
f _{eUSCI} eUSCI input clock frequency	Internal: SMCLK or MODCLK, Duty cycle = 50% ±10%		8	MHz

Table 5-17 lists the characteristics of the eUSCI in SPI master mode.

Table 5-17. eUSCI (SPI Master Mode)

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

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	MAX	UNIT
t _{STE,LEAD} STE lead time, STE active to clock	UCSTEM = 0, UCMODEx = 01 or 10		1		UCxCLK cycles
	UCSTEM = 1, UCMODEx = 01 or 10				
t _{STE,LAG} STE lag time, last clock to STE inactive	UCSTEM = 0, UCMODEx = 01 or 10		1		UCxCLK cycles
	UCSTEM = 1, UCMODEx = 01 or 10				
t _{SU,MI} SOMI input data setup time		2 V	45		ns
		3 V	35		
t _{HD,MI} SOMI input data hold time		2 V	0		ns
		3 V	0		
t _{VALID,MO} SIMO output data valid time ⁽²⁾	UCLK edge to SIMO valid, C _L = 20 pF	2 V		20	ns
		3 V		20	
t _{HD,MO} SIMO output data hold time ⁽³⁾	C _L = 20 pF	2 V	0		ns
		3 V	0		

- (1) $f_{UCxCLK} = 1 / 2t_{LO/Hi}$ with $t_{LO/Hi} = \max(t_{VALID,MO(eUSCI)} + t_{SU,SI(Slave)}, t_{SU,MI(eUSCI)} + t_{VALID,SO(Slave)})$
For the slave parameters $t_{SU,SI(Slave)}$ and $t_{VALID,SO(Slave)}$, see the SPI parameters of the attached slave.
- (2) Specifies the time to drive the next valid data to the SIMO output after the output changing UCLK clock edge. See the timing diagrams in Figure 5-12 and Figure 5-13.
- (3) Specifies how long data on the SIMO output is valid after the output changing UCLK clock edge. Negative values indicate that the data on the SIMO output can become invalid before the output changing clock edge observed on UCLK. See the timing diagrams in Figure 5-12 and Figure 5-13.

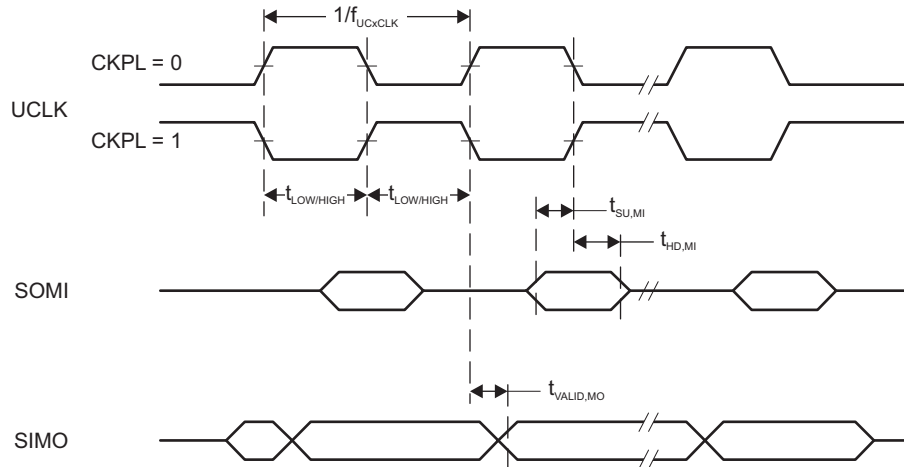


Figure 5-12. SPI Master Mode, CKPH = 0

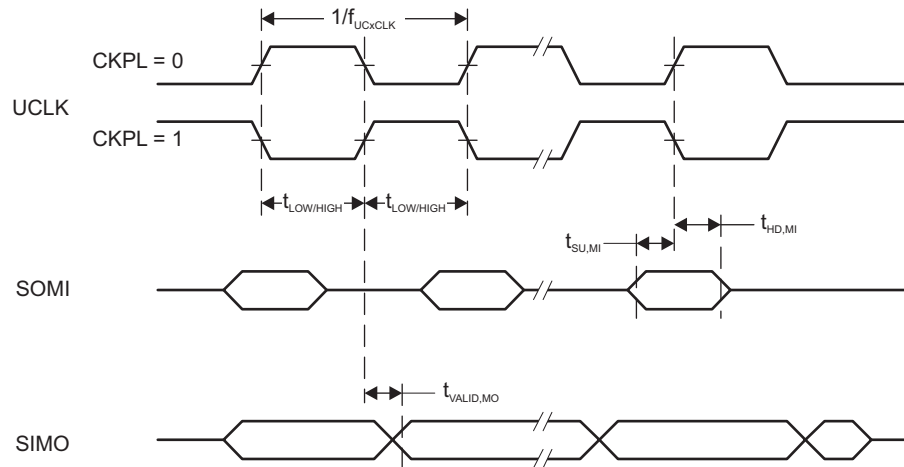


Figure 5-13. SPI Master Mode, CKPH = 1

Table 5-18 lists the characteristics of the eUSCI in SPI slave mode.

Table 5-18. eUSCI (SPI Slave Mode)

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

PARAMETER		TEST CONDITIONS	V _{CC}	MIN	MAX	UNIT
t _{STE,LEAD}	STE lead time, STE active to clock		2 V	55		ns
			3 V	45		
t _{STE,LAG}	STE lag time, Last clock to STE inactive		2 V	20		ns
			3 V	20		
t _{STE,ACC}	STE access time, STE active to SOMI data out		2 V		65	ns
			3 V		40	
t _{STE,DIS}	STE disable time, STE inactive to SOMI high impedance		2 V		40	ns
			3 V		35	
t _{SU,SI}	SIMO input data setup time		2 V	6		ns
			3 V	4		
t _{HD,SI}	SIMO input data hold time		2 V	12		ns
			3 V	12		
t _{VALID,SO}	SOMI output data valid time ⁽²⁾	UCLK edge to SOMI valid, C _L = 20 pF	2 V		65	ns
			3 V		40	
t _{HD,SO}	SOMI output data hold time ⁽³⁾	C _L = 20 pF	2 V	5		ns
			3 V	5		

(1) $f_{UCXCLK} = 1/2t_{LO/HI}$ with $t_{LO/HI} \geq \max(t_{VALID,MO(Master)} + t_{SU,SI(eUSCI)}, t_{SU,MI(Master)} + t_{VALID,SO(eUSCI)})$

For the master parameters $t_{SU,MI(Master)}$ and $t_{VALID,MO(Master)}$, see the SPI parameters of the attached master.

(2) Specifies the time to drive the next valid data to the SOMI output after the output changing UCLK clock edge. See the timing diagrams in Figure 5-14 and Figure 5-15.

(3) Specifies how long data on the SOMI output is valid after the output changing UCLK clock edge. See the timing diagrams in Figure 5-14 and Figure 5-15.

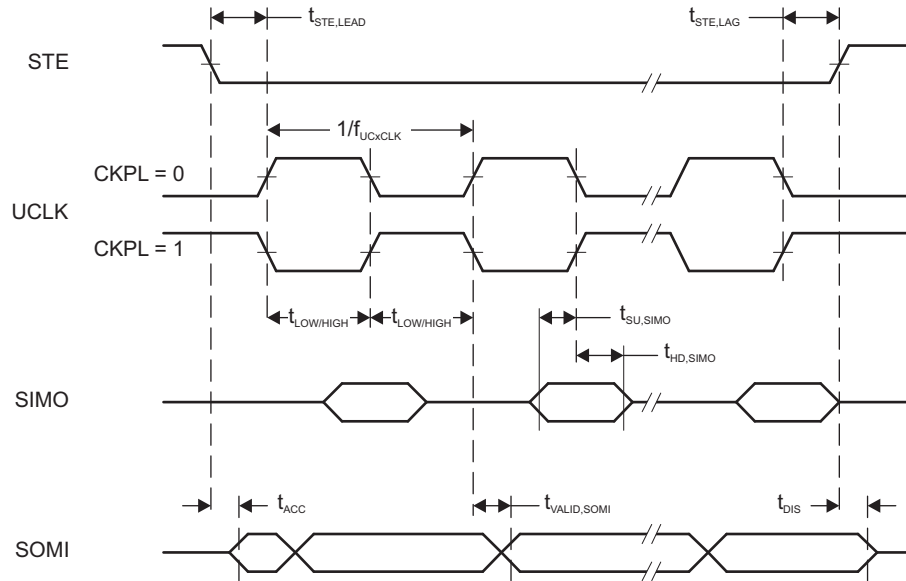


Figure 5-14. SPI Slave Mode, CKPH = 0

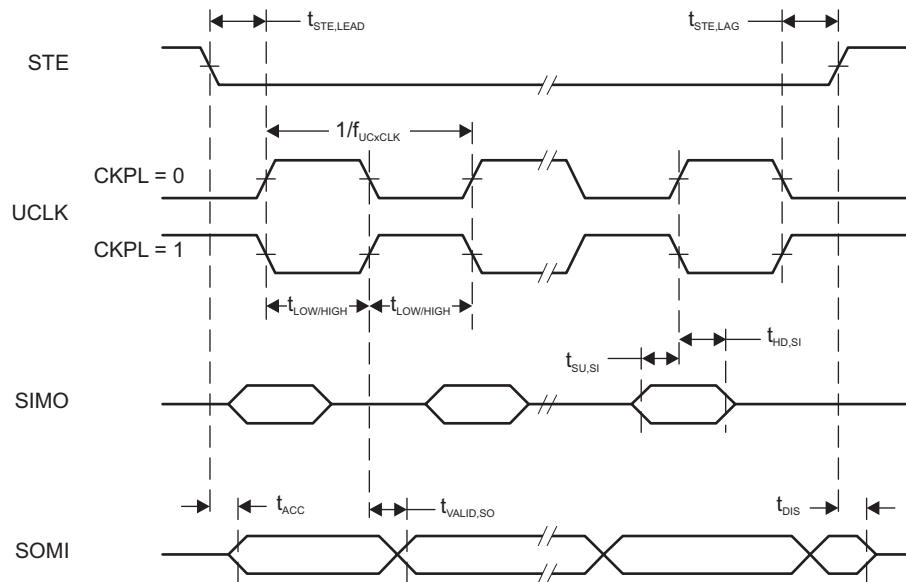


Figure 5-15. SPI Slave Mode, CKPH = 1

Table 5-19 lists the characteristics of the eUSCI in I²C mode.

Table 5-19. eUSCI (I²C Mode)

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Figure 5-16)

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
f _{eUSCI} eUSCI input clock frequency	Internal: SMCLK or MODCLK, External: UCLK Duty cycle = 50% ±10%				16	MHz
f _{SCL} SCL clock frequency		2 V, 3 V	0		400	kHz
t _{HD,STA} Hold time (repeated) START	f _{SCL} = 100 kHz f _{SCL} > 100 kHz	2 V, 3 V	4.0 0.6			μs
t _{SU,STA} Setup time for a repeated START	f _{SCL} = 100 kHz f _{SCL} > 100 kHz	2 V, 3 V	4.7 0.6			μs
t _{HD,DAT} Data hold time		2 V, 3 V	0			ns
t _{SU,DAT} Data setup time		2 V, 3 V	250			ns
t _{SU,STO} Setup time for STOP	f _{SCL} = 100 kHz f _{SCL} > 100 kHz	2 V, 3 V	4.0 0.6			μs
t _{SP} Pulse duration of spikes suppressed by input filter	UCGLITx = 0 UCGLITx = 1 UCGLITx = 2 UCGLITx = 3	2 V, 3 V	50 25 12.5 6.3		600 300 150 75	ns
t _{TIMEOUT} Clock low time-out	UCCLTOx = 1 UCCLTOx = 2 UCCLTOx = 3	2 V, 3 V		27 30 33		ms

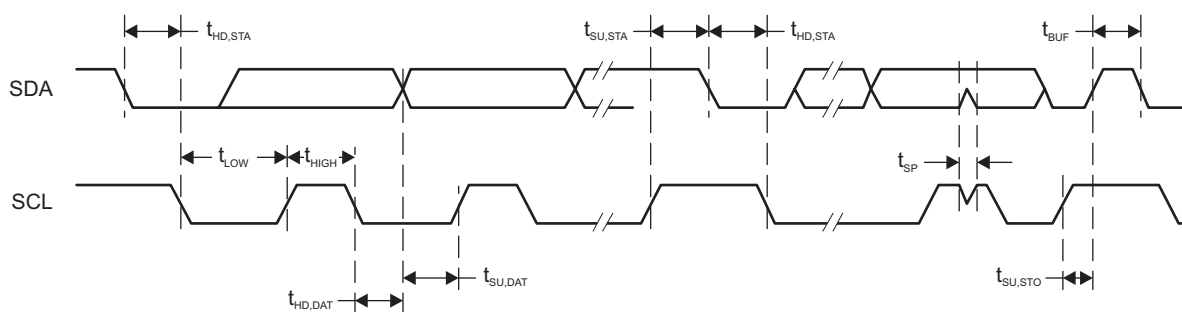


Figure 5-16. I²C Mode Timing

5.11.8 ADC

Table 5-20 lists the input requirements of the ADC.

Table 5-20. ADC, Power Supply and Input Range Conditions

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

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
DV _{CC} ADC supply voltage			2.0		3.6	V
V _(Ax) Analog input voltage range	All ADC pins		0		DV _{CC}	V
I _{ADC} Operating supply current into DVCC terminal, reference current not included, repeat-single-channel mode	f _{ADCCLK} = 5 MHz, ADCON = 1, REFON = 0, SHT0 = 0, SHT1 = 0, ADCDIV = 0, ADCCONSEQx = 10b	2 V		185		μA
		3 V		207		
C _I Input capacitance	Only one terminal Ax can be selected at one time, from the pad to the ADC capacitor array, including wiring and pad	2.2 V		1.6	2.0	pF
R _I Input MUX ON resistance	DV _{CC} = 2 V, 0 V = V _{Ax} = DV _{CC}				2	kΩ

Table 5-21 lists the timing parameters of the ADC.

Table 5-21. ADC, 10-Bit Timing Parameters

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

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
f _{ADCCLK}	For specified performance of ADC linearity parameters	2 V to 3.6 V	0.45	5	5.5	MHz
f _{ADCOSC} Internal ADC oscillator (MODOSC)	ADCDIV = 0, f _{ADCCLK} = f _{ADCOSC}	2 V to 3.6 V	4.5	5.0	5.5	MHz
t _{CONVERT} Conversion time	REFON = 0, Internal oscillator, 10 ADCCLK cycles, 10-bit mode, f _{ADCOSC} = 4.5 MHz to 5.5 MHz	2 V to 3.6 V	2.18		2.67	μs
	External f _{ADCCLK} from ACLK or SMCLK, ADCSSEL ≠ 0	2 V to 3.6 V		12 × 1 / f _{ADCCLK}		
t _{ADCON} Turnon settling time of the ADC	The error in a conversion started after t _{ADCON} is less than ±0.5 LSB, Reference and input signal already settled				100	ns
t _{Sample} Sampling time	R _S = 1000 Ω, R _I = 36000 Ω, C _I = 3.5 pF. Approximately 8 Tau (t) are required for an error of less than ±0.5 LSB.	2 V	1.5			μs
		3 V	2.0			

Table 5-22 lists the linearity parameters of the ADC.

Table 5-22. ADC, 10-Bit Linearity Parameters

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

PARAMETER		TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
E _I	Integral linearity error (10-bit mode)	V _{eref+} as reference	2.4 V to 3.6 V	–2		2	LSB
	Integral linearity error (8-bit mode)		2 V to 3.6 V	–2		2	
E _D	Differential linearity error (10-bit mode)	V _{eref+} as reference	2.4 V to 3.6 V	–1		1	LSB
	Differential linearity error (8-bit mode)		2 V to 3.6 V	–1		1	
E _O	Offset error (10-bit mode)	V _{eref+} as reference	2.4 V to 3.6 V	–6.5		6.5	mV
	Offset error (8-bit mode)		2 V to 3.6 V	–6.5		6.5	
E _G	Gain error (10-bit mode)	V _{eref+} as reference	2.4 V to 3.6 V	–2.0		2.0	LSB
		Internal 1.5-V reference		–3.0%		3.0%	
	Gain error (8-bit mode)	V _{eref+} as reference	2 V to 3.6 V	–2.0		2.0	LSB
		Internal 1.5-V reference		–3.0%		3.0%	
E _T	Total unadjusted error (10-bit mode)	V _{eref+} as reference	2.4 V to 3.6 V	–2.0		2.0	LSB
		Internal 1.5-V reference		–3.0%		3.0%	
	Total unadjusted error (8-bit mode)	V _{eref+} as reference	2 V to 3.6 V	–2.0		2.0	LSB
		Internal 1.5-V reference		–3.0%		3.0%	
V _{SENSOR}	See ⁽¹⁾	ADCON = 1, INCH = 0Ch, T _A = 0°C	3 V		913		mV
TC _{SENSOR}	See ⁽²⁾	ADCON = 1, INCH = 0Ch	3 V		3.35		mV/°C
t _{SENSOR} (sample)	Sample time required if channel 12 is selected ⁽³⁾	ADCON = 1, INCH = 0Ch, Error of conversion result ≤1 LSB, AM and all LPMs above LPM3	3 V		30		μs
		ADCON = 1, INCH = 0Ch, Error of conversion result ≤1 LSB, LPM3	3 V		100		

- (1) The temperature sensor offset can vary significantly. TI recommends a single-point calibration to minimize the offset error of the built-in temperature sensor.
- (2) The device descriptor structure contains calibration values for 30°C ±3°C and 85°C ±3°C for each available reference voltage level. The sensor voltage can be computed as $V_{SENSE} = TC_{SENSOR} \times (\text{Temperature, } ^\circ\text{C}) + V_{SENSOR}$, where TC_{SENSOR} and V_{SENSOR} can be computed from the calibration values for higher accuracy.
- (3) The typical equivalent impedance of the sensor is 700 kΩ. The sample time required includes the sensor on time, t_{SENSOR(on)}.

5.11.9 CapTivate

Table 5-23 lists the characteristics of the CapTivate module.

Table 5-23. CapTivate Electrical Characteristics

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

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V _{REG}	Reference voltage output		1.5	1.55	1.6	V
t _{WAKEUP,COLD}	Voltage regulator wake-up time: LDO completely off then turned on				1	ms
t _{WAKEUP,WARM}	Voltage regulator wake-up time: LDO in low-power mode then turned on				300	us
f _{CAPCLK}	Captivate oscillator frequency, nominal	T _A = 25°C, CAPCLK0, FREQSHFT = 00b	–3%	16	+3%	MHz
f _{CAPCLK,DC}	Duty cycle	Duty cycle (excluding first clock cycle, DC = t _{high} × f)	40%	50%	60%	

5.11.10 FRAM

Table 5-24 lists the characteristics of the FRAM.

Table 5-24. FRAM

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

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
Read and write endurance			10 ¹⁵			cycles
t _{Retention}	Data retention duration	T _J = 25°C	100			years
		T _J = 70°C	40			
		T _J = 85°C	10			
I _{WRITE}	Current to write into FRAM			I _{READ} ⁽¹⁾		nA
I _{ERASE}	Erase current			N/A ⁽²⁾		nA
t _{WRITE}	Write time			t _{READ} ⁽³⁾		ns
t _{READ}	Read time	NWAITSx = 0		1 / f _{SYSTEM} ⁽⁴⁾		ns
		NWAITSx = 1		2 / f _{SYSTEM} ⁽⁴⁾		

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

5.11.11 Debug and Emulation

Table 5-25 lists the characteristics of the Spy-Bi-Wire interface.

Table 5-25. JTAG, Spy-Bi-Wire Interface

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Figure 5-17)

PARAMETER		V _{CC}	MIN	TYP	MAX	UNIT
f _{SBW}	Spy-Bi-Wire input frequency	2 V, 3 V	0		10	MHz
t _{SBW,Low}	Spy-Bi-Wire low clock pulse duration	2 V, 3 V	0.028		15	μs
t _{SU, SBWTDIO}	SBWTDIO setup time (before falling edge of SBWTCK in TMS and TDI slot, Spy-Bi-Wire)	2 V, 3 V	4			ns
t _{HD, SBWTDIO}	SBWTDIO hold time (after rising edge of SBWTCK in TMS and TDI slot, Spy-Bi-Wire)	2 V, 3 V	19			ns
t _{valid, SBWTDIO}	SBWTDIO data valid time (after falling edge of SBWTCK in TDO slot, Spy-Bi-Wire)	2 V, 3 V			31	ns
t _{SBW, En}	Spy-Bi-Wire enable time (TEST high to acceptance of first clock edge) ⁽¹⁾	2 V, 3 V			110	μs
t _{SBW, Ret}	Spy-Bi-Wire return to normal operation time ⁽²⁾	2 V, 3 V	15		100	μs
R _{internal}	Internal pulldown resistance on TEST	2 V, 3 V	20	35	50	kΩ

- (1) Tools that access the Spy-Bi-Wire interface must wait for the t_{SBW,En} time after pulling the TEST/SBWTCK pin high before applying the first SBWTCK clock edge.
- (2) Maximum t_{SBW,Ret} time after pulling or releasing the TEST/SBWTCK pin low until the Spy-Bi-Wire pins revert from their Spy-Bi-Wire function to their application function. This time applies only if the Spy-Bi-Wire mode is selected.

