

# EFR32MG24 Wireless SoC Family Data Sheet



The EFR32MG24 Wireless SoCs are ideal for mesh IoT wireless connectivity using Matter, OpenThread and Zigbee.

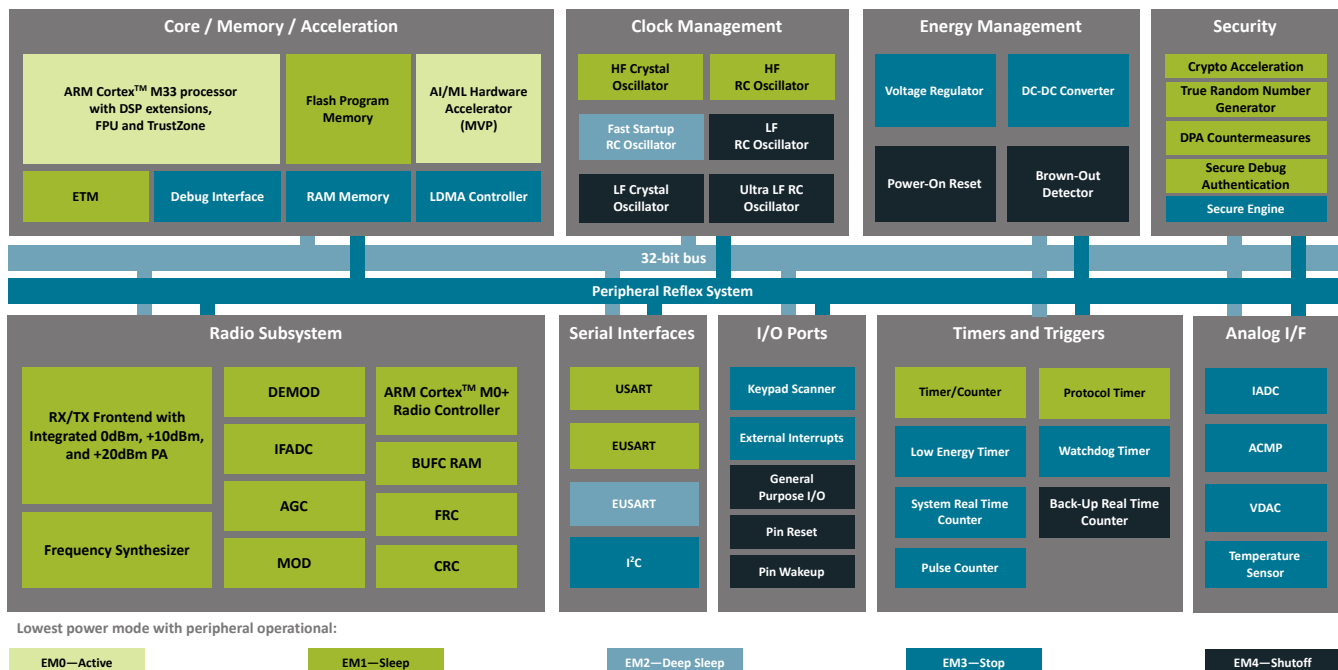
With key features like high performance 2.4 GHz RF, low current consumption, an AI/ML hardware accelerator and Secure Vault, IoT device makers can create smart, robust, and energy-efficient products that are secure from remote and local cyber-attacks. A Cortex®-M33 running up to 78 MHz and up to 1536 kB of Flash and 256 kB of RAM provides resources for demanding applications while leaving room for future growth.

Target applications include:

- Smart Home - Gateways and hubs, sensors, switches, door locks, smart plugs
- Lighting - LED bulbs, luminaires
- Building Automation - Gateways, sensors, switches, location services
- AI/ML - Predictive maintenance, glass break detection, wake-word detection
- Remote Controls
- Passive Keyless Entry (PKE)
- Passive Entry Passive Start (PEPS)
- Tire Pressure Monitoring System (TPMS)
- Tire Monitoring Sensor (TMS)
- Rearview Mirrors
- Garage Door Openers

## KEY FEATURES

- 32-bit ARM® Cortex®-M33 core with 78 MHz maximum operating frequency
- Up to 1536 kB of flash and 256 kB of RAM
- High performance radio with up to +19.5 dBm output power
- Energy efficient design with low active and sleep currents
- Secure Vault™
- AI/ML Hardware Accelerator
- Channel sounding
- AEC-Q100 Grade 1 (selected part numbers only)



## 1. Feature List

The EFR32MG24 highlighted features are listed below.

- **Low Power Wireless System-on-Chip**
  - High Performance 32-bit 78 MHz ARM Cortex<sup>®</sup>-M33 with DSP instruction and floating-point unit for efficient signal processing
  - Up to 1536 kB flash program memory
  - Up to 256 kB RAM data memory
  - 2.4 GHz radio operation
  - Matrix Vector Processor for AI/ML acceleration
- **Radio Performance**
  - -105.4 dBm sensitivity @ 250 kbps O-QPSK DSSS
  - -105.7 dBm sensitivity @ 125 kbps GFSK
  - -97.6 dBm sensitivity @ 1 Mbps GFSK
  - -94.8 dBm sensitivity @ 2 Mbps GFSK
  - TX power up to 19.5 dBm
- **Low System Energy Consumption**
  - 4.4 mA RX current (1 Mbps GFSK)
  - 5.1 mA RX current (250 kbps O-QPSK DSSS)
  - 5 mA TX current @ 0 dBm output power
  - 19.1 mA TX current @ 10 dBm output power
  - 156.8 mA TX current @ 19.5 dBm output power
  - 33.4  $\mu$ A/MHz in Active Mode (EM0) at 39.0 MHz
  - 1.3  $\mu$ A EM2 DeepSleep current (16 kB RAM retention and RTC running from LFRCO)
- **Supported Modulation Format**
  - 2 (G)FSK with fully configurable shaping
  - OQPSK DSSS
  - (G)MSK
- **Protocol Support**
  - Matter
  - OpenThread
  - Zigbee
  - Bluetooth Low Energy
  - Bluetooth Mesh
  - Proprietary 2.4 GHz
  - Multiprotocol
  - Direction finding using Angle-of-Arrival (AoA) and Angle-of-Departure (AoD)
  - Channel sounding
    - 40 MHz crystal required
    - Maximum TX power for Channel Sounding is 10 dBm for all part numbers
- **Wide Operating Range**
  - 1.71 V to 3.8 V single power supply
  - -40 °C to 125 °C
- **Secure Vault**
  - Hardware Cryptographic Acceleration for AES128/192/256, ChaCha20-Poly1305, SHA-1, SHA-2/256/384/512, ECDSA +ECDH(P-192, P-256, P-384, P-521), Ed25519 and Curve25519, J-PAKE, PBKDF2
  - True Random Number Generator (TRNG)
  - ARM<sup>®</sup> TrustZone<sup>®</sup>
  - Secure Boot (Root of Trust Secure Loader)
  - Secure Debug Unlock
  - DPA Countermeasures
  - Secure Key Management with PUF
  - Anti-Tamper
  - Secure Attestation
- **Wide selection of MCU peripherals**
  - Analog to Digital Converter (IADC)
    - 12-bit @ 1 Msps or 16-bit @ 76.9 ksps
    - Select OPNs support High Speed Mode (up to 2 Msps) and High Accuracy Mode (up to 16 bits ENOB at 3.8 ksps)
  - 2  $\times$  Analog Comparator (ACMP)
  - 2  $\times$  Digital to Analog Converter (VDAC)
  - Up to 32 General Purpose I/O pins with output state retention and asynchronous interrupts
  - 8 Channel DMA Controller (LDMA)
  - 16 Asynchronous Channel, 4 Synchronous Channel Peripheral Reflex System (PRS)
  - 3  $\times$  16-bit Timer/Counter with 3 Compare/Capture/PWM channels (TIMER2/3/4)
  - 2  $\times$  32-bit Timer/Counter with 3 Compare/Capture/PWM channels (TIMER0/1)
  - 2  $\times$  32-bit Real Time Counter (SYSRTC/BURTC)
  - 24-bit Low Energy Timer for waveform generation (LETIMER)
  - 16-bit Pulse Counter with asynchronous operation (PCNT)
  - 2  $\times$  Watchdog Timer (WDOG)
  - 1  $\times$  Universal Synchronous/Asynchronous Receiver/Transmitter (USART), supporting UART/SPI/SmartCard (ISO 7816)/IrDA/I<sup>2</sup>S
  - 2  $\times$  Enhanced Universal Synchronous/Asynchronous Receiver/Transmitter (EUSART) supporting UART/SPI/DALI/IrDA
  - 2  $\times$  I<sup>2</sup>C interface with SMBus support
  - Low-Frequency RC Oscillator with precision mode to replace 32 kHz sleep crystal (LFRCO)
  - Keypad scanner supporting up to 6x8 matrix (KEYSCAN)
  - Die temperature sensor with +/-1.5 °C accuracy after single-point calibration
- **Packages**
  - **QFN40** 5 mm  $\times$  5 mm  $\times$  0.85 mm
  - **QFN48** 6 mm  $\times$  6 mm  $\times$  0.85 mm

## 2. Ordering Information

**Table 2.1. Ordering Information**

| Ordering Code                         | Max TX Power | Flash (kB) | RAM (kB) | Secure Vault | IADC High-Speed / High-Accuracy | Multi Vector Processor | GPIO | Package / Pinout |
|---------------------------------------|--------------|------------|----------|--------------|---------------------------------|------------------------|------|------------------|
| EFR32MG24B310F1536IM48-B <sup>1</sup> | 10 dBm       | 1536       | 256      | High         | Yes                             | Yes                    | 28   | QFN48 / ADC      |
| EFR32MG24B220F1536IM48-B <sup>1</sup> | 19.5 dBm     | 1536       | 256      | High         | No                              | Yes                    | 32   | QFN48 / Standard |
| EFR32MG24B210F1536IM48-B <sup>1</sup> | 10 dBm       | 1536       | 256      | High         | No                              | Yes                    | 32   | QFN48 / Standard |
| EFR32MG24B120F1536IM48-B <sup>1</sup> | 19.5 dBm     | 1536       | 256      | High         | Yes                             | No                     | 28   | QFN48 / ADC      |
| EFR32MG24B110F1536IM48-B <sup>1</sup> | 10 dBm       | 1536       | 256      | High         | Yes                             | No                     | 28   | QFN48 / ADC      |
| EFR32MG24B020F1536IM48-B <sup>1</sup> | 19.5 dBm     | 1536       | 256      | High         | No                              | No                     | 32   | QFN48 / Standard |
| EFR32MG24B020F1536IM40-B <sup>1</sup> | 19.5 dBm     | 1536       | 256      | High         | No                              | No                     | 26   | QFN40 / Standard |
| EFR32MG24B020F1024IM48-B <sup>1</sup> | 19.5 dBm     | 1024       | 128      | High         | No                              | No                     | 32   | QFN48 / Standard |
| EFR32MG24B010F1536IM48-B <sup>1</sup> | 10 dBm       | 1536       | 256      | High         | No                              | No                     | 32   | QFN48 / Standard |
| EFR32MG24B010F1536IM40-B <sup>1</sup> | 10 dBm       | 1536       | 256      | High         | No                              | No                     | 26   | QFN40 / Standard |
| EFR32MG24B010F1024IM48-B <sup>1</sup> | 10 dBm       | 1024       | 128      | High         | No                              | No                     | 32   | QFN48 / Standard |
| EFR32MG24A420F1536IM48-B <sup>1</sup> | 19.5 dBm     | 1536       | 256      | Mid          | No                              | No                     | 32   | QFN48 / Standard |
| EFR32MG24A420F1536IM40-B <sup>1</sup> | 19.5 dBm     | 1536       | 256      | Mid          | No                              | No                     | 26   | QFN40 / Standard |
| EFR32MG24A410F1536IM48-B <sup>1</sup> | 10 dBm       | 1536       | 256      | Mid          | No                              | No                     | 32   | QFN48 / Standard |
| EFR32MG24A410F1536IM40-B <sup>1</sup> | 10 dBm       | 1536       | 256      | Mid          | No                              | No                     | 26   | QFN40 / Standard |
| EFR32MG24A110F1024IM48-B <sup>1</sup> | 10 dBm       | 1024       | 128      | Mid          | Yes                             | No                     | 28   | QFN48 / ADC      |
| EFR32MG24A021F1024IM40-B <sup>1</sup> | 19.5 dBm     | 1024       | 128      | Mid          | No                              | No                     | 25   | QFN40 / HFCLKOUT |
| EFR32MG24A020F1536IM48-B <sup>1</sup> | 19.5 dBm     | 1536       | 192      | Mid          | No                              | No                     | 32   | QFN48 / Standard |
| EFR32MG24A020F1536IM40-B <sup>1</sup> | 19.5 dBm     | 1536       | 192      | Mid          | No                              | No                     | 26   | QFN40 / Standard |
| EFR32MG24A020F1024IM48-B <sup>1</sup> | 19.5 dBm     | 1024       | 128      | Mid          | No                              | No                     | 32   | QFN48 / Standard |
| EFR32MG24A020F1024IM40-B <sup>1</sup> | 19.5 dBm     | 1024       | 128      | Mid          | No                              | No                     | 26   | QFN40 / Standard |
| EFR32MG24A010F1536IM48-B <sup>1</sup> | 10 dBm       | 1536       | 192      | Mid          | No                              | No                     | 32   | QFN48 / Standard |
| EFR32MG24A010F1536IM40-B <sup>1</sup> | 10 dBm       | 1536       | 192      | Mid          | No                              | No                     | 26   | QFN40 / Standard |
| EFR32MG24A010F1024IM48-B <sup>1</sup> | 10 dBm       | 1024       | 128      | Mid          | No                              | No                     | 32   | QFN48 / Standard |
| EFR32MG24A010F1024IM40-B <sup>1</sup> | 10 dBm       | 1024       | 128      | Mid          | No                              | No                     | 26   | QFN40 / Standard |

**Note:**

1. AEC-Q100 Grade 1 qualified parts are not Automotive Grade. Refer to [AN1421: AEC Qualification vs Automotive Grade](#) for details.

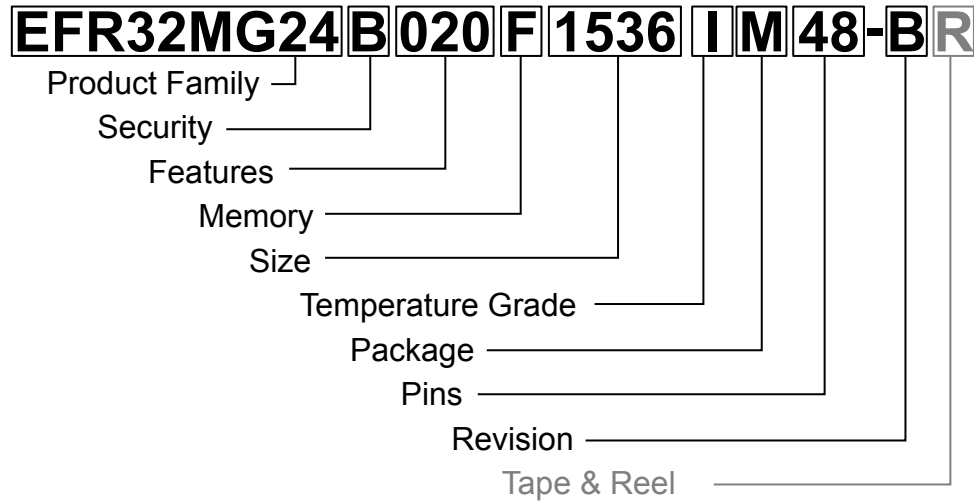


Figure 2.1. Ordering Code Key

| Field                 | Options   |
|-----------------------|---|
| Product Family        | <ul style="list-style-type: none"> <li>• <b>EFR32MG24</b>: Mighty Gecko 24 Family</li> </ul>  |
| Security              | <ul style="list-style-type: none"> <li>• <b>A</b>: Secure Vault Mid</li> <li>• <b>B</b>: Secure Vault High</li> </ul>   |
| Features [f1][f2][f3] | <ul style="list-style-type: none"> <li>• f1                             <ul style="list-style-type: none"> <li>• <b>0</b>: Base Configuration</li> <li>• <b>1</b>: IADC High-Speed / High-Accuracy Available</li> <li>• <b>2</b>: Matrix Vector Processor (MVP) Available</li> <li>• <b>3</b>: IADC High-Speed / High-Accuracy and Matrix Vector Processor (MVP) Available</li> <li>• <b>4</b>: 256K RAM and Secure Vault – Mid</li> </ul> </li> <li>• f2                             <ul style="list-style-type: none"> <li>• <b>1</b>: 10 dBm PA Transmit Power</li> <li>• <b>2</b>: 19.5 dBm PA Transmit Power</li> </ul> </li> <li>• f3                             <ul style="list-style-type: none"> <li>• <b>0</b>: No feature enabled</li> <li>• <b>1</b>: High Quality HFCLKOUT Pin Available</li> </ul> </li> </ul> |
| Memory                | <ul style="list-style-type: none"> <li>• <b>F</b>: Flash</li> </ul>   |
| Size                  | <ul style="list-style-type: none"> <li>• <b>Memory Size</b> in kBytes</li> </ul>  |
| Temperature Grade     | <ul style="list-style-type: none"> <li>• <b>G</b>: -40 to +85 °C</li> <li>• <b>I</b>: -40 to +125 °C</li> </ul>   |
| Package               | <ul style="list-style-type: none"> <li>• <b>M</b>: QFN</li> </ul>   |
| Pins                  | <ul style="list-style-type: none"> <li>• <b>Number of Package Pins</b></li> </ul>   |
| Revision              | <ul style="list-style-type: none"> <li>• <b>B</b>: Revision B</li> </ul>  |
| Tape & Reel           | <ul style="list-style-type: none"> <li>• <b>R</b>: Tape &amp; Reel (optional)</li> </ul>  |

# Table of Contents

|   |          |
|---|----------|
| <b>1. Feature List</b>  | <b>2</b> |
| <b>2. Ordering Information</b>  | <b>3</b> |
| <b>3. System Overview</b>   | <b>9</b> |
| 3.1 Introduction  | 9        |
| 3.2 Radio   | 9        |
| 3.2.1 Antenna Interface   | 9        |
| 3.2.2 Fractional-N Frequency Synthesizer  | 10       |
| 3.2.3 Receiver Architecture   | 10       |
| 3.2.4 Transmitter Architecture  | 10       |
| 3.2.5 Packet and State Trace  | 10       |
| 3.2.6 Data Buffering  | 10       |
| 3.2.7 Radio Controller (RAC)  | 10       |
| 3.2.8 RF Signal Identifier  | 11       |
| 3.3 General Purpose Input/Output (GPIO)   | 11       |
| 3.4 Keypad Scanner (KEYSCAN)  | 11       |
| 3.5 Clocking  | 11       |
| 3.5.1 Clock Management Unit (CMU)   | 11       |
| 3.5.2 Internal and External Oscillators   | 11       |
| 3.6 Counters/Timers and PWM   | 12       |
| 3.6.1 Timer/Counter (TIMER)   | 12       |
| 3.6.2 Low Energy Timer (LETIMER)  | 12       |
| 3.6.3 System Real Time Clock with Capture (SYSRTC)                              | 12       |
| 3.6.4 Back-Up Real Time Counter (BURTC)   | 12       |
| 3.6.5 Watchdog Timer (WDOG)   | 12       |
| 3.7 Communications and Other Digital Peripherals                                | 12       |
| 3.7.1 Universal Synchronous/Asynchronous Receiver/Transmitter (USART)           | 12       |
| 3.7.2 Enhanced Universal Synchronous/Asynchronous Receiver/Transmitter (EUSART) | 12       |
| 3.7.3 Inter-Integrated Circuit Interface (I <sup>2</sup> C)                     | 13       |
| 3.7.4 Peripheral Reflex System (PRS)  | 13       |
| 3.8 Secure Vault Features   | 13       |
| 3.8.1 Secure Boot with Root of Trust and Secure Loader (RTSL)                   | 14       |
| 3.8.2 Cryptographic Accelerator   | 14       |
| 3.8.3 True Random Number Generator  | 14       |
| 3.8.4 Secure Debug with Lock/Unlock   | 14       |
| 3.8.5 DPA Countermeasures   | 14       |
| 3.8.6 Secure Key Management with PUF  | 15       |
| 3.8.7 Anti-Tamper   | 15       |
| 3.8.8 Secure Attestation  | 15       |
| 3.9 Analog  | 15       |
| 3.9.1 Analog to Digital Converter (IADC)  | 15       |
| 3.9.2 Analog Comparator (ACMP)  | 16       |
| 3.9.3 Digital to Analog Converter (VDAC)  | 16       |

|           |  |            |
|-----------|--|------------|
| 3.10      | Power  | .17        |
| 3.10.1    | Energy Management Unit (EMU)                       | .17        |
| 3.10.2    | Voltage Scaling                                    | .17        |
| 3.10.3    | DC-DC Converter                                    | .17        |
| 3.10.4    | Power Domains                                      | .18        |
| 3.11      | Reset Management Unit (RMU)                        | .18        |
| 3.12      | Core, Memory, and Accelerators                     | .19        |
| 3.12.1    | Processor Core                                     | .19        |
| 3.12.2    | Memory System Controller (MSC)                     | .19        |
| 3.12.3    | Linked Direct Memory Access Controller (LDMA)      | .19        |
| 3.12.4    | Matrix Vector Processor (MVP)                      | .19        |
| 3.13      | Memory Map   | .20        |
| 3.14      | Configuration Summary                              | .21        |
| <b>4.</b> | <b>Electrical Specifications</b>                   | <b>.22</b> |
| 4.1       | Electrical Characteristics                         | .22        |
| 4.2       | Absolute Maximum Ratings                           | .23        |
| 4.3       | General Operating Conditions                       | .24        |
| 4.4       | DC-DC Converter                                    | .26        |
| 4.5       | Thermal Characteristics                            | .28        |
| 4.6       | Current Consumption                                | .29        |
| 4.6.1     | MCU current consumption using DC-DC at 3.0 V input | .29        |
| 4.6.2     | Radio current consumption at 3.0V using DCDC       | .32        |
| 4.6.3     | MCU current consumption at 3.0 V                   | .34        |
| 4.6.4     | Radio current consumption at 3.0V                  | .37        |
| 4.6.5     | MCU current consumption at 1.8 V                   | .39        |
| 4.6.6     | Radio current consumption at 1.8V                  | .42        |
| 4.7       | Flash Characteristics                              | .44        |
| 4.8       | Energy Mode Wake-up and Entry Times                | .45        |
| 4.9       | 2.4 GHz RF Transceiver Characteristics             | .46        |
| 4.9.1     | RF Transmitter Characteristics                     | .46        |
| 4.9.2     | RF Receiver Characteristics                        | .54        |
| 4.10      | Oscillators  | .60        |
| 4.10.1    | High Frequency Crystal Oscillator (HFXO)           | .60        |
| 4.10.2    | Low Frequency Crystal Oscillator (LFXO)            | .61        |
| 4.10.3    | High Frequency RC Oscillator (HFRCO)               | .62        |
| 4.10.4    | Fast Start-Up RC Oscillator (FSRCO)                | .63        |
| 4.10.5    | Precision Low Frequency RC Oscillator (LFRCO)      | .64        |
| 4.10.6    | Ultra Low Frequency RC Oscillator (ULFRCO)         | .64        |
| 4.11      | GPIO Pins (GPIO)                                   | .65        |
| 4.12      | Analog to Digital Converter (IADC)                 | .67        |
| 4.13      | Analog Comparator (ACMP)                           | .73        |
| 4.14      | Digital to Analog Converter (VDAC)                 | .75        |

|           |  |            |
|-----------|--|------------|
| 4.15      | Temperature Sensor                                     | .77        |
| 4.16      | Brown Out Detectors                                    | .78        |
| 4.16.1    | DVDD BOD   | .78        |
| 4.16.2    | Low-Energy DVDD BOD                                    | .78        |
| 4.16.3    | AVDD and IOVDD BODs                                    | .79        |
| 4.17      | Pulse Counter (PCNT)                                   | .79        |
| 4.18      | USART SPI Main Timing                                  | .80        |
| 4.18.1    | USART SPI Main Timing, Voltage Scaling = VSCALE2       | .81        |
| 4.18.2    | USART SPI Main Timing, Voltage Scaling = VSCALE1       | .81        |
| 4.19      | USART SPI Secondary Timing                             | .82        |
| 4.19.1    | USART SPI Secondary Timing, Voltage Scaling = VSCALE2  | .83        |
| 4.19.2    | USART SPI Secondary Timing, Voltage Scaling = VSCALE1  | .83        |
| 4.20      | EUSART SPI Main Timing                                 | .84        |
| 4.20.1    | EUSART SPI Main Timing, Voltage Scaling = VSCALE2      | .84        |
| 4.20.2    | EUSART SPI Main Timing, Voltage Scaling = VSCALE1      | .85        |
| 4.21      | EUSART SPI Secondary Timing                            | .86        |
| 4.21.1    | EUSART SPI Secondary Timing, Voltage Scaling = VSCALE2 | .86        |
| 4.21.2    | EUSART SPI Secondary Timing, Voltage Scaling = VSCALE1 | .87        |
| 4.21.3    | EUSART SPI Secondary Timing, Voltage Scaling = VSCALE0 | .87        |
| 4.22      | I2C Electrical Specifications                          | .88        |
| 4.22.1    | I2C Standard-mode (Sm)                                 | .88        |
| 4.22.2    | I2C Fast-mode (Fm)                                     | .89        |
| 4.22.3    | I2C Fast-mode Plus (Fm+)                               | .90        |
| 4.23      | Boot Timing  | .90        |
| 4.24      | Crypto Operation Timing for SE Manager API             | .92        |
| 4.25      | Crypto Operation Average Current for SE Manager API    | .94        |
| 4.26      | Matrix Vector Processor (MVP)                          | .96        |
| 4.27      | Typical Performance Curves                             | .97        |
| 4.27.1    | Supply Current   | .98        |
| 4.27.2    | RF Characteristics                                     | 100        |
| 4.27.3    | DC-DC Converter  | 102        |
| 4.27.4    | IADC   | 103        |
| 4.27.5    | GPIO   | 104        |
| <b>5.</b> | <b>Typical Connections</b>                             | <b>105</b> |
| 5.1       | Power  | 105        |
| 5.2       | Other Connections                                      | 106        |
| <b>6.</b> | <b>Pin Definitions</b>                                 | <b>107</b> |
| 6.1       | QFN48 / Standard Device Pinout                         | 107        |
| 6.2       | QFN48 / ADC Device Pinout                              | 109        |
| 6.3       | QFN40 / Standard Device Pinout                         | 111        |
| 6.4       | QFN40 / HFCLKOUT Device Pinout                         | 113        |
| 6.5       | Alternate Function Table                               | 115        |

- 6.6 Analog Peripheral Connectivity . . . . . 116
- 6.7 Digital Peripheral Connectivity . . . . . 117
- 7. QFN40 Package Specifications. . . . . 121**
  - 7.1 QFN40 Package Dimensions . . . . . 121
  - 7.2 QFN40 PCB Land Pattern . . . . . 123
  - 7.3 QFN40 Package Marking . . . . . 124
- 8. QFN48 Package Specifications. . . . . 125**
  - 8.1 QFN48 Package Dimensions . . . . . 125
  - 8.2 QFN48 PCB Land Pattern . . . . . 127
  - 8.3 QFN48 Package Marking . . . . . 128
- 9. Revision History . . . . . 129**

### 3. System Overview

#### 3.1 Introduction

The EFR32 product family combines an energy-friendly MCU with a high performance radio transceiver. The devices are well suited for secure connected IoT multi-protocol devices requiring high performance and low energy consumption. This section gives a short introduction to the full radio and MCU system. The detailed functional description can be found in the EFR32xG24 Reference Manual.

A block diagram of the EFR32MG24 family is shown in [Figure 3.1 Detailed EFR32MG24 Block Diagram on page 9](#). The diagram shows a superset of features available on the family, which vary by OPN. For more information about specific device features, consult [2. Ordering Information](#).