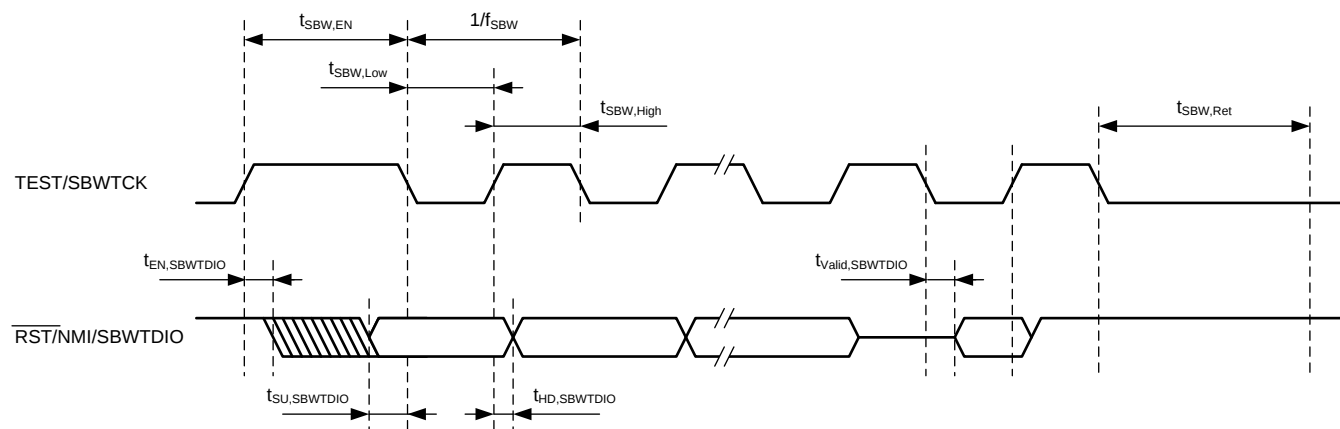


Figure 5-17. JTAG Spy-Bi-Wire Timing

Table 5-26 lists the characteristics of the 4-wire JTAG interface.

Table 5-26. JTAG, 4-Wire Interface

over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Figure 5-18)

PARAMETER		V _{CC}	MIN	TYP	MAX	UNIT
f _{TCK}	TCK input frequency ⁽¹⁾	2 V, 3 V	0		10	MHz
t _{TCK,Low}	TCK low clock pulse duration	2 V, 3 V	15			ns
t _{TCK,High}	TCK high clock pulse duration	2 V, 3 V	15			ns
t _{SU,TMS}	TMS setup time (before rising edge of TCK)	2 V, 3 V	11			ns
t _{HD,TMS}	TMS hold time (after rising edge of TCK)	2 V, 3 V	3			ns
t _{SU,TDI}	TDI setup time (before rising edge of TCK)	2 V, 3 V	13			ns
t _{HD,TDI}	TDI hold time (after rising edge of TCK)	2 V, 3 V	5			ns
t _{Z-Valid,TDO}	TDO high impedance to valid output time (after falling edge of TCK)	2 V, 3 V			26	ns
t _{Valid,TDO}	TDO to new valid output time (after falling edge of TCK)	2 V, 3 V			26	ns
t _{Valid-Z,TDO}	TDO valid to high-impedance output time (after falling edge of TCK)	2 V, 3 V			26	ns
t _{JTAG,Ret}	Spy-Bi-Wire return to normal operation time		15		100	μs
R _{internal}	Internal pulldown resistance on TEST	2 V, 3 V	20	35	50	kΩ

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

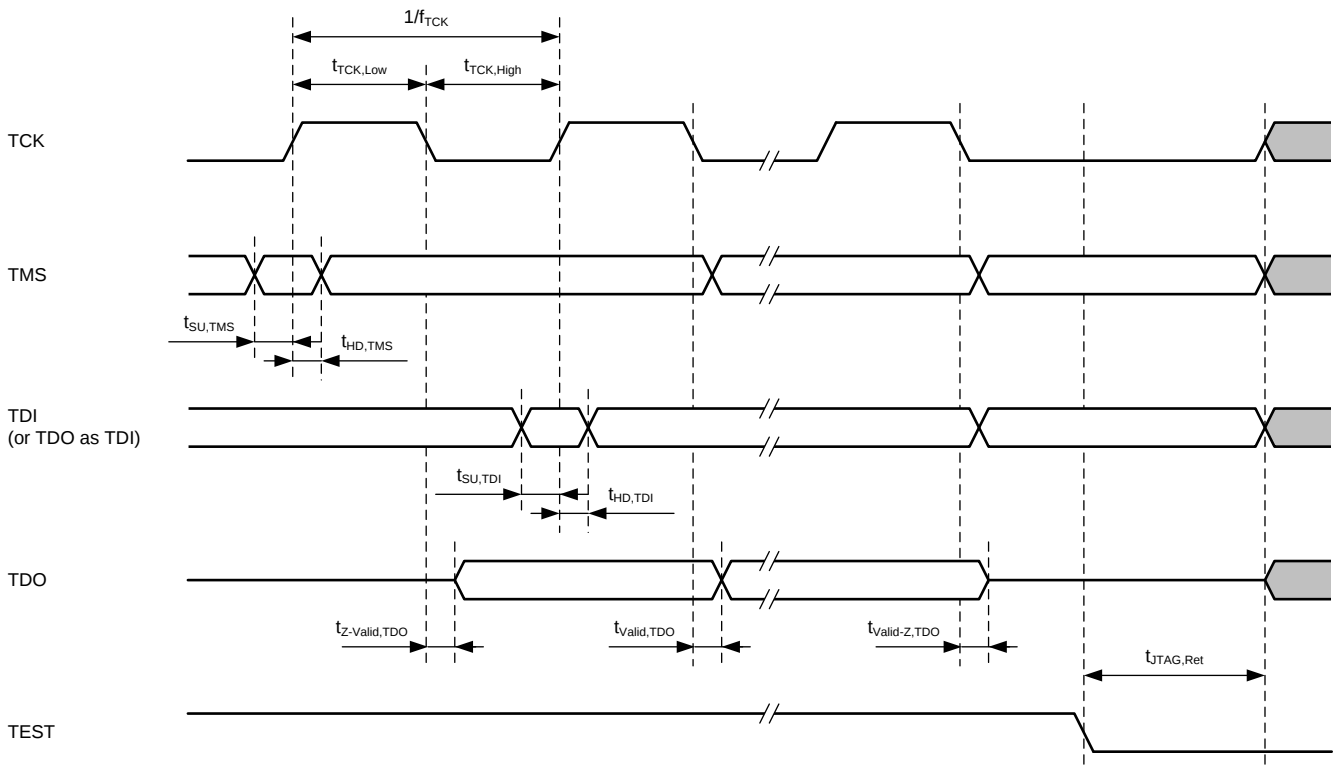


Figure 5-18. JTAG 4-Wire Timing

6 Detailed Description

6.1 Overview

The MSP430FR263x and MSP430FR253x ultra-low-power MCUs are the first FRAM-based MCUs with integrated high-performance charge-transfer CapTIvate technology in ultra-low-power high-reliability high-flexibility MCUs. The MSP430FR263x and MSP430FR253x MCU features up to 16 self-capacitance or 64 mutual-capacitance electrodes, 30-cm proximity sensing, and high accuracy up to 1-fF detection. The MCUs also include four 16-bit timers, eUSCs that support UART, SPI, and I²C, a hardware multiplier, an RTC module with alarm capabilities, and a high-performance 10-bit ADC.

6.2 CPU

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

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

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

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

6.3 Operating Modes

The MSP430FR263x and MSP430FR253x MCUs have one active mode and several software-selectable low-power modes of operation (see [Table 6-1](#)). An interrupt event can wake the MCU from low-power mode (LPM0 or LPM3), service the request, and restore the MCU back to the low-power mode on return from the interrupt program. Low-power modes LPM3.5 and LPM4.5 disable the core supply to minimize power consumption.

Table 6-1. Operating Modes

MODE		AM	LPM0	LPM3	LPM4	LPM3.5	LPM4.5
		ACTIVE MODE (FRAM ON)	CPU OFF	STANDBY	OFF	ONLY RTC	SHUTDOWN
Maximum system clock		16 MHz	16 MHz	40 kHz	0	40 kHz	0
Power consumption at 25°C, 3 V		126 μ A/MHz	40 μ A/MHz	1.7 μ A/button average with 8-Hz scan	0.49 μ A without SVS	0.73 μ A with RTC counter only in LFXT	16 nA without SVS
Wake-up time		N/A	Instant	10 μ s	10 μ s	350 μ s	350 μ s
Wake-up events		N/A	All	All	CapTIvate I/O	RTC I/O	I/O
Power	Regulator	Full Regulation	Full Regulation	Partial Power Down	Partial Power Down	Partial Power Down	Power Down
	SVS	On	On	Optional	Optional	Optional	Optional
	Brownout	On	On	On	On	On	On

Table 6-1. Operating Modes (continued)

MODE		AM	LPM0	LPM3	LPM4	LPM3.5	LPM4.5
		ACTIVE MODE (FRAM ON)	CPU OFF	STANDBY	OFF	ONLY RTC	SHUTDOWN
Clock ⁽¹⁾	MCLK	Active	Off	Off	Off	Off	Off
	SMCLK	Optional	Optional	Off	Off	Off	Off
	FLL	Optional	Optional	Off	Off	Off	Off
	DCO	Optional	Optional	Off	Off	Off	Off
	MODCLK	Optional	Optional	Off	Off	Off	Off
	REFO	Optional	Optional	Optional	Off	Off	Off
	ACLK	Optional	Optional	Optional	Off	Off	Off
	XT1CLK	Optional	Optional	Optional	Off	Optional	Off
	VLOCLK	Optional	Optional	Optional	Off	Optional	Off
	CapTivate MODCLK	Optional	Optional	Optional	Off	Off	Off
Core	CPU	On	Off	Off	Off	Off	Off
	FRAM	On	On	Off	Off	Off	Off
	RAM	On	On	On	On	Off	Off
	Backup memory ⁽²⁾	On	On	On	On	On	Off
Peripherals	Timer0_A3	Optional	Optional	Optional	Off	Off	Off
	Timer1_A3	Optional	Optional	Optional	Off	Off	Off
	Timer2_A2	Optional	Optional	Optional	Off	Off	Off
	Timer3_A2	Optional	Optional	Optional	Off	Off	Off
	WDT	Optional	Optional	Optional	Off	Off	Off
	eUSCI_A0	Optional	Optional	Off	Off	Off	Off
	eUSCI_A1	Optional	Optional	Off	Off	Off	Off
	eUSCI_B0	Optional	Optional	Off	Off	Off	Off
	CRC	Optional	Optional	Off	Off	Off	Off
	ADC	Optional	Optional	Optional	Off	Off	Off
	RTC	Optional	Optional	Optional	Off	Optional	Off
	CapTivate	Optional	Optional	Optional	Off	Off	Off
I/O	General-purpose digital input/output	On	Optional	State Held	State Held	State Held	State Held

(1) The status shown for LPM4 applies to internal clocks only.

(2) Backup memory contains 32 bytes of register space in peripheral memory. See [Table 6-24](#) and [Table 6-43](#) for its memory allocation.

NOTE

XT1CLK and VLOCLK can be active during LPM4 if requested by low-frequency peripherals, such as RTC, WDT, or CapTivate.

6.4 Interrupt Vector Addresses

The interrupt vectors and the power-up start address are in the address range 0FFFFh to 0FF80h (see [Table 6-2](#)). The vector contains the 16-bit address of the appropriate interrupt-handler instruction sequence.

Table 6-2. Interrupt Sources, Flags, and Vectors

INTERRUPT SOURCE	INTERRUPT FLAG	SYSTEM INTERRUPT	WORD ADDRESS	PRIORITY
System Reset Power up, Brownout, Supply supervisor External reset RST Watchdog time-out, Key violation FRAM uncorrectable bit error detection Software POR, BOR FLL unlock error	SVSHIFG PMMRSTIFG WDTIFG PMMPORIFG, PMMBORIFG SYSRSTIV FLLUNLOCKIFG	Reset	FFFEh	63, Highest
System NMI Vacant memory access JTAG mailbox FRAM access time error FRAM bit error detection	VMAIFG JMBINIFG, JMBOUTIFG CBDIFG, UBDIFG	Nonmaskable	FFFCh	62
User NMI External NMI Oscillator fault	NMIIFG OFIFG	Nonmaskable	FFFAh	61
Timer0_A3	TA0CCR0 CCIFG0	Maskable	FFF8h	60
Timer0_A3	TA0CCR1 CCIFG1, TA0CCR2 CCIFG2, TA0IFG (TA0IV)	Maskable	FFF6h	59
Timer1_A3	TA1CCR0 CCIFG0	Maskable	FFF4h	58
Timer1_A3	TA1CCR1 CCIFG1, TA1CCR2 CCIFG2, TA1IFG (TA1IV)	Maskable	FFF2h	57
Timer2_A2	TA2CCR0 CCIFG0	Maskable	FFF0h	56
Timer2_A2	TA2CCR1 CCIFG1, TA2IFG (TA2IV)		FFEEh	55
Timer3_A2	TA3CCR0 CCIFG0	Maskable	FFECh	54
Timer3_A2	TA3CCR1 CCIFG1, TA3IFG (TA3IV)		FFEAh	53
RTC	RTCIFG	Maskable	FFE8h	52
Watchdog timer interval mode	WDTIFG	Maskable	FFE6h	51
eUSCI_A0 receive or transmit	UCTXCPTIFG, UCSTTIFG, UCRXIFG, UCTXIFG (UART mode) UCRXIFG, UCTXIFG (SPI mode) (UCA0IV)	Maskable	FFE4h	50
eUSCI_A1 receive or transmit	UCTXCPTIFG, UCSTTIFG, UCRXIFG, UCTXIFG (UART mode) UCRXIFG, UCTXIFG (SPI mode) (UCA1IV)	Maskable	FFE2h	49
eUSCI_B0 receive or transmit	UCB0RXIFG, UCB0TXIFG (SPI mode) UCALIFG, UCNACKIFG, UCSTTIFG, UCSTPIFG, UCRXIFG0, UCTXIFG0, UCRXIFG1, UCTXIFG1, UCRXIFG2, UCTXIFG2, UCRXIFG3, UCTXIFG3, UCCNTIFG, UCBIT9IFG (I ² C mode) (UCB0IV)	Maskable	FFE0h	48
ADC	ADCIFG0, ADCINIFG, ADCLOIFG, ADCHIIFG, ADCTOVIFG, ADCOVIFG (ADCIV)	Maskable	FFDEh	47
P1	P1IFG.0 to P1IFG.7 (P1IV)	Maskable	FFDCh	46
P2	P2IFG.0 to P2IFG.7 (P2IV)	Maskable	FFDAh	45
CapTivate	(See CapTivate Design Center for details)	Maskable	FFD8h	44, Lowest
Reserved	Reserved	Maskable	FFD6h–FF88h	

Table 6-2. Interrupt Sources, Flags, and Vectors (continued)

INTERRUPT SOURCE	INTERRUPT FLAG	SYSTEM INTERRUPT	WORD ADDRESS	PRIORITY
Signatures	BSL Signature 2		0FF86h	
	BSL Signature 1		0FF84h	
	JTAG Signature 2		0FF82h	
	JTAG Signature 1		0FF80h	

6.5 Bootloader (BSL)

The BSL lets users program the FRAM or RAM using either the UART serial interface or the I²C interface. Access to the MCU memory through the BSL is protected by a user-defined password. Use of the BSL requires four pins (see [Table 6-3](#) and [Table 6-4](#)). The BSL entry requires a specific entry sequence on the $\overline{\text{RST}}$ /NMI/SBWDIO and TEST/SBWTCK pins.

This device can support the blank device detection automatically to invoke the BSL with skipping this special entry sequence for saving time and on board programmable. For the complete description of the feature of the BSL, see the [MSP430FR4xx and MSP430FR2xx Bootloader \(BSL\) User's Guide](#).

Table 6-3. UART BSL Pin Requirements and Functions

DEVICE SIGNAL	BSL FUNCTION
$\overline{\text{RST}}$ /NMI/SBWDIO	Entry sequence signal
TEST/SBWTCK	Entry sequence signal
P1.4	Data transmit
P1.5	Data receive
VCC	Power supply
VSS	Ground supply

Table 6-4. I²C BSL Pin Requirements and Functions

DEVICE SIGNAL	BSL FUNCTION
$\overline{\text{RST}}$ /NMI/SBWDIO	Entry sequence signal
TEST/SBWTCK	Entry sequence signal
P1.2	Data transmit and receive
P1.3	Clock
VCC	Power supply
VSS	Ground supply

6.6 JTAG Standard Interface

The MSP low-power microcontrollers support the standard JTAG interface, which requires four signals for sending and receiving data. The JTAG signals are shared with general-purpose I/O. The TEST/SBWTCK pin enables the JTAG signals. In addition to these signals, the $\overline{\text{RST}}$ /NMI/SBWTIO is required to interface with MSP430 development tools and device programmers. [Table 6-5](#) lists the JTAG pin requirements. For further details on interfacing to development tools and device programmers, see the [MSP430 Hardware Tools User's Guide](#). For details on using the JTAG interface, see [MSP430 Programming With the JTAG Interface](#).

Table 6-5. JTAG Pin Requirements and Function

DEVICE SIGNAL	DIRECTION	JTAG FUNCTION
P1.4/UCA0TXD/UCA0SIMO/TA1.2/TCK/A4/VREF+	IN	JTAG clock input
P1.5/UCA0RXD/UCA0SOMI/TA1.1/TMS/A5	IN	JTAG state control
P1.6/UCA0CLK/TA1CLK/TDI/TCLK/A6	IN	JTAG data input, TCLK input
P1.7/UCA0STE/SMCLK/TDO/A7	OUT	JTAG data output
TEST/SBWTCK	IN	Enable JTAG pins
$\overline{\text{RST}}$ /NMI/SBWTIO	IN	External reset
DVCC		Power supply
DVSS		Ground supply

6.7 Spy-Bi-Wire Interface (SBW)

The MSP low-power microcontrollers support the 2-wire SBW interface. SBW can be used to interface with MSP development tools and device programmers. [Table 6-6](#) lists the SBW interface pin requirements. For further details on interfacing to development tools and device programmers, see the [MSP430 Hardware Tools User's Guide](#). For details on using the SBW interface, see the [MSP430 Programming With the JTAG Interface](#).

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

DEVICE SIGNAL	DIRECTION	SBW FUNCTION
TEST/SBWTCK	IN	Spy-Bi-Wire clock input
$\overline{\text{RST}}$ /NMI/SBWTIO	IN, OUT	Spy-Bi-Wire data input and output
DVCC		Power supply
DVSS		Ground supply

6.8 FRAM

The FRAM can be programmed using the JTAG port, SBW, the BSL, or in-system by the CPU. Features of the FRAM include:

- Byte and word access capability
- Programmable wait state generation
- Error correction coding (ECC)

6.9 Memory Protection

The device features memory protection for user access authority and write protection, including options to:

- Secure the whole memory map to prevent unauthorized access from JTAG port or BSL, by writing JTAG and BSL signatures using the JTAG port, SBW, the BSL, or in-system by the CPU.
- Enable write protection to prevent unwanted write operation to FRAM contents by setting the control bits in the System Configuration 0 register. For detailed information, see the *System Resets, Interrupts, and Operating Modes, System Control Module (SYS)* chapter in the [MP430FR4xx and MP430FR2xx Family User's Guide](#).

6.10 Peripherals

Peripherals are connected to the CPU through data, address, and control buses. All peripherals can be handled by using all instructions in the memory map. For complete module description, see the [MP430FR4xx and MP430FR2xx Family User's Guide](#).

6.10.1 Power-Management Module (PMM)

The PMM includes an integrated voltage regulator that supplies the core voltage to the device. The PMM also includes supply voltage supervisor (SVS) and brownout protection. The brownout reset circuit (BOR) is implemented to provide the proper internal reset signal to the device during power on and power off. The SVS circuitry detects if the supply voltage drops below a user-selectable safe level. SVS circuitry is available on the primary supply.

The device contains two on-chip reference: 1.5 V for internal reference and 1.2 V for external reference.

The 1.5-V reference is internally connected to ADC channel 13. DVCC is internally connected to ADC channel 15. When DVCC is set as the reference voltage for ADC conversion, the DVCC can be easily represent as [Equation 1](#) by using ADC sampling 1.5-V reference without any external components support.

$$\text{DVCC} = (1023 \times 1.5 \text{ V}) \div 1.5\text{-V reference ADC result} \quad (1)$$

A 1.2-V reference voltage can be buffered and output to P1.4/MCLK/TCK/A4/VREF+, when EXTREFEN = 1 in the PMMCTL1 register. ADC channel 4 can also be selected to monitor this voltage. For more detailed information, see the [MP430FR4xx and MP430FR2xx Family User's Guide](#).

6.10.2 Clock System (CS) and Clock Distribution

The clock system includes a 32-kHz crystal oscillator (XT1), an internal very-low-power low-frequency oscillator (VLO), an integrated 32-kHz RC oscillator (REFO), an integrated internal digitally controlled oscillator (DCO) that may use frequency-locked loop (FLL) locking with internal or external 32-kHz reference clock, and an on-chip asynchronous high-speed clock (MODOSC). The clock system is designed for cost-effective designs with minimal external components. A fail-safe mechanism is included for XT1. The clock system module offers the following clock signals.

- **Main Clock (MCLK):** The system clock used by the CPU and all relevant peripherals accessed by the bus. All clock sources except MODOSC can be selected as the source with a predivider of 1, 2, 4, 8, 16, 32, 64, or 128.
- **Sub-Main Clock (SMCLK):** The subsystem clock used by the peripheral modules. SMCLK derives from the MCLK with a predivider of 1, 2, 4, or 8. This means SMCLK is always equal to or less than MCLK.
- **Auxiliary Clock (ACLK):** This clock is derived from the external XT1 clock or internal REFO clock up to 40 kHz.

All peripherals may have one or several clock sources depending on specific functionality. [Table 6-7](#) lists the clock distribution used in this device.

Table 6-7. Clock Distribution

	CLOCK SOURCE SELECT BITS	MCLK	SMCLK	ACLK	MODCLK	XT1CLK	VLOCLK	EXTERNAL PIN
Frequency Range		DC to 16 MHz	DC to 16 MHz	DC to 40 kHz	5 MHz $\pm 10\%$	DC to 40 kHz	10 kHz $\pm 50\%$	
CPU	N/A	Default						
FRAM	N/A	Default						
RAM	N/A	Default						
CRC	N/A	Default						
I/O	N/A	Default						
TA0	TASSEL		10b	01b				00b (TA0CLK pin)
TA1	TASSEL		10b	01b				00b (TA1CLK pin)
TA2	TASSEL		10b	01b				
TA3	TASSEL		10b	01b				
eUSCI_A0	UCSSEL		10b or 11b		01b			00b (UCA0CLK pin)
eUSCI_A1	UCSSEL		10b or 11b		01b			00b (UCA1CLK pin)
eUSCI_B0	UCSSEL		10b or 11b		01b			00b (UCB0CLK pin)
WDT	WDTSSEL		00b	01b			10b or 11b	
ADC	ADCSSEL		11b	01b	00b			
CapTivate	CAPTSSEL			00b			01b	
	CAPCLKSEL		1b					
RTC	RTCSS		01b			10b	11b	

6.10.3 General-Purpose Input/Output Port (I/O)

Up to 19 I/O ports are implemented.

- P1 and P2 are full 8-bit ports; P3 has 3 bits implemented.
- All individual I/O bits are independently programmable.
- Any combination of input, output, and interrupt conditions is possible.
- All ports support programmable pullup or pulldown.
- Edge-selectable interrupt and LPM3.5 and LPM4.5 wake-up input capability is available for P1 and P2.
- Read and write access to port-control registers is supported by all instructions.
- Ports can be accessed byte-wise or word-wise in pairs.
- CapTivate functionality is supported on all CAPx.y pins.

NOTE

Configuration of digital I/Os after BOR reset

To prevent any cross currents during start-up of the device, all port pins are high-impedance with Schmitt triggers and module functions disabled. To enable the I/O functions after a BOR reset, the ports must be configured first and then the LOCKLPM5 bit must be cleared. For details, see the *Configuration After Reset* section in the *Digital I/O* chapter of the [MP430FR4xx and MP430FR2xx Family User's Guide](#).

6.10.4 Watchdog Timer (WDT)

The primary function of the WDT module is to perform a controlled system restart after a software problem occurs. If the selected time interval expires, a system reset is generated. If the watchdog function is not needed in an application, the module can be configured as interval timer and can generate interrupts at selected time intervals. [Table 6-8](#) lists the system clocks that can be used to source the WDT.

Table 6-8. WDT Clocks

WDTSEL	NORMAL OPERATION (WATCHDOG AND INTERVAL TIMER MODE)
00	SMCLK
01	ACLK
10	VLOCLK
11	Reserved

6.10.5 System (SYS) Module

The SYS module handles many of the system functions within the device. These features include power-on reset (POR) and power-up clear (PUC) handling, NMI source selection and management, reset interrupt vector generators, bootloader entry mechanisms, and configuration management (device descriptors). The SYS module also includes a data exchange mechanism through SBW called a JTAG mailbox mail box that can be used in the application. Table 6-9 summarizes the interrupts that are managed by the SYS module.

Table 6-9. System Module Interrupt Vector Registers

INTERRUPT VECTOR REGISTER	ADDRESS	INTERRUPT EVENT	VALUE	PRIORITY
SYSRSTIV, System Reset	015Eh	No interrupt pending	00h	
		Brownout (BOR)	02h	Highest
		RSTIFG RST/NMI (BOR)	04h	
		PMMSWBOR software BOR (BOR)	06h	
		LPMx.5 wake up (BOR)	08h	
		Security violation (BOR)	0Ah	
		Reserved	0Ch	
		SVSHIFG SVSH event (BOR)	0Eh	
		Reserved	10h	
		Reserved	12h	
		PMMSWPOR software POR (POR)	14h	
		WDTIFG watchdog time-out (PUC)	16h	
		WDTPW password violation (PUC)	18h	
		FRCTLPW password violation (PUC)	1Ah	
		Uncorrectable FRAM bit error detection	1Ch	
		Peripheral area fetch (PUC)	1Eh	
		PMMPW PMM password violation (PUC)	20h	
		FLL unlock (PUC)	24h	
		Reserved	22h, 26h to 3Eh	Lowest
SYSSNIV, System NMI	015Ch	No interrupt pending	00h	
		SVS low-power reset entry	02h	Highest
		Uncorrectable FRAM bit error detection	04h	
		Reserved	06h	
		Reserved	08h	
		Reserved	0Ah	
		Reserved	0Ch	
		Reserved	0Eh	
		Reserved	10h	
		VMAIFG Vacant memory access	12h	
		JMBINIFG JTAG mailbox input	14h	
		JMBOUTIFG JTAG mailbox output	16h	
		Correctable FRAM bit error detection	18h	
		Reserved	1Ah to 1Eh	Lowest
SYSUNIV, User NMI	015Ah	No interrupt pending	00h	
		NMIIFG NMI pin or SVS _H event	02h	Highest
		OFIFG oscillator fault	04h	
		Reserved	06h to 1Eh	Lowest

6.10.6 Cyclic Redundancy Check (CRC)

The 16-bit cyclic redundancy check (CRC) module produces a signature based on a sequence of data values and can be used for data checking purposes. The CRC generation polynomial is compliant with CRC-16-CCITT standard of $x^{16} + x^{12} + x^5 + 1$.

6.10.7 Enhanced Universal Serial Communication Interface (eUSCI_A0, eUSCI_B0)

The eUSCI modules are used for serial data communications. The eUSCI_A module supports either UART or SPI communications. The eUSCI_B module supports either SPI or I²C communications. Additionally, eUSCI_A supports automatic baud-rate detection and IrDA. [Table 6-10](#) lists the pin configurations that are required for each eUSCI mode.

Table 6-10. eUSCI Pin Configurations

	PIN	UART	SPI
eUSCI_A0	P1.4	TXD	SIMO
	P1.5	RXD	SOMI
	P1.6	–	SCLK
	P1.7	–	STE
eUSCI_A1	P2.6	TXD	SIMO
	P2.5	RXD	SOMI
	P2.4	–	SCLK
	P3.1	–	STE
eUSCI_B0	PIN	I ² C	SPI
	P1.0	–	STE
	P1.1	–	SCLK
	P1.2	SDA	SIMO
	P1.3	SCL	SOMI

6.10.8 Timers (Timer0_A3, Timer1_A3, Timer2_A2 and Timer3_A2)

The Timer0_A3 and Timer1_A3 modules are 16-bit timers and counters with three capture/compare registers each. Both timers support multiple captures or compares, PWM outputs, and interval timing (see [Table 6-11](#) and [Table 6-12](#)). Both timers have extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each capture/compare register.

The CCR0 registers on Timer0_A3 and Timer1_A3 are not externally connected and can be used only for hardware period timing and interrupt generation. In Up mode, these CCR0 registers can be used to set the overflow value of the counter.

Table 6-11. Timer0_A3 Signal Connections

PORT PIN	DEVICE INPUT SIGNAL	MODULE INPUT NAME	MODULE BLOCK	MODULE OUTPUT SIGNAL	DEVICE OUTPUT SIGNAL
P1.0	TA0CLK	TACLK	Timer	N/A	
	ACLK (internal)	ACLK			
	SMCLK (internal)	SMCLK			
		CCI0A	CCR0	TA0	
		CCI0B			Timer1_A3 CCI0B input
	DVSS	GND			
	DVCC	VCC			
P1.1	TA0.1	CCI1A	CCR1	TA1	TA0.1
	from RTC (internal)	CCI1B			Timer1_A3 CCI1B input
	DVSS	GND			
	DVCC	VCC			
P1.2	TA0.2	CCI2A	CCR2	TA2	TA0.2
		CCI2B			Timer1_A3 CCI2B input, IR Input
	DVSS	GND			
	DVCC	VCC			

Table 6-12. Timer1_A3 Signal Connections

PORT PIN	DEVICE INPUT SIGNAL	MODULE INPUT NAME	MODULE BLOCK	MODULE OUTPUT SIGNAL	DEVICE OUTPUT SIGNAL
P1.6	TA1CLK	TACLK	Timer	N/A	
	ACLK (internal)	ACLK			
	SMCLK (internal)	SMCLK			
		CCI0A	CCR0	TA0	
	Timer0_A3 CCR0B output (internal)	CCI0B			
	DVSS	GND			
	DVCC	VCC			
P1.5	TA1.1	CCI1A	CCR1	TA1	TA1.1
	Timer0_A3 CCR1B output (internal)	CCI1B			to ADC trigger
	DVSS	GND			
	DVCC	VCC			
P1.4	TA1.2	CCI2A	CCR2	TA2	TA1.2
	Timer0_A3 CCR2B output (internal)	CCI2B			IR Input
	DVSS	GND			
	DVCC	VCC			

The interconnection of Timer0_A3 and Timer1_A3 can be used to modulate the eUSCI_A pin of UCA0TXD/UCA0SIMO in either ASK or FSK mode, with which a user can easily acquire a modulated infrared command for directly driving an external IR diode. The IR functions are fully controlled by SYS configuration registers 1 including IREN (enable), IRPSEL (polarity select), IRMSEL (mode select), IRDSEL (data select), and IRDATA (data) bits. For more information, see the *System Resets, Interrupts, and Operating Modes, System Control Module (SYS)* chapter in the [MP430FR4xx and MP430FR2xx Family User's Guide](#).

The Timer2_A2 and Timer3_A2 modules are 16-bit timers and counters with two capture/compare registers each. Both timers support multiple captures or compares and interval timing (see [Table 6-13](#) and [Table 6-14](#)). Both timers have extensive interrupt capabilities. Interrupts may be generated from the counter on overflow conditions and from each capture register.

The CCR0 registers on Timer2_TA2 and Timer3_TA2 are not externally connected and can be used only for hardware period timing and interrupt generation. In Up mode, these CCR0 registers can be used to set the overflow value of the counter. Timer2_A2 and Timer3_A2 are only internally connected and do not support PWM output.

Table 6-13. Timer2_A2 Signal Connections

DEVICE INPUT SIGNAL	MODULE INPUT NAME	MODULE BLOCK	MODULE OUTPUT SIGNAL	DEVICE OUTPUT SIGNAL
ACLK (internal)	ACLK	Timer	N/A	
SMCLK (internal)	SMCLK			
	CCI0A	CCR0	TA0	
	CCI0B			Timer3_A3 CCI0B input
DVSS	GND			
DVCC	VCC			
	CCI1A	CCR1	CCR1	
	CCI1B			Timer3_A3 CCI1B input
DVSS	GND			
DVCC	VCC			

Table 6-14. Timer3_A2 Signal Connections

DEVICE INPUT SIGNAL	MODULE INPUT NAME	MODULE BLOCK	MODULE OUTPUT SIGNAL	DEVICE OUTPUT SIGNAL
ACLK (internal)	ACLK	Timer	N/A	
SMCLK (internal)	SMCLK			
	CCI0A	CCR0	TA0	
Timer3_A3 CCI0B input	CCI0B			
DVSS	GND			
DVCC	VCC			
	CCI1A	CCR1	CCR1	
Timer3_A3 CCI1B input	CCI1B			
DVSS	GND			
DVCC	VCC			

6.10.9 Hardware Multiplier (MPY)

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

6.10.10 Backup Memory (BAKMEM)

The BAKMEM supports data retention during LPM3.5. This device provides up to 32 bytes that are retained during LPM3.5.

6.10.11 Real-Time Clock (RTC)

The RTC is a 16-bit modulo counter that is functional in AM, LPM0, LPM3, and LPM3.5. This module may periodically wake up the CPU from LPM0, LPM3, and LPM3.5 based on timing from a low-power clock source such as the XT1 and VLO clocks. In AM, SMCLK can drive the RTC to generate high-frequency timing events and interrupts. The RTC overflow events trigger:

- Timer0_A3 CCR1B
- ADC conversion trigger when ADCSHSx bits are set as 01b

6.10.12 10-Bit Analog-to-Digital Converter (ADC)

The 10-bit ADC module supports fast 10-bit analog-to-digital conversions with single-ended input. The module implements a 10-bit SAR core, sample select control, reference generator and a conversion result buffer. A window comparator with lower and upper limits allows CPU-independent result monitoring with three window comparator interrupt flags.

The ADC supports 10 external inputs and 4 internal inputs (see [Table 6-15](#)).

Table 6-15. ADC Channel Connections

ADCSHSx	ADC CHANNELS	EXTERNAL PINOUT
0	A0/Veref+	P1.0
1	A1	P1.1
2	A2/Veref-	P1.2
3	A3	P1.3
4	A4 ⁽¹⁾	P1.4
5	A5	P1.5
6	A6	P1.6
7	A7	P1.7
8	A8	NA
9	A9	NA
10	Not used	N/A
11	Not used	N/A
12	On-chip temperature sensor	N/A
13	Reference voltage (1.5 V)	N/A
14	DVSS	N/A
15	DVCC	N/A

(1) When A4 is used, the PMM 1.2-V reference voltage can be output to this pin by setting the PMM control register. The 1.2-V voltage can be directly measured by A4 channel.

Software or a hardware trigger can start the analog-to-digital conversion. [Table 6-16](#) lists the trigger sources that are available.

Table 6-16. ADC Trigger Signal Connections

ADCINCHx		TRIGGER SOURCE
BINARY	DECIMAL	
00	0	ADCSC bit (software trigger)
01	1	RTC event
10	2	TA1.1B
11	3	--

6.10.13 CapTivate

The CapTivate module detects the capacitance changed with a charge-transfer method and is functional in AM, LPM0, LPM3, and LPM4. The CapTivate module can periodically wake the CPU from LPM0, LPM3, or LPM4 based on a CapTivate timer source such as ACLK or VLO clock. The CapTivate module supports the following touch-sensing capability:

- Up to 64 CapTivate buttons composed of 4 CapTivate blocks. Each block consists of 4 I/Os, and these blocks scan in parallel of 4 electrodes.
- Each block can be individually configured in self or mutual mode. Each CapTivate I/O can be used for either self or mutual electrodes.
- Supports a wake-on-touch state machine.
- Supports synchronized conversion on a zero-crossing event trigger.
- Processing logic to perform filter calculation and threshold detection.

6.10.14 Embedded Emulation Module (EEM)

The EEM supports real-time in-system debugging. The EEM on these devices has the following features:

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

6.11 Input/Output Diagrams

6.11.1 Port P1 Input/Output With Schmitt Trigger

Figure 6-1 shows the port diagram. Table 6-17 summarizes the selection of pin function.

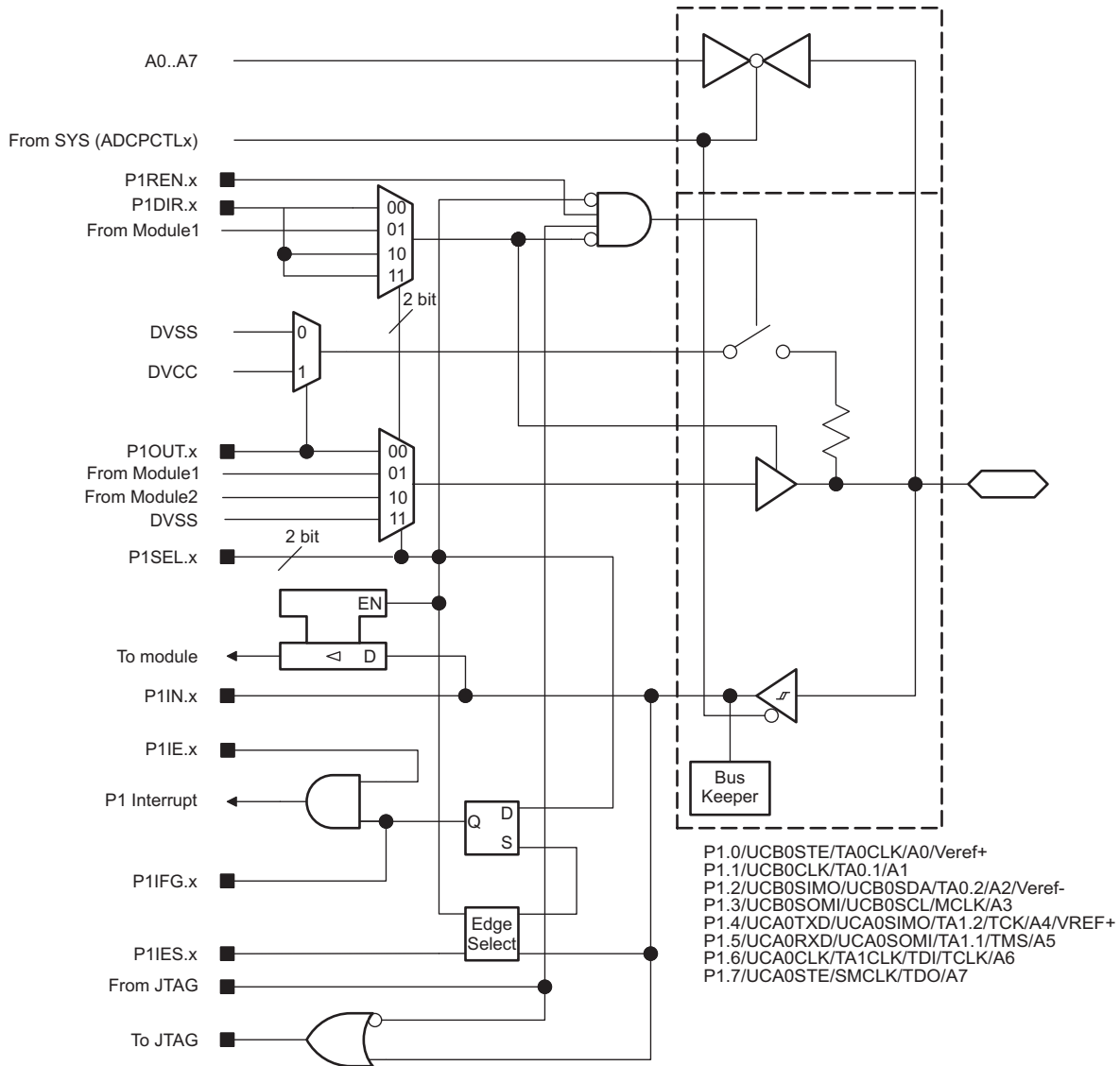


Figure 6-1. Port P1 (P1.0 to P1.7) Input/Output With Schmitt Trigger

Table 6-17. Port P1 (P1.0 to P1.7) Pin Functions

PIN NAME (P1.x)	x	FUNCTION	CONTROL BITS AND SIGNALS ⁽¹⁾			
			P1DIR.x	P1SELx	ADCPCTLx ⁽²⁾	JTAG
P1.0/UCB0STE/ TA0CLK/A0	0	P1.0 (I/O)	I: 0; O: 1	00	0	N/A
		UCB0STE	X	01	0	N/A
		TA0CLK	0	10	0	N/A
		A0/Veref+	X	X	1 (x = 0)	N/A
P1.1/UCB0CLK/TA0.1/ A1	1	P1.1 (I/O)	I: 0; O: 1	00	0	N/A
		UCB0CLK	X	01	0	N/A
		TA0.CCI1A	0	10	0	N/A
		TA0.1	1			
		A1	X	X	1 (x = 1)	N/A
P1.2/UCB0SIMO/ UCB0SDA/TA0.2/A2	2	P1.2 (I/O)	I: 0; O: 1	00	0	N/A
		UCB0SIMO/UCB0SDA	X	01	0	N/A
		TA0.CCI2A	0	10	0	N/A
		TA0.2	1			
		A2/Veref-	X	X	1 (x = 2)	N/A
P1.3/UCB0SOMI/ UCB0SCL/MCLK/A3	3	P1.3 (I/O)	I: 0; O: 1	00	0	N/A
		UCB0SOMI/UCB0SCL	X	01	0	N/A
		MCLK	1	10	0	N/A
		A3	X	X	1 (x = 3)	N/A
P1.4/UCA0TXD/ UCA0SIMO/TA1.2/TCK/ A4 /VREF+	4	P1.4 (I/O)	I: 0; O: 1	00	0	Disabled
		UCA0TXD/UCA0SIMO	X	01	0	Disabled
		TA1.CCI2A	0	10	0	Disabled
		TA1.2	1			
		A4, VREF+	X	X	1 (x = 4)	Disabled
		JTAG TCK	X	X	X	TCK
P1.5/UCA0RXD/ UCA0SOMI/TA1.1/TMS/ A5	5	P1.5 (I/O)	I: 0; O: 1	00	0	Disabled
		UCA0RXD/UCA0SOMI	X	01	0	Disabled
		TA1.CCI1A	0	10	0	Disabled
		TA1.1	1			
		A5	X	X	1 (x = 5)	Disabled
		JTAG TMS	X	X	X	TMS
P1.6/UCA0CLK/ TA1CLK/TDI/TCLK/A6	6	P1.6 (I/O)	I: 0; O: 1	00	0	Disabled
		UCA0CLK	X	01		Disabled
		TA1CLK	0	10	0	Disabled
		A6	X	X	1 (x = 6)	Disabled
		JTAG TDI/TCLK	X	X	X	TDI/TCLK
P1.7/UCA0STE/SMCLK/ TDO/A7	7	P1.7 (I/O)	I: 0; O: 1	00	0	Disabled
		UCA0STE	X	01	0	Disabled
		SMCLK	1	10	0	Disabled
		A7	X	X	1 (x = 7)	Disabled
		JTAG TDO	X	X	X	TDO

(1) X = don't care

(2) Setting the ADCPCTLx bit in SYSCFG2 register disables both the output driver and input Schmitt trigger to prevent leakage when analog signals are applied.

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

Figure 6-2 shows the port diagram. Table 6-18 summarizes the selection of pin function.