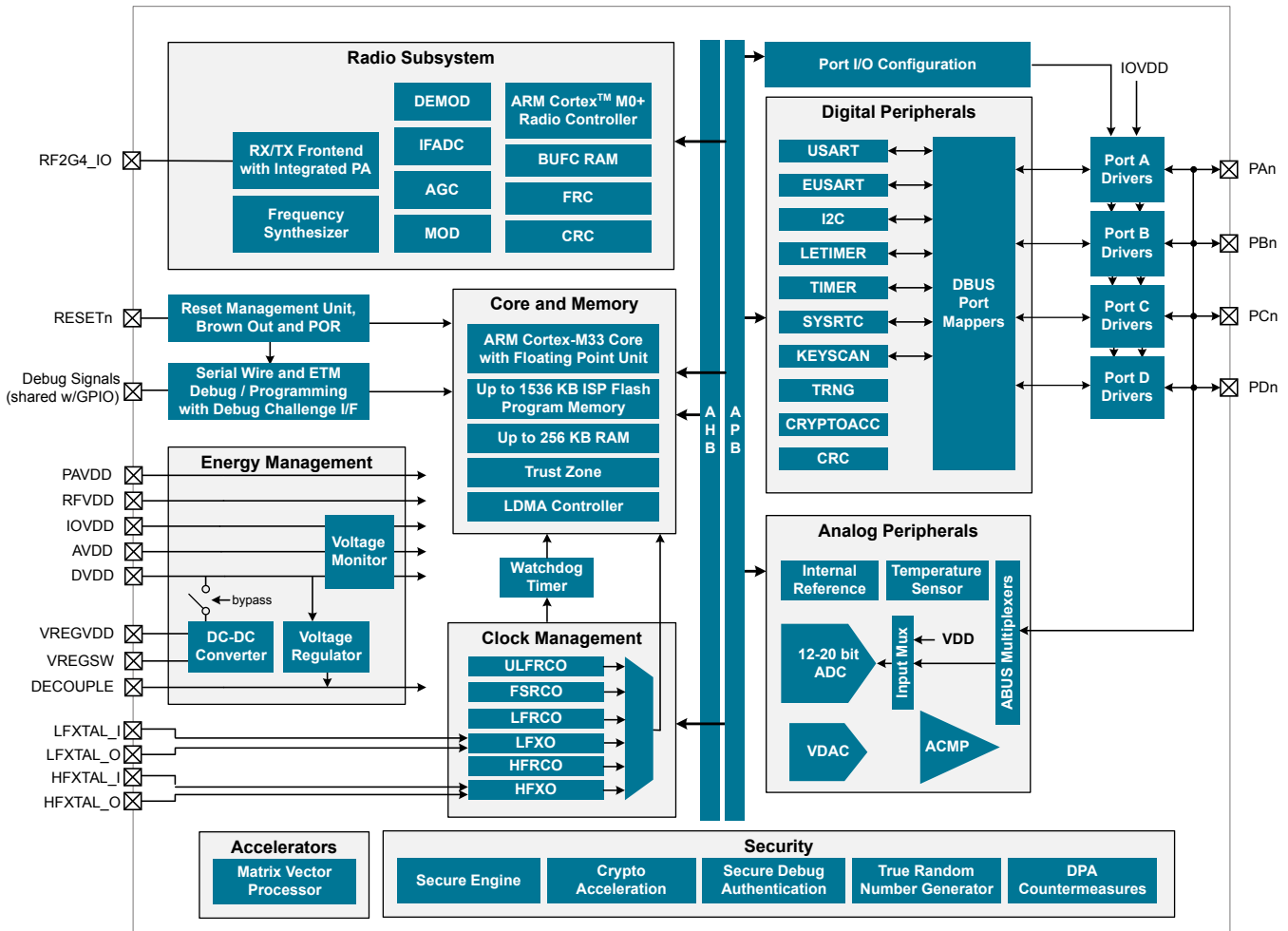


Figure 3.1. Detailed EFR32MG24 Block Diagram

#### 3.2 Radio

The EFR32MG24 Wireless SoC features a highly configurable radio transceiver supporting Zigbee, Bluetooth Low Energy and Bluetooth Mesh wireless protocols.

##### 3.2.1 Antenna Interface

The 2.4 GHz antenna interface consists of a single-ended pin (RF2G4\_IO). The external components for the antenna interface in typical applications are shown in the RF Matching Networks section.

### 3.2.2 Fractional-N Frequency Synthesizer

The EFR32MG24 contains a high performance, low phase noise, fully integrated fractional-N frequency synthesizer. The synthesizer is used in receive mode to generate the LO frequency for the down-conversion mixer. It is also used in transmit mode to directly generate the modulated RF carrier.

The fractional-N architecture provides excellent phase noise performance, frequency resolution better than 100 Hz, and low energy consumption. The synthesizer's fast frequency settling allows for very short receiver and transmitter wake up times to reduce system energy consumption.

### 3.2.3 Receiver Architecture

The EFR32MG24 uses a low-IF receiver architecture, consisting of a Low-Noise Amplifier (LNA) followed by an I/Q down-conversion mixer. The I/Q signals are further filtered and amplified before being sampled by the IF analog-to-digital converter (IFADC).

The IF frequency is configurable from 150 kHz to 1371 kHz. The IF can further be configured for high-side or low-side injection, providing flexibility with respect to known interferers at the image frequency.

The Automatic Gain Control (AGC) module adjusts the receiver gain to optimize performance and avoid saturation for excellent selectivity and blocking performance. The 2.4 GHz radio is calibrated at production to improve image rejection performance.

Demodulation is performed in the digital domain. The demodulator performs configurable decimation and channel filtering to allow receive bandwidths ranging from 0.1 to 2530 kHz. High carrier frequency and baud rate offsets are tolerated by active estimation and compensation. Advanced features supporting high quality communication under adverse conditions include forward error correction by block and convolutional coding as well as Direct Sequence Spread Spectrum (DSSS).

A Received Signal Strength Indicator (RSSI) is available for signal quality metrics, for level-based proximity detection, and for RF channel access by Collision Avoidance (CA) or Listen Before Talk (LBT) algorithms. An RSSI capture value is associated with each received frame and the dynamic RSSI measurement can be monitored throughout reception.

### 3.2.4 Transmitter Architecture

The EFR32MG24 uses a direct-conversion transmitter architecture. For constant envelope modulation formats, the modulator controls phase and frequency modulation in the frequency synthesizer. Transmit symbols or chips are optionally shaped by a digital shaping filter. The shaping filter is fully configurable, including the BT product, and can be used to implement Gaussian or Raised Cosine shaping.

Carrier Sense Multiple Access - Collision Avoidance (CSMA-CA) or Listen Before Talk (LBT) algorithms can be automatically timed by the EFR32MG24. These algorithms are typically defined by regulatory standards to improve inter-operability in a given bandwidth between devices that otherwise lack synchronized RF channel access.

### 3.2.5 Packet and State Trace

The EFR32MG24 Frame Controller has a packet and state trace unit that provides valuable information during the development phase. It features the following:

- Non-intrusive trace of transmit data, receive data and state information
- Data observability on a single-pin UART data output or on a two-pin SPI data output
- Configurable data output bitrate / baudrate
- Multiplexed transmitted data, received data and state / meta information in a single serial data stream

### 3.2.6 Data Buffering

The EFR32MG24 features an advanced Radio Buffer Controller (BUFC) capable of handling up to 4 buffers of adjustable size from 64 bytes to 4096 bytes. Each buffer can be used for RX, TX or both. The buffer data is located in RAM, enabling zero-copy operations.

### 3.2.7 Radio Controller (RAC)

The Radio Controller controls the top level state of the radio subsystem in the EFR32MG24. It performs the following tasks:

- Precisely-timed control of enabling and disabling of the receiver and transmitter circuitry
- Run-time calibration of receiver, transmitter and frequency synthesizer
- Detailed frame transmission timing, including optional LBT or CSMA-CA

### 3.2.8 RF Signal Identifier

When an IoT radio is placed next to a high duty-cycle co-located Wi-Fi radio transmission, IoT radios are blocked from receiving weak signals. The RF Signal Identifier feature available on EFR32MG24 devices enables the IoT radio to detect partial 802.15.4 or BLE/BT Mesh packets. When a partial packet is detected, the IoT radio can communicate this information to the corresponding Wi-Fi device (through serial interface or GPIO asserts), which can consequently halt transmission while the IoT radio waits for a packet retry to be received. This helps provide a higher success rate of receiving packets from other devices on the network, when co-located with an interfering Wi-Fi radio.

### 3.3 General Purpose Input/Output (GPIO)

EFR32MG24 has up to 32 General Purpose Input/Output pins. Each GPIO pin can be individually configured as either an output or input. More advanced configurations including open-drain, open-source, and glitch-filtering can be configured for each individual GPIO pin. The GPIO pins can be overridden by peripheral connections, like SPI communication. Each peripheral connection can be routed to several GPIO pins on the device. The input value of a GPIO pin can be routed through the Peripheral Reflex System to other peripherals. The GPIO subsystem supports asynchronous external pin interrupts.

All of the pins on ports A and port B are EM2 capable. These pins may be used by Low-Energy peripherals in EM2/3 and may also be used as EM2/3 pin wake-ups. Pins on ports C and D are latched/retained in their current state when entering EM2 until EM2 exit upon which internal peripherals could once again drive those pads.

A few GPIOs also have EM4 wake functionality. These pins are listed in the Alternate Function Table.

### 3.4 Keypad Scanner (KEYSCAN)

A low-energy keypad scanner (KEYSCAN) is included, which can scan up to a 6 x 8 matrix of keyboard switches. The KEYSKAN peripheral contains logic for debounce and settling time, allowing it to scan through the switch matrix autonomously in EM0 and EM1, and interrupt the processor when a key press is detected. A wake-on-keypress feature is also supported, allowing for the detection of any key press down to EM3.

### 3.5 Clocking

#### 3.5.1 Clock Management Unit (CMU)

The Clock Management Unit controls oscillators and clocks in the EFR32MG24. Individual enabling and disabling of clocks to all peripheral modules is performed by the CMU. The CMU also controls enabling and configuration of the oscillators. A high degree of flexibility allows software to optimize energy consumption in any specific application by minimizing power dissipation in unused peripherals and oscillators.

#### 3.5.2 Internal and External Oscillators

The EFR32MG24 supports two crystal oscillators and fully integrates four RC oscillators, listed below.

- A high frequency crystal oscillator (HFXO) with integrated load capacitors, tunable in small steps, provides a precise timing reference for the MCU. The HFXO provides excellent RF clocking performance using a 39.0 MHz crystal. The HFXO can also support an external clock source such as a TCXO for applications that require an extremely accurate clock frequency over temperature.
- A 32.768 kHz crystal oscillator (LFXO) provides an accurate timing reference for low energy modes.
- An integrated high frequency RC oscillator (HFRCO) is available for the MCU system, when crystal accuracy is not required. The HFRCO employs fast start-up at minimal energy consumption combined with a wide frequency range, from 1 MHz to 78 MHz.
- An integrated fast start-up RC oscillator (FSRCO) that runs at a fixed 20 MHz
- An integrated low frequency 32.768 kHz RC oscillator (LFRCO) for low power operation without an external crystal. Precision mode enables periodic recalibration against the 39.0 MHz HFXO crystal to improve accuracy to +/- 500 ppm, suitable for BLE sleep interval timing.
- An integrated ultra-low frequency 1 kHz RC oscillator (ULFRCO) is available to provide a timing reference at the lowest energy consumption in low energy modes.

## 3.6 Counters/Timers and PWM

### 3.6.1 Timer/Counter (TIMER)

TIMER peripherals keep track of timing, count events, generate PWM outputs and trigger timed actions in other peripherals through the Peripheral Reflex System (PRS). The core of each TIMER is a 16-bit or 32-bit counter with up to 3 compare/capture channels. Each channel is configurable in one of three modes. In capture mode, the counter state is stored in a buffer at a selected input event. In compare mode, the channel output reflects the comparison of the counter to a programmed threshold value. In PWM mode, the TIMER supports generation of pulse-width modulation (PWM) outputs of arbitrary waveforms defined by the sequence of values written to the compare registers. In addition some timers offer dead-time insertion.

See [3.14 Configuration Summary](#) for information on the feature set of each timer.

### 3.6.2 Low Energy Timer (LETIMER)

The unique LETIMER is a 24-bit timer that is available in energy mode EM0 Active, EM1 Sleep, EM2 Deep Sleep, and EM3 Stop. This allows it to be used for timing and output generation when most of the device is powered down, allowing simple tasks to be performed while the power consumption of the system is kept at an absolute minimum. The LETIMER can be used to output a variety of waveforms with minimal software intervention. The LETIMER is connected to the Peripheral Reflex System (PRS), and can be configured to start counting on compare matches from other peripherals such as the Real Time Clock.

### 3.6.3 System Real Time Clock with Capture (SYSRTC)

The System Real Time Clock (SYSRTC) is a 32-bit counter providing timekeeping down to EM3. The SYSRTC can be clocked by any of the on-board low-frequency oscillators, and it is capable of providing system wake-up at user defined intervals.

### 3.6.4 Back-Up Real Time Counter (BURTC)

The Back-Up Real Time Counter (BURTC) is a 32-bit counter providing timekeeping in all energy modes, including EM4. The BURTC can be clocked by any of the on-board low-frequency oscillators, and it is capable of providing system wake-up at user-defined intervals.

### 3.6.5 Watchdog Timer (WDOG)

The watchdog timer can act both as an independent watchdog or as a watchdog synchronous with the CPU clock. It has windowed monitoring capabilities, and can generate a reset or different interrupts depending on the failure mode of the system. The watchdog can also monitor autonomous systems driven by the Peripheral Reflex System (PRS).

## 3.7 Communications and Other Digital Peripherals

### 3.7.1 Universal Synchronous/Asynchronous Receiver/Transmitter (USART)

The Universal Synchronous/Asynchronous Receiver/Transmitter is a flexible serial I/O module. It supports full duplex asynchronous UART communication with hardware flow control as well as RS-485, SPI, MicroWire and 3-wire. It can also interface with devices supporting:

- ISO7816 SmartCards
- IrDA
- I<sup>2</sup>S

### 3.7.2 Enhanced Universal Synchronous/Asynchronous Receiver/Transmitter (EUSART)

The Enhanced Universal Synchronous/Asynchronous Receiver/Transmitter supports full duplex asynchronous UART communication with hardware flow control, RS-485, and IrDA support. The EUSART also supports high-speed SPI. In EM0 and EM1 the EUSART provides a high-speed, buffered communication interface.

When routed to GPIO ports A or B, the EUSART0 may also be used in a low-energy mode and operate in EM2. A 32.768 kHz clock source allows full duplex UART communication up to 9600 baud. EUSART0 can also act as a SPI secondary device in EM2 and EM3, and wake the system when data is received from an external bus controller.

### 3.7.3 Inter-Integrated Circuit Interface (I<sup>2</sup>C)

The I<sup>2</sup>C module provides an interface between the MCU and a serial I<sup>2</sup>C bus. It is capable of acting as a main or secondary interface and supports multi-drop buses. Standard-mode, fast-mode and fast-mode plus speeds are supported, allowing transmission rates from 10 kbit/s up to 1 Mbit/s. Bus arbitration and timeouts are also available, allowing implementation of an SMBus-compliant system. The interface provided to software by the I<sup>2</sup>C module allows precise timing control of the transmission process and highly automated transfers. Automatic recognition of addresses is provided in active and low energy modes. Not all instances of I<sup>2</sup>C are available in all energy modes.

### 3.7.4 Peripheral Reflex System (PRS)

The Peripheral Reflex System provides a communication network between different peripheral modules without software involvement. Peripheral modules producing Reflex signals are called producers. The PRS routes Reflex signals from producers to consumer peripherals which in turn perform actions in response. Edge triggers and other functionality such as simple logic operations (AND, OR, NOT) can be applied by the PRS to the signals. The PRS allows peripherals to act autonomously without waking the MCU core, saving power.

## 3.8 Secure Vault Features

A dedicated hardware secure engine containing its own CPU enables the Secure Vault functions. It isolates cryptographic functions and data from the host Cortex-M33 core, and provides several additional security features. The EFR32MG24 family includes devices with Secure Vault High and Secure Vault Mid capabilities, which are summarized in the table below.

**Table 3.1. Secure Vault Features**

| Feature   | Secure Vault Mid  | Secure Vault High  |
|---|---|--|
| True Random Number Generator (TRNG)                     | Yes   | Yes  |
| Secure Boot with Root of Trust and Secure Loader (RTSL) | Yes   | Yes  |
| Secure Debug with Lock/Unlock                           | Yes   | Yes  |
| DPA Countermeasures                                     | Yes   | Yes  |
| Anti-Tamper   |   | Yes  |
| Secure Attestation                                      |   | Yes  |
| Secure Key Management                                   |   | Yes  |
| Symmetric Encryption                                    | <ul style="list-style-type: none"> <li>AES 128 / 192 / 256 bit</li> <li>ECB, CTR, CBC, CFB, CCM, GCM, CBC-MAC, and GMAC</li> </ul>          | <ul style="list-style-type: none"> <li>AES 128 / 192 / 256 bit</li> <li>ECB, CTR, CBC, CFB, CCM, GCM, CBC-MAC, and GMAC</li> <li>ChaCha20</li> </ul> |
| Public Key Encryption - ECDSA / ECDH / EdDSA            | <ul style="list-style-type: none"> <li>p192 and p256</li> <li>Curve25519 (ECDH)<sup>1</sup></li> <li>Ed25519 (EdDSA)<sup>1</sup></li> </ul> | <ul style="list-style-type: none"> <li>p192, p256, p384 and p521</li> <li>Curve25519 (ECDH)</li> <li>Ed25519 (EdDSA)</li> </ul>                      |
| Key Derivation  | <ul style="list-style-type: none"> <li>ECJ-PAKE p192 and p256</li> </ul>  | <ul style="list-style-type: none"> <li>ECJ-PAKE p192, p256, p384, and p521</li> <li>PBKDF2</li> <li>HKDF</li> </ul>                                  |
| Hashes  | <ul style="list-style-type: none"> <li>SHA-1</li> <li>SHA-2/256</li> </ul>  | <ul style="list-style-type: none"> <li>SHA-1</li> <li>SHA-2 256, 384, and 512</li> <li>Poly1305</li> </ul>   |

**Note:**

1. These curves are supported in devices running SE v2.1.7 and higher

### 3.8.1 Secure Boot with Root of Trust and Secure Loader (RTSL)

The Secure Boot with RTSL authenticates a chain of trusted firmware that begins from an immutable memory (ROM).

It prevents malware injection, prevents rollback, ensures that only authentic firmware is executed, and protects Over The Air updates.

For more information about this feature, see [AN1218: Series 2 Secure Boot with RTSL](#).

### 3.8.2 Cryptographic Accelerator

The Cryptographic Accelerator is an autonomous hardware accelerator with Differential Power Analysis (DPA) countermeasures to protect keys.

It supports AES encryption and decryption with 128/192/256-bit keys, ChaCha20 encryption, and Elliptic Curve Cryptography (ECC) to support public key operations, and hashes.

Supported block cipher modes of operation for AES include:

- ECB (Electronic Code Book)
- CTR (Counter Mode)
- CBC (Cipher Block Chaining)
- CFB (Cipher Feedback)
- GCM (Galois Counter Mode)
- CCM (Counter with CBC-MAC)
- CBC-MAC (Cipher Block Chaining Message Authentication Code)
- GMAC (Galois Message Authentication Code)

The Cryptographic Accelerator accelerates Elliptic Curve Cryptography and supports the NIST (National Institute of Standards and Technology) recommended curves including P-192, P-256, P-384, and P-521 for ECDH (Elliptic Curve Diffie-Hellman) key derivation, and ECDSA (Elliptic Curve Digital Signature Algorithm) sign and verify operations. Also supported is the non-NIST Curve25519 for ECDH and Ed25519 for EdDSA (Edwards-curve Digital Signature Algorithm) sign and verify operations.

Secure Vault also supports ECJ-PAKE (Elliptic Curve variant of Password Authenticated Key Exchange by Juggling) and PBKDF2 (Password-Based Key Derivation Function 2).

Supported hashes include SHA-1, SHA-2/256/384/512 and Poly1305.

This implementation provides a fast and energy efficient solution to state of the art cryptographic needs.

### 3.8.3 True Random Number Generator

The True Random Number Generator module is a non-deterministic random number generator that harvests entropy from a thermal energy source. It includes start-up health tests for the entropy source as required by NIST SP800-90B and AIS-31 as well as online health tests required for NIST SP800-90C.

The TRNG is suitable for periodically generating entropy to seed an approved pseudo random number generator.

### 3.8.4 Secure Debug with Lock/Unlock

For obvious security reasons, it is critical for a product to have its debug interface locked before being released in the field.

Secure Vault also provides a secure debug unlock function that allows authenticated access based on public key cryptography. This functionality is particularly useful for supporting failure analysis while maintaining confidentiality of IP and sensitive end-user data.

For more information about this feature, see [AN1190: Series 2 Secure Debug](#).

### 3.8.5 DPA Countermeasures

The AES and ECC accelerators have Differential Power Analysis (DPA) countermeasures support. This makes it very expensive from a time and effort standpoint to use DPA to recover secret keys.

### 3.8.6 Secure Key Management with PUF

Key material in Secure Vault High products is protected by "key wrapping" with a standardized symmetric encryption mechanism. This method has the advantage of protecting a virtually unlimited number of keys, limited only by the storage that is accessible by the Cortex-M33, which includes off-chip storage as well. The symmetric key used for this wrapping and unwrapping must be highly secure because it can expose all other key materials in the system. The Secure Vault Key Management system uses a Physically Unclonable Function (PUF) to generate a persistent device-unique seed key on power up to dynamically generate this critical wrapping/unwrapping key which is only visible to the AES encryption engine and is not retained when the device loses power.

### 3.8.7 Anti-Tamper

Secure Vault High devices provide internal tamper protection which monitors parameters such as voltage, temperature, and electromagnetic pulses as well as detecting tamper of the security sub-system itself. Additionally, 8 external configurable tamper pins support external tamper sources, such as enclosure tamper switches.

For each tamper event, the user is able to select the severity of the tamper response ranging from an interrupt, to a reset, to destroying the PUF reconstruction data which will make all protected key materials un-recoverable and effectively render the device inoperable. The tamper system also has an internal resettable event counter with programmable trigger threshold and refresh periods to mitigate false positive tamper events.

For more information about this feature, see [AN1247: Anti-Tamper Protection Configuration and Use](#).

### 3.8.8 Secure Attestation

Secure Vault High products support Secure Attestation, which begins with a secure identity that is created during the Silicon Labs manufacturing process. During device production, each device generates its own public/private keypair and securely stores the wrapped private key into immutable OTP memory and this key never leaves the device. The corresponding public key is extracted from the device and inserted into a binary DER-encoded X.509 device certificate, which is signed into a Silicon Labs CA chain and then programmed back into the chip into an immutable OTP memory.

The secure identity can be used to authenticate the chip at any time in the life of the product. The production certification chain can be requested remotely from the product. This certification chain can be used to verify that the device was authentically produced by Silicon Labs. The device unique public key is also bound to the device certificate in the certification chain. A challenge can be sent to the chip at any point in time to be signed by the device private key. The public key in the device certificate can then be used to verify the challenge response, proving that the device has access to the securely-stored private key, which prevents counterfeit products or impersonation attacks.

For more information about this feature, see [AN1268: Authenticating Silicon Labs Devices Using Device Certificates](#).

## 3.9 Analog

### 3.9.1 Analog to Digital Converter (IADC)

The IADC is a hybrid architecture combining techniques from both SAR and Delta-Sigma style converters. Flexible controls allow fine-tuned performance and speed to meet the needs of a wide variety of applications. Hardware oversampling reduces system-level noise over multiple front-end samples. The IADC includes integrated voltage reference options. Inputs are selectable from a wide range of sources, including pins configurable as either single-ended or differential.

The IADC supports three operational modes:

- Normal Mode (all devices): Flexible speed and performance, 12-16 bits output resolution
  - 11.7 bits ENOB performance at 1 Msps (OSR = 2)
  - 14.3 bits ENOB performance at 76.9 ksps (OSR = 32)
- High Speed Mode (select devices): Doubles output speed of Normal mode with similar performance, 12-16 bits output resolution
  - 11.7 bits ENOB performance at 2 Msps (OSR = 2)
  - 14.3 bits ENOB performance at 153.8 ksps (OSR = 32)
- High Accuracy Mode (select devices): Optimized for low-rate, high performance applications, with 20 bit output resolution
  - 16 bits ENOB performance at 3.8 ksps (OSR = 256)
  - 15 bits ENOB performance at 15.3 ksps (OSR = 64)

### 3.9.2 Analog Comparator (ACMP)

The Analog Comparator is used to compare the voltage of two analog inputs, with a digital output indicating which input voltage is higher. Inputs are selected from among internal references and external pins. The tradeoff between response time and current consumption is configurable by software. Two 6-bit reference dividers allow for a wide range of internally-programmable reference sources. The ACMP can also be used to monitor the supply voltage. An interrupt can be generated when the supply falls below or rises above the programmable threshold.

### 3.9.3 Digital to Analog Converter (VDAC)

The Digital to Analog Converter (VDAC) can convert a digital value to an analog output voltage. The VDAC is a fully differential, 500 ksp/s, 12-bit converter. The VDAC may be used for a number of different applications such as sensor interfaces or sound output. The VDAC can generate high-resolution analog signals while the MCU is operating at low frequencies and with low total power consumption. Using DMA and a timer, the VDAC can be used to generate waveforms without any CPU intervention. The VDAC is available in all energy modes down to and including EM3.

### 3.10 Power

The EFR32MG24 has an Energy Management Unit (EMU) and efficient integrated regulators to generate internal supply voltages. Only a single external supply voltage is required, from which all internal voltages are created. An optional integrated DC-DC buck regulator can be utilized to further reduce the current consumption. The DC-DC regulator requires one external inductor and one external capacitor.

The EFR32MG24 device family includes support for internal supply voltage scaling, as well as two different power domains groups for peripherals. These enhancements allow for further supply current reductions and lower overall power consumption.

#### 3.10.1 Energy Management Unit (EMU)

The Energy Management Unit manages transitions of energy modes in the device. Each energy mode defines which peripherals and features are available and the amount of current the device consumes. The EMU can also be used to implement system-wide voltage scaling and turn off the power to unused RAM blocks to optimize the energy consumption in the target application. The DC-DC regulator operation is tightly integrated with the EMU.

#### 3.10.2 Voltage Scaling

The EFR32MG24 supports supply voltage scaling for the LDO powering DECOUPLE, with independent selections for EM0 / EM1 and EM2 / EM3. Voltage scaling helps to optimize the energy efficiency of the system by operating at lower voltages when possible. The EM0 / EM1 voltage scaling level defaults to VSCALE2, which allows the core to operate in active mode at full speed. The intermediate level, VSCALE1, allows operation in EM0 and EM1 at up to 40 MHz. The lowest level, VSCALE0, can be used to conserve power further in EM2 and EM3. The EMU will automatically switch the target voltage scaling level when transitioning between energy modes.

#### 3.10.3 DC-DC Converter

The DC-DC buck converter covers a wide range of load currents, providing high efficiency in energy modes EM0, EM1, EM2 and EM3. RF noise mitigation allows operation of the DC-DC converter without significantly degrading sensitivity of radio components. An on-chip supply-monitor signals when the supply voltage is low to allow bypass of the regulator via programmable software interrupt. It employs soft switching at boot and DCDC regulating-to-bypass transitions to limit the max supply slew-rate and mitigate inrush current.

### 3.10.4 Power Domains

Peripherals may exist on one of several independent power domains which are powered down to minimize supply current when not in use. Power domains are managed automatically by the EMU.