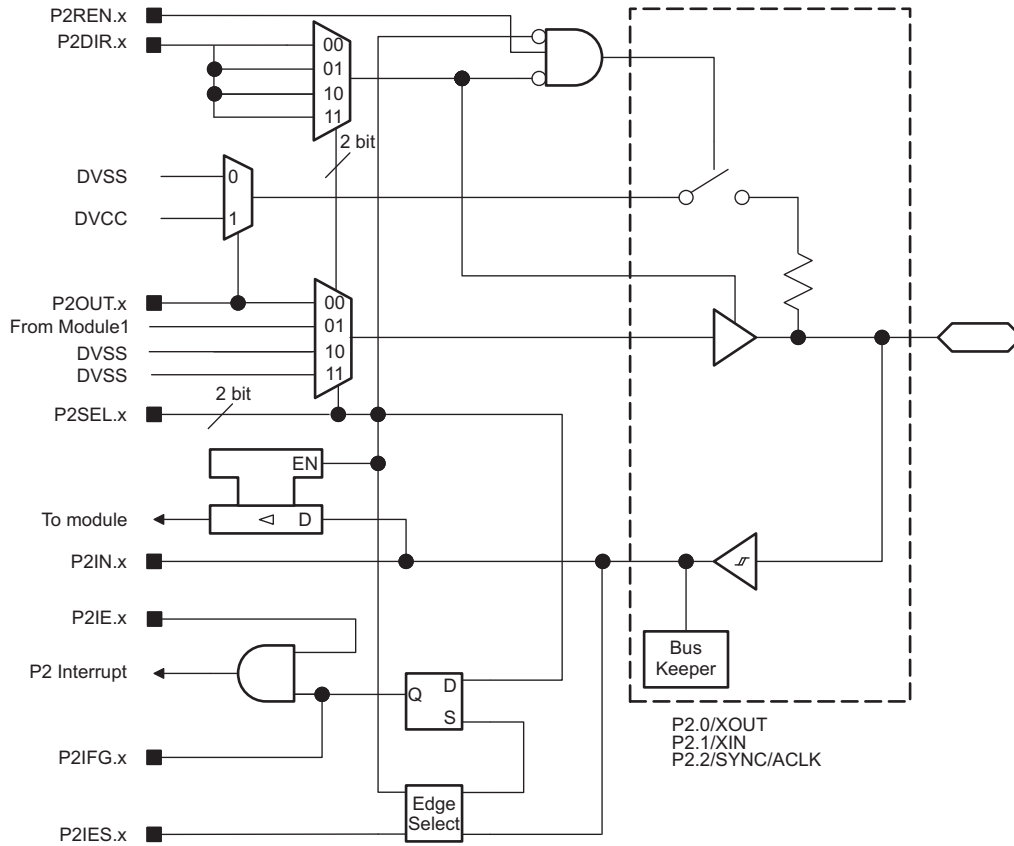


Figure 6-2. Port P2 (P2.0 to P2.2) Input/Output With Schmitt Trigger

Table 6-18. Port P2 (P2.0 to P2.2) Pin Functions

PIN NAME (P2.x)	x	FUNCTION	CONTROL BITS AND SIGNALS ⁽¹⁾	
			P2DIR.x	P2SELx
P2.0/XOUT	0	P2.0 (I/O)	I: 0; O: 1	00
		XOUT	X	01
P2.1/XIN	1	P2.1 (I/O)	I: 0; O: 1	00
		XIN	X	01
P2.2/SYNC/ACLK	2	P2.2 (I/O)	I: 0; O: 1	00
		SYNC	0	01
		ACLK	1	10

(1) X = don't care

6.11.3 Port P2 (P2.3 to P2.7) Input/Output With Schmitt Trigger

Figure 6-3 shows the port diagram. Table 6-19 summarizes the selection of pin function.

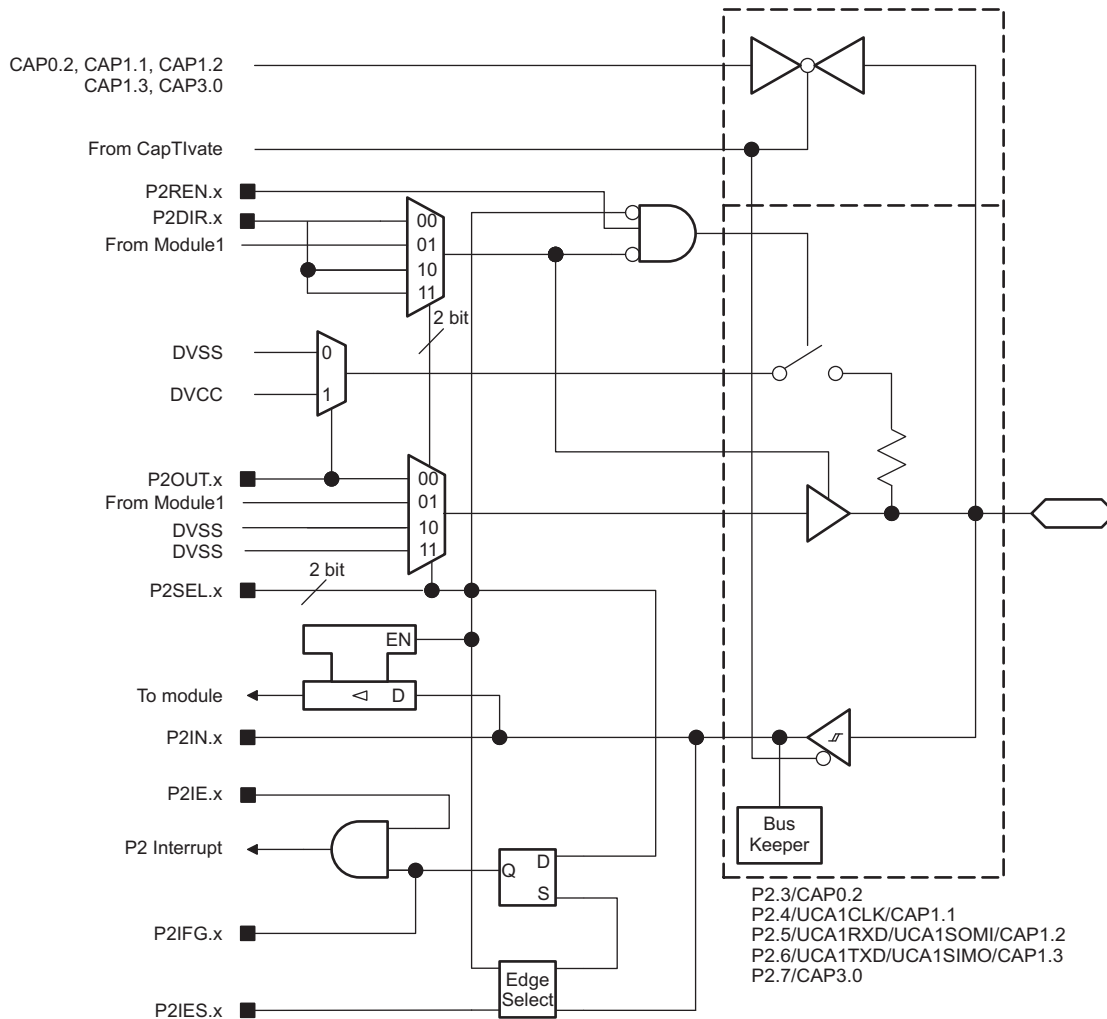


Figure 6-3. Port P2 (P2.3 to P2.7) Input/Output With Schmitt Trigger

Table 6-19. Port P2 (P2.3 to P2.7) Pin Functions

PIN NAME (P2.x)	x	FUNCTION	CONTROL BITS AND SIGNALS ⁽¹⁾		
			P2DIR.x	P2SELx	ANALOG FUNCTION
P2.3/CAP0.2	3	P2.3 (I/O)	I: 0; O: 1	00	0
		CAP0.2	X	X	1
P2.4/UCA1CLK/ CAP1.1	4	P2.4 (I/O)	I: 0; O: 1	00	0
		UCA1CLK	X	01	0
		CAP1.1	X	X	1
P2.5/UCA1RXD/ UCA1SOMI/CAP1.2	5	P2.5 (I/O)	I: 0; O: 1	00	0
		UCA1RXD/UCA1SOMI	X	01	0
		CAP1.2	X	X	1
P2.6/UCA1TXD/ UCA1SIMO/CAP1.3	6	P2.6 (I/O)	I: 0; O: 1	00	0
		UCA1TXD/UCA1SIMO	X	01	0
		CAP1.3	X	X	1
P2.7/CAP3.0	7	P2.7 (I/O)	I: 0; O: 1	0	0
		CAP3.0	X	X	1

(1) X = don't care

6.11.4 Port P3 (P3.0 to P3.2) Input/Output With Schmitt Trigger

Figure 6-4 shows the port diagram. Table 6-20 summarizes the selection of pin function.

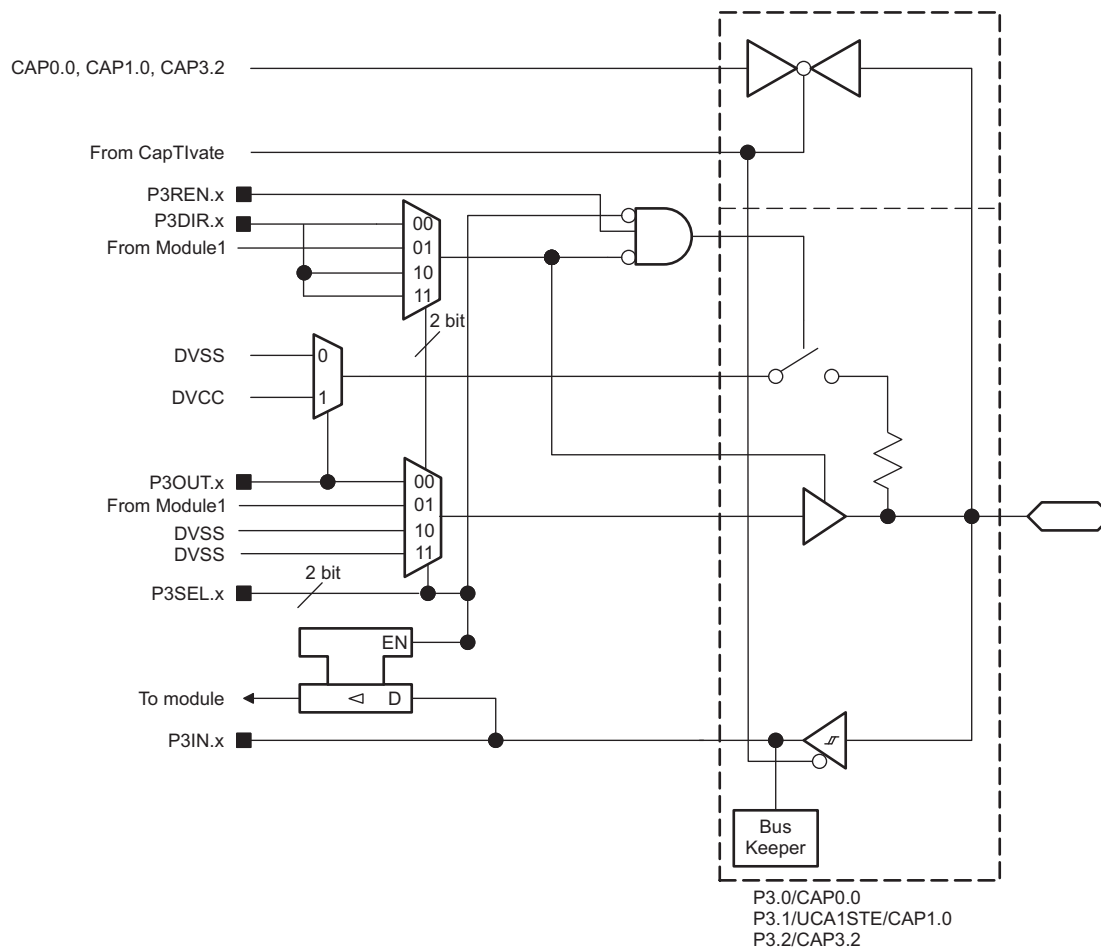


Figure 6-4. Port P3 (P3.0 to P3.2) Input/Output With Schmitt Trigger

NOTE

CapTlvate shared with I/Os configuration

The CapTivate function and GPIOs are powered by different power supplies (1.5 V and 3.3 V, respectively).

To prevent pad damage when changing the function, TI recommends checking the external application circuit of each pad before enabling the alternate function.

Table 6-20. Port P3 (P3.0 to P3.2) Pin Functions

PIN NAME (P3.x)	x	FUNCTION	CONTROL BITS AND SIGNALS ⁽¹⁾		
			P3DIR.x	P3SEL.x	ANALOG FUNCTION
P3.0/CAP0.0	0	P3.0 (I/O)	I: 0; O: 1	00	0
		CAP0.0	X	X	1
P3.1/UCA1STE/ CAP1.0	1	P3.1 (I/O)	I: 0; O: 1	00	0
		UCA1STE	X	01	0
		CAP1.0	X	X	1
P3.2/CAP3.2	2	P3.2 (I/O)	I: 0; O: 1	00	0
		CAP3.2	X	X	1

(1) X = don't care

6.12 Device Descriptors

Table 6-21 lists the Device IDs of the devices. Table 6-22 lists the contents of the device descriptor tag-length-value (TLV) structure for the devices.

Table 6-21. Device IDs

DEVICE	DEVICE ID	
	1A05h	1A04h
MSP430FR2633	82h	3Ch
MSP430FR2533	82h	3Dh
MSP430FR2632	82h	3Eh
MSP430FR2532	82h	3Fh

Table 6-22. Device Descriptors

DESCRIPTION		MSP430FR2633, MSP430FR2632, MSP430FR2533, MSP430FR2532	
		ADDRESS	VALUE
Information Block	Info length	1A00h	06h
	CRC length	1A01h	06h
	CRC value ⁽¹⁾	1A02h	Per unit
		1A03h	Per unit
	Device ID	1A04h	See Table 6-21.
		1A05h	
	Hardware revision	1A06h	Per unit
	Firmware revision	1A07h	Per unit
Die Record	Die record tag	1A08h	08h
	Die record length	1A09h	0Ah
	Lot wafer ID	1A0Ah	Per unit
		1A0Bh	Per unit
		1A0Ch	Per unit
		1A0Dh	Per unit
	Die X position	1A0Eh	Per unit
		1A0Fh	Per unit
	Die Y position	1A10h	Per unit
		1A11h	Per unit
	Test result	1A12h	Per unit
		1A13h	Per unit
ADC Calibration	ADC calibration tag	1A14h	Per unit
	ADC calibration length	1A15h	Per unit
	ADC gain factor	1A16h	Per unit
		1A17h	Per unit
	ADC offset	1A18h	Per unit
		1A19h	Per unit
	ADC 1.5-V reference temperature 30°C	1A1Ah	Per unit
		1A1Bh	Per unit
	ADC 1.5-V reference temperature 85°C	1A1Ch	Per unit
		1A1Dh	Per unit

(1) The CRC value covers the check sum from 0x1A04h to 0x1AEFh by applying the CRC-CCITT-16 polynomial of $x^{16} + x^{12} + x^5 + 1$.

Table 6-22. Device Descriptors (continued)

DESCRIPTION		MSP430FR2633, MSP430FR2632, MSP430FR2533, MSP430FR2532	
		ADDRESS	VALUE
Reference and DCO Calibration	Calibration tag	1A1Eh	12h
	Calibration length	1A1Fh	04h
	1.5-V reference factor	1A20h	Per unit
		1A21h	Per unit
	DCO tap setting for 16 MHz, temperature 30°C ⁽²⁾	1A22h	Per unit
		1A23h	Per unit

- (2) This value can be directly loaded into DCO bits in CSCTL0 registers to get accurate 16-MHz frequency at room temperature, especially when the MCU exits from LPM3 and below. TI suggests using the predivider to decrease the frequency if the temperature drift might result an overshoot beyond 16 MHz.

6.13 Memory

6.13.1 Memory Organization

Table 6-23 summarizes the memory map of the devices.

Table 6-23. Memory Organization

	ACCESS	MSP430FR2633	MSP430FR2632	MSP430FR2533	MSP430FR2532
Memory (FRAM) Main: interrupt vectors and signatures Main: code memory	Read/Write (Optional Write Protect) ⁽¹⁾	15KB FFFFh–FF80h FFFFh–C400h	8KB FFFFh–FF80h FFFFh–E000h	15KB FFFFh–FF80h FFFFh–C400h	8KB FFFFh–FF80h FFFFh–E000h
RAM	Read/Write	4KB 2FFFh–2000h	2KB 27FFh–2000h	2KB 27FFh–2000h	1KB 23FFh–2000h
Information Memory (FRAM)	Read/Write (Optional Write Protect) ⁽²⁾	512B 19FFh–1800h	512B 19FFh–1800h	512B 19FFh–1800h	512B 19FFh–1800h
Bootstrap loader (BSL1) Memory (ROM)	Read only	2KB 17FFh–1000h	2KB 17FFh–1000h	2KB 17FFh–1000h	2KB 17FFh–1000h
Bootstrap loader (BSL2) Memory (ROM)	Read only	1KB FFFFh–FFC00h	1KB FFFFh–FFC00h	1KB FFFFh–FFC00h	1KB FFFFh–FFC00h
CapTivate Libraries and Driver Libraries (ROM)	Read only	12KB 6FFFh–4000h	12KB 6FFFh–4000h	12KB 6FFFh–4000h	12KB 6FFFh–4000h
Peripherals	Read/Write	4KB 0FFFh–0000h	4KB 0FFFh–0000h	4KB 0FFFh–0000h	4KB 0FFFh–0000h

- (1) The Program FRAM can be write protected by setting the PFWP bit in the SYSCFG0 register. See the SYS chapter in the [MSP430FR4xx and MSP430FR2xx Family User's Guide](#) for more details.
- (2) The Information FRAM can be write protected by setting the DFWP bit in the SYSCFG0 register. See the SYS chapter in the [MSP430FR4xx and MSP430FR2xx Family User's Guide](#) for more details.

6.13.2 Peripheral File Map

Table 6-24 lists the available peripherals and the register base address for each. Table 6-25 to list the registers and address offsets for each peripheral.

Table 6-24. Peripherals Summary

MODULE NAME	BASE ADDRESS	SIZE
Special Functions (See Table 6-25)	0100h	0010h
PMM (See Table 6-26)	0120h	0020h
SYS (See Table 6-27)	0140h	0040h
CS (See Table 6-28)	0180h	0020h
FRAM (See Table 6-29)	01A0h	0010h
CRC (See Table 6-30)	01C0h	0008h
WDT (See Table 6-31)	01CCh	0002h
Port P1, P2 (See Table 6-32)	0200h	0020h
Port P3 (See Table 6-33)	0220h	0020h
RTC (See Table 6-34)	0300h	0010h
Timer0_A3 (See Table 6-35)	0380h	0030h
Timer1_A3 (See Table 6-36)	03C0h	0030h
Timer2_A2 (See Table 6-37)	0400h	0030h
Timer3_A2 (See Table 6-38)	0440h	0030h
MPY32 (See Table 6-39)	04C0h	0030h
eUSCI_A0 (See Table 6-40)	0500h	0020h
eUSCI_A1 (See Table 6-41)	0520h	0020h
eUSCI_B0 (See Table 6-42)	0540h	0030h
Backup Memory (See Table 6-43)	0660h	0020h
ADC (See Table 6-44)	0700h	0040h
CapTivate (See CapTivate Design Center for details)	0A00h	0200h

Table 6-25. Special Function Registers (Base Address: 0100h)

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

Table 6-26. PMM Registers (Base Address: 0120h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
PMM control 0	PMMCTL0	00h
PMM control 1	PMMCTL1	02h
PMM control 2	PMMCTL2	04h
PMM interrupt flags	PMMIFG	0Ah
PM5 control 0	PM5CTL0	10h

Table 6-27. SYS Registers (Base Address: 0140h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
System control	SYSCTL	00h
Bootloader configuration area	SYSBSLC	02h
JTAG mailbox control	SYSJMBBC	06h
JTAG mailbox input 0	SYSJMBI0	08h
JTAG mailbox input 1	SYSJMBI1	0Ah
JTAG mailbox output 0	SYSJMBO0	0Ch
JTAG mailbox output 1	SYSJMBO1	0Eh
Bus error vector generator	SYSBERRIV	18h
User NMI vector generator	SYSUNIV	1Ah
System NMI vector generator	SYSSNIV	1Ch
Reset vector generator	SYSRSTIV	1Eh
System configuration 0	SYSCFG0	20h
System configuration 1	SYSCFG1	22h
System configuration 2	SYSCFG2	24h

Table 6-28. CS Registers (Base Address: 0180h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
CS control 0	CSCTL0	00h
CS control 1	CSCTL1	02h
CS control 2	CSCTL2	04h
CS control 3	CSCTL3	06h
CS control 4	CSCTL4	08h
CS control 5	CSCTL5	0Ah
CS control 6	CSCTL6	0Ch
CS control 7	CSCTL7	0Eh
CS control 8	CSCTL8	10h

Table 6-29. FRAM Registers (Base Address: 01A0h)

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

Table 6-30. CRC Registers (Base Address: 01C0h)

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

Table 6-31. WDT Registers (Base Address: 01CCh)

REGISTER DESCRIPTION	ACRONYM	OFFSET
Watchdog timer control	WDTCTL	00h

Table 6-32. Port P1, P2 Registers (Base Address: 0200h)

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

Table 6-33. Port P3 Registers (Base Address: 0220h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
Port P3 input	P3IN	00h
Port P3 output	P3OUT	02h
Port P3 direction	P3DIR	04h
Port P3 pulling enable	P3REN	06h
Port P3 selection 0	P3SEL0	0Ah
Port P3 selection 1	P3SEL1	0

Table 6-34. RTC Registers (Base Address: 0300h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
RTC control	RTCCTL	00h
RTC interrupt vector	RTCIV	04h
RTC modulo	RTCMOD	08h
RTC counter	RTCCNT	0Ch

Table 6-35. Timer0_A3 Registers (Base Address: 0380h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
TA0 control	TA0CTL	00h
Capture/compare control 0	TA0CCTL0	02h
Capture/compare control 1	TA0CCTL1	04h
Capture/compare control 2	TA0CCTL2	06h
TA0 counter	TA0R	10h
Capture/compare 0	TA0CCR0	12h
Capture/compare 1	TA0CCR1	14h
Capture/compare 2	TA0CCR2	16h
TA0 expansion 0	TA0EX0	20h
TA0 interrupt vector	TA0IV	2Eh

Table 6-36. Timer1_A3 Registers (Base Address: 03C0h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
TA1 control	TA1CTL	00h
Capture/compare control 0	TA1CCTL0	02h
Capture/compare control 1	TA1CCTL1	04h
Capture/compare control 2	TA1CCTL2	06h
TA1 counter	TA1R	10h
Capture/compare 0	TA1CCR0	12h
Capture/compare 1	TA1CCR1	14h
Capture/compare 2	TA1CCR2	16h
TA1 expansion 0	TA1EX0	20h
TA1 interrupt vector	TA1IV	2Eh

Table 6-37. Timer2_A2 Registers (Base Address: 0400h)

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

Table 6-38. Timer3_A2 Registers (Base Address: 0440h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
TA3 control	TA3CTL	00h
Capture/compare control 0	TA3CCTL0	02h
Capture/compare control 1	TA3CCTL1	04h
TA3 counter	TA3R	10h
Capture/compare 0	TA3CCR0	12h
Capture/compare 1	TA3CCR1	14h
TA3 expansion 0	TA3EX0	20h
TA3 interrupt vector	TA3IV	2Eh