The lowest-energy power domain is the "high-voltage" power domain (PDHV), which supports extremely low-energy infrastructure and peripherals. Circuits powered from PDHV are always on and available in all energy modes down to EM4.

The next power domain is the low power domain (PD0), which is further divided to power subsets of peripherals. All PD0 power domains are shut down in EM4. Circuits powered from PD0 power domains may be available in EM0, EM1, EM2, and EM3.

Low power domain A (PD0A) is the base power domain for EM2 and EM3 and will always remain on in EM0-EM3. It powers the most commonly-used EM2 and EM3-capable peripherals and infrastructure required to operate in EM2 and EM3. Auxiliary PD0 power domains (PD0B, PD0C, PD0D, PD0E) power additional EM2 and EM3-capable peripherals on demand. If any peripherals on one of the auxiliary power domains is enabled, that power domain will be active in EM2 and EM3. Otherwise, the auxiliary PD0 power domains will be shut down to reduce current.

**Note:** Power domain PD0E is also turned on when peripherals on PD0B, PD0C, or PD0D are used.

The active power domain (PD1) powers the rest of the device circuitry, including the CPU core and EM0 / EM1 peripherals. PD1 is always powered on in EM0 and EM1. PD1 is always shut down in EM2, EM3, and EM4.

[Table 3.2 Peripheral Power Subdomains on page 18](#) shows the peripherals on the PDHV and PD0x domains. Any peripheral not listed is on PD1.

**Table 3.2. Peripheral Power Subdomains**

| Always On in EM2/EM3       |        | Selectively On in EM2/3 |                                    |                   |         |
|----------------------------|--------|-------------------------|------------------------------------|-------------------|---------|
| PDHV <sup>1</sup>          | PD0A   | PD0B <sup>2</sup>       | PD0C <sup>2</sup>                  | PD0D <sup>2</sup> | PD0E    |
| LFRCO (Non-precision Mode) | SYSRTC | LETIMER0                | LFRCO (Precision Calibration Mode) | DEBUG             | GPIO    |
| LFXO                       | FSRCO  | IADC0                   | HFRCOEM23                          | WDOG0/1           | KEYSCAN |
| BURTC                      |        | PCNT0                   | HFXO                               | EUSART0           | PRS     |
| BURAM                      |        | ACMP0/1                 |                                    | I2C0              |         |
| ULFRCO                     |        | VDAC0/1                 |                                    |                   |         |

**Note:**

1. Peripherals on PDHV are also available in EM4.
2. If any of PD0B, PD0C, or PD0D are enabled, PD0E will also be automatically enabled.

### 3.11 Reset Management Unit (RMU)

The RMU is responsible for handling reset of the EFR32MG24. A wide range of reset sources are available, including several power supply monitors, pin reset, software controlled reset, core lockup reset, and watchdog reset.

## 3.12 Core, Memory, and Accelerators

### 3.12.1 Processor Core

The ARM Cortex-M processor includes a 32-bit RISC processor integrating the following features and tasks in the system:

- ARM Cortex-M33 RISC processor achieving 1.50 Dhrystone MIPS/MHz
- ARM TrustZone security technology
- Embedded Trace Macrocell (ETM) for real-time trace and debug
- Up to 1536 KB flash program memory
- Up to 256 KB RAM data memory
- Configuration and event handling of all modules
- 2-pin Serial-Wire debug interface

### 3.12.2 Memory System Controller (MSC)

The Memory System Controller (MSC) is the program memory unit of the microcontroller. The flash memory is readable and writable from both the Cortex-M33 and LDMA. In addition to the main flash array where Program code is normally written the MSC also provides an Information block where additional information such as special user information or flash-lock bits are stored. There is also a read-only page in the information block containing system and device calibration data. Read and write operations are supported in energy modes EM0 Active and EM1 Sleep.

### 3.12.3 Linked Direct Memory Access Controller (LDMA)

The Linked Direct Memory Access (LDMA) controller allows the system to perform memory operations independently of software. This reduces both energy consumption and software workload. The LDMA allows operations to be linked together and staged, enabling sophisticated operations to be implemented.

### 3.12.4 Matrix Vector Processor (MVP)

The Matrix Vector Processor (MVP) is designed to offload the major computationally intensive floating point operations, particularly matrixed complex floating point multiplications and additions. The MVP supports the acceleration of the key Angle-of-Arrival (AoA) MUSIC (MUltiple Signal Classification) algorithm computations, as well as other heavily floating-point computational problems such as Machine Learning (ML) or linear algebra.

### 3.13 Memory Map

The EFR32MG24 memory map is shown in the figures below. RAM and flash sizes are for the largest memory configuration.

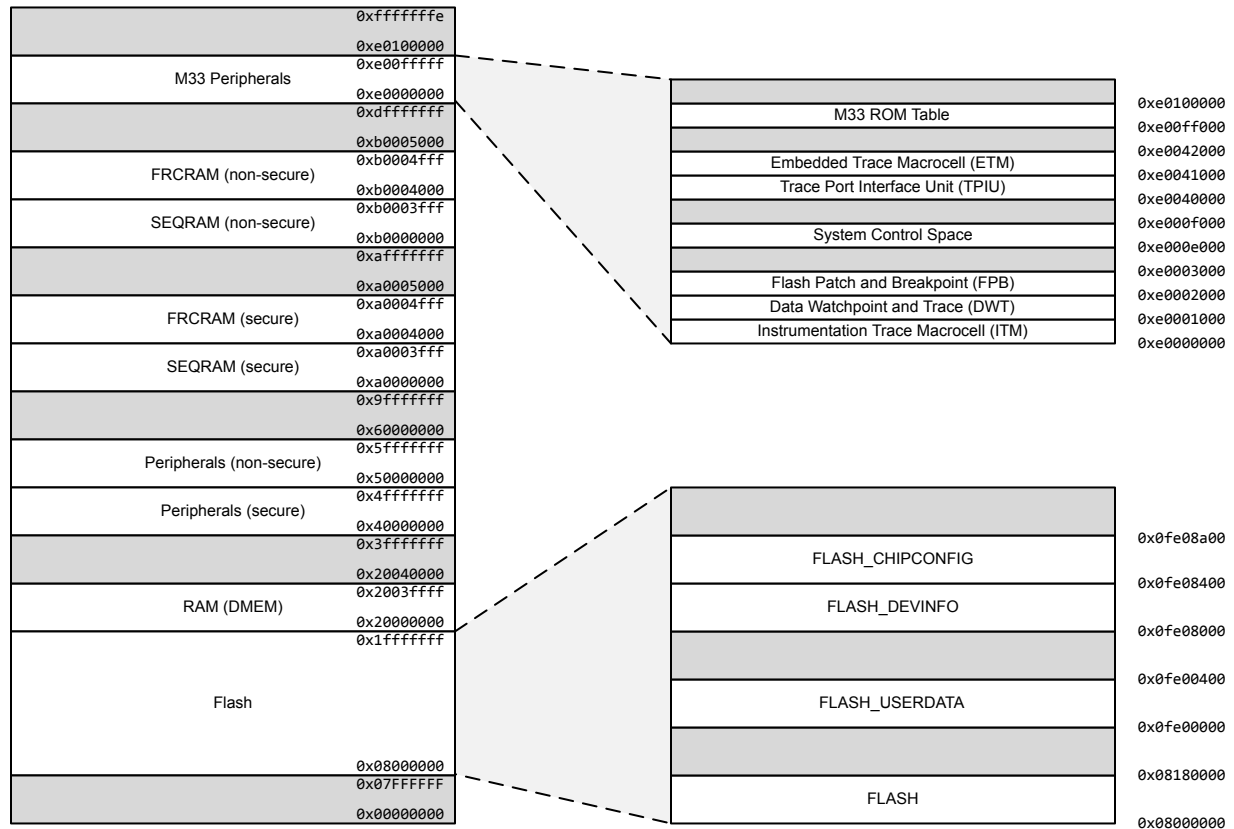


Figure 3.2. EFR32MG24 Memory Map — Core Peripherals and Code Space

### 3.14 Configuration Summary

The features of the EFR32MG24 are a subset of the feature set described in the device reference manual. The table below describes device specific implementation of the features. Remaining modules support full configuration. Refer to the Energy Modes table in the Reference Manual EMU Chapter for a more comprehensive list of energy mode support for all device peripherals.

**Table 3.3. Configuration Summary**

| Module  | Lowest Energy Mode  | Configuration                   |
|---|---|---------------------------------|
| I2C0  | EM1 - Full functionality<br>EM2/3 <sup>1</sup> - Functionality limited to receive address recognition   |                                 |
| I2C1  | EM1 - Full functionality  |                                 |
| LETIMER0  | EM2/3 <sup>1</sup>  | 24-bit, 2-channels              |
| TIMER0  | EM1   | 32-bit, 3-channels, +DTI        |
| TIMER1  | EM1   | 32-bit, 3-channels, +DTI        |
| TIMER2  | EM1   | 16-bit, 3-channels, +DTI        |
| TIMER3  | EM1   | 16-bit, 3-channels, +DTI        |
| TIMER4  | EM1   | 16-bit, 3-channels, +DTI        |
| EUSART0   | EM1 - Full high-speed operation, all modes<br>EM2 <sup>1</sup> - Low-energy UART operation, 9600 Baud<br>EM2/3 <sup>1</sup> - Low-energy SPI secondary receiver | UART, SPI, IrDA, DALI           |
| EUSART1   | EM1   | UART, SPI, IrDA, DALI           |
| USART0  | EM1   | UART, SPI, IrDA, I2S, SmartCard |
| <b>Note:</b><br>1. EM2 and EM3 operation is only supported for digital peripheral I/O on Port A and Port B. All GPIO ports support digital peripheral operation in EM0 and EM1. |   |                                 |

## 4. Electrical Specifications

### 4.1 Electrical Characteristics

All electrical parameters in all tables are specified under the following conditions, unless stated otherwise:

- Typical values are based on  $T_A=25\text{ }^\circ\text{C}$  and all supplies at 3.0 V, by production test and/or technology characterization.
- Radio performance numbers are measured in conducted mode, based on Silicon Laboratories reference designs using output power-specific external RF impedance-matching networks for interfacing to a 50  $\Omega$  antenna.
- Minimum and maximum values represent the worst conditions across supply voltage, process variation, and operating temperature, unless stated otherwise.

Due to on-chip circuitry (e.g., diodes), some EFR32MG24 power supply pins have a dependent relationship with one or more other power supply pins. These internal relationships between the external voltages applied to the various EFR32MG24 supply pins are defined below. Exceeding the below constraints can result in damage to the device and/or increased current draw.

- VREGVDD and DVDD
  - In systems using the DCDC converter, DVDD (the buck converter output) should not be driven externally and VREGVDD (the buck converter input) must be greater than DVDD ( $VREGVDD \geq DVDD$ )
  - In systems not using the DCDC converter, DVDD must be shorted to VREGVDD on the PCB ( $VREGVDD = DVDD$ )
- AVDD, IOVDD: No dependency with each other or any other supply pin. Additional leakage may occur if DVDD remains unpowered with power applied to these supplies.
- $DVDD \geq DECOUPLE$
- $PAVDD \geq RFVDD$

## 4.2 Absolute Maximum Ratings

Stresses beyond those listed below may cause permanent damage to the device. This is a stress rating only and functional operation of the devices at those or any other conditions beyond those indicated in the operation listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability. For more information on the available quality and reliability data, see the Quality and Reliability Monitor Report at <http://www.silabs.com/support/quality/pages/default.aspx>.

**Table 4.1. Absolute Maximum Ratings**

| Parameter   | Symbol                 | Test Condition | Min  | Typ | Max                      | Unit   |
|---|------------------------|----------------|------|-----|--------------------------|--------|
| Storage temperature range   | T <sub>STG</sub>       |                | -50  | —   | +150                     | °C     |
| Voltage on any supply pin <sup>1</sup>  | V <sub>DDMAX</sub>     |                | -0.3 | —   | 3.8                      | V      |
| Junction temperature  | T <sub>JMAX</sub>      | -I grade       | —    | —   | +125                     | °C     |
| Voltage ramp rate on any supply pin   | V <sub>DDRAMPMAX</sub> |                | —    | —   | 1.0                      | V / μs |
| Voltage on HFXO pins  | V <sub>HFXOPIN</sub>   |                | -0.3 | —   | 1.2                      | V      |
| DC voltage on any GPIO pin  | V <sub>DIGPIN</sub>    |                | -0.3 | —   | V <sub>IOVDD</sub> + 0.3 | V      |
| DC voltage on RESETn pin <sup>2</sup>   | V <sub>RESETn</sub>    |                | -0.3 | —   | 3.8                      | V      |
| DC voltage on RF pin RF2G4_IO   | V <sub>MAX2G4</sub>    |                | -0.3 | —   | 1.2                      | V      |
| Total current into VDD power lines  | I <sub>VDDMAX</sub>    | Source         | —    | —   | 200                      | mA     |
| Total current into VSS ground lines   | I <sub>VSSMAX</sub>    | Sink           | —    | —   | 200                      | mA     |
| Current per I/O pin   | I <sub>IOMAX</sub>     | Sink           | —    | —   | 50                       | mA     |
|   |                        | Source         | —    | —   | 50                       | mA     |
| Current for all I/O pins  | I <sub>IOALLMAX</sub>  | Sink           | —    | —   | 200                      | mA     |
|   |                        | Source         | —    | —   | 200                      | mA     |
| <b>Note:</b>  |                        |                |      |     |                          |        |
| 1. The maximum supply voltage on VREGVDD is limited under certain conditions when using the DC-DC. See the DC-DC specifications for more details. |                        |                |      |     |                          |        |
| 2. The RESETn pin has a pull-up device to the DVDD supply. For minimum leakage, RESETn should not exceed the voltage at DVDD.                     |                        |                |      |     |                          |        |

## 4.3 General Operating Conditions

Table 4.2. General Operating Conditions

| Parameter  | Symbol            | Test Condition   | Min  | Typ  | Max         | Unit    |
|--|-------------------|--|------|------|-------------|---------|
| Operating ambient temperature range              | $T_A$             | -I temperature grade <sup>1</sup>  | -40  | —    | +125        | ° C     |
| DVDD supply voltage                              | $V_{DVDD}$        | EM0/1  | 1.71 | 3.0  | 3.8         | V       |
|  |                   | EM2/3/4 <sup>2</sup>   | 1.71 | 3.0  | 3.8         | V       |
| AVDD supply voltage                              | $V_{AVDD}$        | AVDDBODEN=0 <sup>3</sup>   | 1.71 | 3.0  | 3.8         | V       |
| IOVDDx operating supply voltage (All IOVDD pins) | $V_{IOVDDx}$      | IOVDDxBODEN=0 <sup>3</sup>   | 1.71 | 3.0  | 3.8         | V       |
| RFVDD operating supply voltage                   | $V_{RFVDD}$       |  | 1.71 | 3.0  | $V_{PAVDD}$ | V       |
| VREGVDD operating supply voltage                 | $V_{VREGVDD}$     | DC-DC in regulation <sup>4</sup>   | 2.2  | 3.0  | 3.8         | V       |
|  |                   | DC-DC in bypass 60 mA load   | 1.8  | 3.0  | 3.8         | V       |
|  |                   | DC-DC in bypass 120 mA load  | 1.8  | 3.0  | 3.8         | V       |
|  |                   | DC-DC not in use. DVDD externally shorted to VREGVDD                       | 1.71 | 3.0  | 3.8         | V       |
| PAVDD operating supply voltage                   | $V_{PAVDD}$       |  | 1.71 | 3.0  | 3.8         | V       |
| DECOUPLE output capacitor <sup>5</sup>           | $C_{DECOUPLE}$    | 1.0 $\mu$ F $\pm$ 10% X8L capacitor used for performance characterization. | 1.0  | —    | 2.75        | $\mu$ F |
| HCLK and SYSCLK frequency                        | $f_{HCLK}$        | VSCALE2, MODE = WS1  | —    | —    | 78          | MHz     |
|  |                   | VSCALE2, MODE = WS0  | —    | —    | 40          | MHz     |
|  |                   | VSCALE1, MODE = WS1  | —    | —    | 40          | MHz     |
|  |                   | VSCALE1, MODE = WS0  | —    | —    | 20          | MHz     |
| PCLK frequency                                   | $f_{PCLK}$        | VSCALE2 or VSCALE1   | —    | —    | 40          | MHz     |
| EM01 Group A clock frequency                     | $f_{EM01GRPACLK}$ | VSCALE2  | —    | —    | 78          | MHz     |
|  |                   | VSCALE1  | —    | —    | 40          | MHz     |
| EM01 Group C clock frequency                     | $f_{EM01GRPCCLK}$ | VSCALE2  | —    | —    | 78          | MHz     |
|  |                   | VSCALE1  | —    | —    | 40          | MHz     |
| Radio HCLK frequency <sup>6</sup>                | $f_{RHCLK}$       | VSCALE2 or VSCALE1   | —    | 39.0 | —           | MHz     |
| External Clock Input                             | $f_{CLKIN}$       | VSCALE2 or VSCALE1, IOVDD $\geq$ 2.7 V                                     | —    | —    | 40          | MHz     |
| DPLL Reference Clock                             | $f_{DPLLREFCLK}$  | VSCALE2 or VSCALE1   | —    | —    | 40          | MHz     |

| Parameter  | Symbol | Test Condition | Min | Typ | Max | Unit |
|--|--------|----------------|-----|-----|-----|------|
| <b>Note:</b>   |        |                |     |     |     |      |
| <ol style="list-style-type: none"> <li>1. The device may operate continuously at the maximum allowable ambient <math>T_A</math> rating as long as the absolute maximum <math>T_{JMAX}</math> is not exceeded. For an application with significant power dissipation, the allowable <math>T_A</math> may be lower than the maximum <math>T_A</math> rating. <math>T_A = T_{JMAX} - (\text{THETA}_{JA} \times \text{PowerDissipation})</math>. Refer to the Absolute Maximum Ratings table and the Thermal Characteristics table for <math>T_{JMAX}</math> and <math>\text{THETA}_{JA}</math>.</li> <li>2. The DVDD supply is monitored by the DVDD BOD in EM0/1 and the LE DVDD BOD in EM2/3/4.</li> <li>3. The AVDD and IOVDD enable bits are in the EMU_BOD3SENSE register. These BODs are disabled on reset.</li> <li>4. The maximum supply voltage on VREGVDD is limited under certain conditions when using the DC-DC. See the DC-DC specifications for more details.</li> <li>5. Murata GCM21BL81C105KA58L used for performance characterization. Actual capacitor values can be significantly de-rated from their specified nominal value by the rated tolerance, as well as the application's AC voltage, DC bias, and temperature. The minimum capacitance counting all error sources should be no less than 0.6 <math>\mu\text{F}</math>.</li> <li>6. The recommended radio crystal frequency for the 2.4GHz radio is 39 MHz. The minimum and maximum RHCLK frequency in this table represent the design timing limits, which are much wider than the typical crystal tolerance.</li> </ol> |        |                |     |     |     |      |

#### 4.4 DC-DC Converter

Test conditions:  $L_{DCDC} = 2.2 \mu\text{H}$  (Murata DFE2HCAH2R2MJ0),  $C_{DCDC} = 4.7 \mu\text{F}$  (TDK CGA5L3X8R1C475K160AB),  $V_{VREGVDD} = 3.0 \text{ V}$ ,  $V_{OUT} = 1.8 \text{ V}$ , IPKVAL in EM0/1 modes is set to 150 mA, and in EM2/3 modes is set to 90 mA, unless otherwise indicated.

**Table 4.3. DC-DC Converter**

| Parameter                          | Symbol        | Test Condition  | Min        | Typ   | Max | Unit          |
|------------------------------------|---------------|---|------------|-------|-----|---------------|
| Input voltage range at VREGVDD pin | $V_{VREGVDD}$ | DCDC in regulation, $I_{LOAD} = I_{LOAD MAX}^1$ , EM0/EM1 mode                              | 2.2        | —     | 3.8 | V             |
|                                    |               | DCDC in regulation, $I_{LOAD} = 5 \text{ mA}$ , EM0/EM1 or EM2/EM3 mode                     | 1.8        | —     | 3.8 | V             |
|                                    |               | Bypass Mode, $I_{LOAD} \leq 60 \text{ mA}$  | 1.8        | —     | 3.8 | V             |
|                                    |               | Bypass Mode, $I_{LOAD} \leq 120 \text{ mA}$   | 1.9        | —     | 3.8 | V             |
| Regulated output voltage           | $V_{OUT}$     |   | —          | 1.8   | —   | V             |
| Regulation DC accuracy             | $ACC_{DC}$    | $V_{VREGVDD} \geq 2.2 \text{ V}$ , Steady state in EM0/EM1 mode or EM2/EM3 mode             | -2.5       | —     | 4.0 | %             |
| Regulation total accuracy          | $ACC_{TOT}$   | All error sources (including DC errors, overshoot, undershoot)                              | -5         | —     | 7   | %             |
| Steady-state output ripple         | $V_R$         | $I_{LOAD} = 20 \text{ mA}$ in EM0/EM1 mode  | —          | 12    | —   | mVpp          |
| DC line regulation                 | $V_{REG}$     | $I_{LOAD} = I_{LOAD MAX}$ in EM0/EM1 mode, $V_{VREGVDD} \geq 2.2 \text{ V}$                 | —          | -2.6  | —   | mV/V          |
| Efficiency                         | EFF           | Load current between 100 $\mu\text{A}$ and 60 mA in EM0/EM1 mode                            | —          | 90    | —   | %             |
|                                    |               | Load current between 10 $\mu\text{A}$ and 5 mA in EM2/EM3 mode                              | —          | 89    | —   | %             |
| DC load regulation                 | $I_{REG}$     | Load current between 100 $\mu\text{A}$ and $I_{LOAD MAX}$ in EM0/EM1 mode                   | —          | -0.08 | —   | mV/mA         |
| Output load current                | $I_{LOAD}$    | EM0/EM1 mode, DCDC in regulation, DCDC_EM01CTRL0.IPKVAL = 9, Radio not transmitting         | —          | —     | 60  | mA            |
|                                    |               | EM0/EM1 mode, DCDC in regulation, Radio in receive mode                                     | —          | —     | 36  | mA            |
|                                    |               | EM0/EM1 mode, DCDC in regulation, Radio transmitting <sup>1</sup>                           | —          | —     | 120 | mA            |
|                                    |               | EM2/EM3 mode, DCDC in regulation  | —          | —     | 5   | mA            |
|                                    |               | Bypass mode, $1.8 \text{ V} \leq V_{VREGVDD} \leq 3.8 \text{ V}$                            | —          | —     | 60  | mA            |
|                                    |               | Bypass mode, $1.9 \text{ V} \leq V_{VREGVDD} \leq 3.8 \text{ V}$                            | —          | —     | 120 | mA            |
| Nominal output capacitor           | $C_{DCDC}$    | 4.7 $\mu\text{F} \pm 10\%$ X7R capacitor used for performance characterization <sup>2</sup> | —          | 4.7   | 10  | $\mu\text{F}$ |
| Nominal inductor                   | $L_{DCDC}$    | $\pm 20\%$ tolerance  | —          | 2.2   | —   | $\mu\text{H}$ |
| Nominal input capacitor            | $C_{IN}$      |   | $C_{DCDC}$ | —     | —   | $\mu\text{F}$ |

| Parameter                                  | Symbol                 | Test Condition  | Min | Typ  | Max  | Unit |
|--|------------------------|---|-----|------|------|------|
| Resistance in bypass mode                  | R <sub>BYP</sub>       | Bypass switch from VREGVDD to DVDD, V <sub>VREGVDD</sub> = 1.8 V                      | —   | 0.45 | 0.69 | Ω    |
|  |                        | Powertrain PFET switch from VREGVDD to VREGSW, V <sub>VREGVDD</sub> = 1.8 V           | —   | 0.6  | 0.9  | Ω    |
| Supply monitor threshold programming range | V <sub>CMP_RNG</sub>   | Programmable in 0.1 V steps   | 2   | —    | 2.3  | V    |
| Supply monitor threshold accuracy          | V <sub>CMP_ACC</sub>   | Supply falling edge trip point  | -5  | —    | 5    | %    |
| Supply monitor threshold hysteresis        | V <sub>CMP_HYST</sub>  | Positive hysteresis on the supply rising edge referred to the falling edge trip point | —   | 4    | —    | %    |
| Supply monitor response time               | t <sub>CMP_DELAY</sub> | Supply falling edge at -100 mV / μs   | —   | 0.6  | —    | μs   |

**Note:**

1. During radio transmit operations, the RAIL library will place the DCDC into a mode that increases the maximum load current, to support higher TX output power supplied from the DCDC converter.
2. Actual capacitor values can be significantly de-rated from their specified nominal value by the rated tolerance, as well as the application's AC voltage, DC bias, and temperature. The minimum capacitance counting all error sources should be no less than 3.6 μF.

## 4.5 Thermal Characteristics

**Table 4.4. Thermal Characteristics**

| Package          | Board  | Parameter                                  | Symbol        | Test Condition   | Value | Unit |
|------------------|--|--|---------------|--|-------|------|
| 40QFN<br>(5x5mm) | JEDEC - High Thermal Cond. (2s2p) <sup>1</sup> | Thermal Resistance, Junction to Ambient    | $\Theta_{JA}$ | Still Air  | 29.2  | °C/W |
|                  |  | Thermal Resistance, Junction to Board      | $\Theta_{JB}$ |  | 15.2  | °C/W |
|                  |  | Thermal Resistance, Junction to Top Center | $\Psi_{JT}$   |  | 0.3   | °C/W |
|                  |  | Thermal Resistance, Junction to Board      | $\Psi_{JB}$   |  | 11.2  | °C/W |
|                  | No Board                                       | Thermal Resistance, Junction to Case       | $\Theta_{JC}$ | Temperature controlled heat sink on top of package, all other sides of package insulated to prevent heat flow. | 24.6  | °C/W |
| 48QFN<br>(6x6mm) | JEDEC - High Thermal Cond. (2s2p) <sup>1</sup> | Thermal Resistance, Junction to Ambient    | $\Theta_{JA}$ | Still Air  | 27.7  | °C/W |
|                  |  | Thermal Resistance, Junction to Board      | $\Theta_{JB}$ |  | 14.6  | °C/W |
|                  |  | Thermal Resistance, Junction to Top Center | $\Psi_{JT}$   |  | 0.69  | °C/W |
|                  |  | Thermal Resistance, Junction to Board      | $\Psi_{JB}$   |  | 11.85 | °C/W |
|                  | No Board                                       | Thermal Resistance, Junction to Case       | $\Theta_{JC}$ | Temperature controlled heat sink on top of package, all other sides of package insulated to prevent heat flow. | 23.0  | °C/W |

**Note:**

1. Based on 4 layer PCB with dimension 3" x 4.5", PCB Thickness of 1.6 mm, per JEDEC. PCB Center Land with 9 Via to top internal plane of PCB.

## 4.6 Current Consumption

### 4.6.1 MCU current consumption using DC-DC at 3.0 V input

Unless otherwise indicated, typical conditions are: VREGVDD = AVDD = IOVDD = 3.0 V. DVDD = RFVDD = PAVDD = 1.8 V from DC-DC. Voltage scaling level = VSCALE1.  $T_A = 25\text{ }^\circ\text{C}$ . Minimum and maximum values in this table represent the worst conditions across process variation at  $T_A = 25\text{ }^\circ\text{C}$ .

**Table 4.5. MCU current consumption using DC-DC at 3.0 V input**

| Parameter   | Symbol       | Test Condition   | Min | Typ   | Max | Unit                     |
|---|--------------|--|-----|-------|-----|--------------------------|
| Current consumption in EM0 mode with all peripherals disabled | $I_{ACTIVE}$ | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, CPU running Prime from flash, VSCALE2         | —   | 33.3  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, CPU running while loop from flash, VSCALE2    | —   | 32.8  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, CPU running CoreMark loop from flash, VSCALE2 | —   | 49.1  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 39 MHz crystal, CPU running Prime from flash   | —   | 33.9  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 39 MHz crystal, CPU running while loop from flash  | —   | 33.4  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 39 MHz crystal, CPU running CoreMark loop from flash   | —   | 49.4  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 38 MHz HFRCO, CPU running while loop from flash  | —   | 28.1  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 26 MHz HFRCO, CPU running while loop from flash  | —   | 31.0  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 16 MHz HFRCO, CPU running while loop from flash  | —   | 37.6  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 1 MHz HFRCO, CPU running while loop from flash   | —   | 281.8 | —   | $\mu\text{A}/\text{MHz}$ |
| Current consumption in EM1 mode with all peripherals disabled | $I_{EM1}$    | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, VSCALE2                                       | —   | 22.6  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 39 MHz crystal   | —   | 24.4  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 38 MHz HFRCO   | —   | 19.0  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 26 MHz HFRCO   | —   | 22.0  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 16 MHz HFRCO   | —   | 28.5  | —   | $\mu\text{A}/\text{MHz}$ |
|   |              | 1 MHz HFRCO  | —   | 272.1 | —   | $\mu\text{A}/\text{MHz}$ |

| Parameter  | Symbol                     | Test Condition  | Min | Typ   | Max | Unit |
|--|----------------------------|---|-----|-------|-----|------|
| Current consumption in EM2 mode, VSCALE0   | I <sub>EM2_VS</sub>        | 256 kB RAM and full Radio RAM retention, RTC running from LFXO <sup>1</sup>                   | —   | 2.9   | —   | μA   |
|  |                            | 256 kB RAM and full Radio RAM retention, RTC running from LFRCO <sup>1</sup>                  | —   | 2.9   | —   | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from LFXO <sup>1</sup>                    | —   | 1.3   | —   | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from LFRCO <sup>1</sup>                   | —   | 1.3   | —   | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from LFRCO in precision mode <sup>1</sup> | —   | 1.9   | —   | μA   |
| Current consumption in EM3 mode, VSCALE0   | I <sub>EM3_VS</sub>        | 256 kB RAM and full Radio RAM retention, RTC running from ULFRCO <sup>1</sup>                 | —   | 2.7   | —   | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from ULFRCO <sup>1</sup>                  | —   | 1.1   | —   | μA   |
| Change in current consumption if CPU cached unre-tained in EM2 or EM3                | I <sub>EM23_CPUCACHE</sub> |   | —   | -0.06 | —   | μA   |
| Change in current consumption if EM0/1 peripheral states unretained in EM2 or EM3    | I <sub>EM23_STATERET</sub> |   | —   | -0.01 | —   | μA   |
| Change in current consumption for retained RAM bank in EM2 or EM3                    | I <sub>EM23_RAM</sub>      | Per 16 kB RAM bank  | —   | 0.11  | —   | μA   |
| Additional current in EM2 or EM3 when any peripheral in PD0B is enabled <sup>2</sup> | I <sub>PD0B_VS</sub>       |   | —   | 0.93  | —   | μA   |
| Additional current in EM2 or EM3 when any peripheral in PD0C is enabled <sup>2</sup> | I <sub>PD0C_VS</sub>       |   | —   | 0.26  | —   | μA   |
| Additional current in EM2 or EM3 when any peripheral in PD0D is enabled <sup>2</sup> | I <sub>PD0D_VS</sub>       |   | —   | 1.1   | —   | μA   |
| Additional current in EM2 or EM3 when any peripheral in PD0E is enabled <sup>2</sup> | I <sub>PD0E_VS</sub>       |   | —   | 0.09  | —   | μA   |
| Current consumption in EM4 mode  | I <sub>EM4</sub>           | No BURTC, no LF oscillator  | —   | 0.25  | —   | μA   |
|  |                            | BURTC with LFXO   | —   | 0.64  | —   | μA   |

| Parameter   | Symbol | Test Condition | Min | Typ | Max | Unit |
|---|--------|----------------|-----|-----|-----|------|
| <b>Note:</b> <ol style="list-style-type: none"><li>1. CPU cache retained, EM0/1 peripheral states retained</li><li>2. Extra current consumed by power domain. Does not include current associated with the enabled peripherals. See <a href="#">3.10.4 Power Domains</a> for a list of the peripherals in each power domain. Note that if the PD0B, PD0C, or PD0D domains are enabled, PD0E will also automatically be enabled.</li></ol> |        |                |     |     |     |      |

#### 4.6.2 Radio current consumption at 3.0V using DCDC

RF current consumption measured with MCU in EM1, HCLK = 39.0 MHz, and all MCU peripherals disabled. Unless otherwise indicated, typical conditions are: VREGVDD = IOVDD = 3.0 V. AVDD = DVDD = RFVDD = PAVDD = 1.8 V powered from DCDC. T<sub>A</sub> = 25 °C. Minimum and maximum values in this table represent the worst conditions across process variation at T<sub>A</sub> = 25 °C.

**Table 4.6. Radio current consumption at 3.0V using DCDC**

| Parameter   | Symbol                 | Test Condition   | Min | Typ | Max | Unit |
|---|------------------------|--|-----|-----|-----|------|
| System current consumption in receive mode, active packet reception | I <sub>RX_ACTIVE</sub> | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)        | —   | 4.6 | —   | mA   |
|   |                        | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                  | —   | 4.9 | —   | mA   |
|   |                        | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                  | —   | 5.2 | —   | mA   |
|   |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)        | —   | 4.7 | —   | mA   |
|   |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                  | —   | 5   | —   | mA   |
|   |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                  | —   | 5.2 | —   | mA   |
|   |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)          | —   | 4.4 | —   | mA   |
|   |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                    | —   | 4.7 | —   | mA   |
|   |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                    | —   | 4.9 | —   | mA   |
|   |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)          | —   | 5.1 | —   | mA   |
|   |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                    | —   | 5.4 | —   | mA   |
|   |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                    | —   | 5.6 | —   | mA   |
|   |                        | 802.15.4 receiving frame, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only) | —   | 5.1 | —   | mA   |
|   |                        | 802.15.4 receiving frame, f = 2.4 GHz, VSCALE1                           | —   | 5.4 | —   | mA   |
|   |                        | 802.15.4 receiving frame, f = 2.4 GHz, VSCALE2                           | —   | 5.7 | —   | mA   |

| Parameter  | Symbol                 | Test Condition  | Min | Typ   | Max | Unit |
|--|------------------------|---|-----|-------|-----|------|
| System current consumption in receive mode, listening for packet | I <sub>RX_LISTEN</sub> | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)                   | —   | 4.7   | —   | mA   |
|  |                        | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1   | —   | 4.9   | —   | mA   |
|  |                        | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2   | —   | 5.2   | —   | mA   |
|  |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)                   | —   | 4.7   | —   | mA   |
|  |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1   | —   | 5     | —   | mA   |
|  |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2   | —   | 5.2   | —   | mA   |
|  |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)                     | —   | 4.3   | —   | mA   |
|  |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1   | —   | 4.6   | —   | mA   |
|  |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2   | —   | 4.9   | —   | mA   |
|  |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)                     | —   | 5.1   | —   | mA   |
|  |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1   | —   | 5.4   | —   | mA   |
|  |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2   | —   | 5.7   | —   | mA   |
|  |                        | 802.15.4, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)                            | —   | 5     | —   | mA   |
|  |                        | 802.15.4, f = 2.4 GHz, VSCALE1  | —   | 5.3   | —   | mA   |
|  |                        | 802.15.4, f = 2.4 GHz, VSCALE2  | —   | 5.6   | —   | mA   |
| System current consumption in transmit mode                      | I <sub>TX</sub>        | f = 2.4 GHz, CW, 0 dBm PA, 0 dBm output power, VSCALE1                              | —   | 5     | —   | mA   |
|  |                        | f = 2.4 GHz, CW, 10 dBm PA, 10 dBm output power, VSCALE1                            | —   | 19.1  | —   | mA   |
|  |                        | f = 2.4 GHz, CW, 20 dBm PA, 19.5 dBm output power, VSCALE1, VREGVDD = PAVDD = 3.3 V | —   | 156.8 | —   | mA   |
|  |                        | f = 2.4 GHz, CW, 0 dBm PA, 0 dBm output power, VSCALE2                              | —   | 5.2   | —   | mA   |
|  |                        | f = 2.4 GHz, CW, 10 dBm PA, 10 dBm output power, VSCALE2                            | —   | 19.2  | —   | mA   |
|  |                        | f = 2.4 GHz, CW, 20 dBm PA, 19.5 dBm output power, VSCALE2, VREGVDD = PAVDD = 3.3 V | —   | 157.2 | —   | mA   |

### 4.6.3 MCU current consumption at 3.0 V

Unless otherwise indicated, typical conditions are: AVDD = DVDD = RFVDD = PAVDD = VREGVDD = 3.0 V. DC-DC not used. Voltage scaling level = VSCALE1. T<sub>A</sub> = 25 °C. Minimum and maximum values in this table represent the worst conditions across process variation at T<sub>A</sub> = 25 °C.

**Table 4.7. MCU current consumption at 3.0 V**

| Parameter   | Symbol              | Test Condition   | Min | Typ   | Max  | Unit   |
|---|---------------------|--|-----|-------|------|--------|
| Current consumption in EM0 mode with all peripherals disabled | I <sub>ACTIVE</sub> | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, CPU running Prime from flash, VSCALE2         | —   | 47.3  | —    | μA/MHz |
|   |                     | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, CPU running while loop from flash, VSCALE2    | —   | 46.1  | —    | μA/MHz |
|   |                     | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, CPU running CoreMark loop from flash, VSCALE2 | —   | 69.5  | —    | μA/MHz |
|   |                     | 39 MHz crystal, CPU running Prime from flash   | —   | 48.4  | —    | μA/MHz |
|   |                     | 39 MHz crystal, CPU running while loop from flash  | —   | 47.1  | —    | μA/MHz |
|   |                     | 39 MHz crystal, CPU running CoreMark loop from flash   | —   | 69.6  | —    | μA/MHz |
|   |                     | 38 MHz HFRCO, CPU running while loop from flash  | —   | 39.4  | 62   | μA/MHz |
|   |                     | 26 MHz HFRCO, CPU running while loop from flash  | —   | 43.6  | —    | μA/MHz |
|   |                     | 16 MHz HFRCO, CPU running while loop from flash  | —   | 52.7  | —    | μA/MHz |
|   |                     | 1 MHz HFRCO, CPU running while loop from flash   | —   | 392.4 | 1170 | μA/MHz |
| Current consumption in EM1 mode with all peripherals disabled | I <sub>EM1</sub>    | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, VSCALE2                                       | —   | 32.2  | —    | μA/MHz |
|   |                     | 39 MHz crystal   | —   | 34.5  | —    | μA/MHz |
|   |                     | 38 MHz HFRCO   | —   | 26.8  | 49   | μA/MHz |
|   |                     | 26 MHz HFRCO   | —   | 30.9  | —    | μA/MHz |
|   |                     | 16 MHz HFRCO   | —   | 40.0  | —    | μA/MHz |
|   |                     | 1 MHz HFRCO  | —   | 380.0 | 1160 | μA/MHz |

| Parameter  | Symbol                     | Test Condition  | Min | Typ   | Max  | Unit |
|--|----------------------------|---|-----|-------|------|------|
| Current consumption in EM2 mode, VSCALE0   | I <sub>EM2_VS</sub>        | 256 kB RAM and full Radio RAM retention, RTC running from LFXO <sup>1</sup>                   | —   | 4.2   | —    | μA   |
|  |                            | 256 kB RAM and full Radio RAM retention, RTC running from LFRCO <sup>1</sup>                  | —   | 4.2   | 9.2  | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from LFXO <sup>1</sup>                    | —   | 1.8   | —    | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from LFRCO <sup>1</sup>                   | —   | 1.9   | —    | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from LFRCO in precision mode <sup>1</sup> | —   | 2.8   | —    | μA   |
| Current consumption in EM3 mode, VSCALE0   | I <sub>EM3_VS</sub>        | 256 kB RAM and full Radio RAM retention, RTC running from ULFRCO <sup>1</sup>                 | —   | 3.9   | —    | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from ULFRCO <sup>1</sup>                  | —   | 1.5   | 2.5  | μA   |
| Change in current consumption if CPU cached unre-<br>tained in EM2 or EM3                  | I <sub>EM23_CPUCACHE</sub> |   | —   | -0.07 | —    | μA   |
| Change in current consumption if EM0/1 peripheral<br>states unretrained in EM2 or<br>EM3   | I <sub>EM23_STATERET</sub> |   | —   | -0.01 | —    | μA   |
| Change in current consumption for retained RAM bank in<br>EM2 or EM3                       | I <sub>EM23_RAM</sub>      | Per 16 kB RAM bank  | —   | 0.16  | —    | μA   |
| Additional current in EM2 or<br>EM3 when any peripheral in<br>PD0B is enabled <sup>2</sup> | I <sub>PD0B_VS</sub>       |   | —   | 1.4   | —    | μA   |
| Additional current in EM2 or<br>EM3 when any peripheral in<br>PD0C is enabled <sup>2</sup> | I <sub>PD0C_VS</sub>       |   | —   | 0.39  | —    | μA   |
| Additional current in EM2 or<br>EM3 when any peripheral in<br>PD0D is enabled <sup>2</sup> | I <sub>PD0D_VS</sub>       |   | —   | 1.6   | —    | μA   |
| Additional current in EM2 or<br>EM3 when any peripheral in<br>PD0E is enabled <sup>2</sup> | I <sub>PD0E_VS</sub>       |   | —   | 0.11  | —    | μA   |
| Current consumption in EM4<br>mode   | I <sub>EM4</sub>           | No BURTC, no LF oscillator  | —   | 0.26  | 0.65 | μA   |
|  |                            | BURTC with LFXO   | —   | 0.64  | —    | μA   |
| Current consumption during<br>reset  | I <sub>RST</sub>           | Hard pin reset held   | —   | 457   | —    | μA   |

| Parameter   | Symbol | Test Condition | Min | Typ | Max | Unit |
|---|--------|----------------|-----|-----|-----|------|
| <b>Note:</b> <ol style="list-style-type: none"><li>1. CPU cache retained, EM0/1 peripheral states retained</li><li>2. Extra current consumed by power domain. Does not include current associated with the enabled peripherals. See <a href="#">3.10.4 Power Domains</a> for a list of the peripherals in each power domain. Note that if the PD0B, PD0C, or PD0D domains are enabled, PD0E will also automatically be enabled.</li></ol> |        |                |     |     |     |      |

#### 4.6.4 Radio current consumption at 3.0V

RF current consumption measured with MCU in EM1, HCLK = 39.0 MHz, and all MCU peripherals disabled. Unless otherwise indicated, typical conditions are: AVDD = DVDD = IOVDD = RFVDD = PAVDD = 3.0 V. DCDC disabled. T<sub>A</sub> = 25 °C. Minimum and maximum values in this table represent the worst conditions across process variation at T<sub>A</sub> = 25 °C.

**Table 4.8. Radio current consumption at 3.0V**

| Parameter  | Symbol                 | Test Condition   | Min | Typ | Max | Unit |
|--|------------------------|--|-----|-----|-----|------|
| Current consumption in receive mode, active packet reception | I <sub>RX_ACTIVE</sub> | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)        | —   | 7.1 | —   | mA   |
|  |                        | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                  | —   | 7.5 | —   | mA   |
|  |                        | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                  | —   | 7.9 | —   | mA   |
|  |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)        | —   | 7.2 | —   | mA   |
|  |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                  | —   | 7.6 | —   | mA   |
|  |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                  | —   | 8   | —   | mA   |
|  |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)          | —   | 6.7 | —   | mA   |
|  |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                    | —   | 7.1 | —   | mA   |
|  |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                    | —   | 7.4 | —   | mA   |
|  |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)          | —   | 7.7 | —   | mA   |
|  |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                    | —   | 8.1 | —   | mA   |
|  |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                    | —   | 8.6 | —   | mA   |
|  |                        | 802.15.4 receiving frame, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only) | —   | 7.8 | —   | mA   |
|  |                        | 802.15.4 receiving frame, f = 2.4 GHz, VSCALE1                           | —   | 8.2 | —   | mA   |
|  |                        | 802.15.4 receiving frame, f = 2.4 GHz, VSCALE2                           | —   | 8.6 | —   | mA   |

| Parameter   | Symbol                 | Test Condition  | Min | Typ   | Max | Unit |
|---|------------------------|---|-----|-------|-----|------|
| Current consumption in receive mode, listening for packet | I <sub>RX_LISTEN</sub> | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)         | —   | 7.1   | —   | mA   |
|   |                        | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                   | —   | 7.5   | —   | mA   |
|   |                        | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                   | —   | 7.9   | —   | mA   |
|   |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)         | —   | 7.1   | —   | mA   |
|   |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                   | —   | 7.5   | —   | mA   |
|   |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                   | —   | 7.9   | —   | mA   |
|   |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)           | —   | 6.6   | —   | mA   |
|   |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                     | —   | 7     | —   | mA   |
|   |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                     | —   | 7.4   | —   | mA   |
|   |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)           | —   | 7.7   | —   | mA   |
|   |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                     | —   | 8.2   | —   | mA   |
|   |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                     | —   | 8.6   | —   | mA   |
|   |                        | 802.15.4, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)                  | —   | 7.6   | —   | mA   |
|   |                        | 802.15.4, f = 2.4 GHz, VSCALE1  | —   | 8     | —   | mA   |
|   |                        | 802.15.4, f = 2.4 GHz, VSCALE2  | —   | 8.5   | —   | mA   |
| Current consumption in transmit mode                      | I <sub>TX</sub>        | f = 2.4 GHz, CW, 0 dBm PA, 0 dBm output power, VSCALE2                    | —   | 8     | —   | mA   |
|   |                        | f = 2.4 GHz, CW, 10 dBm PA, 10 dBm output power, VSCALE2                  | —   | 28.7  | —   | mA   |
|   |                        | f = 2.4 GHz, CW, 20 dBm PA, 19.5 dBm output power, VSCALE2, PAVDD = 3.3 V | —   | 159.3 | —   | mA   |
|   |                        | f = 2.4 GHz, CW, 0 dBm PA, 0 dBm output power, VSCALE1                    | —   | 7.8   | —   | mA   |
|   |                        | f = 2.4 GHz, CW, 10 dBm PA, 10 dBm output power, VSCALE1                  | —   | 28.4  | —   | mA   |
|   |                        | f = 2.4 GHz, CW, 20 dBm PA, 19.5 dBm output power, VSCALE1, PAVDD = 3.3 V | —   | 160   | —   | mA   |

#### 4.6.5 MCU current consumption at 1.8 V

Unless otherwise indicated, typical conditions are: AVDD = DVDD = RFVDD = PAVDD = VREGVDD = 1.8 V. DC-DC not used. Voltage scaling level = VSCALE1. T<sub>A</sub> = 25 °C. Minimum and maximum values in this table represent the worst conditions across process variation at T<sub>A</sub> = 25 °C.

**Table 4.9. MCU current consumption at 1.8 V**

| Parameter   | Symbol              | Test Condition   | Min | Typ   | Max | Unit   |
|---|---------------------|--|-----|-------|-----|--------|
| Current consumption in EM0 mode with all peripherals disabled | I <sub>ACTIVE</sub> | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, CPU running Prime from flash, VSCALE2         | —   | 47.8  | —   | μA/MHz |
|   |                     | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, CPU running while loop from flash, VSCALE2    | —   | 46.1  | —   | μA/MHz |
|   |                     | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, CPU running CoreMark loop from flash, VSCALE2 | —   | 69.4  | —   | μA/MHz |
|   |                     | 39 MHz crystal, CPU running Prime from flash   | —   | 48.1  | —   | μA/MHz |
|   |                     | 39 MHz crystal, CPU running while loop from flash  | —   | 47.1  | —   | μA/MHz |
|   |                     | 39 MHz crystal, CPU running CoreMark loop from flash   | —   | 69.8  | —   | μA/MHz |
|   |                     | 38 MHz HFRCO, CPU running while loop from flash  | —   | 39.4  | —   | μA/MHz |
|   |                     | 26 MHz HFRCO, CPU running while loop from flash  | —   | 43.5  | —   | μA/MHz |
|   |                     | 16 MHz HFRCO, CPU running while loop from flash  | —   | 52.5  | —   | μA/MHz |
|   |                     | 1 MHz HFRCO, CPU running while loop from flash   | —   | 390.0 | —   | μA/MHz |
| Current consumption in EM1 mode with all peripherals disabled | I <sub>EM1</sub>    | 78 MHz HFRCO w/ DPLL referenced to 39 MHz crystal, VSCALE2                                       | —   | 32.2  | —   | μA/MHz |
|   |                     | 39 MHz crystal   | —   | 34.5  | —   | μA/MHz |
|   |                     | 38 MHz HFRCO   | —   | 26.7  | —   | μA/MHz |
|   |                     | 26 MHz HFRCO   | —   | 30.8  | —   | μA/MHz |
|   |                     | 16 MHz HFRCO   | —   | 39.8  | —   | μA/MHz |
|   |                     | 1 MHz HFRCO  | —   | 377.3 | —   | μA/MHz |

| Parameter  | Symbol                     | Test Condition  | Min | Typ   | Max | Unit |
|--|----------------------------|---|-----|-------|-----|------|
| Current consumption in EM2 mode, VSCALE0   | I <sub>EM2_VS</sub>        | 256 kB RAM and full Radio RAM retention, RTC running from LFXO <sup>1</sup>                   | —   | 4.1   | —   | μA   |
|  |                            | 256 kB RAM and full Radio RAM retention, RTC running from LFRCO <sup>1</sup>                  | —   | 4.1   | —   | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from LFXO <sup>1</sup>                    | —   | 1.8   | —   | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from LFRCO <sup>1</sup>                   | —   | 1.8   | —   | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from LFRCO in precision mode <sup>1</sup> | —   | 2.7   | —   | μA   |
| Current consumption in EM3 mode, VSCALE0   | I <sub>EM3_VS</sub>        | 256 kB RAM and full Radio RAM retention, RTC running from ULFRCO <sup>1</sup>                 | —   | 3.7   | —   | μA   |
|  |                            | 16 kB RAM and full Radio RAM retention, RTC running from ULFRCO <sup>1</sup>                  | —   | 1.4   | —   | μA   |
| Change in current consumption if CPU cached unre-tained in EM2 or EM3                | I <sub>EM23_CPUCACHE</sub> |   | —   | -0.07 | —   | μA   |
| Change in current consumption if EM0/1 peripheral states unretained in EM2 or EM3    | I <sub>EM23_STATERET</sub> |   | —   | -0.01 | —   | μA   |
| Change in current consumption for retained RAM bank in EM2 or EM3                    | I <sub>EM23_RAM</sub>      | Per 16 kB RAM bank  | —   | 0.16  | —   | μA   |
| Additional current in EM2 or EM3 when any peripheral in PD0B is enabled <sup>2</sup> | I <sub>PD0B_VS</sub>       |   | —   | 1.4   | —   | μA   |
| Additional current in EM2 or EM3 when any peripheral in PD0C is enabled <sup>2</sup> | I <sub>PD0C_VS</sub>       |   | —   | 0.38  | —   | μA   |
| Additional current in EM2 or EM3 when any peripheral in PD0D is enabled <sup>2</sup> | I <sub>PD0D_VS</sub>       |   | —   | 1.6   | —   | μA   |
| Additional current in EM2 or EM3 when any peripheral in PD0E is enabled <sup>2</sup> | I <sub>PD0E_VS</sub>       |   | —   | 0.12  | —   | μA   |
| Current consumption in EM4 mode  | I <sub>EM4</sub>           | No BURTC, no LF oscillator  | —   | 0.18  | —   | μA   |
|  |                            | BURTC with LFXO   | —   | 0.53  | —   | μA   |
| Current consumption during reset   | I <sub>RST</sub>           | Hard pin reset held   | —   | 391   | —   | μA   |

| Parameter   | Symbol | Test Condition | Min | Typ | Max | Unit |
|---|--------|----------------|-----|-----|-----|------|
| <b>Note:</b> <ol style="list-style-type: none"><li>1. CPU cache retained, EM0/1 peripheral states retained</li><li>2. Extra current consumed by power domain. Does not include current associated with the enabled peripherals. See <a href="#">3.10.4 Power Domains</a> for a list of the peripherals in each power domain. Note that if the PD0B, PD0C, or PD0D domains are enabled, PD0E will also automatically be enabled.</li></ol> |        |                |     |     |     |      |

#### 4.6.6 Radio current consumption at 1.8V

RF current consumption measured with MCU in EM1, HCLK = 39.0 MHz, and all MCU peripherals disabled. Unless otherwise indicated, typical conditions are: AVDD = DVDD = IOVDD = RFVDD = PAVDD = 1.8 V. DCDC disabled. T<sub>A</sub> = 25 °C. Minimum and maximum values in this table represent the worst conditions across process variation at T<sub>A</sub> = 25 °C.

**Table 4.10. Radio current consumption at 1.8V**

| Parameter  | Symbol                 | Test Condition   | Min | Typ | Max | Unit |
|--|------------------------|--|-----|-----|-----|------|
| Current consumption in receive mode, active packet reception | I <sub>RX_ACTIVE</sub> | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)        | —   | 7   | —   | mA   |
|  |                        | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                  | —   | 7.5 | —   | mA   |
|  |                        | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                  | —   | 7.9 | —   | mA   |
|  |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)        | —   | 7.1 | —   | mA   |
|  |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                  | —   | 7.6 | —   | mA   |
|  |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                  | —   | 8   | —   | mA   |
|  |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)          | —   | 6.6 | —   | mA   |
|  |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                    | —   | 7.1 | —   | mA   |
|  |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                    | —   | 7.4 | —   | mA   |
|  |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)          | —   | 7.7 | —   | mA   |
|  |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1                                    | —   | 8.1 | —   | mA   |
|  |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                                    | —   | 8.6 | —   | mA   |
|  |                        | 802.15.4 receiving frame, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only) | —   | 7.8 | —   | mA   |
|  |                        | 802.15.4 receiving frame, f = 2.4 GHz, VSCALE1                           | —   | 8.2 | —   | mA   |
|  |                        | 802.15.4 receiving frame, f = 2.4 GHz, VSCALE2                           | —   | 8.6 | —   | mA   |

| Parameter   | Symbol                 | Test Condition  | Min | Typ  | Max | Unit |
|---|------------------------|---|-----|------|-----|------|
| Current consumption in receive mode, listening for packet | I <sub>RX_LISTEN</sub> | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only) | —   | 7.1  | —   | mA   |
|   |                        | 125 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                           | —   | 7.9  | —   | mA   |
|   |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only) | —   | 7.1  | —   | mA   |
|   |                        | 500 kbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                           | —   | 7.9  | —   | mA   |
|   |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)   | —   | 6.6  | —   | mA   |
|   |                        | 1 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                             | —   | 7.4  | —   | mA   |
|   |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)   | —   | 7.7  | —   | mA   |
|   |                        | 2 Mbit/s, 2GFSK, f = 2.4 GHz, VSCALE2                             | —   | 8.6  | —   | mA   |
|   |                        | 802.15.4, f = 2.4 GHz, VSCALE1, EM1P (Radio clocks only)          | —   | 7.6  | —   | mA   |
|   |                        | 802.15.4, f = 2.4 GHz, VSCALE2                                    | —   | 8.4  | —   | mA   |
| Current consumption in transmit mode                      | I <sub>TX</sub>        | f = 2.4 GHz, CW, 0 dBm PA, 0 dBm output power, VSCALE2            | —   | 7.8  | —   | mA   |
|   |                        | f = 2.4 GHz, CW, 10 dBm PA, 10 dBm output power, VSCALE2          | —   | 28.5 | —   | mA   |
|   |                        | f = 2.4 GHz, CW, 0 dBm PA, 0 dBm output power, VSCALE1            | —   | 7.5  | —   | mA   |
|   |                        | f = 2.4 GHz, CW, 10 dBm PA, 10 dBm output power, VSCALE1          | —   | 28.2 | —   | mA   |

## 4.7 Flash Characteristics

**Table 4.11. Flash Characteristics**

| Parameter                                      | Symbol        | Test Condition   | Min    | Typ   | Max   | Unit          |
|--|---------------|--|--------|-------|-------|---------------|
| Flash Supply voltage during write or erase     | $V_{FLASH}$   |  | 1.71   | —     | 3.8   | V             |
| Flash data retention <sup>1</sup>              | $RET_{FLASH}$ | $T_A \leq 125\text{ }^\circ\text{C}$                               | 10     | —     | —     | years         |
| Flash erase cycles before failure <sup>1</sup> | $EC_{FLASH}$  | $T_A \leq 125\text{ }^\circ\text{C}$                               | 10,000 | —     | —     | cycles        |
| Program Time                                   | $t_{PROG}$    | $T_A = 25\text{ }^\circ\text{C}$ , one word (32-bits)              | 41.9   | 43.4  | 45.0  | $\mu\text{s}$ |
|  |               | $T_A = 25\text{ }^\circ\text{C}$ , average per word over 128 words | 10.6   | 10.9  | 11.3  | $\mu\text{s}$ |
| Page Erase Time <sup>2</sup>                   | $t_{PERASE}$  | $T_A = 25\text{ }^\circ\text{C}$                                   | 11.6   | 12.9  | 14.0  | ms            |
| Mass Erase Time <sup>3 4</sup>                 | $t_{MERASE}$  | $T_A = 25\text{ }^\circ\text{C}$ , 1536kB                          | 144.3  | 150.5 | 156.8 | ms            |
| Program Current                                | $I_{WRITE}$   |  | —      | —     | 2.8   | mA            |
| Page Erase Current                             | $I_{PERASE}$  | Page Erase   | —      | —     | 1.9   | mA            |
| Mass Erase Current                             | $I_{MERASE}$  | Mass Erase   | —      | —     | 2.0   | mA            |

**Note:**

- Flash data retention information is published in the Quarterly Quality and Reliability Report.
- Page Erase time is measured from setting the ERASEPAGE bit in the MSC\_WRITECMD register until the BUSY bit in the MSC-STATUS register is cleared to 0. Internal set-up and hold times are included.
- Mass Erase is issued by the CPU and erases all of User space.
- Mass Erase time is measured from setting the ERASEMAIN0 bit in the MSC\_WRITECMD register until the BUSY bit in the MSC-STATUS register is cleared to 0. Internal set-up and hold times are included.