Table 6-39. MPY32 Registers (Base Address: 04C0h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
16-bit operand 1 – multiply	MPY	00h
16-bit operand 1 – signed multiply	MPYS	02h
16-bit operand 1 – multiply accumulate	MAC	04h
16-bit operand 1 – signed multiply accumulate	MACS	06h
16-bit operand 2	OP2	08h
16 × 16 result low word	RESLO	0Ah
16 × 16 result high word	RESHI	0Ch
16 × 16 sum extension	SUMEXT	0Eh
32-bit operand 1 – multiply low word	MPY32L	10h
32-bit operand 1 – multiply high word	MPY32H	12h
32-bit operand 1 – signed multiply low word	MPYS32L	14h
32-bit operand 1 – signed multiply high word	MPYS32H	16h
32-bit operand 1 – multiply accumulate low word	MAC32L	18h
32-bit operand 1 – multiply accumulate high word	MAC32H	1Ah
32-bit operand 1 – signed multiply accumulate low word	MACS32L	1Ch
32-bit operand 1 – signed multiply accumulate high word	MACS32H	1Eh
32-bit operand 2 – low word	OP2L	20h
32-bit operand 2 – high word	OP2H	22h
32 × 32 result 0 – least significant word	RES0	24h
32 × 32 result 1	RES1	26h
32 × 32 result 2	RES2	28h
32 × 32 result 3 – most significant word	RES3	2Ah
MPY32 control 0	MPY32CTL0	2Ch

Table 6-40. eUSCI_A0 Registers (Base Address: 0500h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
eUSCI_A control word 0	UCA0CTLW0	00h
eUSCI_A control word 1	UCA0CTLW1	02h
eUSCI_A control rate 0	UCA0BR0	06h
eUSCI_A control rate 1	UCA0BR1	07h
eUSCI_A modulation control	UCA0MCTLW	08h
eUSCI_A status	UCA0STAT	0Ah
eUSCI_A receive buffer	UCA0RXBUF	0Ch
eUSCI_A transmit buffer	UCA0TXBUF	0Eh
eUSCI_A LIN control	UCA0ABCTL	10h
eUSCI_A IrDA transmit control	IUCA0IRTCTL	12h
eUSCI_A IrDA receive control	IUCA0IRRCTL	13h
eUSCI_A interrupt enable	UCA0IE	1Ah
eUSCI_A interrupt flags	UCA0IFG	1Ch
eUSCI_A interrupt vector word	UCA0IV	1Eh

Table 6-41. eUSCI_A1 Registers (Base Address: 0520h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
eUSCI_A control word 0	UCA1CTLW0	00h
eUSCI_A control word 1	UCA1CTLW1	02h
eUSCI_A control rate 0	UCA1BR0	06h
eUSCI_A control rate 1	UCA1BR1	07h
eUSCI_A modulation control	UCA1MCTLW	08h
eUSCI_A status	UCA1STAT	0Ah
eUSCI_A receive buffer	UCA1RXBUF	0Ch
eUSCI_A transmit buffer	UCA1TXBUF	0Eh
eUSCI_A LIN control	UCA1ABCTL	10h
eUSCI_A IrDA transmit control	IUCA1IRTCTL	12h
eUSCI_A IrDA receive control	IUCA1IRRCTL	13h
eUSCI_A interrupt enable	UCA1IE	1Ah
eUSCI_A interrupt flags	UCA1IFG	1Ch
eUSCI_A interrupt vector word	UCA1IV	1Eh

Table 6-42. eUSCI_B0 Registers (Base Address: 0540h)

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

Table 6-43. Backup Memory Registers (Base Address: 0660h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
Backup memory 0	BAKMEM0	00h
Backup memory 1	BAKMEM1	02h
Backup memory 2	BAKMEM2	04h
Backup memory 3	BAKMEM3	06h
Backup memory 4	BAKMEM4	08h
Backup memory 5	BAKMEM5	0Ah
Backup memory 6	BAKMEM6	0Ch
Backup memory 7	BAKMEM7	0Eh
Backup memory 8	BAKMEM8	10h
Backup memory 9	BAKMEM9	12h
Backup memory 10	BAKMEM10	14h
Backup memory 11	BAKMEM11	16h
Backup memory 12	BAKMEM12	18h
Backup memory 13	BAKMEM13	1Ah
Backup memory 14	BAKMEM14	1Ch
Backup memory 15	BAKMEM15	1Eh

Table 6-44. ADC Registers (Base Address: 0700h)

REGISTER DESCRIPTION	ACRONYM	OFFSET
ADC control 0	ADCCTL0	00h
ADC control 1	ADCCTL1	02h
ADC control 2	ADCCTL2	04h
ADC window comparator low threshold	ADCLO	06h
ADC window comparator high threshold	ADCHI	08h
ADC memory control 0	ADCMCTL0	0Ah
ADC conversion memory	ADCMEM0	12h
ADC interrupt enable	ADCIE	1Ah
ADC interrupt flags	ADCIFG	1Ch
ADC interrupt vector word	ADCIV	1Eh

6.14 Identification

6.14.1 Revision Identification

The device revision information is included as part of the top-side marking on the device package. The device-specific errata sheet describes these markings (see [§ 8.4](#)).

The hardware revision is also stored in the Device Descriptor structure in the Information Block section. For details on this value, see the Hardware Revision entries in [Table 6-22](#).

6.14.2 Device Identification

The device type can be identified from the top-side marking on the device package. The device-specific errata sheet describes these markings (see [§ 8.4](#)).

A device identification value is also stored in the Device Descriptor structure in the Information Block section. For details on this value, see the Device ID entries in [Table 6-22](#).

6.14.3 JTAG Identification

Programming through the JTAG interface, including reading and identifying the JTAG ID, is described in detail in [MSP430 Programming With the JTAG Interface](#).

7 Applications, Implementation, and Layout

NOTE

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

7.1 Device Connection and Layout Fundamentals

This section discusses the recommended guidelines when designing with the MSP430 devices. These guidelines are to make sure that the device has proper connections for powering, programming, debugging, and optimum analog performance.

7.1.1 Power Supply Decoupling and Bulk Capacitors

TI recommends connecting a combination of a 10- μ F plus a 100-nF low-ESR ceramic decoupling capacitor to the DVCC and DVSS pins (see [Figure 7-1](#)). Higher-value capacitors may be used but can impact supply rail ramp-up time. Decoupling capacitors must be placed as close as possible to the pins that they decouple (within a few millimeters). Additionally, TI recommends separated grounds with a single-point connection for better noise isolation from digital-to-analog circuits on the board and to achieve high analog accuracy.

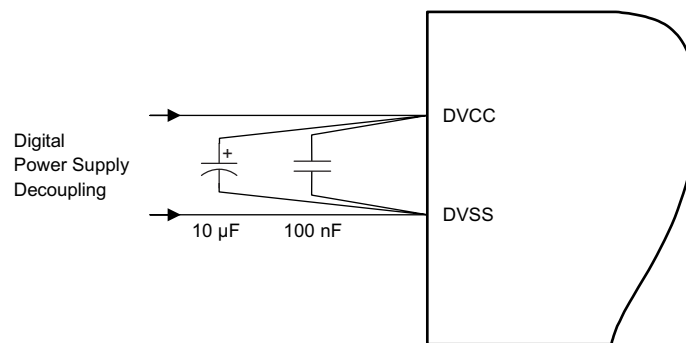


Figure 7-1. Power Supply Decoupling

7.1.2 External Oscillator

This device supports only a low-frequency crystal (32 kHz) on the XIN and XOUT pins. External bypass capacitors for the crystal oscillator pins are required.

It is also possible to apply digital clock signals to the XIN input pin that meet the specifications of the respective oscillator if the appropriate XT1BYPASS mode is selected. In this case, the associated XOUT pin can be used for other purposes. If the XIN and XOUT pins are not used, they must be terminated according to [Section 4.6](#).

[Figure 7-2](#) shows a typical connection diagram.

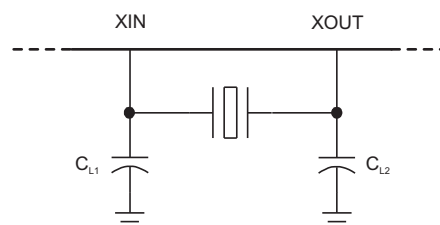


Figure 7-2. Typical Crystal Connection

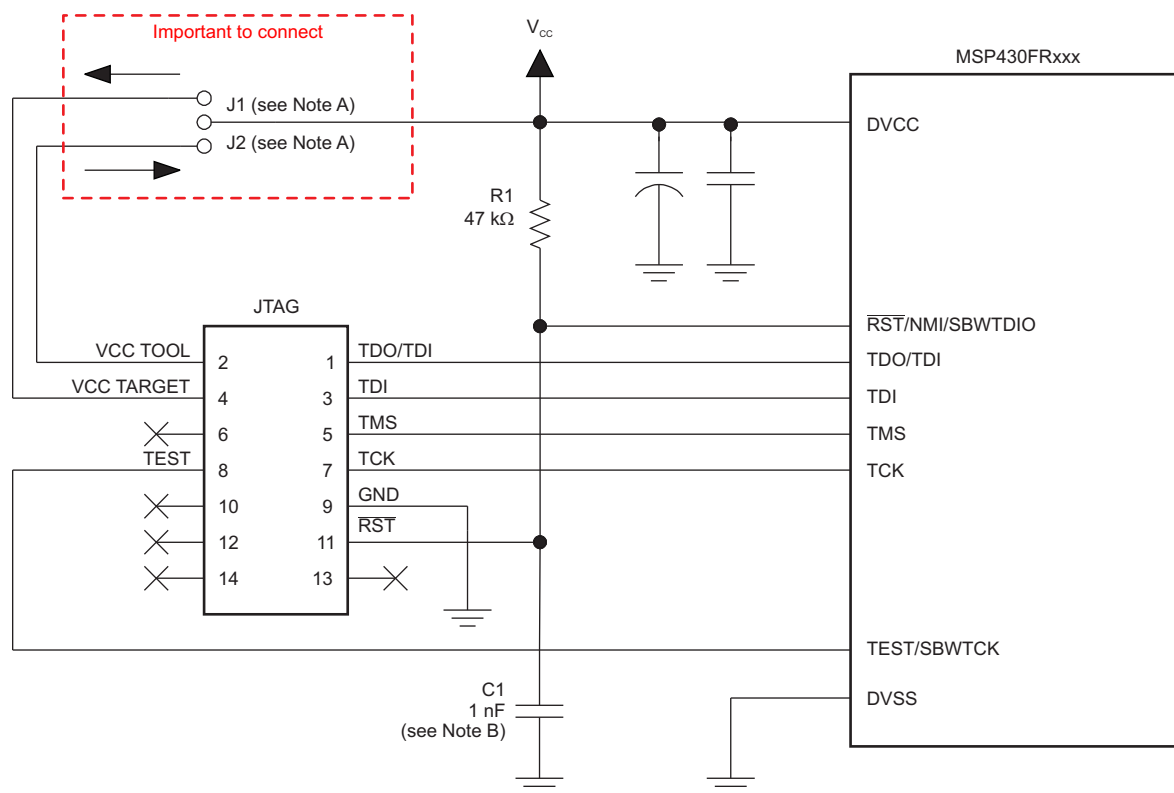
See [MSP430 32-kHz Crystal Oscillators](#) for more information on selecting, testing, and designing a crystal oscillator with the MSP430 devices.

7.1.3 JTAG

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

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

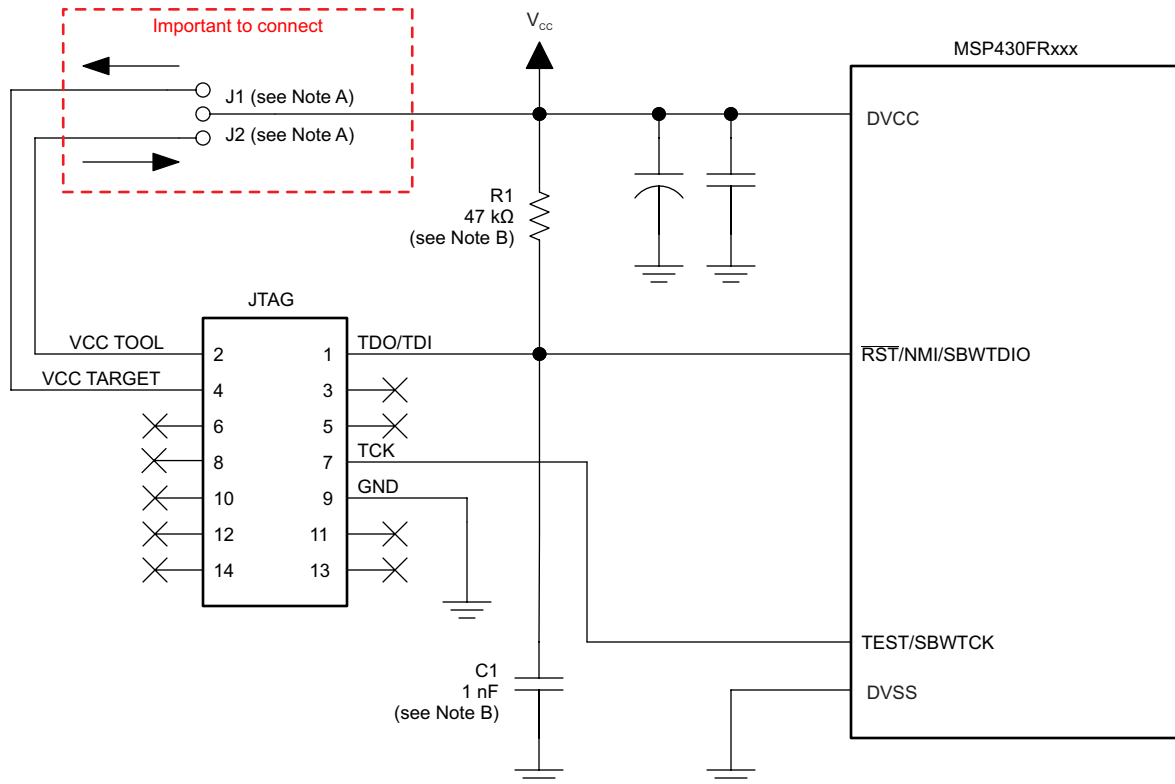
For additional design information regarding the JTAG interface, see the [MSP430 Hardware Tools User's Guide](#).



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- A. If a local target power supply is used, make connection J1. If power from the debug or programming adapter is used, make connection J2.
- B. The upper limit for C1 is 1.1 nF when using current TI tools.

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



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- Make connection J1 if a local target power supply is used, or make connection J2 if the target is powered from the debug or programming adapter.
- The device $\overline{\text{RST}}/\text{NMI}/\text{SBWDIO}$ pin is used in 2-wire mode for bidirectional communication with the device during JTAG access, and any capacitance that is attached to this signal may affect the ability to establish a connection with the device. The upper limit for C1 is 1.1 nF when using current TI tools.

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

7.1.4 Reset

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

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

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

The $\overline{\text{RST}}/\text{NMI}$ pin can have either a pullup or pulldown that is enabled or not. SYSRSTUP selects either pullup or pulldown, and SYSRSTRE causes the pullup (default) or pulldown to be enabled (default) or not. If the $\overline{\text{RST}}/\text{NMI}$ pin is unused, it is required either to select and enable the internal pullup or to connect an external 47-k Ω pullup resistor to the $\overline{\text{RST}}/\text{NMI}$ pin with a 1.1-nF pulldown capacitor. The pulldown capacitor should not exceed 1.1 nF when using devices with Spy-Bi-Wire interface in Spy-Bi-Wire mode or in 4-wire JTAG mode with TI tools like FET interfaces or GANG programmers.

See the [MSP430FR4xx and MSP430FR2xx Family User's Guide](#) for more information on the referenced control registers and bits.

7.1.5 Unused Pins

For details on the connection of unused pins, see [Section 4.6](#).

7.1.6 General Layout Recommendations

- Proper grounding and short traces for external crystal to reduce parasitic capacitance. For recommended layout guidelines, see [MSP430 32-kHz Crystal Oscillators](#).
- Proper bypass capacitors on DVCC and reference pins, if used.
- Avoid routing any high-frequency signal close to an analog signal line. For example, keep digital switching signals such as PWM or JTAG signals away from the oscillator circuit and ADC signals.
- For a detailed discussion of PCB layout considerations, see [Circuit Board Layout Techniques](#). This document is written primarily about op amps, but the guidelines are generally applicable for all mixed-signal applications.
- Proper ESD level protection should be considered to protect the device from unintended high-voltage electrostatic discharge. For guidelines see [MSP430 System-Level ESD Considerations](#).

7.1.7 Do's and Don'ts

During power up, power down, and device operation, DVCC must not exceed the limits specified in [Section 5.1](#). Exceeding the specified limits may cause malfunction of the device including erroneous writes to RAM and FRAM.

7.2 Peripheral- and Interface-Specific Design Information

7.2.1 ADC Peripheral

7.2.1.1 Partial Schematic

[Figure 7-5](#) shows the recommended decoupling circuit when an external voltage reference is used.

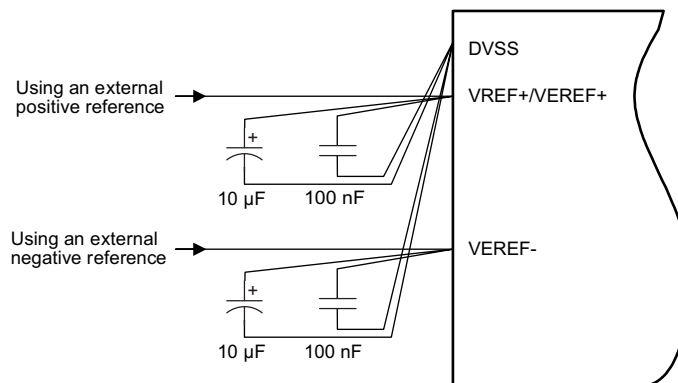


Figure 7-5. ADC Grounding and Noise Considerations

7.2.1.2 Design Requirements

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

Ground loops are formed when return current from the ADC flows through paths that are common with other analog or digital circuitry. If care is not taken, this current can generate small unwanted offset voltages that can add to or subtract from the reference or input voltages of the ADC. The general guidelines in [Section 7.1.1](#) combined with the connections shown in [Figure 7-5](#) prevent this.

Quickly switching digital signals and noisy power supply lines can corrupt the conversion results, so keep the ADC input trace shielded from those digital and power supply lines. Putting the MCU in low-power mode during the ADC conversion improves the ADC performance in a noisy environment. If the device includes the analog power pair inputs (AVCC and AVSS), TI recommends a noise-free design using separate analog and digital ground planes with a single-point connection to achieve high accuracy.

Figure 7-5 shows the recommended decoupling circuit when an external voltage reference is used. The internal reference module has a maximum drive current as described in the sections *ADC Pin Enable* and *1.2-V Reference Settings* of the [MSP430FR4xx and MSP430FR2xx Family User's Guide](#).

The reference voltage must be a stable voltage for accurate measurements. The capacitor values that are selected in the general guidelines filter out the high- and low-frequency ripple before the reference voltage enters the device. In this case, the 10- μ F capacitor buffers the reference pin and filters any low-frequency ripple. A bypass capacitor of 100 nF filters out any high-frequency noise.

7.2.1.3 Layout Guidelines

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

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

7.2.2 CapTIvate Peripheral

This section provides a brief introduction to the CapTIvate technology with examples of PCB layout and performance from the design kit. A more detailed description of the CapTIvate technology and the tools needed to be successful, application development tools, hardware design guides, and software library, can be found in the [CapTIvate Technology Design Center](#).

7.2.2.1 Device Connection and Layout Fundamentals

7.2.2.1.1 VREG

The VREG pin requires a 1- μ F capacitor to regulate the 1.5-V LDO internal to the device (Vreg). This capacitor must be placed as close as possible to the microcontroller. Figure 7-6 shows the layout of the CAPTIVATE-FR2633, zooming in on the capacitor connected to the VREG pin.

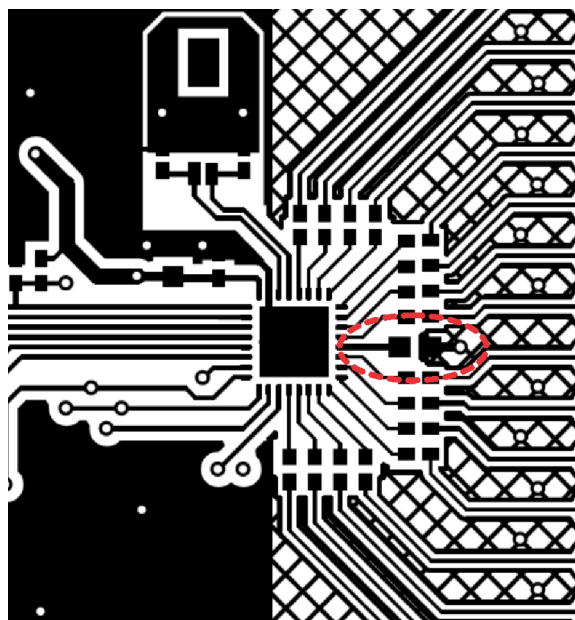


Figure 7-6. VREG Capacitor and Channel Series Resistors

7.2.2.1.2 ESD Protection

Typically, the laminate overlay provides several kilovolts of breakdown isolation to protect the circuit from ESD strikes. More ESD protection can be added with a series resistor placed on each channel used. A value of $470\ \Omega$ is recommended and is found on the development tool.

7.2.2.1.3 Mutual- and Self-Capacitance

CapTivate technology enables both self-mode and mutual-mode capacitance measurements. [Section 7.2.2.1.4](#) and [Section 7.2.2.1.5](#) provide a brief description and examples, taken from the CAPTIVATE-PHONE and CAPTIVATE-BSWP panels found in the design kit, for self- and mutual-mode capacitance measurements, respectively.

7.2.2.1.4 Self-Capacitance

Self-capacitance electrodes are characterized by having only one channel from the IC that both excites and measures the capacitance. The capacitance being measured is between the electrode and earth ground, so any capacitance local to the PCB or outside of the PCB (a touch event) influences the measurement.