#### 4.8 Energy Mode Wake-up and Entry Times

Unless otherwise specified, these times are measured using the HFRCO at 19 MHz.

**Table 4.12. Energy Mode Wake-up and Entry Times**

| Parameter                                | Symbol         | Test Condition                                | Min | Typ  | Max | Unit    |
|--|----------------|---|-----|------|-----|---------|
| Wake-up Time from EM1                    | $t_{EM1\_WU}$  | Code execution from flash                     | —   | 3    | —   | HCLKs   |
|  |                | Code execution from RAM                       | —   | 1.4  | —   | $\mu$ s |
| Wake-up Time from EM2                    | $t_{EM2\_WU}$  | Code execution from flash, No Voltage Scaling | —   | 13.7 | —   | $\mu$ s |
|  |                | Code execution from RAM, No Voltage Scaling   | —   | 5.1  | —   | $\mu$ s |
|  |                | Voltage scaling up one level <sup>1</sup>     | —   | 37.7 | —   | $\mu$ s |
|  |                | Voltage scaling up two levels <sup>2</sup>    | —   | 50.7 | —   | $\mu$ s |
| Wake-up Time from EM3                    | $t_{EM3\_WU}$  | Code execution from flash, No Voltage Scaling | —   | 13.7 | —   | $\mu$ s |
|  |                | Code execution from RAM, No Voltage Scaling   | —   | 5.1  | —   | $\mu$ s |
|  |                | Voltage scaling up one level <sup>1</sup>     | —   | 37.7 | —   | $\mu$ s |
|  |                | Voltage scaling up two levels <sup>2</sup>    | —   | 50.7 | —   | $\mu$ s |
| Wake-up Time from EM4                    | $t_{EM4\_WU}$  | Code execution from flash                     | —   | 21.7 | —   | ms      |
| Entry time to EM1                        | $t_{EM1\_ENT}$ | Code execution from flash                     | —   | 1.5  | —   | $\mu$ s |
| Entry time to EM2                        | $t_{EM2\_ENT}$ | Code execution from flash                     | —   | 6.1  | —   | $\mu$ s |
| Entry time to EM3                        | $t_{EM3\_ENT}$ | Code execution from flash                     | —   | 6.0  | —   | $\mu$ s |
| Entry time to EM4                        | $t_{EM4\_ENT}$ | Code execution from flash                     | —   | 11.2 | —   | $\mu$ s |
| Voltage scaling time in EM0 <sup>3</sup> | $t_{SCALE}$    | Up from VSCALE1 to VSCALE2                    | —   | 32   | —   | $\mu$ s |
|  |                | Down from VSCALE2 to VSCALE1                  | —   | 172  | —   | $\mu$ s |

**Note:**

1. Voltage scaling one level is between VSCALE0 and VSCALE1 or between VSCALE1 and VSCALE2.
2. Voltage scaling two levels is between VSCALE0 and VSCALE2.
3. During voltage scaling in EM0, RAM is inaccessible and processor will be halted until complete.

## 4.9 2.4 GHz RF Transceiver Characteristics

### 4.9.1 RF Transmitter Characteristics

#### 4.9.1.1 RF Transmitter General Characteristics for the 2.4 GHz Band

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ , Crystal frequency=39.0 MHz, RF center frequency = 2.45 GHz.

- For 0 dBm / 10 dBm PA: VREGVDD = IOVDD = AVDD = 3.0 V, DVDD = RFVDD = PAVDD = 1.8 V powered from DCDC
- For 20 dBm PA: VREGVDD = IOVDD = AVDD = PAVDD = 3.3 V, DVDD = RFVDD = 1.8 V powered from DCDC

**Table 4.13. RF Transmitter General Characteristics for the 2.4 GHz Band**

| Parameter  | Symbol                      | Test Condition   | Min  | Typ   | Max    | Unit |
|--|-----------------------------|--|------|-------|--------|------|
| RF tuning frequency range  | $F_{\text{RANGE}}$          |  | 2400 | —     | 2483.5 | MHz  |
| Radio-only current consumption while transmitting <sup>1</sup>                 | $I_{\text{TX\_RADIO}}$      | f = 2.4 GHz, CW, 0 dBm PA, 0 dBm output power  | —    | 3.5   | —      | mA   |
|  |                             | f = 2.4 GHz, CW, 10 dBm PA, 10 dBm output power  | —    | 17.6  | —      | mA   |
| Maximum TX power <sup>2</sup>  | $POUT_{\text{MAX}}$         | 20 dBm PA, PAVDD = 3.3 V   | —    | 19.5  | —      | dBm  |
|  |                             | 10 dBm PA <sup>3</sup>   | —    | 10    | —      | dBm  |
|  |                             | 0 dBm PA   | —    | -0.7  | —      | dBm  |
| Minimum active TX power  | $POUT_{\text{MIN}}$         | 20 dBm PA, PAVDD = 3.3 V   | —    | -34   | —      | dBm  |
|  |                             | 10 dBm PA  | —    | -29.8 | —      | dBm  |
|  |                             | 0 dBm PA   | —    | -25.2 | —      | dBm  |
| Output power variation vs supply voltage variation, frequency = 2450 MHz       | $POUT_{\text{VAR\_V}}$      | 20 dBm PA $P_{\text{out}} = POUT_{\text{MAX}}$ output power with PAVDD voltage swept from 3.0 V to 3.8 V | —    | 0.75  | —      | dB   |
|  |                             | 10 dBm PA output power with PAVDD voltage swept from 1.8 V to 3.0 V                                      | —    | 0.03  | —      | dB   |
|  |                             | 0 dBm PA output power with PAVDD voltage swept from 1.8 V to 3.0 V                                       | —    | 0.02  | —      | dB   |
| Output power variation vs temperature, Frequency = 2450 MHz                    | $POUT_{\text{VAR\_T}}$      | PAVDD = 3.3 V supply, 20 dBm PA at $POUT_{\text{MAX}}$ , (-40 to +125 °C)                                | —    | 0.7   | —      | dB   |
|  |                             | 10 dBm PA at 10 dBm, (-40 to +125 °C)  | —    | 0.2   | —      | dB   |
|  |                             | 0 dBm PA at 0 dBm, (-40 to +125 °C)  | —    | 1.23  | —      | dB   |
| Output power variation vs RF frequency   | $POUT_{\text{VAR\_F}}$      | 20 dBm PA, $POUT_{\text{MAX}}$ , PAVDD = 3.3 V   | —    | 0.17  | —      | dB   |
|  |                             | 10 dBm PA, 10 dBm  | —    | 0.11  | —      | dB   |
|  |                             | 0 dBm PA, 0 dBm  | —    | 0.16  | —      | dB   |
| Spurious emissions of harmonics in restricted bands per FCC Part 15.205/15.209 | $SPUR_{\text{HRM\_FCC\_R}}$ | Continuous transmission of CW carrier, $P_{\text{out}} = POUT_{\text{MAX}}$ , Test Frequency = 2450 MHz. | —    | -47   | —      | dBm  |

| Parameter   | Symbol                      | Test Condition   | Min | Typ | Max | Unit |
|---|-----------------------------|--|-----|-----|-----|------|
| Spurious emissions of harmonics in non-restricted bands per FCC Part 15.247/15.35                                 | SPUR <sub>HRM_FCC_NRR</sub> | Continuous transmission of CW carrier. P <sub>out</sub> = POUT <sub>MAX</sub> . Test Frequency = 2450 MHz.   | —   | -26 | —   | dBc  |
| Spurious emissions out-of-band (above 2.483 GHz or below 2.4 GHz) in restricted bands, per FCC part 15.205/15.209 | SPUR <sub>OOB_FCC_R</sub>   | Restricted bands 30-88 MHz, Continuous transmission of CW carrier, P <sub>out</sub> = POUT <sub>MAX</sub> , Test Frequency = 2450 MHz                | —   | -61 | —   | dBm  |
|   |                             | Restricted bands 88 - 216 MHz, Continuous transmission of CW carrier, P <sub>out</sub> = POUT <sub>MAX</sub> , Test Frequency = 2450 MHz             | —   | -58 | —   | dBm  |
|   |                             | Restricted bands 216 - 960 MHz, Continuous transmission of CW carrier, P <sub>out</sub> = POUT <sub>MAX</sub> , Test Frequency = 2450 MHz            | —   | -55 | —   | dBm  |
|   |                             | Restricted bands > 960 MHz, Continuous transmission of CW carrier, P <sub>out</sub> = POUT <sub>MAX</sub> , Test Frequency = 2450 MHz                | —   | -47 | —   | dBm  |
| Spurious emissions out-of-band in non-restricted bands per FCC Part 15.247  | SPUR <sub>OOB_FCC_NR</sub>  | Frequencies above 2.483 GHz or below 2.4 GHz, continuous transmission CW carrier, P <sub>out</sub> = POUT <sub>MAX</sub> , Test Frequency = 2450 MHz | —   | -26 | —   | dBc  |
| Spurious emissions per ETSI EN300.440   | SPUR <sub>ETSI440</sub>     | 47-74 MHz, 87.5-108 MHz, 174-230 MHz, 470-862 MHz, P <sub>out</sub> = 10 dBm, Test Frequency = 2450 MHz  | —   | -60 | —   | dBm  |
|   |                             | 25-1000 MHz, excluding above frequencies. P <sub>out</sub> = 10 dBm, Test Frequency = 2450 MHz   | —   | -42 | —   | dBm  |
|   |                             | 1G-14G, P <sub>out</sub> = 10 dBm, Test Frequency = 2450 MHz   | —   | -36 | —   | dBm  |
| Spurious emissions out-of-band, per ETSI 300.328  | SPUR <sub>ETSI328</sub>     | [2400-2BW to 2400-BW], [2483.5+BW to 2483.5+2BW], P <sub>out</sub> = 10 dBm, Test Frequency = 2450 MHz   | —   | -26 | —   | dBm  |
|   |                             | 47-74 MHz, 87.5-118 MHz, 174-230 MHz, 470-862 MHz, P <sub>out</sub> = 10 dBm, Test Frequency = 2450 MHz  | —   | -60 | —   | dBm  |
|   |                             | 30-47 MHz, 74-87.5 MHz, 118-174 MHz, 230-470 MHz, 862-1000 MHz, P <sub>out</sub> = 10 dBm, Test Frequency = 2450 MHz                                 | —   | -42 | —   | dBm  |
|   |                             | 1G-12.75 GHz, excluding bands listed above, P <sub>out</sub> = 10 dBm, Test Frequency = 2450 MHz   | —   | -36 | —   | dBm  |
|   |                             | [2400-BW to 2400], [2483.5 to 2483.5+BW] P <sub>out</sub> = 10 dBm, Test Frequency = 2450 MHz  | —   | -16 | —   | dBm  |

| Parameter | Symbol | Test Condition | Min | Typ | Max | Unit |
|-----------|--------|----------------|-----|-----|-----|------|
|-----------|--------|----------------|-----|-----|-----|------|

**Note:**

1. Supply current to radio, supplied by DC-DC with 3.0 V, measured at VREGVDD.
2. Supported transmit power levels are determined by the ordering part number (OPN). Transmit power ratings for all devices covered in this data sheet can be found in the Max TX Power column of the Ordering Information Table.
3. The PA is capable of delivering higher than 10 dBm output power (refer to Output Power plots in [4.27.2 RF Characteristics](#)). However, all transmitter characteristics and recommended application circuits are specified at 10 dBm output. If used with the recommended application circuits above 10 dBm, harmonics may be higher than regulatory limits.

#### 4.9.1.2 RF Transmitter Characteristics for 802.15.4 DSSS-OQPSK in the 2.4 GHz Band

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ , Crystal frequency=39.0 MHz, RF center frequency = 2.45 GHz.

- For 0 dBm / 10 dBm PA: VREGVDD = IOVDD = AVDD = 3.0 V, DVDD = RFVDD = PAVDD = 1.8 V powered from DCDC
- For 20 dBm PA: VREGVDD = IOVDD = AVDD = PAVDD = 3.3 V, DVDD = RFVDD = 1.8 V powered from DCDC

**Table 4.14. RF Transmitter Characteristics for 802.15.4 DSSS-OQPSK in the 2.4 GHz Band**

| Parameter                                     | Symbol                 | Test Condition   | Min | Typ   | Max | Unit       |
|---|------------------------|--|-----|-------|-----|------------|
| Error vector magnitude per 802.15.4-2011      | EVM                    | Average across frequency, signal is DSSS-OQPSK reference packet, PAVDD = 3.3 V, $P_{out} = P_{OUT\_MAX}$ | —   | 3     | —   | % rms      |
|   |                        | Average across frequency, signal is DSSS-OQPSK reference packet, $P_{out} = 10\text{ dBm}$               | —   | 2.9   | —   | % rms      |
|   |                        | Average across frequency, signal is DSSS-OQPSK reference packet, $P_{out} = 0\text{ dBm}$                | —   | 2.9   | —   | % rms      |
| Power spectral density limit                  | PSD <sub>LIMIT</sub>   | Relative, at carrier $\pm 3.5\text{ MHz}$ , PAVDD = 3.3 V, $P_{out} = P_{OUT\_MAX}$                      | —   | -50.2 | —   | dBc/100kHz |
|   |                        | Relative, at carrier $\pm 3.5\text{ MHz}$ , $P_{out} = 10\text{ dBm}$                                    | —   | -50.1 | —   | dBc/100kHz |
|   |                        | Relative, at carrier $\pm 3.5\text{ MHz}$ , $P_{out} = 0\text{ dBm}$                                     | —   | -50.7 | —   | dBc/100kHz |
|   |                        | Absolute, at carrier $\pm 3.5\text{ MHz}$ , PAVDD = 3.3 V, $P_{out} = P_{OUT\_MAX}$                      | —   | -38.3 | —   | dBm/100kHz |
|   |                        | Absolute, at carrier $\pm 3.5\text{ MHz}$ , $P_{out} = 10\text{ dBm}$                                    | —   | -48.7 | —   | dBm/100kHz |
|   |                        | Absolute, at carrier $\pm 3.5\text{ MHz}$ , $P_{out} = 0\text{ dBm}$                                     | —   | -59.2 | —   | dBm/100kHz |
|   |                        | Per FCC part 15.247, PAVDD = 3.3 V, $P_{out} = P_{OUT\_MAX}$   | —   | 0.5   | —   | dBm/3kHz   |
|   |                        | Per FCC part 15.247, $P_{out} = 10\text{ dBm}$   | —   | -9.2  | —   | dBm/3kHz   |
|   |                        | Per FCC part 15.247, $P_{out} = 0\text{ dBm}$  | —   | -19.9 | —   | dBm/3kHz   |
|   |                        | ETSI 300.328 $P_{out} = 10\text{ dBm}$   | —   | 8     | —   | dBm        |
|   |                        | ETSI 300.328 $P_{out} = 0\text{ dBm}$  | —   | -2.8  | —   | dBm        |
| Occupied channel bandwidth per ETSI EN300.328 | OCP <sub>ETSI328</sub> | 99% BW at highest and lowest channels in band, $P_{out} = 10\text{ dBm}$                                 | —   | 2.2   | —   | MHz        |
|   |                        | 99% BW at highest and lowest channels in band, $P_{out} = 0\text{ dBm}$                                  | —   | 2.2   | —   | MHz        |

#### 4.9.1.3 RF Transmitter Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 1 Mbps Data Rate

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ , Crystal frequency=39.0 MHz, RF center frequency = 2.45 GHz.

- For 0 dBm / 10 dBm PA: VREGVDD = IOVDD = AVDD = 3.0 V, DVDD = RFVDD = PAVDD = 1.8 V powered from DCDC
- For 20 dBm PA: VREGVDD = IOVDD = AVDD = PAVDD = 3.3 V, DVDD = RFVDD = 1.8 V powered from DCDC

**Table 4.15. RF Transmitter Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 1 Mbps Data Rate**

| Parameter   | Symbol                 | Test Condition  | Min | Typ   | Max | Unit         |
|---|------------------------|---|-----|-------|-----|--------------|
| Transmit 6 dB bandwidth   | TXBW                   | PAVDD = 3.3 V, $P_{out} = POUT_{MAX}$   | —   | 718   | —   | kHz          |
|   |                        | $P_{out} = 10\text{ dBm}$   | —   | 714   | —   | kHz          |
|   |                        | $P_{out} = 0\text{ dBm}$  | —   | 715   | —   | kHz          |
| Power spectral density limit  | PSD <sub>LIMIT</sub>   | PAVDD = 3.3 V, $P_{out} = POUT_{MAX}$ ,<br>Per FCC part 15.247                | —   | -0.5  | —   | dBm/<br>3kHz |
|   |                        | $P_{out} = 10\text{ dBm}$ , Per FCC part<br>15.247 at 10 dBm                  | —   | -10.4 | —   | dBm/<br>3kHz |
|   |                        | $P_{out} = 0\text{ dBm}$ , Per FCC part<br>15.247 at 0 dBm                    | —   | -21.2 | —   | dBm/<br>3kHz |
|   |                        | Per ETSI 300.328 at 10 dBm/1<br>MHz   | —   | 9.7   | —   | dBm          |
| Occupied channel bandwidth<br>per ETSI EN300.328                    | OCP <sub>ETSI328</sub> | $P_{out} = 10\text{ dBm}$ 99% BW at highest<br>and lowest channels in band    | —   | 1     | —   | MHz          |
|   |                        | $P_{out} = 0\text{ dBm}$ 99% BW at highest<br>and lowest channels in band     | —   | 1     | —   | MHz          |
| In-band spurious emissions,<br>with allowed exceptions <sup>1</sup> | SPUR <sub>INB</sub>    | PAVDD = 3.3 V, $P_{out} = POUT_{MAX}$ ,<br>Inband spurs at $\pm 2\text{ MHz}$ | —   | -26.9 | —   | dBm          |
|   |                        | $P_{out} = 10\text{ dBm}$ , Inband spurs at $\pm$<br>2 MHz                    | —   | -38.8 | —   | dBm          |
|   |                        | $P_{out} = 0\text{ dBm}$ , Inband spurs at $\pm 2$<br>MHz                     | —   | -49.8 | —   | dBm          |
|   |                        | PAVDD = 3.3 V, $P_{out} = POUT_{MAX}$<br>Inband spurs at $\pm 3\text{ MHz}$   | —   | -33.2 | —   | dBm          |
|   |                        | $P_{out} = 10\text{ dBm}$ Inband spurs at $\pm 3$<br>MHz                      | —   | -43.8 | —   | dBm          |
|   |                        | $P_{out} = 0\text{ dBm}$ Inband spurs at $\pm 3$<br>MHz                       | —   | -54.6 | —   | dBm          |

**Note:**

1. Per Bluetooth Core\_5.1, Vol.6 Part A, Section 3.2.2, exceptions are allowed in up to three bands of 1 MHz width, centered on a frequency which is an integer multiple of 1 MHz. These exceptions shall have an absolute value of -20 dBm or less.

#### 4.9.1.4 RF Transmitter Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 2 Mbps Data Rate

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ , Crystal frequency=39.0 MHz, RF center frequency = 2.45 GHz.

- For 0 dBm / 10 dBm PA: VREGVDD = IOVDD = AVDD = 3.0 V, DVDD = RFVDD = PAVDD = 1.8 V powered from DCDC
- For 20 dBm PA: VREGVDD = IOVDD = AVDD = PAVDD = 3.3 V, DVDD = RFVDD = 1.8 V powered from DCDC

**Table 4.16. RF Transmitter Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 2 Mbps Data Rate**

| Parameter   | Symbol                 | Test Condition   | Min | Typ   | Max | Unit         |
|---|------------------------|--|-----|-------|-----|--------------|
| Transmit 6 dB bandwidth   | TXBW                   | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$   | —   | 1307  | —   | kHz          |
|   |                        | $P_{out} = 10\text{ dBm}$  | —   | 1308  | —   | kHz          |
|   |                        | $P_{out} = 0\text{ dBm}$   | —   | 1306  | —   | kHz          |
| Power spectral density limit  | PSD <sub>LIMIT</sub>   | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$ ,<br>Per FCC part 15.247                | —   | 1.5   | —   | dBm/<br>3kHz |
|   |                        | $P_{out} = 10\text{ dBm}$ , Per FCC part<br>15.247 at 10 dBm                     | —   | -8.5  | —   | dBm/<br>3kHz |
|   |                        | $P_{out} = 0\text{ dBm}$ , Per FCC part<br>15.247 at 0 dBm                       | —   | -19.3 | —   | dBm/<br>3kHz |
|   |                        | Per ETSI 300.328 at 10 dBm/1<br>MHz  | —   | 8.7   | —   | dBm          |
| Occupied channel bandwidth<br>per ETSI EN300.328                    | OCP <sub>ETSI328</sub> | $P_{out} = 10\text{ dBm}$ 99% BW at highest<br>and lowest channels in band       | —   | 2.1   | —   | MHz          |
|   |                        | $P_{out} = 0\text{ dBm}$ 99% BW at highest<br>and lowest channels in band        | —   | 2.1   | —   | MHz          |
| In-band spurious emissions,<br>with allowed exceptions <sup>1</sup> | SPUR <sub>INB</sub>    | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$ ,<br>Inband spurs at $\pm 4\text{ MHz}$ | —   | -33.7 | —   | dBm          |
|   |                        | $P_{out} = 10\text{ dBm}$ , Inband spurs at $\pm 4\text{ MHz}$                   | —   | -43.7 | —   | dBm          |
|   |                        | $P_{out} = 0\text{ dBm}$ , Inband spurs at $\pm 4\text{ MHz}$                    | —   | -54.5 | —   | dBm          |
|   |                        | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$<br>Inband spurs at $\pm 6\text{ MHz}$   | —   | -38.9 | —   | dBm          |
|   |                        | $P_{out} = 10\text{ dBm}$ Inband spurs at $\pm 6\text{ MHz}$                     | —   | -48.8 | —   | dBm          |
|   |                        | $P_{out} = 0\text{ dBm}$ Inband spurs at $\pm 6\text{ MHz}$                      | —   | -59.5 | —   | dBm          |

**Note:**

1. Per Bluetooth Core\_5.1, Vol.6 Part A, Section 3.2.2, exceptions are allowed in up to three bands of 1 MHz width, centered on a frequency which is an integer multiple of 1 MHz. These exceptions shall have an absolute value of -20 dBm or less.

#### 4.9.1.5 RF Transmitter Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 500 kbps Data Rate

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ , Crystal frequency=39.0 MHz, RF center frequency = 2.45 GHz.

- For 0 dBm / 10 dBm PA: VREGVDD = IOVDD = AVDD = 3.0 V, DVDD = RFVDD = PAVDD = 1.8 V powered from DCDC
- For 20 dBm PA: VREGVDD = IOVDD = AVDD = PAVDD = 3.3 V, DVDD = RFVDD = 1.8 V powered from DCDC

**Table 4.17. RF Transmitter Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 500 kbps Data Rate**

| Parameter   | Symbol                 | Test Condition   | Min | Typ   | Max | Unit         |
|---|------------------------|--|-----|-------|-----|--------------|
| Transmit 6 dB bandwidth   | TXBW                   | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$   | —   | 717   | —   | kHz          |
|   |                        | $P_{out} = 10\text{ dBm}$  | —   | 718   | —   | kHz          |
|   |                        | $P_{out} = 0\text{ dBm}$   | —   | 717   | —   | kHz          |
| Power spectral density limit  | PSD <sub>LIMIT</sub>   | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$ ,<br>Per FCC part 15.247                | —   | -0.5  | —   | dBm/<br>3kHz |
|   |                        | $P_{out} = 10\text{ dBm}$ , Per FCC part<br>15.247 at 10 dBm                     | —   | -10.4 | —   | dBm/<br>3kHz |
|   |                        | $P_{out} = 0\text{ dBm}$ , Per FCC part<br>15.247 at 0 dBm                       | —   | -21.2 | —   | dBm/<br>3kHz |
|   |                        | Per ETSI 300.328 at 10 dBm/1<br>MHz  | —   | 9.7   | —   | dBm          |
| Occupied channel bandwidth<br>per ETSI EN300.328                    | OCP <sub>ETSI328</sub> | $P_{out} = 10\text{ dBm}$ 99% BW at highest<br>and lowest channels in band       | —   | 1     | —   | MHz          |
|   |                        | $P_{out} = 0\text{ dBm}$ 99% BW at highest<br>and lowest channels in band        | —   | 1     | —   | MHz          |
| In-band spurious emissions,<br>with allowed exceptions <sup>1</sup> | SPUR <sub>INB</sub>    | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$ ,<br>Inband spurs at $\pm 2\text{ MHz}$ | —   | -26.9 | —   | dBm          |
|   |                        | $P_{out} = 10\text{ dBm}$ , Inband spurs at $\pm$<br>2 MHz                       | —   | -38.9 | —   | dBm          |
|   |                        | $P_{out} = 0\text{ dBm}$ , Inband spurs at $\pm 2$<br>MHz                        | —   | -49.8 | —   | dBm          |
|   |                        | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$<br>Inband spurs at $\pm 3\text{ MHz}$   | —   | -33.2 | —   | dBm          |
|   |                        | $P_{out} = 10\text{ dBm}$ Inband spurs at $\pm 3$<br>MHz                         | —   | -43.8 | —   | dBm          |
|   |                        | $P_{out} = 0\text{ dBm}$ Inband spurs at $\pm 3$<br>MHz                          | —   | -54.6 | —   | dBm          |

**Note:**

1. Per Bluetooth Core\_5.1, Vol.6 Part A, Section 3.2.2, exceptions are allowed in up to three bands of 1 MHz width, centered on a frequency which is an integer multiple of 1 MHz. These exceptions shall have an absolute value of -20 dBm or less.

#### 4.9.1.6 RF Transmitter Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 125 kbps Data Rate

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ , Crystal frequency=39.0 MHz, RF center frequency = 2.45 GHz.

- For 0 dBm / 10 dBm PA: VREGVDD = IOVDD = AVDD = 3.0 V, DVDD = RFVDD = PAVDD = 1.8 V powered from DCDC
- For 20 dBm PA: VREGVDD = IOVDD = AVDD = PAVDD = 3.3 V, DVDD = RFVDD = 1.8 V powered from DCDC

**Table 4.18. RF Transmitter Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 125 kbps Data Rate**

| Parameter   | Symbol                 | Test Condition   | Min | Typ   | Max | Unit         |
|---|------------------------|--|-----|-------|-----|--------------|
| Transmit 6 dB bandwidth   | TXBW                   | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$   | —   | 651   | —   | kHz          |
|   |                        | $P_{out} = 10\text{ dBm}$  | —   | 651   | —   | kHz          |
|   |                        | $P_{out} = 0\text{ dBm}$   | —   | 651   | —   | kHz          |
| Power spectral density limit  | PSD <sub>LIMIT</sub>   | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$ ,<br>Per FCC part 15.247                | —   | 13.7  | —   | dBm/<br>3kHz |
|   |                        | $P_{out} = 10\text{ dBm}$ , Per FCC part<br>15.247 at 10 dBm                     | —   | 3.8   | —   | dBm/<br>3kHz |
|   |                        | $P_{out} = 0\text{ dBm}$ , Per FCC part<br>15.247 at 0 dBm                       | —   | -7    | —   | dBm/<br>3kHz |
|   |                        | Per ETSI 300.328 at 10 dBm/1<br>MHz  | —   | 9.7   | —   | dBm          |
| Occupied channel bandwidth<br>per ETSI EN300.328                    | OCP <sub>ETSI328</sub> | $P_{out} = 10\text{ dBm}$ 99% BW at highest<br>and lowest channels in band       | —   | 1     | —   | MHz          |
|   |                        | $P_{out} = 0\text{ dBm}$ 99% BW at highest<br>and lowest channels in band        | —   | 1     | —   | MHz          |
| In-band spurious emissions,<br>with allowed exceptions <sup>1</sup> | SPUR <sub>INB</sub>    | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$ ,<br>Inband spurs at $\pm 2\text{ MHz}$ | —   | -26.9 | —   | dBm          |
|   |                        | $P_{out} = 10\text{ dBm}$ , Inband spurs at $\pm$<br>2 MHz                       | —   | -39   | —   | dBm          |
|   |                        | $P_{out} = 0\text{ dBm}$ , Inband spurs at $\pm 2$<br>MHz                        | —   | -49.7 | —   | dBm          |
|   |                        | PAVDD = 3.3 V, $P_{out} = P_{OUT_{MAX}}$<br>Inband spurs at $\pm 3\text{ MHz}$   | —   | -33.1 | —   | dBm          |
|   |                        | $P_{out} = 10\text{ dBm}$ Inband spurs at $\pm 3$<br>MHz                         | —   | -43.7 | —   | dBm          |
|   |                        | $P_{out} = 0\text{ dBm}$ Inband spurs at $\pm 3$<br>MHz                          | —   | -54.5 | —   | dBm          |

**Note:**

1. Per Bluetooth Core\_5.1, Vol.6 Part A, Section 3.2.2, exceptions are allowed in up to three bands of 1 MHz width, centered on a frequency which is an integer multiple of 1 MHz. These exceptions shall have an absolute value of -20 dBm or less.

## 4.9.2 RF Receiver Characteristics

### 4.9.2.1 RF Receiver General Characteristics for the 2.4 GHz Band

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ ,  $V_{REGVDD} = I_{OVDD} = AVDD = PAVDD = 3.0\text{V}$ ,  $RFVDD = DVDD = 1.8\text{V}$  powered from DCDC. Crystal frequency = 39.0 MHz, RF center frequency = 2.45 GHz.

**Table 4.19. RF Receiver General Characteristics for the 2.4 GHz Band**

| Parameter   | Symbol           | Test Condition                            | Min  | Typ    | Max    | Unit |
|---|------------------|---|------|--------|--------|------|
| RF tuning frequency range   | $F_{RANGE}$      |   | 2400 | —      | 2483.5 | MHz  |
| Radio-only current consumption in receive mode <sup>1</sup>               | $I_{RX\_RADIO}$  |   | —    | 2.8    | —      | mA   |
| Receive mode maximum spurious emission                                    | $SPUR_{RX}$      | 30 MHz to 1 GHz                           | —    | -63    | —      | dBm  |
|   |                  | 1 GHz to 12 GHz                           | —    | -53    | —      | dBm  |
| Max spurious emissions during active receive mode, per FCC Part 15.109(a) | $SPUR_{RX\_FCC}$ | 216 MHz to 960 MHz, conducted measurement | —    | -55    | —      | dBm  |
|   |                  | Above 960 MHz, conducted measurement.     | —    | -47    | —      | dBm  |
| 2GFSK Sensitivity   | $SENS_{2GFSK}$   | 2 Mbps 2GFSK signal, 1% PER               | —    | -92.5  | —      | dBm  |
|   |                  | 250 kbps 2GFSK signal, 0.1% BER           | —    | -102.9 | —      | dBm  |

**Note:**

1. Supply current to radio, supplied by DC-DC with 3.0 V, measured at  $V_{REGVDD}$ .

#### 4.9.2.2 RF Receiver Characteristics for 802.15.4 DSSS-OQPSK in the 2.4 GHz Band

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ ,  $V_{REGVDD} = I_{OVDD} = AVDD = PAVDD = 3.0\text{V}$ ,  $RFVDD = DVDD = 1.8\text{V}$  powered from DCDC. Crystal frequency = 39.0 MHz, RF center frequency = 2.45 GHz.

**Table 4.20. RF Receiver Characteristics for 802.15.4 DSSS-OQPSK in the 2.4 GHz Band**

| Parameter   | Symbol       | Test Condition   | Min | Typ    | Max | Unit |
|---|--------------|--|-----|--------|-----|------|
| Rx Max Strong Signal Input Level for 1% PER   | $RX_{SAT}$   | Signal is reference signal <sup>1</sup> , packet length is 20 octets | —   | 10     | —   | dBm  |
| Sensitivity, 1% PER   | SENS         | Signal is reference signal, packet length is 20 octets               | —   | -105.4 | —   | dBm  |
| Co-channel interferer rejection, 1% PER   | CCR          | Desired signal 3 dB above sensitivity limit                          | —   | -0.7   | —   | dB   |
| Adjacent channel rejection, Interferer is reference signal, 1% PER, desired is reference signal at 3 dB above reference sensitivity level <sup>2</sup>                | $ACR_{REF1}$ | Interferer is reference signal at +1 channel spacing                 | —   | 36.8   | —   | dB   |
|   |              | Interferer is reference signal at -1 channel spacing                 | —   | 37.5   | —   | dB   |
| Alternate channel rejection, interferer is reference signal, 1% PER, desired is reference signal at 3 dB above reference sensitivity level <sup>2</sup>               | $ACR_{REF2}$ | Interferer is reference signal at +2 channel spacing                 | —   | 48.9   | —   | dB   |
|   |              | Interferer is reference signal at -2 channel spacing                 | —   | 49.4   | —   | dB   |
| Image rejection, 1% PER, desired is reference signal at 3 dB above reference sensitivity level <sup>2</sup>   | IR           | Interferer is CW in image band <sup>3</sup>                          | —   | 53.5   | —   | dB   |
| Blocking rejection of all other channels, 1% PER, desired is reference signal at 3 dB above reference sensitivity level <sup>2</sup> , interferer is reference signal | BLOCK        | Interferer frequency < desired frequency -3 channel spacing          | —   | 55.3   | —   | dB   |
|   |              | Interferer frequency > desired frequency +3 channel spacing          | —   | 55.1   | —   | dB   |
| RSSI resolution   | $RSSI_{RES}$ | -100 dBm to +5 dBm   | —   | 0.25   | —   | dB   |
| RSSI accuracy in the linear region as defined by 802.15.4-2003  | $RSSI_{LIN}$ |  | —   | +/-6   | —   | dB   |

**Note:**

- Reference signal is defined as O-QPSK DSSS per 802.15.4, Frequency range = 2400-2483.5 MHz, Symbol rate = 62.5 ksymbs/s.
- Reference sensitivity level is -85 dBm.
- Due to low-IF frequency, there is some overlap of adjacent channel and image channel bands. Adjacent channel CW blocker tests place the Interferer center frequency at the Desired frequency  $\pm 5$  MHz on the channel raster, whereas the image rejection test places the CW interferer near the image frequency of the Desired signal carrier, regardless of the channel raster.

#### 4.9.2.3 RF Receiver Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 1 Mbps Data Rate

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ ,  $V_{REGVDD} = IOVDD = AVDD = PAVDD = 3.0\text{V}$ ,  $RFVDD = DVDD = 1.8\text{V}$  powered from DCDC. Crystal frequency = 39.0 MHz, RF center frequency = 2.45 GHz, Packet length is 255 bytes.

**Table 4.21. RF Receiver Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 1 Mbps Data Rate**

| Parameter                                     | Symbol        | Test Condition   | Min | Typ   | Max | Unit |
|---|---------------|--|-----|-------|-----|------|
| Rx Max Strong Signal Input Level for 0.1% BER | $RX_{SAT}$    | Signal is reference signal <sup>1</sup>  | —   | 10    | —   | dBm  |
| Sensitivity                                   | SENS          | Signal is reference signal, 37 byte payload <sup>2</sup>                                     | —   | -97.6 | —   | dBm  |
|   |               | Signal is reference signal, 255 byte payload <sup>1</sup>                                    | —   | -96   | —   | dBm  |
|   |               | With non-ideal signals <sup>3 1</sup>  | —   | -95.7 | —   | dBm  |
| Signal to co-channel interferer               | $C/I_{CC}$    | (see notes) <sup>1 4</sup>   | —   | 8.7   | —   | dB   |
| $N \pm 1$ Adjacent channel selectivity        | $C/I_1$       | Interferer is reference signal at +1 MHz offset <sup>1 5 4 6</sup>                           | —   | -5.4  | —   | dB   |
|   |               | Interferer is reference signal at -1 MHz offset <sup>1 5 4 6</sup>                           | —   | -5.3  | —   | dB   |
| $N \pm 2$ Alternate channel selectivity       | $C/I_2$       | Interferer is reference signal at +2 MHz offset <sup>1 5 4 6</sup>                           | —   | -40.9 | —   | dB   |
|   |               | Interferer is reference signal at -2 MHz offset <sup>1 5 4 6</sup>                           | —   | -39.7 | —   | dB   |
| $N \pm 3$ Alternate channel selectivity       | $C/I_3$       | Interferer is reference signal at +3 MHz offset <sup>1 5 4 6</sup>                           | —   | -45.5 | —   | dB   |
|   |               | Interferer is reference signal at -3 MHz offset <sup>1 5 4 6</sup>                           | —   | -45.7 | —   | dB   |
| Selectivity to image frequency                | $C/I_{IM}$    | Interferer is reference signal at image frequency with 1 MHz precision <sup>1 6</sup>        | —   | -23.3 | —   | dB   |
| Selectivity to image frequency $\pm 1$ MHz    | $C/I_{IM\_1}$ | Interferer is reference signal at image frequency +1 MHz with 1 MHz precision <sup>1 6</sup> | —   | -40.9 | —   | dB   |
|   |               | Interferer is reference signal at image frequency -1 MHz with 1 MHz precision <sup>1 6</sup> | —   | -5.4  | —   | dB   |
| Intermodulation performance                   | IM            | $n = 3$ (see note <sup>7</sup> )   | —   | -17.3 | —   | dBm  |

**Note:**

1. 0.017% Bit Error Rate.
2. 0.1% Bit Error Rate.
3. With non-ideal signals as specified in Bluetooth Test Specification RF-PHY.TS.5.0.1 section 4.7.1
4. Desired signal -67 dBm.
5. Desired frequency  $2402\text{ MHz} \leq F_c \leq 2480\text{ MHz}$ .
6. With allowed exceptions.
7. As specified in Bluetooth Core specification version 5.1, Vol 6, Part A, Section 4.4

#### 4.9.2.4 RF Receiver Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 2 Mbps Data Rate

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ ,  $V_{REGVDD} = IOVDD = AVDD = PAVDD = 3.0\text{V}$ ,  $RFVDD = DVDD = 1.8\text{V}$  powered from DCDC. Crystal frequency = 39.0 MHz, RF center frequency = 2.45 GHz, Packet length is 255 bytes.

**Table 4.22. RF Receiver Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 2 Mbps Data Rate**

| Parameter                                     | Symbol        | Test Condition   | Min | Typ   | Max | Unit |
|---|---------------|--|-----|-------|-----|------|
| Rx Max Strong Signal Input Level for 0.1% BER | $RX_{SAT}$    | Signal is reference signal <sup>1</sup>  | —   | 10    | —   | dBm  |
| Sensitivity                                   | SENS          | Signal is reference signal, 37 byte payload <sup>2</sup>                                     | —   | -94.8 | —   | dBm  |
|   |               | Signal is reference signal, 255 byte payload <sup>1</sup>                                    | —   | -93.3 | —   | dBm  |
|   |               | With non-ideal signals <sup>3 1</sup>  | —   | -93.1 | —   | dBm  |
| Signal to co-channel interferer               | $C/I_{CC}$    | (see notes) <sup>1 4</sup>   | —   | 8.6   | —   | dB   |
| $N \pm 1$ Adjacent channel selectivity        | $C/I_1$       | Interferer is reference signal at +2 MHz offset <sup>1 5 4 6</sup>                           | —   | -5.3  | —   | dB   |
|   |               | Interferer is reference signal at -2 MHz offset <sup>1 5 4 6</sup>                           | —   | -5.8  | —   | dB   |
| $N \pm 2$ Alternate channel selectivity       | $C/I_2$       | Interferer is reference signal at +4 MHz offset <sup>1 5 4 6</sup>                           | —   | -42.2 | —   | dB   |
|   |               | Interferer is reference signal at -4 MHz offset <sup>1 5 4 6</sup>                           | —   | -44.2 | —   | dB   |
| $N \pm 3$ Alternate channel selectivity       | $C/I_3$       | Interferer is reference signal at +6 MHz offset <sup>1 5 4 6</sup>                           | —   | -48.1 | —   | dB   |
|   |               | Interferer is reference signal at -6 MHz offset <sup>1 5 4 6</sup>                           | —   | -50.2 | —   | dB   |
| Selectivity to image frequency                | $C/I_{IM}$    | Interferer is reference signal at image frequency with 1 MHz precision <sup>1 6</sup>        | —   | -22.8 | —   | dB   |
| Selectivity to image frequency $\pm 2$ MHz    | $C/I_{IM\_1}$ | Interferer is reference signal at image frequency +2 MHz with 1 MHz precision <sup>1 6</sup> | —   | -42.2 | —   | dB   |
|   |               | Interferer is reference signal at image frequency -2 MHz with 1 MHz precision <sup>1 6</sup> | —   | -5.3  | —   | dB   |
| Intermodulation performance                   | IM            | $n = 3$ (see note <sup>7</sup> )   | —   | -18.3 | —   | dBm  |

**Note:**

1. 0.017% Bit Error Rate.
2. 0.1% Bit Error Rate.
3. With non-ideal signals as specified in Bluetooth Test Specification RF-PHY.TS.5.0.1 section 4.7.1
4. Desired signal -64 dBm.
5. Desired frequency  $2402\text{ MHz} \leq F_c \leq 2480\text{ MHz}$ .
6. With allowed exceptions.
7. As specified in Bluetooth Core specification version 5.1, Vol 6, Part A, Section 4.4

#### 4.9.2.5 RF Receiver Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 500 kbps Data Rate

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ ,  $V_{REGVDD} = IOVDD = AVDD = PAVDD = 3.0\text{V}$ ,  $RFVDD = DVDD = 1.8\text{V}$  powered from DCDC. Crystal frequency = 39.0 MHz, RF center frequency = 2.45 GHz, Packet length is 255 bytes.

**Table 4.23. RF Receiver Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 500 kbps Data Rate**

| Parameter                                     | Symbol        | Test Condition   | Min | Typ    | Max | Unit |
|---|---------------|--|-----|--------|-----|------|
| Rx Max Strong Signal Input Level for 0.1% BER | $RX_{SAT}$    | Signal is reference signal <sup>1</sup>  | —   | 10     | —   | dBm  |
| Sensitivity                                   | SENS          | Signal is reference signal, 37 byte payload <sup>2</sup>                                     | —   | -101.4 | —   | dBm  |
|   |               | Signal is reference signal, 255 byte payload <sup>1</sup>                                    | —   | -100.1 | —   | dBm  |
|   |               | With non-ideal signals <sup>3 1</sup>  | —   | -99.1  | —   | dBm  |
| Signal to co-channel interferer               | $C/I_{CC}$    | (see notes) <sup>1 4</sup>   | —   | 2.7    | —   | dB   |
| $N \pm 1$ Adjacent channel selectivity        | $C/I_1$       | Interferer is reference signal at +1 MHz offset <sup>1 5 4 6</sup>                           | —   | -7.1   | —   | dB   |
|   |               | Interferer is reference signal at -1 MHz offset <sup>1 5 4 6</sup>                           | —   | -7.4   | —   | dB   |
| $N \pm 2$ Alternate channel selectivity       | $C/I_2$       | Interferer is reference signal at +2 MHz offset <sup>1 5 4 6</sup>                           | —   | -46.8  | —   | dB   |
|   |               | Interferer is reference signal at -2 MHz offset <sup>1 5 4 6</sup>                           | —   | -49.7  | —   | dB   |
| $N \pm 3$ Alternate channel selectivity       | $C/I_3$       | Interferer is reference signal at +3 MHz offset <sup>1 5 4 6</sup>                           | —   | -49.4  | —   | dB   |
|   |               | Interferer is reference signal at -3 MHz offset <sup>1 5 4 6</sup>                           | —   | -54.5  | —   | dB   |
| Selectivity to image frequency                | $C/I_{IM}$    | Interferer is reference signal at image frequency with 1 MHz precision <sup>1 6</sup>        | —   | -49    | —   | dB   |
| Selectivity to image frequency $\pm 1$ MHz    | $C/I_{IM\_1}$ | Interferer is reference signal at image frequency +1 MHz with 1 MHz precision <sup>1 6</sup> | —   | -49.4  | —   | dB   |
|   |               | Interferer is reference signal at image frequency -1 MHz with 1 MHz precision <sup>1 6</sup> | —   | -46.8  | —   | dB   |

**Note:**

1. 0.017% Bit Error Rate.
2. 0.1% Bit Error Rate.
3. With non-ideal signals as specified in Bluetooth Test Specification RF-PHY.TS.5.0.1 section 4.7.1
4. Desired signal -72 dBm.
5. Desired frequency  $2402\text{ MHz} \leq F_c \leq 2480\text{ MHz}$ .
6. With allowed exceptions.

#### 4.9.2.6 RF Receiver Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 125 kbps Data Rate

Unless otherwise indicated, typical conditions are:  $T_A = 25\text{ }^\circ\text{C}$ ,  $V_{REGVDD} = IOVDD = AVDD = PAVDD = 3.0\text{V}$ ,  $RFVDD = DVDD = 1.8\text{V}$  powered from DCDC. Crystal frequency = 39.0 MHz, RF center frequency = 2.45 GHz, Packet length is 255 bytes.

**Table 4.24. RF Receiver Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 125 kbps Data Rate**

| Parameter                                     | Symbol        | Test Condition   | Min | Typ    | Max | Unit |
|---|---------------|--|-----|--------|-----|------|
| Rx Max Strong Signal Input Level for 0.1% BER | $RX_{SAT}$    | Signal is reference signal <sup>1</sup>  | —   | 10     | —   | dBm  |
| Sensitivity                                   | SENS          | Signal is reference signal, 37 byte payload <sup>2</sup>                                     | —   | -105.7 | —   | dBm  |
|   |               | Signal is reference signal, 255 byte payload <sup>1</sup>                                    | —   | -105.3 | —   | dBm  |
|   |               | With non-ideal signals <sup>3 1</sup>  | —   | -104.8 | —   | dBm  |
| Signal to co-channel interferer               | $C/I_{CC}$    | (see notes) <sup>1 4</sup>   | —   | 0.9    | —   | dB   |
| $N \pm 1$ Adjacent channel selectivity        | $C/I_1$       | Interferer is reference signal at +1 MHz offset <sup>1 5 4 6</sup>                           | —   | -12.4  | —   | dB   |
|   |               | Interferer is reference signal at -1 MHz offset <sup>1 5 4 6</sup>                           | —   | -12.8  | —   | dB   |
| $N \pm 2$ Alternate channel selectivity       | $C/I_2$       | Interferer is reference signal at +2 MHz offset <sup>1 5 4 6</sup>                           | —   | -52.6  | —   | dB   |
|   |               | Interferer is reference signal at -2 MHz offset <sup>1 5 4 6</sup>                           | —   | -55.5  | —   | dB   |
| $N \pm 3$ Alternate channel selectivity       | $C/I_3$       | Interferer is reference signal at +3 MHz offset <sup>1 5 4 6</sup>                           | —   | -53.8  | —   | dB   |
|   |               | Interferer is reference signal at -3 MHz offset <sup>1 5 4 6</sup>                           | —   | -60    | —   | dB   |
| Selectivity to image frequency                | $C/I_{IM}$    | Interferer is reference signal at image frequency with 1 MHz precision <sup>1 6</sup>        | —   | -53    | —   | dB   |
| Selectivity to image frequency $\pm 1$ MHz    | $C/I_{IM\_1}$ | Interferer is reference signal at image frequency +1 MHz with 1 MHz precision <sup>1 6</sup> | —   | -53.8  | —   | dB   |
|   |               | Interferer is reference signal at image frequency -1 MHz with 1 MHz precision <sup>1 6</sup> | —   | -52.6  | —   | dB   |

**Note:**

1. 0.017% Bit Error Rate.
2. 0.1% Bit Error Rate.
3. With non-ideal signals as specified in Bluetooth Test Specification RF-PHY.TS.5.0.1 section 4.7.1
4. Desired signal -79 dBm.
5. Desired frequency  $2402\text{ MHz} \leq F_c \leq 2480\text{ MHz}$ .
6. With allowed exceptions.

## 4.10 Oscillators

## 4.10.1 High Frequency Crystal Oscillator (HFXO)

Unless otherwise indicated, typical conditions are: AVDD = DVDD = 3.0 V. T<sub>A</sub> = 25 °C. Minimum and maximum values in this table represent the worst conditions across process variation, operating supply voltage range, and operating temperature range.

Table 4.25. High Frequency Crystal Oscillator (HFXO)

| Parameter  | Symbol                  | Test Condition  | Min  | Typ   | Max  | Unit |
|--|-------------------------|---|------|-------|------|------|
| Crystal Frequency  | F <sub>HFXO</sub>       | see note <sup>1 2 3</sup>                               | 38.0 | 39.0  | 40.0 | MHz  |
| Supported crystal maximum equivalent series resistance (ESR)                 | ESR <sub>HFXO</sub>     | Crystal Frequency = 39.0 MHz                            | —    | —     | 60   | Ω    |
| Supported range of crystal load capacitance <sup>4</sup>                     | C <sub>L_HFXO</sub>     | 39.0 MHz, ESR = 40 Ω <sup>5</sup>                       | —    | 10    | —    | pF   |
| Supply Current   | I <sub>HFXO</sub>       | 39.0 MHz  | —    | 565   | —    | μA   |
| Startup Time <sup>6</sup>  | T <sub>STARTUP</sub>    | 39.0 MHz, ESR = 40 Ω, C <sub>L</sub> = 10 pF            | —    | 188   | —    | μs   |
| On-chip tuning cap step size <sup>7</sup>                                    | SS <sub>HFXO</sub>      |   | —    | 0.04  | —    | pF   |
| HFCLKOUT load capacitance  | C <sub>HFCLKOUT</sub>   |   | —    | 20    | 30   | pF   |
| HFCLKOUT output voltage  | V <sub>HFCLKOUT</sub>   |   | 0    | —     | 1.2  | V    |
| HFCLKOUT AC output amplitude, XOUTBIASANA = 5, C <sub>HFCLKOUT</sub> = 20 pF | V <sub>ACHFCLKOUT</sub> | XOUTCFANA = 0   | —    | 470   | —    | mVpp |
|  |                         | XOUTCFANA = 1   | —    | 510   | —    | mVpp |
|  |                         | XOUTCFANA = 2   | —    | 560   | —    | mVpp |
|  |                         | XOUTCFANA = 3   | —    | 615   | —    | mVpp |
| HFCLKOUT current consumption   | I <sub>HFCLKOUT</sub>   | C <sub>HFCLKOUT</sub> ≤ 10 pF, XOUTBIASANA = 3          | —    | 3.1   | —    | mA   |
|  |                         | 10 pF < C <sub>HFCLKOUT</sub> ≤ 20 pF, XOUTBIASANA = 5  | —    | 3.9   | —    | mA   |
|  |                         | 20 pF < C <sub>HFCLKOUT</sub> ≤ 30 pF, XOUTBIASANA = 15 | —    | 6.3   | —    | mA   |
| Frequency shift of HFXTAL when HFCLKOUT is active                            | FS <sub>HFCLKOUT</sub>  | Assuming crystal pullability of 13 ppm/pF               | -1.5 | —     | 4.5  | ppm  |
| HFCLKOUT shorting output resistance  | RS <sub>HFCLKOUT</sub>  | When output is disabled                                 | —    | 150   | —    | Ω    |
| Total harmonic distortion, XOUTBIASANA = 5, C <sub>HFCLKOUT</sub> = 20 pF    | THD <sub>HFCLKOUT</sub> | XOUTCFANA = 0   | —    | 8.53  | —    | %    |
|  |                         | XOUTCFANA = 1   | —    | 10.05 | —    | %    |
|  |                         | XOUTCFANA = 2   | —    | 11.98 | —    | %    |
|  |                         | XOUTCFANA = 3   | —    | 14.39 | —    | %    |

| Parameter  | Symbol | Test Condition | Min | Typ | Max | Unit |
|--|--------|----------------|-----|-----|-----|------|
| <b>Note:</b>   |        |                |     |     |     |      |
| 1. The BLE radio requires a 38.4 Mhz or 39.0 MHz crystal with a tolerance of $\pm 50$ ppm over temperature and aging. Please use a crystal with the recommended frequency and tolerance (refer to AN0016.2 for recommended crystals).    |        |                |     |     |     |      |
| 2. The ZigBee radio requires a 38.4 Mhz or 39.0 MHz crystal with a tolerance of $\pm 40$ ppm over temperature and aging. Please use a crystal with the recommended frequency and tolerance (refer to AN0016.2 for recommended crystals). |        |                |     |     |     |      |
| 3. The radio requires additional software configuration based on crystal frequency. Refer to the Simplicity Studio component "RAIL Utility, Built-in PHYs Across HFXO Frequencies".  |        |                |     |     |     |      |
| 4. Total load capacitance as seen by the crystal.  |        |                |     |     |     |      |
| 5. RF performance characteristics have been determined using crystals with an ESR of 40 $\Omega$ and $C_L$ of 10 pF.   |        |                |     |     |     |      |
| 6. Startup time does not include time implemented by programmable TIMEOUTSTEADY delay.   |        |                |     |     |     |      |
| 7. The tuning step size is the effective step size when incrementing both of the tuning capacitors by one count. The step size for the each of the individual tuning capacitors is twice this value.                                     |        |                |     |     |     |      |

#### 4.10.2 Low Frequency Crystal Oscillator (LFXO)

Table 4.26. Low Frequency Crystal Oscillator (LFXO)

| Parameter  | Symbol          | Test Condition   | Min  | Typ    | Max  | Unit       |
|--|-----------------|--|------|--------|------|------------|
| Crystal Frequency  | $F_{LFXO}$      |  | —    | 32.768 | —    | kHz        |
| Supported Crystal equivalent series resistance (ESR)           | $ESR_{LFXO}$    | GAIN = 0   | —    | —      | 80   | k $\Omega$ |
|  |                 | GAIN = 1 to 3  | —    | —      | 100  | k $\Omega$ |
| Supported range of crystal load capacitance <sup>1</sup>       | $C_{L\_LFXO}$   | GAIN = 0   | 4    | —      | 6    | pF         |
|  |                 | GAIN = 1   | 6    | —      | 10   | pF         |
|  |                 | GAIN = 2 (see note <sup>2</sup> )  | 10   | —      | 12.5 | pF         |
|  |                 | GAIN = 3 (see note <sup>2</sup> )  | 12.5 | —      | 18   | pF         |
| Current consumption  | $I_{CL12p5}$    | ESR = 70 k $\Omega$ , $C_L$ = 12.5 pF, GAIN <sup>3</sup> = 2, AGC <sup>4</sup> = 1 | —    | 294    | —    | nA         |
| Startup Time   | $T_{STARTUP}$   | ESR = 70 k $\Omega$ , $C_L$ = 7 pF, GAIN <sup>3</sup> = 1, AGC <sup>4</sup> = 1    | —    | 52     | —    | ms         |
| On-chip tuning cap step size                                   | $SS_{LFXO}$     |  | —    | 0.26   | —    | pF         |
| On-chip tuning capacitor value at minimum setting <sup>5</sup> | $C_{LFXO\_MIN}$ | CAPTUNE = 0  | —    | 5.2    | —    | pF         |
| On-chip tuning capacitor value at maximum setting <sup>5</sup> | $C_{LFXO\_MAX}$ | CAPTUNE = 0x4F   | —    | 26.2   | —    | pF         |

|  |  |  |  |  |  |  |
|--|--|--|--|--|--|--|
| <b>Note:</b>   |  |  |  |  |  |  |
| 1. Total load capacitance seen by the crystal  |  |  |  |  |  |  |
| 2. Crystals with a load capacitance of greater than 12 pF require external load capacitors.  |  |  |  |  |  |  |
| 3. In LFXO_CAL Register  |  |  |  |  |  |  |
| 4. In LFXO_CFG Register  |  |  |  |  |  |  |
| 5. The effective load capacitance seen by the crystal will be $C_{LFXO}/2$ . This is because each XTAL pin has a tuning cap and the two caps will be seen in series by the crystal |  |  |  |  |  |  |

### 4.10.3 High Frequency RC Oscillator (HFRCO)

Unless otherwise indicated, typical conditions are: AVDD = DVDD = 3.0 V. T<sub>A</sub> = 25 °C. Minimum and maximum values in this table represent the worst conditions across process variation, operating supply voltage range, and operating temperature range.