PCB layout design guidelines to minimize local parasitic capacitances and maximize the affect of external capacitances (a touch) can be found in the [CapTivate Technology Design Center](#). [Figure 7-7](#), taken from the CAPTIVATE-BSWP panel, shows that the area of the button should be consistent with the touch area, in this case a 400-mil (10.16-mm) diameter circle. To minimize parasitics on the PCB, the ground pour on the bottom layer is hatched and there is no pour directly below the electrode: 50-mil (1.27-mm) spacing between the electrode and ground fill.

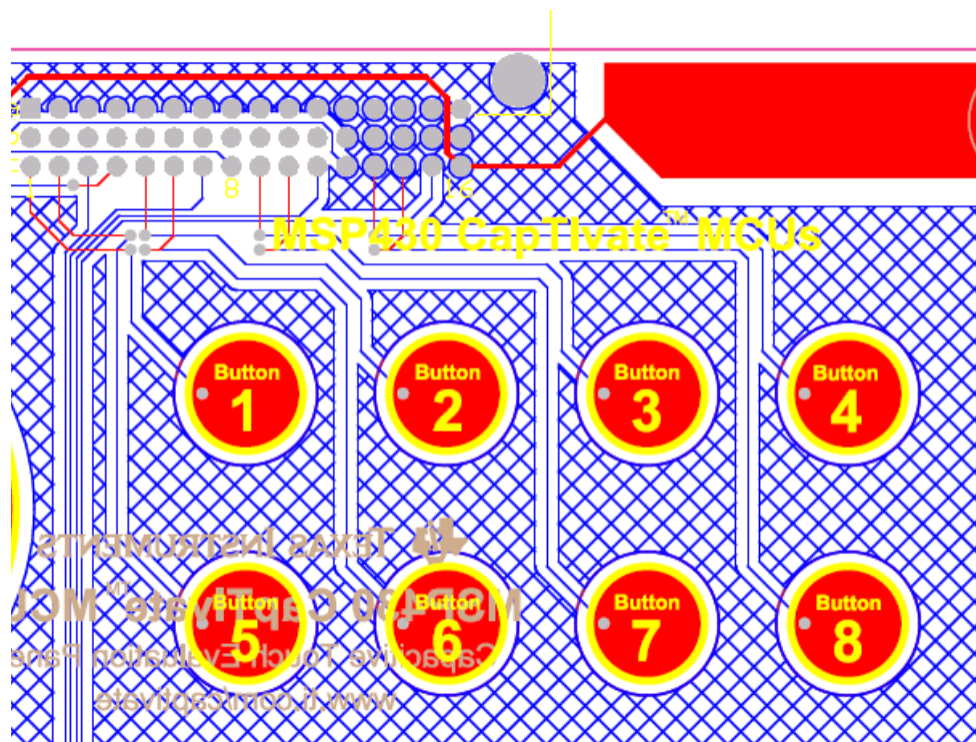


Figure 7-7. Self-Capacitance Electrodes

7.2.2.1.5 Mutual Capacitance

Mutual capacitance is characterized by having two channels, receive (Rx) and transmit (Tx), from the IC with the focus being the capacitance between the two. Coupling to earth ground still has an affect, but this is secondary to the mutual capacitance between the Rx and Tx electrodes.

PCB layout design guidelines for mutual capacitance structures can also be found in the [CapTivate Technology Design Center](#). Figure 7-8, taken from CAPTIVATE-PHONE, shows that the Tx electrode is a copy of the Rx electrode expanded to surround the Rx electrode. Both the Rx and Tx electrodes are in the shape of hollow squares: the Tx electrode is 300×300 mils (7.62×7.62 mm) and the Rx electrode is 150×150 mils (3.81×3.81 mm). Both electrodes are 50 mils (1.27 mm) wide.

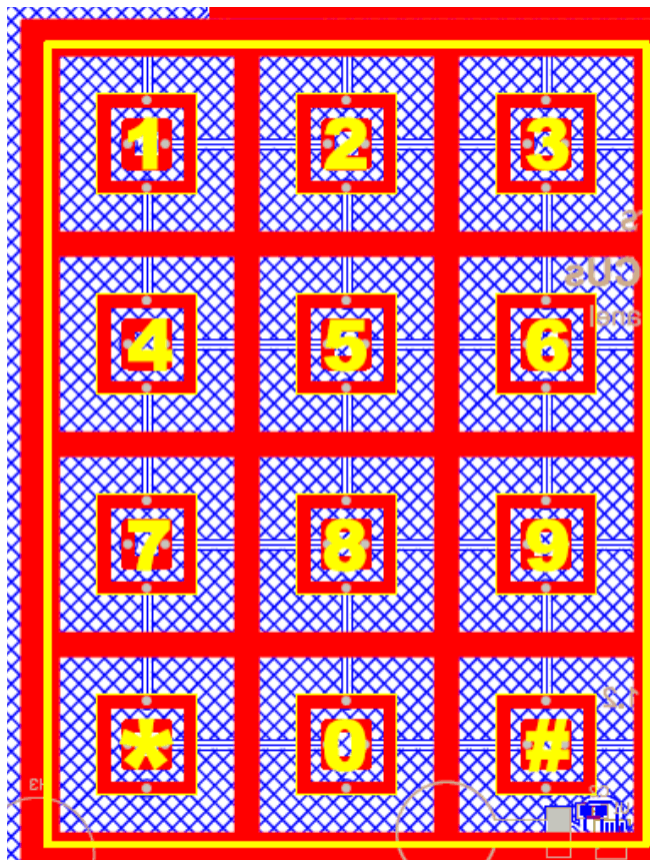


Figure 7-8. Mutual-Capacitance Electrodes

7.2.2.2 Measurements

The following measurements are taken from the [CapTivate Technology Design Center](#), using the CAPTIVATE-PHONE and CAPTIVATE-BSWP panels (see [Figure 7-9](#)). Unless otherwise stated, the settings used are the out-of-box settings, which can be found in the example projects. The intent of these measurements is to show performance in a configuration that is readily available and reproducible.



Figure 7-9. CAPTIVATE-PHONE and CAPTIVATE-BSWP Panels

7.2.2.2.1 SNR

The [CapTivate technology Design Center](#) provides a specific view for analyzing the signal-to-noise ratio of each element. [Figure 7-10](#) shows that the SNR tab can be used to establish a confidence level in the settings that are chosen.

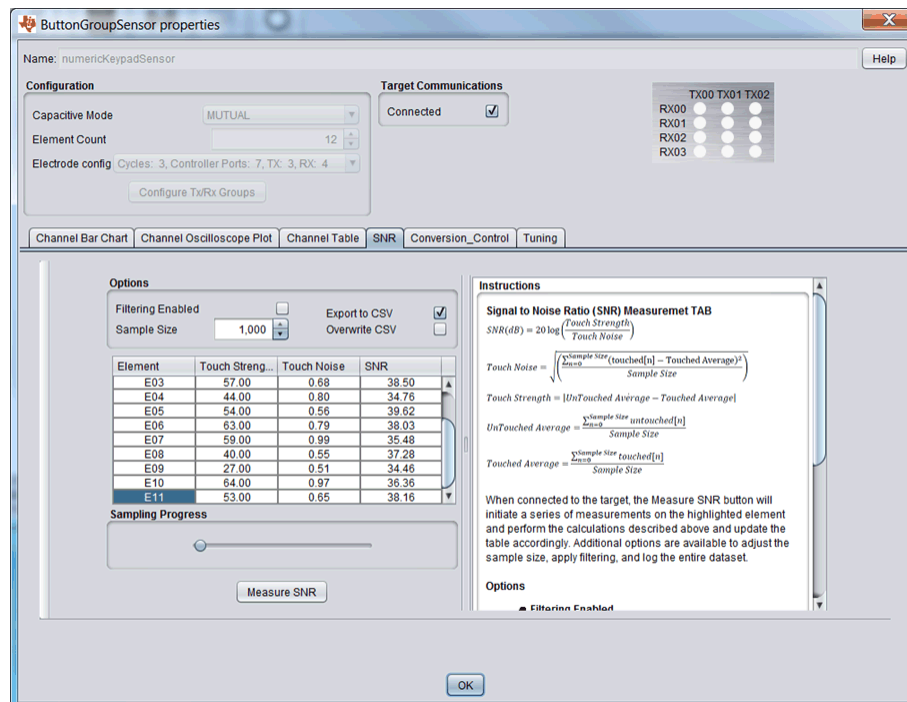


Figure 7-10. SNR Tab

[Table 7-1](#) summarizes the SNR results from the CAPTIVATE-PHONE panel keypad, numericKeypadSensor.

Table 7-1. CAPTIVATE-PHONE SNR Results

ELEMENT	SNR (dB)	ELEMENT	SNR (dB)
E00	31.49	E06	38.03
E01	37.20	E07	35.48
E02	36.34	E08	37.28
E03	38.50	E09	–
E04	34.76	E10	–
E05	39.62	E11	–

Table 7-2 summarizes the SNR results from the CAPTIVATE-BSWP panel keypad, keypadSensor.

Table 7-2. CAPTIVATE-BSWP SNR Results

ELEMENT	SNR (dB)	ELEMENT	SNR (dB)
E00	37.90	E04	39.28
E01	47.26	E05	29.67
E02	36.79	E06	36.63
E03	33.73	E07	34.07

7.2.2.2.2 Sensitivity

To show sensitivity, in terms of farads, the internal reference capacitor is used as the change in capacitance. In the mutual-capacitance case, the 0.1-pF capacitor is used. In the self-capacitance case, the 1-pF reference capacitor is used. For simplicity, the results for only button 1 on both the CAPTIVATE-PHONE and CAPTIVATE-BSWP panels are reported in Table 7-3.

Table 7-3. Button Sensitivity

CONVERSION COUNT	CONVERSION GAIN	CAPTIVATE-PHONE BUTTON 1		CAPTIVATE-BSWP BUTTON 1	
		CONVERSION TIME (μs)	COUNTS FOR 0.1-pF CHANGE	CONVERSION TIME (μs)	COUNTS FOR 1-pF CHANGE
100	100	25	6	50	8
200	200	50	10	100	16
200	100	50	21	100	31
800	400	200	70	400	112
800	200	200	140	400	202
800	100	200	257	400	333

An alternative measure in sensitivity is the ability to resolve capacitance change over a wide range of base capacitance. Table 7-4 shows example conversion times (for a self-mode measurement of discrete capacitors) that can be used to achieve the desired resolution for a given parasitic load capacitance.

Table 7-4. Button Sensitivity

CAPACITANCE, C _p (pF) ⁽¹⁾	CONVERSION COUNT/GAIN	CONVERSION TIME (μs)	COUNTS FOR 0.130-pF CHANGE	COUNTS FOR 0.260-pF CHANGE	COUNTS FOR 0.520-pF CHANGE
23	400/100	200	10	23	35
50	550/100	275	11	24	37
78	650/100	325	11	23	36
150	850/100	425	11	22	35
150 ⁽²⁾	1200/200	600	11	23	37
200 ⁽²⁾	1200/150	600	13	26	41

(1) These measurements were taken with the CapTivate MCU processor board with the 470-Ω series resistors replaced with 0-Ω resistors.

(2) 0-V discharge voltage is used.

7.2.2.2.3 Power

The low-power mode LPM3 specifications in [Section 5.7](#) are derived from the CapTivate technology design kit as indicated in the notes.

7.3 Typical Applications

[Table 7-5](#) lists tools that demonstrate the use of the MSP430FR263x devices in various real-world application scenarios. Consult these designs for additional guidance regarding schematics, layout, and software implementation. For the most up-to-date list of available TI Designs, see the device-specific product folders listed in [节 8.5](#).

Table 7-5. TI Designs

DESIGN NAME	LINK
MSP CapTivate™ MCU Development Kit Evaluation Model	http://www.ti.com/tool/msp-capt-fr2633
Capacitive Touch Thermostat User Interface Reference Design	http://www.ti.com/tool/tidm-captivate-thermostat-ui

8 器件和文档支持

8.1 入门和下一步

有关 MSP 低功耗微控制器以及开发协助工具和库的更多信息，请访问[入门](#)页面。

8.2 器件命名规则

为了指明产品开发周期所处的阶段，TI 为所有 MSP430 MCU 器件和支持工具的产品型号分配了前缀。每个 MSP430 MCU 商用系列产品成员具有以下三个前缀中的一个：MSP、PMS 或 XMS（例如 MSP430F2633）。德州仪器 (TI) 建议为其支持的工具使用三个可能前缀指示符中的两个：MSP 和 MSPX。这些前缀代表了产品从工程原型机（其中 XMS 针对器件，而 MSPX 针对工具）直到完全合格的生产器件和工具（其中 MSP 针对器件，而 MSP 针对工具）的产品开发进化阶段。

器件开发进化流程：

XMS - 试验器件不一定代表最终器件的电气技术规格

MSP - 完全合格的生产器件

支持工具开发进化流程：

MSPX - 还未经德州仪器 (TI) 完整内部质量测试的开发支持产品。

MSP - 完全合格的开发支持产品

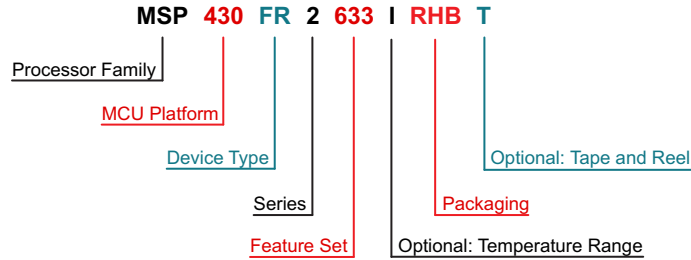
XMS 器件和 MSPX 器件开发支持工具在供货时附带如下免责条款：

“开发的产品用于内部评估用途。”

MSP 器件和 MSP 开发支持工具已进行完全特性描述，并且器件的质量和可靠性已经完全论证。TI 的标准保修证书适用。

预测显示原型器件 (XMS) 的故障率大于标准生产器件。由于这些器件的预计最终使用故障率仍未定义，德州仪器 (TI) 建议不要将它们用于任何生产系统。只有合格的产品器件将被使用。

TI 器件的命名规则也包括一个带有器件系列名称的后缀。该后缀包括封装类型（例如 RHB）和温度范围（如 T）。图 8-1 提供了解读任一系列产品成员的完整器件名称的图例。



Processor Family	MSP = Mixed-signal processor XMS = Experimental silicon
MCU Platform	430 = MSP430 16-bit low-power platform
Device Type	Memory Type FR = FRAM
Series	4 = Up to 16 MHz with LCD 2 = Up to 16 MHz without LCD
Feature Set (see Note)	CapTIvate Performance 633 = 4 CapTIvate blocks, 16KB of FRAM, 4KB of SRAM, up to 16 CapTIvate I/Os 533 = 4 CapTIvate blocks, 16KB of FRAM, 2KB of SRAM, up to 16 CapTIvate I/Os 632 = 4 CapTIvate blocks, 8KB of FRAM, 2KB of SRAM, up to 8 CapTIvate I/Os 532 = 4 CapTIvate blocks, 8KB of FRAM, 1KB of SRAM, up to 8 CapTIvate I/Os
Optional: Temperature Range	S = 0°C to 50°C I = –40°C to 85°C T = –40°C to 105°C
Packaging	www.ti.com/packaging
Optional: Distribution Format	T = Small reel R = Large reel No marking = Tube or tray

NOTE: 有关采用 CapTIvate 触控技术的器件的更多指导，请参阅《CapTIvate 技术指南》中的器件选择基准。

图 8-1. 器件命名规则

8.3 工具与软件

所有 MSP 微控制器均受多种软件和硬件开发工具的支持。相关工具由 TI 以及多家第三方供应商提供。可从 [低功耗 MCU 开发套件和软件](#) 获取全部信息。

表 8-1 列出了 MSP430FR599x 和 MSP430FR596x MCU 硬件 的调试功能。关于可用特性的详细信息，请参见《[适用于 MSP430 的 Code Composer Studio 用户指南](#)》的反馈。

表 8-1. 硬件调试 特性

MSP430 架构	4 线制 JTAG	2 线制 JTAG	断点 (N)	范围断点	时钟控制	状态序列发生器	跟踪缓冲器	LPMx.5 调试支持	EEM 版本
MSP430Xv2	是	是	3	是	有	无	无	无	S

设计套件与评估模块

MSP CapTivate MCU 开发套件 MSP CapTivate MCU 开发套件是一种用于评估采用电容式触控技术的 MSP430FR2633 微控制器的易用综合性平台。此套件包含基于 MSP430FR2633 的处理器板、采用 EnergyTrace 技术的编程器和调试器板（用于通过 Code Composer Studio IDE 测量能耗），以及用于评估自电容、互电容、手势和接近传感的传感器板。

软件

MSPWare 软件 MSPWare 软件集合了所有 MSP 器件的代码示例、产品说明书以及其他设计资源，打包提供给用户。除了提供已有设计资源的完整集合外，MSPWare 软件还包含名为 MSP 驱动程序库的高级 API。该库可简化针对 MSP 硬件的编程操作。MSPWare 软件以 CCS 组件或独立软件包两种形式提供。

MSP430FR243x、MSP430FR253x、MSP430FR263x 代码示例 根据不同应用需求配置各集成外设的每个 MSP 器件均具备相应的 C 代码示例。

MSP 驱动程序库 MSP 驱动程序库的抽象 API 提供易用的函数调用，无需直接操纵 MSP430 硬件的位与字节。完整的文档通过具有帮助意义的 API 指南交付，其中包括有关每个函数调用和经过验证的参数详细信息。开发人员可以使用驱动程序库功能，以最低开销编写完整项目。

MSP EnergyTrace™ 技术 适用于 MSP430 微控制器的 EnergyTrace 技术是基于电能的代码分析工具，适用于测量和显示应用的电能系统配置并帮助优化应用以实现超低功耗。

ULP（超低功耗）Advisor ULP Advisor™ 软件是一款辅助工具，旨在指导开发人员编写更为高效的代码，从而充分利用 MSP 和 MSP432 微控制器独特的 超低功耗 功能。ULP Advisor 的目标人群是微控制器的资深开发者和开发新手，可以根据详尽的 ULP 检验表检查代码，以便最大限度地减少应用程序的能耗。在编译时，ULP Advisor 会提供通知和备注以突出显示代码中可以进一步优化的区域，进而实现更低功耗。

IEC60730 软件包 IEC60730 MSP430 软件包经过专门开发，用于协助客户达到 IEC 60730-1:2010（家用及类似用途的自动化电气控制 - 第 1 部分：一般要求）B 类产品的要求。其中涵盖家用电器、电弧检测器、电源转换器、电动工具、电动自行车及其他诸多产品。IEC60730 MSP430 软件包可以嵌入在 MSP430 中 运行的客户应用程序，从而帮助客户简化其消费类器件在功能安全方面遵循 IEC 60730-1:2010 B 类规范的认证工作。

适用于 MSP 的定点数学运算库 MSP IQmath 和 Qmath 库是一套经过高度优化的高精度数学运算函数集合，适用于 C 语言开发者，能够将浮点算法无缝嵌入 MSP430 和 MSP432 器件的定点代码中。这些例程通常用于计算密集的实时应用，而优化的执行速度、高精度以及超低能耗通常是影响这些实时应用的关键因素。与使用浮点数学算法编写的同等代码相比，使用 IQmath 和 Qmath 库可以大幅提高执行速度并显著降低能耗。

适用于 MSP430 的浮点数学运算库 TI 在低功耗和低成本微控制器领域锐意创新，为您提供 MSPMATHLIB。此标量函数的浮点数学运算库，能够充分利用器件的智能外设，使速度最高达到标准 MSP430 数学函数的 26 倍。Mathlib 能够轻松集成到您的设计中。该运算库免费使用并集成在 Code Composer Studio IDE 和 IAR Embedded Workbench IDE 中。

开发工具

适用于 MSP 微控制器的 Code Composer Studio™ 集成开发环境 Code Composer Studio (CCS) 是一种集成开发环境 (IDE)，支持所有 MSP 微控制器器件。CCS 包含一整套用于开发和调试嵌入式应用程序的嵌入式软件实用工具。它包含了优化的 C/C++ 编译器、源代码编辑器、项目构建环境、调试器、描述器以及其他多种功能的反馈。

命令行编程器 MSP Flasher 是一款基于 shell 的开源接口，可使用 JTAG 或 Spy-Bi-Wire (SBW) 通信通过 FET 编程器或 eZ430 对 MSP 微控制器进行编程。MSP Flasher 可用于将二进制文件 (.txt 或 .hex 文件) 直接下载到 MSP 微控制器，而无需使用 IDE。

MSP MCU 编程器和调试器 MSP-FET 是一款强大的仿真开发工具（通常称为调试探针），可帮助用户在 MSP 低功耗微控制器 (MCU) 中快速开发应用。创建 MCU 软件通常需要将生成的二进制程序下载到 MSP 器件中，从而进行验证和调试。

MSP-GANG 生产编程器 MSP Gang 编程器是一款 MSP430 或 MSP432 器件编程器，可同时对多达八个完全相同的 MSP430 或 MSP432 闪存或 FRAM 器件进行编程。MSP Gang 编程器可使用标准的 RS-232 或 USB 连接与主机 PC 相连并提供灵活的编程选项，允许用户完全自定义流程。

8.4 文档支持

以下文档对 MSP430FR263x 和 MSP430FR253x MCU 进行了介绍。www.ti.com.cn 网站上提供了这些文档的副本。

接收文档更新通知

要接收文档更新通知（包括芯片勘误表），请转至 ti.com 上您的器件对应的产品文件夹（请参见节 8.5 获取产品文件夹链接）。单击右上角的“提醒我”(Alert me) 按钮。点击后，您将每周定期收到已更改的产品信息（如果有的话）。有关更改的详细信息，请查阅已修订文档的修订历史记录。

勘误

- 《[MSP430FR2633 器件勘误表](#)》 介绍了针对该 MCU 的所有芯片修订版本功能技术规格的已知例外情况。
- 《[MSP430FR2533 器件勘误表](#)》 介绍了针对该 MCU 的所有芯片修订版本功能技术规格的已知例外情况。
- 《[MSP430FR2632 器件勘误表](#)》 介绍了针对该 MCU 的所有芯片修订版本功能技术规格的已知例外情况。
- 《[MSP430FR2532 器件勘误表](#)》 介绍了针对该 MCU 的所有芯片修订版本功能技术规格的已知例外情况。