**Table 4.27. High Frequency RC Oscillator (HFRCO)**

| Parameter  | Symbol                        | Test Condition                            | Min | Typ | Max | Unit   |
|--|-------------------------------|---|-----|-----|-----|--------|
| Frequency Accuracy                               | F <sub>HFRCO_ACC</sub>        | For all production calibrated frequencies | -3  | —   | 3   | %      |
| Current consumption on all supplies <sup>1</sup> | I <sub>HFRCO</sub>            | F <sub>HFRCO</sub> = 4 MHz                | —   | 28  | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 5 MHz <sup>2</sup>   | —   | 29  | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 7 MHz                | —   | 59  | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 10 MHz <sup>2</sup>  | —   | 63  | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 13 MHz               | —   | 77  | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 16 MHz               | —   | 87  | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 19 MHz               | —   | 90  | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 20 MHz <sup>2</sup>  | —   | 107 | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 26 MHz               | —   | 116 | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 32 MHz               | —   | 139 | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 38 MHz <sup>3</sup>  | —   | 170 | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 40 MHz <sup>2</sup>  | —   | 172 | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 48 MHz <sup>3</sup>  | —   | 207 | —   | μA     |
|  |                               | F <sub>HFRCO</sub> = 56 MHz <sup>3</sup>  | —   | 228 | —   | μA     |
| F <sub>HFRCO</sub> = 64 MHz <sup>3</sup>         | —                             | 269                                       | —   | μA  |     |        |
| F <sub>HFRCO</sub> = 80 MHz <sup>3</sup>         | —                             | 285                                       | —   | μA  |     |        |
| Clock Out current for HFRCODPLL <sup>4</sup>     | I <sub>CLKOUT_HFRCODPLL</sub> | FORCEEN bit of HFRCO0_CTRL = 1            | —   | 4.5 | —   | μA/MHz |
| Clock Out current for HFRCOEM23 <sup>4</sup>     | I <sub>CLKOUT_HFRCOEM23</sub> | FORCEEN bit of HFRCOEM23_CTRL = 1         | —   | 2.0 | —   | μA/MHz |
| Startup Time <sup>5</sup>                        | T <sub>STARTUP</sub>          | FREQRANGE = 0 to 7                        | —   | 1.2 | —   | μs     |
|  |                               | FREQRANGE = 8 to 15                       | —   | 0.6 | —   | μs     |

| Parameter                          | Symbol                  | Test Condition | Min  | Typ | Max  | Unit |
|------------------------------------|-------------------------|----------------|------|-----|------|------|
| Band Frequency Limits <sup>6</sup> | f <sub>HFRCO_BAND</sub> | FREQRANGE = 0  | 3.71 | —   | 5.24 | MHz  |
|                                    |                         | FREQRANGE = 1  | 4.39 | —   | 6.26 | MHz  |
|                                    |                         | FREQRANGE = 2  | 5.25 | —   | 7.55 | MHz  |
|                                    |                         | FREQRANGE = 3  | 6.22 | —   | 9.01 | MHz  |
|                                    |                         | FREQRANGE = 4  | 7.88 | —   | 11.6 | MHz  |
|                                    |                         | FREQRANGE = 5  | 9.9  | —   | 14.6 | MHz  |
|                                    |                         | FREQRANGE = 6  | 11.5 | —   | 17.0 | MHz  |
|                                    |                         | FREQRANGE = 7  | 14.1 | —   | 20.9 | MHz  |
|                                    |                         | FREQRANGE = 8  | 16.4 | —   | 24.7 | MHz  |
|                                    |                         | FREQRANGE = 9  | 19.8 | —   | 30.4 | MHz  |
|                                    |                         | FREQRANGE = 10 | 22.7 | —   | 34.9 | MHz  |
|                                    |                         | FREQRANGE = 11 | 28.6 | —   | 44.4 | MHz  |
|                                    |                         | FREQRANGE = 12 | 33.0 | —   | 51.0 | MHz  |
|                                    |                         | FREQRANGE = 13 | 42.2 | —   | 64.6 | MHz  |
|                                    |                         | FREQRANGE = 14 | 48.8 | —   | 74.8 | MHz  |
| FREQRANGE = 15                     | 57.6                    | —              | 87.4 | MHz |      |      |

**Note:**

1. Does not include additional clock tree current. See specifications for additional current when selected as a clock source for a particular clock multiplexer.
2. This frequency is calibrated for the HFRCOEM23 only.
3. This frequency is calibrated for the HFRCODPLL (HFRCO0) only.
4. When the HFRCO is enabled for characterization using the FORCEEN bit, the total current will be the HFRCO core current plus the specified CLKOUT current. When the HFRCO is enabled on demand, the clock current may be different.
5. Hardware delay ensures settling to within ± 0.5%. Hardware also enforces this delay on a band change.
6. The frequency band limits represent the lowest and highest frequency which each band can achieve over the operating range.

#### 4.10.4 Fast Start-Up RC Oscillator (FSRCO)

**Table 4.28. Fast Start-Up RC Oscillator (FSRCO)**

| Parameter       | Symbol             | Test Condition | Min  | Typ | Max  | Unit |
|-----------------|--------------------|----------------|------|-----|------|------|
| FSRCO frequency | F <sub>FSRCO</sub> |                | 17.2 | 20  | 21.2 | MHz  |

#### 4.10.5 Precision Low Frequency RC Oscillator (LFRCO)

**Table 4.29. Precision Low Frequency RC Oscillator (LFRCO)**

| Parameter                     | Symbol           | Test Condition  | Min  | Typ    | Max | Unit    |
|-------------------------------|------------------|---|------|--------|-----|---------|
| Nominal oscillation frequency | $F_{LFRCO}$      |   | —    | 32.768 | —   | kHz     |
| Frequency accuracy            | $F_{LFRCO\_ACC}$ | Normal mode   | -3   | —      | 3   | %       |
|                               |                  | Precision mode <sup>1</sup> , across operating temperature range <sup>2</sup> | -500 | —      | 500 | ppm     |
| Startup time                  | $t_{STARTUP}$    | Normal mode   | —    | 204    | —   | $\mu$ s |
|                               |                  | Precision mode <sup>1</sup>   | —    | 11.7   | —   | ms      |
| Current consumption           | $I_{LFRCO}$      | Normal mode   | —    | 189.9  | —   | nA      |
|                               |                  | Precision mode <sup>1</sup> , T = stable at 25 °C <sup>3</sup>                | —    | 649.8  | —   | nA      |

**Note:**

1. The LFRCO operates in high-precision mode when CFG\_HIGHPRECEN is set to 1. High-precision mode is not available in EM4.
2. Includes  $\pm 40$  ppm frequency tolerance of the HFXO crystal.
3. Includes periodic re-calibration against HFXO crystal oscillator.

#### 4.10.6 Ultra Low Frequency RC Oscillator (ULFRCO)

**Table 4.30. Ultra Low Frequency RC Oscillator (ULFRCO)**

| Parameter             | Symbol       | Test Condition | Min   | Typ | Max   | Unit |
|-----------------------|--------------|----------------|-------|-----|-------|------|
| Oscillation Frequency | $F_{ULFRCO}$ |                | 0.944 | 1.0 | 1.095 | kHz  |

#### 4.11 GPIO Pins (GPIO)

Table 4.31. GPIO Pins (GPIO)

| Parameter                            | Symbol                 | Test Condition   | Min          | Typ  | Max         | Unit |
|--------------------------------------|------------------------|--|--------------|------|-------------|------|
| Leakage current                      | I <sub>LEAK_IO</sub>   | MODEx = DISABLED, IOVDD = 1.71 V   | —            | 1.9  | —           | nA   |
|                                      |                        | MODEx = DISABLED, IOVDD = 3.0 V  | —            | 2.5  | —           | nA   |
|                                      |                        | MODEx = DISABLED, IOVDD = 3.8 V T <sub>A</sub> = 125 °C, PB00-PB03, PC06-PC09, PA00                        | —            | —    | 250         | nA   |
|                                      |                        | MODEx = DISABLED, IOVDD = 3.8 V T <sub>A</sub> = 125 °C, All Other Pins                                    | —            | —    | 200         | nA   |
| Input low voltage <sup>1</sup>       | V <sub>IL</sub>        | Any GPIO pin   | —            | —    | 0.3 * IOVDD | V    |
|                                      |                        | RESETn   | —            | —    | 0.3 * DVDD  | V    |
| Input high voltage <sup>1</sup>      | V <sub>IH</sub>        | Any GPIO pin   | 0.7 * IOVDD  | —    | —           | V    |
|                                      |                        | RESETn   | 0.7 * DVDD   | —    | —           | V    |
| Hysteresis of input voltage          | V <sub>HYS</sub>       | Any GPIO pin   | 0.05 * IOVDD | —    | —           | V    |
|                                      |                        | RESETn   | 0.05 * DVDD  | —    | —           | V    |
| Output high voltage                  | V <sub>OH</sub>        | Sourcing 20mA, IOVDD = 3.0 V   | 0.8 * IOVDD  | —    | —           | V    |
|                                      |                        | Sourcing 8mA, IOVDD = 1.71 V   | 0.6 * IOVDD  | —    | —           | V    |
| Output low voltage                   | V <sub>OL</sub>        | Sinking 20mA, IOVDD = 3.0 V  | —            | —    | 0.2 * IOVDD | V    |
|                                      |                        | Sinking 8mA, IOVDD = 1.71 V  | —            | —    | 0.4 * IOVDD | V    |
| GPIO rise time                       | T <sub>GPIO_RISE</sub> | IOVDD = 3.0 V, C <sub>load</sub> = 50pF, SLEWRATE = 4, 10% to 90%  | —            | 8.4  | —           | ns   |
|                                      |                        | IOVDD = 1.7 V, C <sub>load</sub> = 50pF, SLEWRATE = 4, 10% to 90%  | —            | 13   | —           | ns   |
| GPIO fall time                       | T <sub>GPIO_FALL</sub> | IOVDD = 3.0 V, C <sub>load</sub> = 50pF, SLEWRATE = 4, 90% to 10%  | —            | 7.1  | —           | ns   |
|                                      |                        | IOVDD = 1.7 V, C <sub>load</sub> = 50pF, SLEWRATE = 4, 90% to 10%  | —            | 11.9 | —           | ns   |
| Pull up/down resistance <sup>2</sup> | R <sub>PULL</sub>      | Any GPIO pin. Pull-up to IOVDD: MODEn = DISABLE DOUT=1. Pull-down to VSS: MODEn = WIREORPULLDOWN DOUT = 0. | 35           | 44   | 55          | kΩ   |
|                                      |                        | RESETn pin. Pull-up to DVDD  | 35           | 44   | 55          | kΩ   |
| Maximum filtered glitch width        | T <sub>GF</sub>        | MODE = INPUT, DOUT = 1   | —            | 27   | —           | ns   |

| Parameter                           | Symbol             | Test Condition | Min | Typ | Max | Unit |
|-------------------------------------|--------------------|----------------|-----|-----|-----|------|
| RESETn low time to ensure pin reset | T <sub>RESET</sub> |                | 100 | —   | —   | ns   |

**Note:**

1. GPIO input thresholds are proportional to the IOVDD pin. RESETn input thresholds are proportional to DVDD.
2. GPIO pull-ups connect to IOVDD supply, pull-downs connect to VSS. RESETn pull-up connects to DVDD.

#### 4.12 Analog to Digital Converter (IADC)

Specified at 1 Msps, ADCCLK = 10 MHz, OSR=2, unless otherwise indicated.

**Table 4.32. Analog to Digital Converter (IADC)**

| Parameter                        | Symbol               | Test Condition  | Min              | Typ                     | Max              | Unit |
|----------------------------------|----------------------|---|------------------|-------------------------|------------------|------|
| Main analog supply               | V <sub>AVDD</sub>    | Normal mode   | 1.71             | —                       | 3.8              | V    |
|                                  |                      | High-Speed mode   | 1.71             | —                       | 3.8              | V    |
|                                  |                      | High-Accuracy mode  | 1.71             | —                       | 3.8              | V    |
| Maximum Input Range <sup>1</sup> | V <sub>IN_MAX</sub>  | Maximum allowable input voltage                             | 0                | —                       | AVDD             | V    |
| Full-Scale Voltage               | V <sub>FS</sub>      | Voltage required for Full-Scale measurement                 | —                | V <sub>REF</sub> / Gain | —                | V    |
| Input Measurement Range          | V <sub>IN</sub>      | Differential Mode - Plus and Minus inputs                   | -V <sub>FS</sub> | —                       | +V <sub>FS</sub> | V    |
|                                  |                      | Single Ended Mode - One input tied to ground                | 0                | —                       | V <sub>FS</sub>  | V    |
| Input Sampling Capacitance       | C <sub>s</sub>       | Analog Gain = 1x  | —                | 1.8                     | —                | pF   |
|                                  |                      | Analog Gain = 2x  | —                | 3.6                     | —                | pF   |
|                                  |                      | Analog Gain = 3x  | —                | 5.4                     | —                | pF   |
|                                  |                      | Analog Gain = 4x  | —                | 7.2                     | —                | pF   |
|                                  |                      | Analog Gain = 0.5x  | —                | 0.9                     | —                | pF   |
| ADC clock frequency              | f <sub>ADC_CLK</sub> | Normal mode, Gain = 1x or 0.5x                              | —                | —                       | 10               | MHz  |
|                                  |                      | Normal mode, Gain = 2x                                      | —                | —                       | 5                | MHz  |
|                                  |                      | Normal mode, Gain = 3x or 4x                                | —                | —                       | 2.5              | MHz  |
|                                  |                      | High-Speed mode, Gain = 1x or 0.5x                          | —                | —                       | 20               | MHz  |
|                                  |                      | High-Speed mode, Gain = 2x                                  | —                | —                       | 10               | MHz  |
|                                  |                      | High-Speed mode, Gain = 3x or 4x                            | —                | —                       | 5                | MHz  |
|                                  |                      | High-Accuracy mode  | —                | —                       | 5                | MHz  |
| Input sampling frequency         | f <sub>s</sub>       | Normal Mode   | —                | f <sub>ADC_CLK</sub> /4 | —                | MHz  |
|                                  |                      | High-Speed Mode   | —                | f <sub>ADC_CLK</sub> /4 | —                | MHz  |
|                                  |                      | High-Accuracy Mode  | —                | f <sub>ADC_CLK</sub> /5 | —                | MHz  |
| Throughput rate                  | f <sub>SAMPLE</sub>  | Normal mode, f <sub>ADC_CLK</sub> = 10 MHz, OSR = 2         | —                | —                       | 1                | Msps |
|                                  |                      | Normal mode, f <sub>ADC_CLK</sub> = 10 MHz, OSR = 32        | —                | —                       | 76.9             | ksps |
|                                  |                      | High-Speed mode, f <sub>ADC_CLK</sub> = 20 MHz, OSR = 2     | —                | —                       | 2                | Msps |
|                                  |                      | High-Accuracy mode, f <sub>ADC_CLK</sub> = 5 MHz, OSR = 92  | —                | —                       | 10.7             | ksps |
|                                  |                      | High-Accuracy mode, f <sub>ADC_CLK</sub> = 5 MHz, OSR = 256 | —                | —                       | 3.88             | ksps |

| Parameter  | Symbol                   | Test Condition  | Min  | Typ      | Max | Unit  |
|--|--------------------------|---|------|----------|-----|-------|
| Current from all supplies, Continuous operation                        | I <sub>ADC_CONT</sub>    | Normal Mode, 1 Msps, OSR = 2, f <sub>ADC_CLK</sub> = 10 MHz   | —    | 305      | 385 | μA    |
|  |                          | High-Speed Mode, 2 Msps, OSR = 2, f <sub>ADC_CLK</sub> = 20 MHz   | —    | 550      | 655 | μA    |
|  |                          | High-Accuracy Mode, 10.7 ksps, OSR = 92, f <sub>ADC_CLK</sub> = 5 MHz   | —    | 108      | 170 | μA    |
| Current in Standby mode. ADC is not functional but can wake up in 1us. | I <sub>STBY</sub>        | Normal mode   | —    | 17       | —   | μA    |
|  |                          | High-Speed mode   | —    | 21       | —   | μA    |
|  |                          | High-Accuracy mode  | —    | 10       | —   | μA    |
| ADC Startup Time   | t <sub>startup</sub>     | From power down state   | —    | 5        | —   | μs    |
|  |                          | From standby state  | —    | 1        | —   | μs    |
| Normal Mode ADC Resolution <sup>2</sup>                                | Resolution               | OSR = 2   | —    | 12       | —   | bits  |
|  |                          | OSR = 32  | —    | 16       | —   | bits  |
| High-Speed Mode ADC Resolution <sup>2</sup>                            | Resolution <sub>HS</sub> | OSR = 2   | —    | 12       | —   | bits  |
|  |                          | OSR = 32  | —    | 16       | —   | bits  |
| High-Accuracy Mode ADC Resolution                                      | Resolution <sub>HA</sub> | High Accuracy mode. Typical value is for default OSR = 92 for 10.7 ksps, max value is limited by code length. | —    | 16       | 20  | bits  |
| Differential Nonlinearity  | DNL                      | Normal mode. Differential Input. OSR = 2 (No missing codes)   | -1   | +/- 0.25 | 1.5 | LSB12 |
|  |                          | High Speed mode. Differential Input. OSR = 2  | -1   | +/- 0.25 | 1.5 | LSB12 |
|  |                          | High-Accuracy mode <sup>3</sup> . Differential Input. 10.7 ksps with OSR = 92                                 | -1   | —        | 1   | LSB16 |
| Integral Nonlinearity  | INL                      | Normal mode. Differential Input, OSR = 2  | -2.5 | +/- 0.65 | 2.5 | LSB12 |
|  |                          | High-Speed mode. Differential Input.  | -2.5 | +/- 0.65 | 2.5 | LSB12 |
|  |                          | High-Accuracy mode <sup>3</sup> . Differential Input. External VREF = 1.25 V. 10.7 ksps with OSR = 92         | —    | +/- 0.25 | —   | LSB16 |

| Parameter   | Symbol             | Test Condition  | Min  | Typ  | Max | Unit |
|---|--------------------|---|------|------|-----|------|
| Effective number of bits <sup>4</sup>                       | ENOB               | Normal Mode, Differential Input. Gain = 1x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21V   | 10.7 | 11.7 | —   | bits |
|   |                    | Normal Mode, Differential Input. Gain = 1x, OSR = 32, $f_{IN}$ = 2.5 kHz, Internal VREF = 1.21 V.                                     | —    | 13.5 | —   | bits |
|   |                    | Normal Mode, Differential Input. Gain = 1x, OSR = 32, $f_{IN}$ = 2.5 kHz, External VREF = 1.25 V.                                     | —    | 14.3 | —   | bits |
|   |                    | High Speed mode. Differential Input. Gain = 1x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21 V                                    | 10.7 | 11.5 | —   | bits |
|   |                    | High-Accuracy mode <sup>3</sup> . Differential Input. Gain = 1x, $f_{IN}$ = 100 Hz, External VREF = 1.25 V. 10.7 kspcs with OSR = 92  | 14.0 | 15.3 | —   | bits |
|   |                    | High-Accuracy mode <sup>3</sup> . Differential Input. Gain = 1x, $f_{IN}$ = 100 Hz, External VREF = 1.25 V. 3.88 kspcs with OSR = 256 | —    | 16.1 | —   | bits |
| Signal to Noise + Distortion Ratio Normal Mode <sup>4</sup> | SNDR               | Differential Input. Gain=1x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21V  | 66   | 72.3 | —   | dB   |
|   |                    | Differential Input. Gain=2x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21V  | —    | 72.3 | —   | dB   |
|   |                    | Differential Input. Gain=4x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21V  | —    | 68.8 | —   | dB   |
|   |                    | Differential Input. Gain=0.5x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21V  | —    | 72.5 | —   | dB   |
|   |                    | Differential Input. Gain = 1x, OSR = 64, $f_{IN}$ = 1.25 kHz, Internal VREF = 1.21 V  | —    | 83.9 | —   | dB   |
| Signal to Noise + Distortion Ratio High-Speed mode          | SNDR <sub>HS</sub> | High Speed mode. Differential Input. Gain = 1x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21 V                                    | 66   | 72.3 | —   | dB   |
|   |                    | High Speed mode. Differential Input. Gain = 2x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21 V                                    | —    | 72.3 | —   | dB   |
|   |                    | High Speed mode. Differential Input. Gain = 4x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21 V                                    | —    | 68.8 | —   | dB   |
|   |                    | High Speed mode. Differential Input. Gain = 0.5x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21 V                                  | —    | 72.5 | —   | dB   |

| Parameter  | Symbol             | Test Condition   | Min | Typ   | Max | Unit |
|--|--------------------|--|-----|-------|-----|------|
| Signal to Noise + Distortion Ratio High-Accuracy mode <sup>3</sup> | SNDR <sub>HA</sub> | High-Accuracy. Differential Input. Gain = 1x, $f_{IN}$ = 100 Hz, External VREF = 1.25 V. 3.88 ksps with OSR = 256        | —   | 98.7  | —   | dB   |
|  |                    | High-Accuracy. Differential Input. Gain = 1x, $f_{IN}$ = 100 Hz, External VREF = 1.25 V. 10.7 ksps with OSR = 92         | 86  | 93.8  | —   | dB   |
|  |                    | High-Accuracy. Differential Input. Gain = 2x, $f_{IN}$ = 100 Hz, External VREF = 1.25 V. 10.7 ksps with OSR = 92         | —   | 93.5  | —   | dB   |
|  |                    | High-Accuracy. Differential Input. Gain = 4x, $f_{IN}$ = 100 Hz, External VREF = 1.25 V. 10.7 ksps with OSR = 92         | —   | 91.0  | —   | dB   |
|  |                    | High-Accuracy. Differential Input. Gain = 0.5x, $f_{IN}$ = 100 Hz, External VREF = 1.25 V. 10.7 ksps with OSR = 92       | —   | 94.7  | —   | dB   |
| Total Harmonic Distortion  | THD                | Normal mode, Differential Input. Gain = 1x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21 V                           | —   | -80.8 | -70 | dB   |
|  |                    | High Speed mode, Differential Input. Gain = 1x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21 V                       | —   | -84.3 | -70 | dB   |
|  |                    | High-Accuracy mode <sup>3</sup> , Differential Input. $f_{IN}$ = 100 Hz, External VREF = 1.25 V. 10.7 ksps with OSR = 92 | —   | -101  | -80 | dB   |
| Spurious-Free Dynamic Range  | SFDR               | Normal mode, Differential Input. Gain = 1x, OSR = 2, $f_{IN}$ = 10 kHz, Internal VREF = 1.21 V                           | 72  | 86.5  | —   | dB   |
|  |                    | High Speed mode, Differential Input. Gain = 1x, $f_{IN}$ = 10 kHz, Internal VREF = 1.21 V                                | 72  | 84.3  | —   | dB   |
|  |                    | High-Accuracy mode <sup>3</sup> , Differential Input. $f_{IN}$ = 100 Hz, External VREF = 1.25 V. 10.7 ksps with OSR = 92 | 100 | 118.1 | —   | dB   |
| Common Mode Rejection Ratio  | CMRR               | Normal mode. DC to 100 Hz  | —   | 87.0  | —   | dB   |
|  |                    | Normal mode. AC high frequency.  | —   | 68.6  | —   | dB   |
|  |                    | High-Speed mode. DC to 100 Hz  | —   | 86.3  | —   | dB   |
|  |                    | High-Speed mode. AC high frequency.  | —   | 59.0  | —   | dB   |
|  |                    | High-Accuracy mode <sup>3</sup> . DC to 100 Hz   | —   | 93.8  | —   | dB   |
|  |                    | High Accuracy mode <sup>3</sup> . AC high frequency.   | —   | 87.0  | —   | dB   |

| Parameter                                     | Symbol               | Test Condition  | Min  | Typ    | Max  | Unit  |
|---|----------------------|---|------|--------|------|-------|
| Power Supply Rejection Ratio                  | PSRR                 | Normal mode. DC to 100 Hz   | —    | 80.4   | —    | dB    |
|   |                      | Normal mode. AC high frequency, using internal VBGR                               | —    | 33.4   | —    | dB    |
|   |                      | Normal mode. AC high frequency, using VREF pad                                    | —    | 65.2   | —    | dB    |
|   |                      | High Speed modes. DC to 100 Hz  | —    | 79.8   | —    | dB    |
|   |                      | High-Speed mode. AC high frequency, using internal VBGR                           | —    | 31.0   | —    | dB    |
|   |                      | High Speed mode. AC high frequency, using VREF pad                                | —    | 65.0   | —    | dB    |
|   |                      | High Accuracy mode <sup>3</sup> . DC to 100 Hz                                    | —    | 124    | —    | dB    |
|   |                      | High-Accuracy mode <sup>3</sup> . AC high frequency, using external VREF pin.     | —    | 85.0   | —    | dB    |
| External reference voltage range <sup>1</sup> | V <sub>EVREF</sub>   |   | 1.0  | —      | AVDD | V     |
| Offset Error, Normal mode                     | OFFSET               | GAIN = 1 and 0.5, Differential Input  | -3   | 0.27   | 3    | LSB12 |
|   |                      | GAIN = 2, Differential Input  | -4   | 0.27   | 4    | LSB12 |
|   |                      | GAIN = 3, Differential Input  | -4   | 0.25   | 4    | LSB12 |
|   |                      | GAIN = 4, Differential Input  | -4   | 0.29   | 4    | LSB12 |
| Offset Error, High-speed mode                 | OFFSET <sub>HS</sub> | GAIN = 1 and 0.5, Differential Input  | -3   | 0.27   | 3    | LSB12 |
|   |                      | GAIN = 2, Differential Input  | -4   | 0.27   | 4    | LSB12 |
|   |                      | GAIN = 3, Differential Input  | -4   | 0.25   | 4    | LSB12 |
|   |                      | GAIN = 4, Differential Input  | -4   | 0.29   | 4    | LSB12 |
| Offset Error, High-accuracy mode <sup>3</sup> | OFFSET <sub>HA</sub> | All GAIN settings, Differential Input   | -7   | -0.011 | 7    | LSB16 |
| Gain Error, Normal mode                       | GE                   | GAIN = 1 and 0.5, using external VREF, direct mode, f <sub>ADC_CLK</sub> = 10 MHz | -0.6 | -0.155 | 0.6  | %     |
|   |                      | GAIN = 2, using external VREF, direct mode, f <sub>ADC_CLK</sub> = 5 MHz          | -0.6 | -0.155 | 0.6  | %     |
|   |                      | GAIN = 3, using external VREF, direct mode, f <sub>ADC_CLK</sub> = 2.5 MHz        | -0.7 | 0.186  | 0.7  | %     |
|   |                      | GAIN = 4, using external VREF, direct mode, f <sub>ADC_CLK</sub> = 2.5 MHz        | -1.1 | 0.227  | 1.1  | %     |
|   |                      | Internal VREF <sup>5</sup> , all GAIN settings                                    | -1.5 | 0.023  | 1.5  | %     |

| Parameter                                   | Symbol            | Test Condition  | Min  | Typ    | Max | Unit |
|---|-------------------|---|------|--------|-----|------|
| Gain Error, High-speed mode                 | GE <sub>HS</sub>  | GAIN = 1 and 0.5, using external VREF, direct mode, f <sub>ADC_CLK</sub> = 20 MHz | -0.6 | -0.155 | 0.6 | %    |
|   |                   | GAIN = 2, using external VREF, direct mode, f <sub>ADC_CLK</sub> = 10 MHz         | -0.6 | -0.055 | 0.6 | %    |
|   |                   | GAIN = 3, using external VREF, direct mode, f <sub>ADC_CLK</sub> = 5 MHz          | -0.7 | 0.186  | 0.7 | %    |
|   |                   | GAIN = 4, using external VREF, direct mode, f <sub>ADC_CLK</sub> = 5 MHz          | -1.1 | 0.227  | 1.1 | %    |
|   |                   | Internal VREF <sup>5</sup> , all GAIN settings                                    | -1.5 | 0.023  | 1.5 | %    |
| Gain Error, High-accuracy mode <sup>3</sup> | GE <sub>HA</sub>  | GAIN = 1 and 0.5, using external VREF, direct mode.                               | -0.5 | 0.006  | 0.5 | %    |
|   |                   | GAIN = 2, using external VREF, direct mode.                                       | -0.5 | -0.067 | 0.5 | %    |
|   |                   | GAIN = 3, using external VREF, direct mode.                                       | -0.5 | -0.070 | 0.5 | %    |
|   |                   | GAIN = 4, using external VREF, direct mode.                                       | -0.5 | -0.098 | 0.5 | %    |
| Internal Reference voltage                  | V <sub>VREF</sub> |   | —    | 1.21   | —   | V    |

**Note:**

1. When inputs are routed to external GPIO pins, the maximum pin voltage is limited to the lower of the IOVDD and AVDD supplies.
2. ADC output resolution depends on the OSR and digital averaging settings. With no digital averaging, ADC output resolution is 12 bits at OSR = 2, 13 bits at OSR = 4, 14 bits at OSR = 8, 15 bits at OSR = 16, 16 bits at OSR = 32 and 17 bits at OSR = 64. Digital averaging has a similar impact on ADC output resolution. See the product reference manual for additional details.
3. High-Accuracy mode performance specifications are tested with inputs applied to the dedicated AIN pins.
4. The relationship between ENOB and SNDR is specified according to the equation: ENOB = (SNDR - 1.76) / 6.02.
5. Includes error from internal VREF drift.