用户指南

《[MSP430FR4xx 和 MSP430FR2xx 系列用户指南](#)》详细介绍了该器件系列提供的模块和外设。

《[MSP430FR4xx 和 MSP430FR2xx 引导加载程序 \(BSL\) 用户指南](#)》在 MSP430 MCU 项目开发和更新阶段，引导加载程序 (BSL) 提供存储器的编程方法。该程序可由使用串行协议发送命令的工具激活。BSL 支持用户控制 MSP430 MCU 的活动，可与个人计算机或其他设备进行数据交换。

《[MSP430 硬件工具用户指南](#)》本手册介绍了 TI MSP-FET430 闪存仿真工具 (FET) 的硬件。FET 是针对 MSP430 超低功耗微控制器的程序开发工具。

应用报告

MSP430 FRAM 技术 – 操作方法和最佳实践 FRAM 采用非易失性存储器技术，行为与 SRAM 类似，支持大量新应用程序的同时，还改变了固件的设计方式。该应用程序报告从嵌入式软件开发方面概述了 FRAM 技术在 MSP430 中的使用方法和最佳实践。其中介绍了如何按照应用程序特定的代码、常量、数据空间要求实施存储器布局以及如何使用 FRAM 优化应用程序的能耗。

MSP430FR4xx 和 MSP430FR2xx 系列的 VLO 校准 MSP430FR4xx 和 MSP430FR2xx (FR4xx/FR2xx) 系列微控制器 (MCU) 提供了各种时钟源，包括一些高速、高精度时钟以及一些低功耗、低系统成本时钟。用户可以选择以最佳方式权衡了性能、功耗和系统成本的时钟。片上超低频振荡器 (VLO) 是 FR4xx/FR2xx 系列 MCU 中包含的频率为 10kHz (典型值) 的时钟源。VLO 具有超低的功耗，因而广泛适用于各种应用。

MSP430 32kHz 晶体振荡器 对于稳定的晶体振荡器，选择合适的晶振、正确的负载电路和适当的电路板布局布线至关重要。该应用报告总结了晶体振荡器的功能，介绍了为实现 MSP430 超低功耗运行而选择正确晶体的参数。此外，还给出了正确电路板布局布线的提示和示例。本文档还包含与可能振荡器测试相关的详细信息以确保大批量生产中的稳定振荡器运行。

《[MSP430 系统级 ESD 注意事项](#)》系统级 ESD 对于低电压下的硅晶技术以及经济高效型和超低功耗组件的需求日益增加。该应用报告提出了三项不同的 ESD 主题，旨在帮助电路板设计人员和 OEM 理解并设计出稳健耐用的系统级设计。

8.5 相关链接

表 8-2 列出了快速访问链接。类别包括技术文档、支持与社区资源、工具和软件，以及申请样片或购买产品的快速链接。

表 8-2. 相关链接

器件	产品文件夹	立即订购	技术文档	工具和软件	支持和社区
MSP430FR2633	请单击此处	请单击此处	请单击此处	请单击此处	请单击此处
MSP430FR2533	请单击此处	请单击此处	请单击此处	请单击此处	请单击此处
MSP430FR2632	请单击此处	请单击此处	请单击此处	请单击此处	请单击此处
MSP430FR2532	请单击此处	请单击此处	请单击此处	请单击此处	请单击此处

8.6 社区资源

下列链接提供到 TI 社区资源的连接。链接的内容由各个分销商“按照原样”提供。这些内容并不构成 TI 技术规范，并且不一定反映 TI 的观点；请参见 TI 的《[使用条款](#)》。

TI E2E™ 社区

TI 的工程师交流 (E2E) 社区。此社区的创建目的是为了促进工程师之间协作。在 [e2e.ti.com](#) 中，您可以提问、共享知识、拓展思路，在同领域工程师的帮助下解决问题。

TI 嵌入式处理器维基网页

德州仪器 (TI) 嵌入式处理器维基网页。此网站的建立是为了帮助开发人员熟悉德州仪器 (TI) 的嵌入式处理器，并且也为了促进与这些器件相关的硬件和软件的总体知识的创新和增长。

8.7 商标

CapTIvate, MSP430, EnergyTrace, ULP Advisor, 适用于 MSP 微控制器的 Code Composer Studio, E2E are trademarks of Texas Instruments.

8.8 静电放电警告



ESD 可能会损坏该集成电路。德州仪器 (TI) 建议通过适当的预防措施处理所有集成电路。如果不遵守正确的处理措施和安装程序，可能会损坏集成电路。

ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

8.9 出口管制提示

接收方同意：如果美国或其他适用法律限制或禁止将通过非披露义务的披露方获得的任何产品或技术数据（其中包括软件）（见美国、欧盟和其他出口管理条例之定义）、或者其他适用国家条例限制的任何受管制产品或此项技术的任何直接产品出口或再出口至任何目的地，那么在没有事先获得美国商务部和其他相关政府机构授权的情况下，接收方不得在知情的情况下，以直接或间接的方式将其出口。

8.10 术语表

TI 术语表 这份术语表列出并解释术语、缩写和定义。

9 机械、封装和可订购信息

以下页面包含机械、封装和可订购信息。这些信息是指定器件的最新可用数据。这些数据会在无通知且不对本文档进行修订的情况下发生改变。欲获得该产品说明书的浏览器版本，请查阅左侧的导航栏。

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
MSP430FR2532IRGER	ACTIVE	VQFN	RGE	24	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	FR2532	Samples
MSP430FR2532IRGET	ACTIVE	VQFN	RGE	24	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	FR2532	Samples
MSP430FR2533IDA	ACTIVE	TSSOP	DA	32	46	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	FR2533	Samples
MSP430FR2533IDAR	ACTIVE	TSSOP	DA	32	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	FR2533	Samples
MSP430FR2533IRHBR	ACTIVE	VQFN	RHB	32	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 85	FR2533	Samples
MSP430FR2533IRHBT	ACTIVE	VQFN	RHB	32	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 85	FR2533	Samples
MSP430FR2632IRGER	ACTIVE	VQFN	RGE	24	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	FR2632	Samples
MSP430FR2632IRGET	ACTIVE	VQFN	RGE	24	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	FR2632	Samples
MSP430FR2632IYQWR	ACTIVE	DSBGA	YQW	24	3000	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 85	430FR2632	Samples
MSP430FR2632IYQWT	ACTIVE	DSBGA	YQW	24	250	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 85	430FR2632	Samples
MSP430FR2633IDA	ACTIVE	TSSOP	DA	32	46	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	FR2633	Samples
MSP430FR2633IDAR	ACTIVE	TSSOP	DA	32	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 85	FR2633	Samples
MSP430FR2633IRHBR	ACTIVE	VQFN	RHB	32	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 85	FR2633	Samples
MSP430FR2633IRHBT	ACTIVE	VQFN	RHB	32	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR	-40 to 85	FR2633	Samples
MSP430FR2633IYQWR	ACTIVE	DSBGA	YQW	24	3000	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 85	430FR2633	Samples
MSP430FR2633IYQWT	ACTIVE	DSBGA	YQW	24	250	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 85	430FR2633	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.

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

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

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

OBSOLETE: TI has discontinued the production of the device.

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

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

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

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

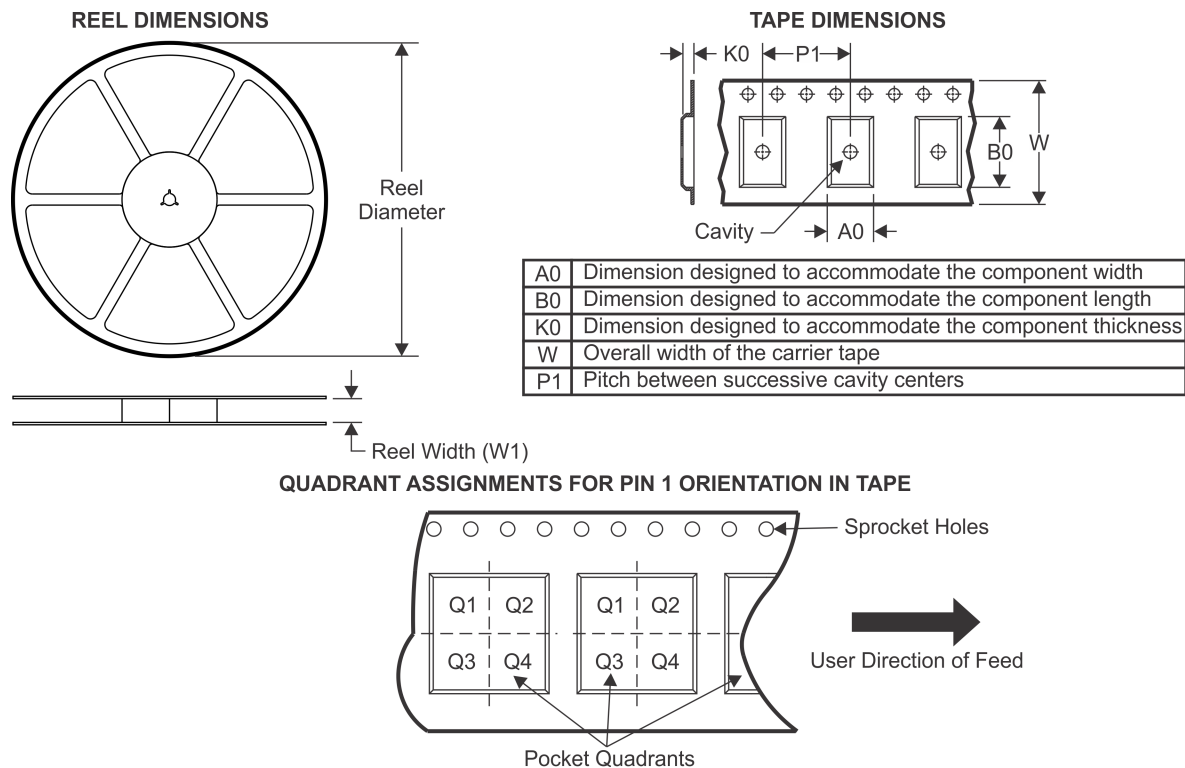
⁽⁴⁾ There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

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

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

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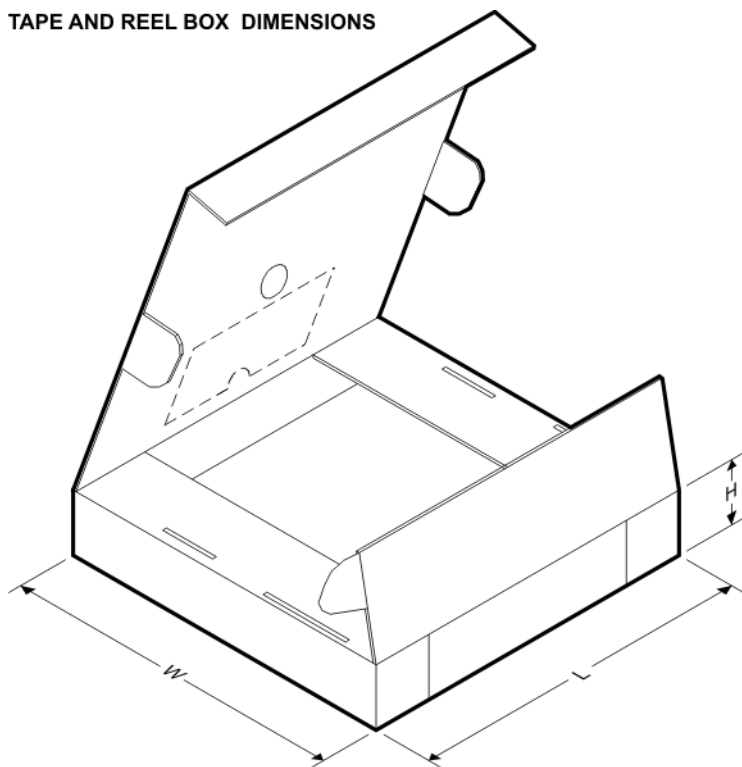
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
MSP430FR2532IRGER	VQFN	RGE	24	3000	330.0	12.4	4.25	4.25	1.15	8.0	12.0	Q2
MSP430FR2533IDAR	TSSOP	DA	32	2000	330.0	24.4	8.6	11.5	1.6	12.0	24.0	Q1
MSP430FR2533IRHBR	VQFN	RHB	32	3000	330.0	12.4	5.3	5.3	1.1	8.0	12.0	Q2
MSP430FR2632IRGER	VQFN	RGE	24	3000	330.0	12.4	4.25	4.25	1.15	8.0	12.0	Q2
MSP430FR2632IYQWR	DSBGA	YQW	24	3000	180.0	8.4	2.38	2.4	0.8	4.0	8.0	Q1
MSP430FR2632IYQWT	DSBGA	YQW	24	250	180.0	8.4	2.38	2.4	0.8	4.0	8.0	Q1
MSP430FR2633IDAR	TSSOP	DA	32	2000	330.0	24.4	8.6	11.5	1.6	12.0	24.0	Q1
MSP430FR2633IRHBR	VQFN	RHB	32	3000	330.0	12.4	5.3	5.3	1.1	8.0	12.0	Q2
MSP430FR2633IYQWR	DSBGA	YQW	24	3000	180.0	8.4	2.38	2.4	0.8	4.0	8.0	Q1
MSP430FR2633IYQWT	DSBGA	YQW	24	250	180.0	8.4	2.38	2.4	0.8	4.0	8.0	Q1

TAPE AND REEL BOX DIMENSIONS



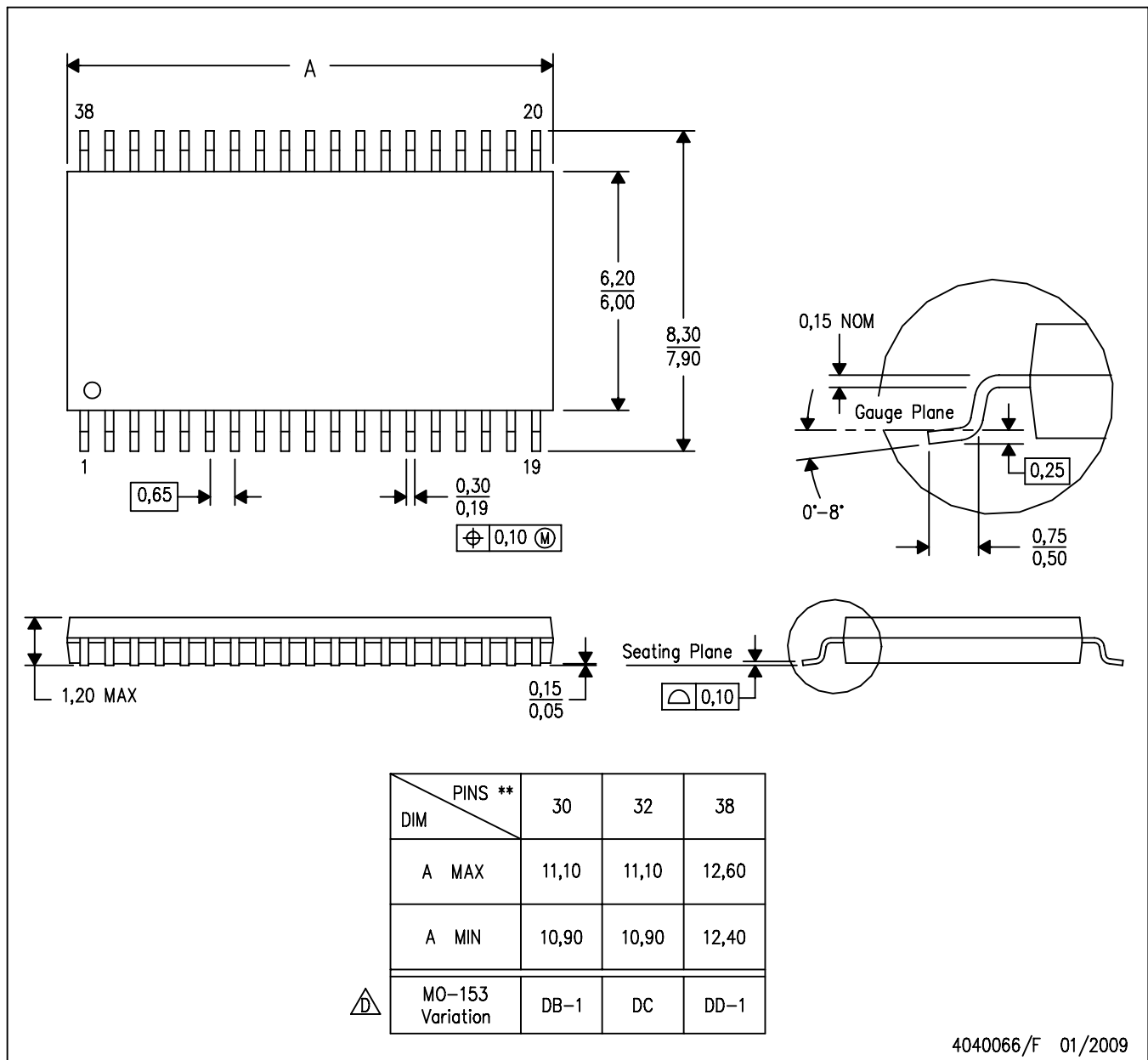
*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
MSP430FR2532IRGER	VQFN	RGE	24	3000	367.0	367.0	35.0
MSP430FR2533IDAR	TSSOP	DA	32	2000	367.0	367.0	45.0
MSP430FR2533IRHBR	VQFN	RHB	32	3000	367.0	367.0	35.0
MSP430FR2632IRGER	VQFN	RGE	24	3000	367.0	367.0	35.0
MSP430FR2632IYQWR	DSBGA	YQW	24	3000	210.0	185.0	35.0
MSP430FR2632IYQWT	DSBGA	YQW	24	250	210.0	185.0	35.0
MSP430FR2633IDAR	TSSOP	DA	32	2000	367.0	367.0	45.0
MSP430FR2633IRHBR	VQFN	RHB	32	3000	367.0	367.0	35.0
MSP430FR2633IYQWR	DSBGA	YQW	24	3000	210.0	185.0	35.0
MSP430FR2633IYQWT	DSBGA	YQW	24	250	210.0	185.0	35.0

DA (R-PDSO-G**)

PLASTIC SMALL-OUTLINE PACKAGE

38 PIN SHOWN



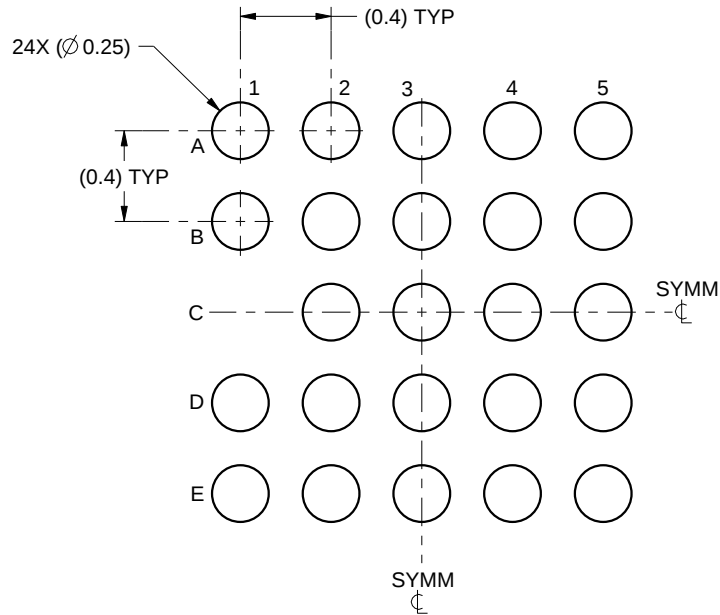
- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
 - D. Falls within JEDEC MO-153, except 30 pin body length.

EXAMPLE BOARD LAYOUT

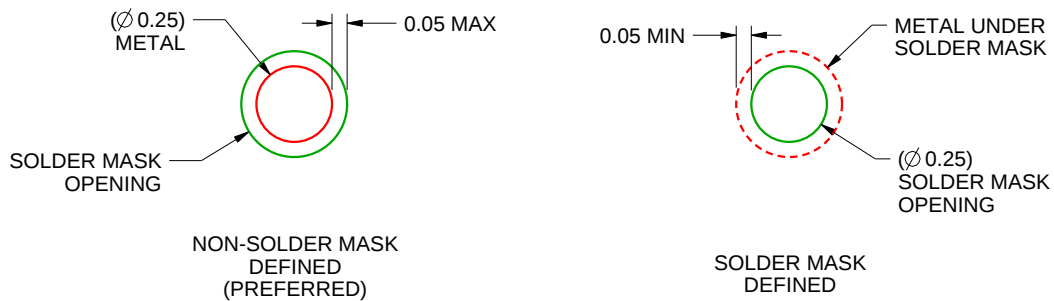
YQW0024

DSBGA - 0.625 mm max height

DIE SIZE BALL GRID ARRAY



LAND PATTERN EXAMPLE
SCALE:30X



SOLDER MASK DETAILS
NOT TO SCALE

4221561/A 02/2016

NOTES: (continued)

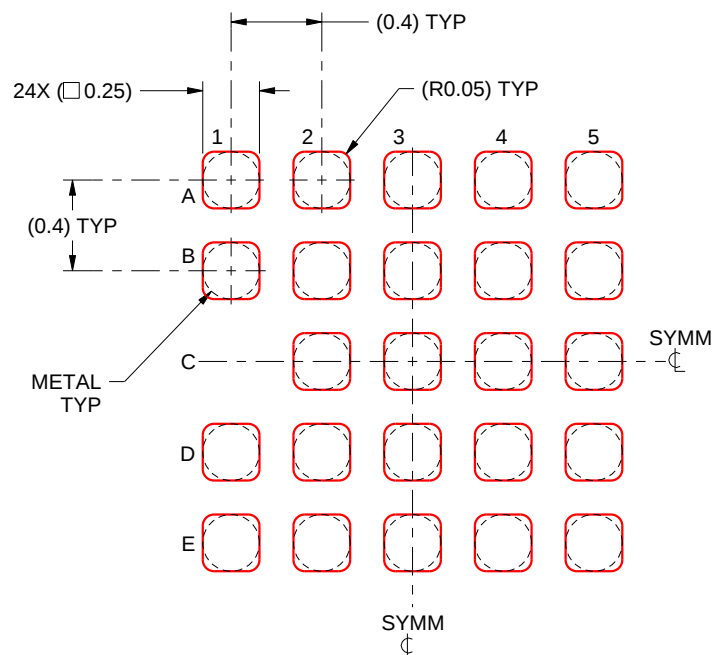
- Final dimensions may vary due to manufacturing tolerance considerations and also routing constraints. See Texas Instruments Literature No. SNVA009 (www.ti.com/lit/snva009).

EXAMPLE STENCIL DESIGN

YQW0024

DSBGA - 0.625 mm max height

DIE SIZE BALL GRID ARRAY



SOLDER PASTE EXAMPLE
BASED ON 0.1 mm THICK STENCIL
SCALE:30X

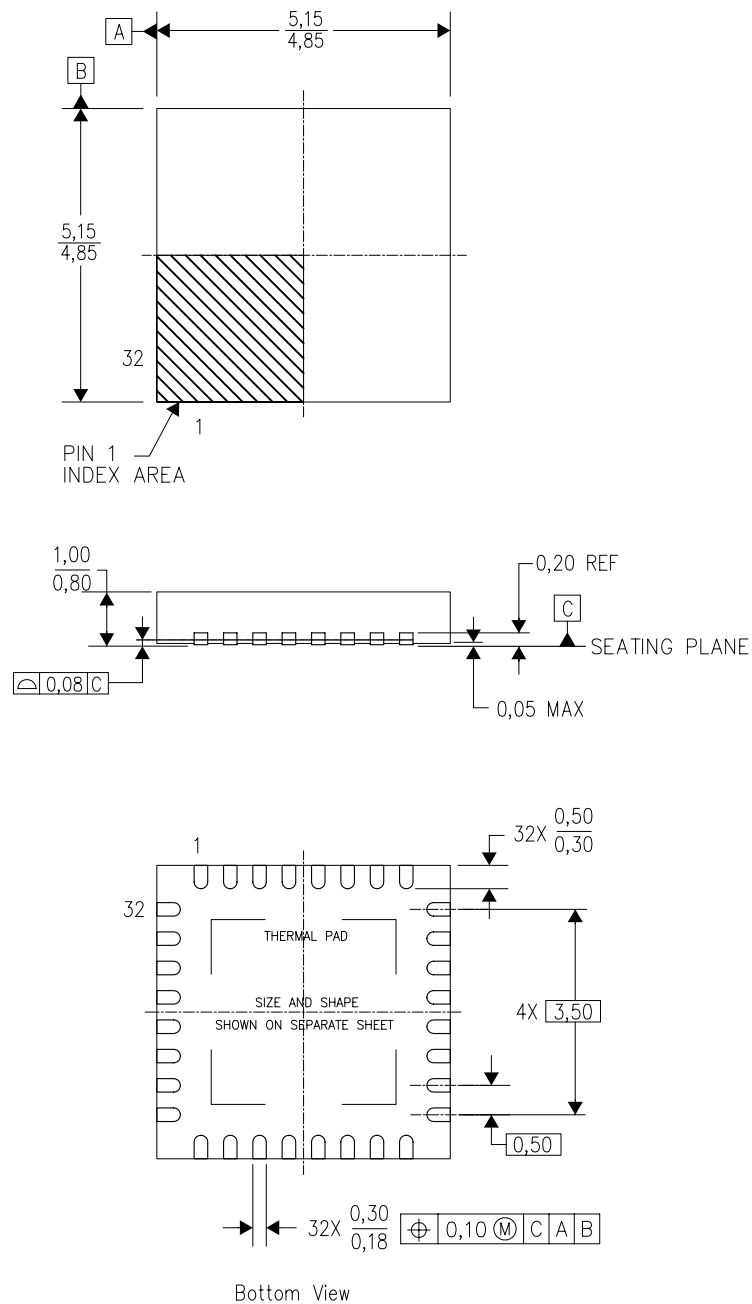
4221561/A 02/2016

NOTES: (continued)

4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release.

RHB (S-PVQFN-N32)

PLASTIC QUAD FLATPACK NO-LEAD



4204326/D 06/11

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

RHB (S-PVQFN-N32)

PLASTIC QUAD FLATPACK NO-LEAD

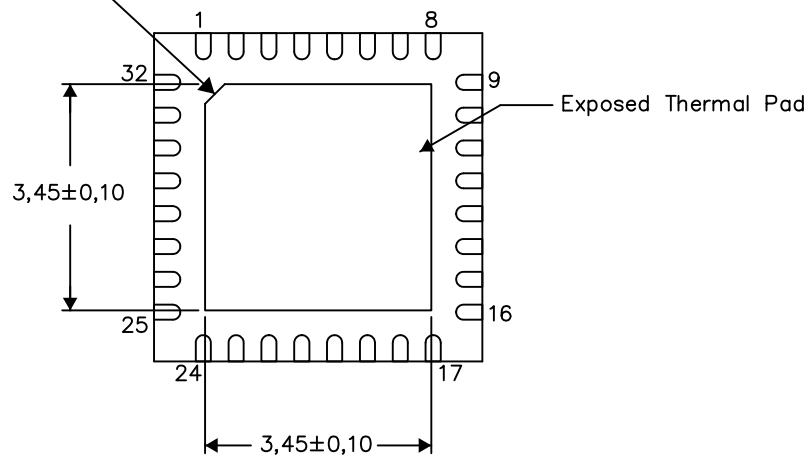
THERMAL INFORMATION

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

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

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

PIN 1 INDICATOR
(OPTIONAL)



Bottom View

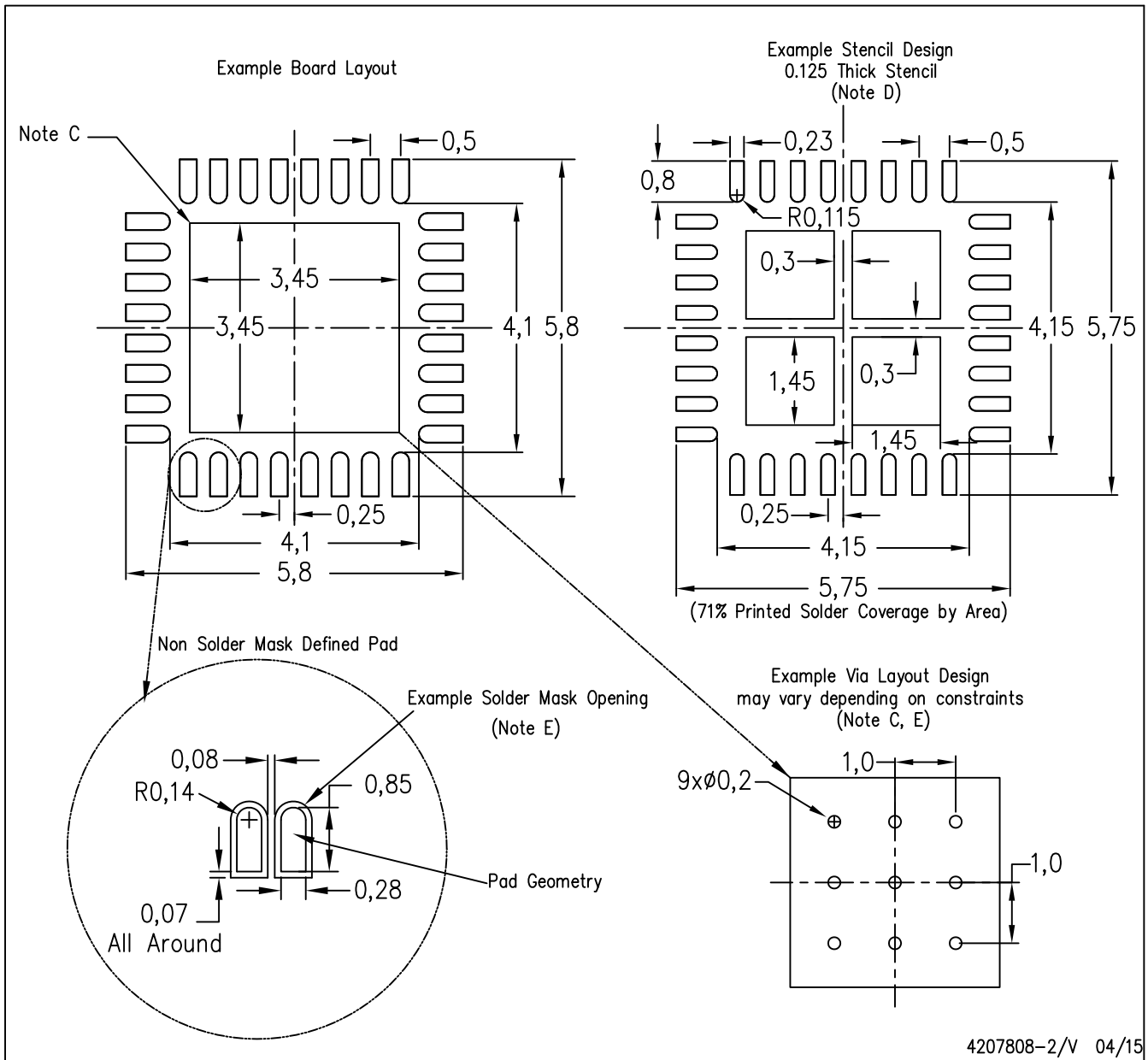
Exposed Thermal Pad Dimensions

4206356-2/AC 05/15

NOTE: A. All linear dimensions are in millimeters

RHB (S-PVQFN-N32)

PLASTIC QUAD FLATPACK NO-LEAD



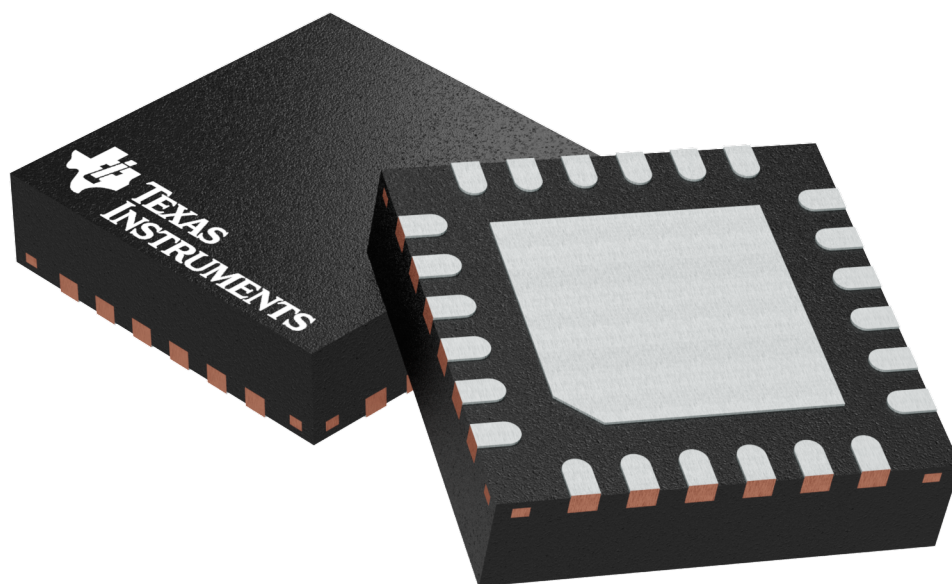
- NOTES:
- All linear dimensions are in millimeters.
 - This drawing is subject to change without notice.
 - This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat-Pack Packages, Texas Instruments Literature No. SLUA271, and also the Product Data Sheets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

RGE 24

GENERIC PACKAGE VIEW

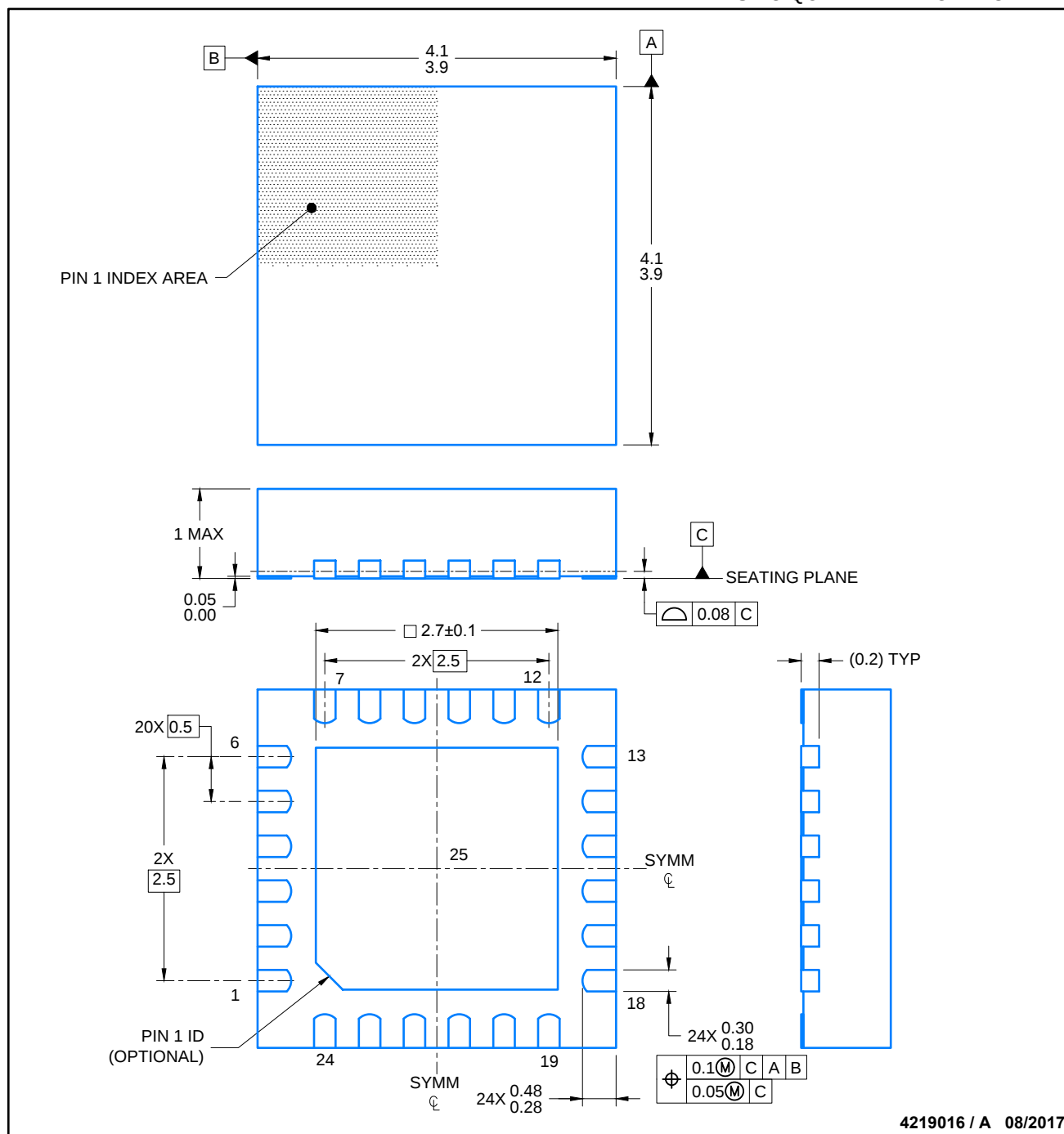
VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



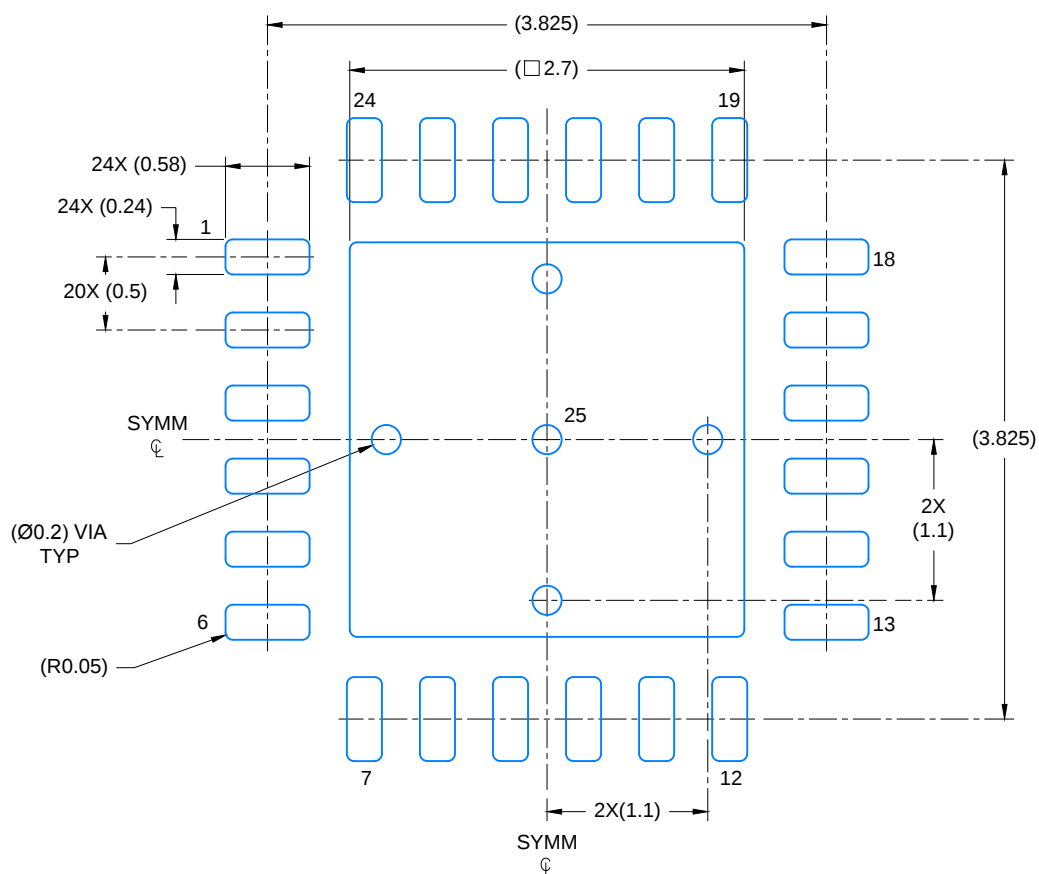
Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

4204104/H

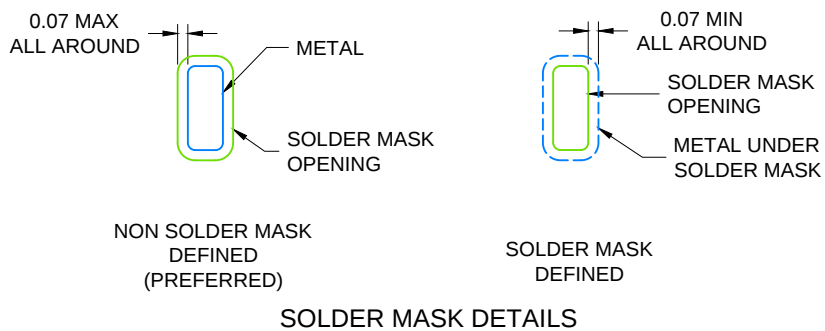


NOTES:

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



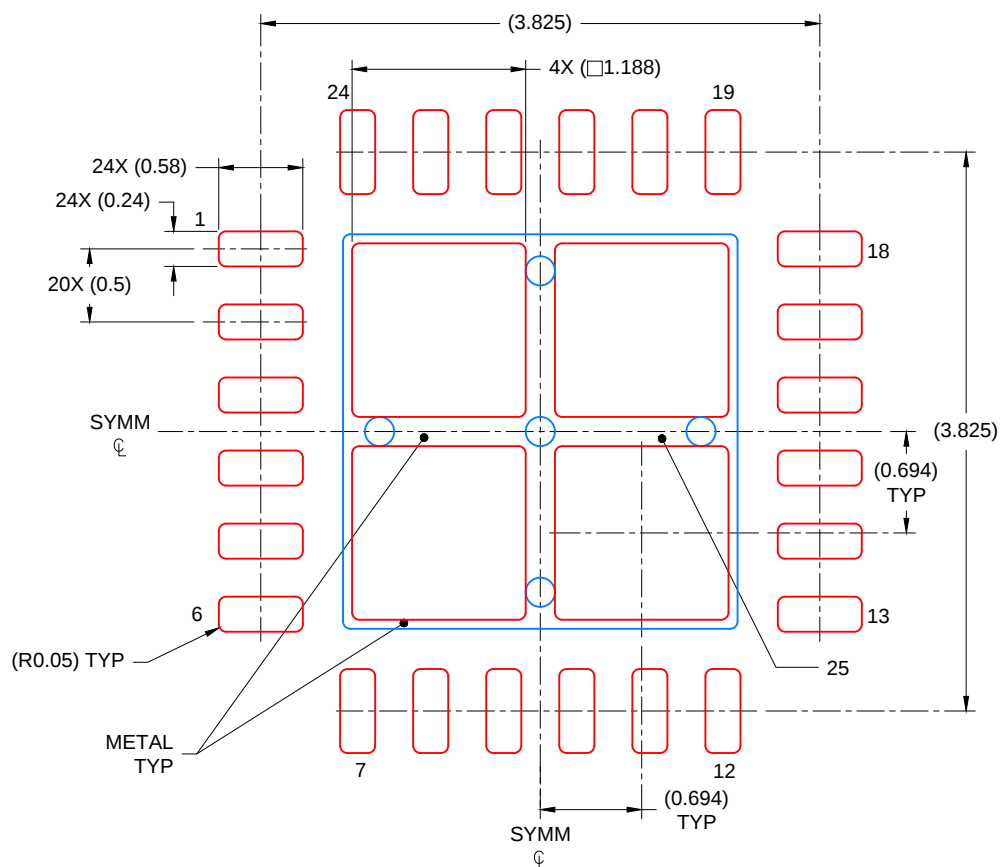
LAND PATTERN EXAMPLE
SCALE: 20X



4219016 / A 08/2017

NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/sluea271).
5. Solder mask tolerances between and around signal pads can vary based on board fabrication site.



SOLDER PASTE EXAMPLE
 BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD
 78% PRINTED COVERAGE BY AREA
 SCALE: 20X

4219016 / A 08/2017

NOTES: (continued)

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

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