### 4.13 Analog Comparator (ACMP)

**Table 4.33. Analog Comparator (ACMP)**

| Parameter  | Symbol              | Test Condition                                       | Min  | Typ  | Max  | Unit |
|--|---------------------|--|------|------|------|------|
| ACMP Supply current                                    | $I_{ACMP}$          | BIAS = 0 <sup>1</sup> , HYST = DISABLED (100 °C max) | —    | 71   | —    | nA   |
|  |                     | BIAS = 1 <sup>1</sup> , HYST = DISABLED              | —    | 270  | —    | nA   |
|  |                     | BIAS = 2 <sup>1</sup> , HYST = DISABLED              | —    | 668  | —    | nA   |
|  |                     | BIAS = 3 <sup>1</sup> , HYST = DISABLED              | —    | 2.5  | —    | μA   |
|  |                     | BIAS = 4, HYST = DISABLED                            | —    | 5.4  | —    | μA   |
|  |                     | BIAS = 5, HYST = DISABLED                            | —    | 10.6 | —    | μA   |
|  |                     | BIAS = 6, HYST = DISABLED                            | —    | 27   | —    | μA   |
|  |                     | BIAS = 7, HYST = DISABLED                            | —    | 50   | 100  | μA   |
| ACMP Supply current with Hysteresis <sup>2</sup>       | $I_{ACMP\_WHYS}$    | BIAS = 3 <sup>1</sup> , HYST = SYM30MV               | —    | 3.4  | —    | μA   |
|  |                     | BIAS = 4, HYST = SYM30MV                             | —    | 7.3  | —    | μA   |
|  |                     | BIAS = 5, HYST = SYM30MV                             | —    | 15   | —    | μA   |
|  |                     | BIAS = 6, HYST = SYM30MV                             | —    | 38   | —    | μA   |
|  |                     | BIAS = 7, HYST = SYM30MV                             | —    | 71   | —    | μA   |
| Current consumption from VREFDIV in continuous mode    | $I_{VREFDIV}$       | NEGSEL = VREFDIVAVDD                                 | —    | 3.2  | —    | μA   |
|  |                     | NEGSEL = VREFDIV1V25                                 | —    | 4.3  | —    | μA   |
|  |                     | NEGSEL = VREFDIV2V5                                  | —    | 7.1  | —    | μA   |
| Current consumption from VREFDIV in sample/hold mode   | $I_{VREFDIV\_SH}$   | NEGSEL = VREFDIV2V5LP                                | —    | 81   | —    | nA   |
|  |                     | NEGSEL = VREFDIV1V25LP                               | —    | 74   | —    | nA   |
|  |                     | NEGSEL = VREFDIVAVDDLP                               | —    | 76   | —    | nA   |
| Current consumption from VSENSEDIV in continuous mode  | $I_{VSENSEDIV}$     | NEGSEL = VSENSE01DIV4                                | —    | 1.7  | —    | μA   |
| Current consumption from VSENSEDIV in sample/hold mode | $I_{VSENSEDIV\_SH}$ | NEGSEL = VSENSE01DIV4LP                              | —    | 59.1 | —    | nA   |
| Hysteresis (BIAS = 4) <sup>2</sup>                     | $V_{HYST}$          | HYST = SYM10MV <sup>3</sup>                          | —    | 18   | —    | mV   |
|  |                     | HYST = SYM20MV <sup>3</sup>                          | —    | 33   | —    | mV   |
|  |                     | HYST = SYM30MV <sup>3</sup>                          | —    | 47   | —    | mV   |
| Reference Voltage                                      | $V_{ACMPREF}$       | Internal 1.25 V Reference                            | 1.19 | 1.25 | 1.31 | V    |
|  |                     | Internal 2.5 V Reference                             | 2.34 | 2.5  | 2.75 | V    |

| Parameter                              | Symbol                | Test Condition                        | Min | Typ  | Max  | Unit |
|--|-----------------------|---------------------------------------|-----|------|------|------|
| Input offset voltage                   | V <sub>OFFSET</sub>   | BIAS = 0, VCM = 0.15 to AVDD - 0.15 V | -25 | —    | 25   | mV   |
|  |                       | BIAS = 3, VCM = 0.15 to AVDD - 0.15 V | -25 | —    | 25   | mV   |
|  |                       | BIAS = 4, VCM = 0.15 to AVDD - 0.15 V | -25 | —    | 25   | mV   |
|  |                       | BIAS = 7, VCM = 0.15 to AVDD - 0.15 V | -30 | —    | 30   | mV   |
| Input Range                            | V <sub>IN</sub>       | Input Voltage Range                   | 0   | —    | AVDD | V    |
| Comparator delay with 100 mV overdrive | T <sub>DELAY</sub>    | BIAS = 0, (100 °C max)                | —   | 10   | —    | µs   |
|  |                       | BIAS = 1                              | —   | 2.7  | —    | µs   |
|  |                       | BIAS = 2                              | —   | 1.4  | —    | µs   |
|  |                       | BIAS = 3                              | —   | 0.58 | —    | µs   |
|  |                       | BIAS = 4                              | —   | 224  | —    | ns   |
|  |                       | BIAS = 5                              | —   | 133  | —    | ns   |
|  |                       | BIAS = 6                              | —   | 80   | —    | ns   |
|  |                       | BIAS = 7                              | —   | 63   | —    | ns   |
| Capacitive Sense Oscillator Resistance | R <sub>CSRESSEL</sub> | CSRESSEL = 0                          | —   | 15.9 | —    | kΩ   |
|  |                       | CSRESSEL = 1                          | —   | 25.3 | —    | kΩ   |
|  |                       | CSRESSEL = 2                          | —   | 43.6 | —    | kΩ   |
|  |                       | CSRESSEL = 3                          | —   | 61.9 | —    | kΩ   |
|  |                       | CSRESSEL = 4                          | —   | 80.2 | —    | kΩ   |
|  |                       | CSRESSEL = 5                          | —   | 98.6 | —    | kΩ   |
|  |                       | CSRESSEL = 6                          | —   | 117  | —    | kΩ   |

**Note:**

1. When using the 1.25 V or 2.5 V VREF in continuous mode (VREFDIV1V25 or VREFDIV2V5) and BIAS < 4, an additional 1 µA of supply current is required.
2. Hysteresis is not supported for BIAS=0/1/2. Software should set HYST=DISABLED if using BIAS=0/1/2.
3. V<sub>CM</sub> = 1.25 V

#### 4.14 Digital to Analog Converter (VDAC)

**Table 4.34. Digital to Analog Converter (VDAC)**

| Parameter  | Symbol             | Test Condition  | Min  | Typ   | Max   | Unit       |
|--|--------------------|---|------|-------|-------|------------|
| Output voltage   | $V_{DACOUT}$       |   | 0    | —     | VREF  | V          |
| Output Current   | $I_{DACOUT}$       |   | -10  | —     | 10    | mA         |
| DAC clock frequency  | $f_{DAC}$          |   | —    | —     | 1     | MHz        |
| Sample rate  | $SR_{DAC}$         | $f_{DAC} = f_{DAC(max)}$  | —    | —     | 500   | ksps       |
| Resolution   | $N_{RESOLUTION}$   |   | —    | 12    | —     | bits       |
| Load Capacitance <sup>1</sup>  | $C_{LOAD}$         | High Power and Lower Power Modes  | —    | —     | 50    | pF         |
|  |                    | High Capacitance Load Mode  | 25   | —     | —     | nF         |
| Load Resistance  | $R_{LOAD}$         |   | 5    | —     | —     | k $\Omega$ |
| Current consumption, Dynamic, 500 ksps, 1 channel active <sup>2</sup>  | $I_{DAC\_1\_500}$  | High Power Mode   | —    | 281   | —     | $\mu$ A    |
|  |                    | Low Power Mode  | —    | 179   | —     | $\mu$ A    |
| Current consumption, Dynamic, 500 ksps, 2 channels active <sup>2</sup> | $I_{DAC\_2\_500}$  | High Power Mode   | —    | 445   | —     | $\mu$ A    |
|  |                    | Low Power Mode  | —    | 242   | —     | $\mu$ A    |
| Current consumption, Static, 1 channel active <sup>3</sup>             | $I_{DAC\_1\_STAT}$ | High Power Mode   | —    | 135   | —     | $\mu$ A    |
|  |                    | Low Power Mode  | —    | 31    | —     | $\mu$ A    |
|  |                    | High Capacitance Mode   | —    | 43    | —     | $\mu$ A    |
| Current consumption, Static, 2 channels active <sup>3</sup>            | $I_{DAC\_2\_STAT}$ | High Power Mode   | —    | 262   | —     | $\mu$ A    |
|  |                    | Low Power Mode  | —    | 53    | —     | $\mu$ A    |
|  |                    | High Capacitance Mode   | —    | 78    | —     | $\mu$ A    |
| Startup time   | $t_{DACSTARTUP}$   | Enable to 90% full scale output, settling to 10 LSB   | —    | 4.5   | 4.9   | $\mu$ s    |
| Settling time  | $t_{DACSETTLE}$    | High Power Mode, 25% to 75% of full scale, settling to 10 LSB                                     | —    | 1.1   | 1.6   | $\mu$ s    |
|  |                    | Low Power Mode, 25% to 75% of full scale, settling to 1%  | —    | 2.7   | —     | $\mu$ s    |
| Output impedance   | $R_{OUT}$          | Main Output, High Power Mode  | —    | 2.1   | —     | $\Omega$   |
|  |                    | Main Output, Low Power Mode   | —    | 3.4   | —     | $\Omega$   |
| Power supply rejection ratio <sup>4</sup>                              | PSRR               | $V_{out} = 50\%$ full scale, DC output  | —    | 88.6  | —     | dB         |
| Signal to noise and distortion ratio                                   | $SNDR_{DAC}$       | High Power mode, 500 ksps, internal 2.5 V reference, 1 kHz sine wave input, BW limited to 250 kHz | 65.8 | 67.2  | —     | dB         |
|  |                    | High Power mode, 500 ksps, internal 2.5 V reference, 1 kHz sine wave input, BW limited to 22 kHz  | 68.0 | 70.6  | —     | dB         |
| Total Harmonic Distortion  | THD                | High Power Mode, internal 2.5 V reference, 1 kHz sine wave input                                  | —    | -72.5 | -68.7 | dB         |

| Parameter                               | Symbol              | Test Condition                                 | Min  | Typ | Max    | Unit |
|---|---------------------|--|------|-----|--------|------|
| Integral Non-Linearity                  | INL <sub>DAC</sub>  | High Power Mode, Across full temperature range | -5   | —   | 5      | LSB  |
| Differential Non-Linearity <sup>5</sup> | DNL <sub>DAC</sub>  | High Power Mode, Across full temperature range | -1   | —   | 1.3    | LSB  |
| Offset error <sup>6</sup>               | V <sub>OFFSET</sub> | High Power mode                                | -15  | —   | 15     | mV   |
|   |                     | Low Power Mode                                 | -25  | —   | 25     | mV   |
|   |                     | High Capacitance Load mode                     | -35  | —   | 35     | mV   |
| Gain error <sup>6</sup>                 | V <sub>GAIN</sub>   | 1.25 V internal reference                      | -1.5 | —   | 1.5    | %    |
|   |                     | 2.5 V internal reference                       | -2   | —   | 2      | %    |
|   |                     | External Reference                             | -0.6 | —   | 0.6    | %    |
| External Reference Voltage <sup>7</sup> | V <sub>EXTREF</sub> |  | 1.1  | —   | V_AVDD | V    |

**Note:**

1. Main outputs only.
2. Dynamic current specifications are for VDAC circuitry operating at max clock frequency with the output updated at the specified sampling rate using DMA transfers. Output is a 1 kHz sine wave from 10% to 90% full scale. Specified current does not include current required to drive the external load. Measurement includes all current from AVDD and DVDD supplies.
3. Static current specifications are for VDAC circuitry operating after a one-time update to a static output at 50% full scale, with the VDAC APB clock disabled. Specified current does not include current required to drive the external load. Measurement includes all current from AVDD and DVDD supplies.
4. PSRR calculated as  $20 * \log_{10}(\Delta V_{DD} / \Delta V_{OUT})$ .
5. Entire range is monotonic and has no missing codes.
6. Gain is calculated by measuring the slope from 10% to 90% of full scale. Offset is calculated by comparing actual VDAC output at 10% of full scale to ideal VDAC output at 10% of full scale with the measured gain.
7. External reference voltage on VREFP pin or PA00 when used for VREFP

## 4.15 Temperature Sensor

Table 4.35. Temperature Sensor

| Parameter                                  | Symbol                  | Test Condition   | Min | Typ    | Max | Unit |
|--|-------------------------|--|-----|--------|-----|------|
| Temperature sensor range <sup>1</sup>      | T <sub>RANGE</sub>      |  | -40 | —      | 125 | °C   |
| Temperature sensor resolution              | T <sub>RESOLUTION</sub> |  | —   | 0.25   | —   | °C   |
| Measurement noise (RMS)                    | T <sub>NOISE</sub>      | Single measurement   | —   | 0.6    | —   | °C   |
|  |                         | 16-sample average (TEMPAVG-<br>NUM = 0)  | —   | 0.17   | —   | °C   |
|  |                         | 64-sample average (TEMPAVG-<br>NUM = 1)  | —   | 0.12   | —   | °C   |
| Temperature offset                         | T <sub>OFF</sub>        | Mean error of uncorrected output across full temperature range                             | —   | 3.2    | —   | °C   |
| Temperature sensor accuracy <sup>2 3</sup> | T <sub>ACC</sub>        | Direct output accuracy after mean error (T <sub>OFF</sub> ) removed                        | —   | +/-3   | —   | °C   |
|  |                         | After linearization in software, no calibration  | —   | +/-2   | —   | °C   |
|  |                         | After linearization in software, with single-temperature calibration at 25 °C <sup>4</sup> | —   | +/-1.5 | —   | °C   |
| Measurement interval                       | t <sub>MEAS</sub>       |  | —   | 250    | —   | ms   |

**Note:**

1. The sensor reports absolute die temperature in Kelvin (K). All specifications are in °C to match the units of the specified product temperature range.
2. Error is measured as the deviation of the mean temperature reading from the expected die temperature. Accuracy numbers represent statistical minimum and maximum using  $\pm 4$  standard deviations of measured error.
3. The raw output of the temperature sensor is a predictable curve. It can be linearized with a polynomial function for additional accuracy.
4. Assuming calibration accuracy of  $\pm 0.25$  °C.

## 4.16 Brown Out Detectors

### 4.16.1 DVDD BOD

BOD thresholds on DVDD in EM0 and EM1 only, unless otherwise noted. Typical conditions are at  $T_A = 25\text{ }^\circ\text{C}$ . Minimum and maximum values in this table represent the worst conditions across process variation, operating supply voltage range, and operating temperature range.

**Table 4.36. DVDD BOD**

| Parameter         | Symbol                  | Test Condition  | Min  | Typ  | Max  | Unit    |
|-------------------|-------------------------|---|------|------|------|---------|
| BOD threshold     | $V_{DVDD\_BOD}$         | Supply Rising   | —    | 1.67 | 1.71 | V       |
|                   |                         | Supply Falling  | 1.62 | 1.65 | —    | V       |
| BOD response time | $t_{DVDD\_BOD\_DELAY}$  | Supply dropping at 100 mV/ $\mu$ s slew rate <sup>1</sup> | —    | 0.95 | —    | $\mu$ s |
| BOD hysteresis    | $V_{DVDD\_BOD\_HYS\_T}$ |   | —    | 25   | —    | mV      |

**Note:**

1. If the supply slew rate exceeds the specified slew rate, the BOD may trip later than expected (at a threshold below the minimum specified threshold), or the BOD may not trip at all (e.g., if the supply ramps down and then back up at a very fast rate)

### 4.16.2 Low-Energy DVDD BOD

BOD thresholds on DVDD pin for low energy modes EM2 to EM4, unless otherwise noted.

**Table 4.37. Low-Energy DVDD BOD**

| Parameter         | Symbol                     | Test Condition  | Min | Typ | Max  | Unit    |
|-------------------|----------------------------|---|-----|-----|------|---------|
| BOD threshold     | $V_{DVDD\_LE\_BOD}$        | Supply Falling  | 1.5 | —   | 1.71 | V       |
| BOD response time | $t_{DVDD\_LE\_BOD\_DELAY}$ | Supply dropping at 2 mV/ $\mu$ s slew rate <sup>1</sup> | —   | 50  | —    | $\mu$ s |
| BOD hysteresis    | $V_{DVDD\_LE\_BOD\_HYST}$  |   | —   | 20  | —    | mV      |

**Note:**

1. If the supply slew rate exceeds the specified slew rate, the BOD may trip later than expected (at a threshold below the minimum specified threshold), or the BOD may not trip at all (e.g., if the supply ramps down and then back up at a very fast rate)

### 4.16.3 AVDD and IOVDD BODs

BOD thresholds for AVDD BOD and IOVDD BOD. Available in all energy modes.

**Table 4.38. AVDD and IOVDD BODs**

| Parameter         | Symbol           | Test Condition  | Min  | Typ | Max  | Unit    |
|-------------------|------------------|---|------|-----|------|---------|
| BOD threshold     | $V_{BOD}$        | Supply falling  | 1.45 | —   | 1.71 | V       |
| BOD response time | $t_{BOD\_DELAY}$ | Supply dropping at 2 mV/ $\mu$ s slew rate <sup>1</sup> | —    | 50  | —    | $\mu$ s |
| BOD hysteresis    | $V_{BOD\_HYST}$  |   | —    | 24  | —    | mV      |

**Note:**

1. If the supply slew rate exceeds the specified slew rate, the BOD may trip later than expected (at a threshold below the minimum specified threshold), or the BOD may not trip at all (e.g., if the supply ramps down and then back up at a very fast rate)

### 4.17 Pulse Counter (PCNT)

**Table 4.39. Pulse Counter (PCNT)**

| Parameter                                      | Symbol             | Test Condition                               | Min | Typ | Max | Unit |
|--|--------------------|--|-----|-----|-----|------|
| Input frequency                                | $F_{IN}$           | Asynchronous Single and Quadrature Modes     | —   | —   | 1.0 | MHz  |
|  |                    | Sampled Modes with Debounce filter set to 0. | —   | —   | 8   | kHz  |
| Setup time in asynchronous external clock mode | $t_{SU\_S1N\_S0N}$ | S1N (data) to S0N (clock)                    | 53  | —   | —   | ns   |
| Hold time in asynchronous external clock mode  | $t_{HD\_S0N\_S1N}$ | S0N (clock) to S1N (data)                    | 47  | —   | —   | ns   |

#### 4.18 USART SPI Main Timing

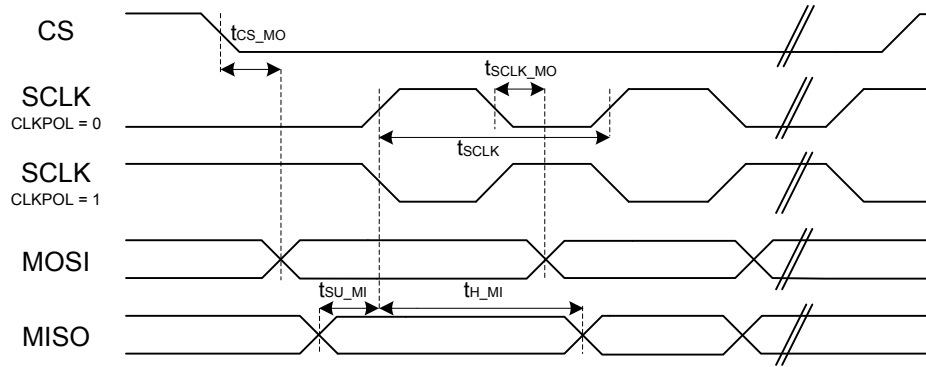


Figure 4.1. SPI Main Timing (SMSDELAY = 0)

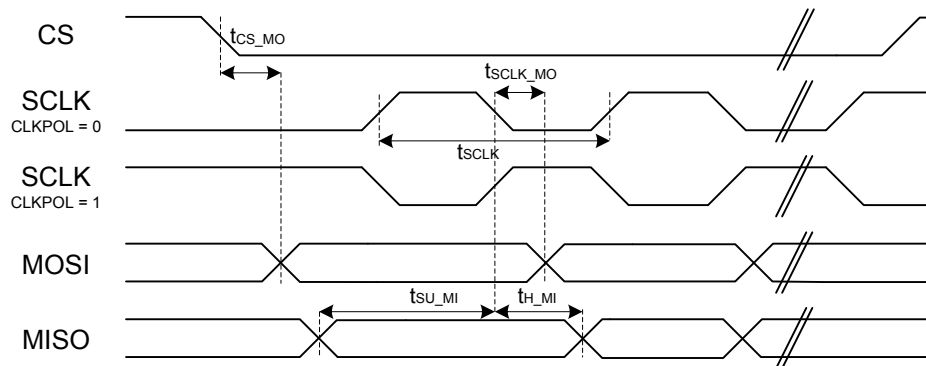


Figure 4.2. SPI Main Timing (SMSDELAY = 1)

#### 4.18.1 USART SPI Main Timing, Voltage Scaling = VSCALE2

Timing specifications are for all SPI signals routed to the same DBUS (DBUSAB or DBUSCD). All GPIO set to slew rate = 6.

**Table 4.40. USART SPI Main Timing, Voltage Scaling = VSCALE2**

| Parameter                      | Symbol               | Test Condition | Min                 | Typ | Max | Unit |
|--------------------------------|----------------------|----------------|---------------------|-----|-----|------|
| SCLK period <sup>1 2 3</sup>   | t <sub>SCLK</sub>    |                | 2*t <sub>PCLK</sub> | —   | —   | ns   |
| CS to MOSI <sup>1 2</sup>      | t <sub>CS_MO</sub>   |                | -15                 | —   | 15  | ns   |
| SCLK to MOSI <sup>1 2</sup>    | t <sub>SCLK_MO</sub> |                | -6                  | —   | 13  | ns   |
| MISO setup time <sup>1 2</sup> | t <sub>SU_MI</sub>   | IOVDD = 1.62 V | 40                  | —   | —   | ns   |
|                                |                      | IOVDD = 3.0 V  | 31                  | —   | —   | ns   |
| MISO hold time <sup>1 2</sup>  | t <sub>H_MI</sub>    |                | -9                  | —   | —   | ns   |

**Note:**

1. Applies for both CLKPHA = 0 and CLKPHA = 1.
2. Measurement done with 8 pF output loading at 10% and 90% of the I/O supply.
3. t<sub>PCLK</sub> is one period of the selected PCLK.

#### 4.18.2 USART SPI Main Timing, Voltage Scaling = VSCALE1

Timing specifications are for all SPI signals routed to the same DBUS (DBUSAB or DBUSCD). All GPIO set to slew rate = 6.

**Table 4.41. USART SPI Main Timing, Voltage Scaling = VSCALE1**

| Parameter                      | Symbol               | Test Condition | Min                 | Typ | Max | Unit |
|--------------------------------|----------------------|----------------|---------------------|-----|-----|------|
| SCLK period <sup>1 2 3</sup>   | t <sub>SCLK</sub>    |                | 2*t <sub>PCLK</sub> | —   | —   | ns   |
| CS to MOSI <sup>1 2</sup>      | t <sub>CS_MO</sub>   |                | -26                 | —   | 25  | ns   |
| SCLK to MOSI <sup>1 2</sup>    | t <sub>SCLK_MO</sub> |                | -7                  | —   | 24  | ns   |
| MISO setup time <sup>1 2</sup> | t <sub>SU_MI</sub>   | IOVDD = 1.62 V | 50                  | —   | —   | ns   |
|                                |                      | IOVDD = 3.0 V  | 42                  | —   | —   | ns   |
| MISO hold time <sup>1 2</sup>  | t <sub>H_MI</sub>    |                | -9                  | —   | —   | ns   |

**Note:**

1. Applies for both CLKPHA = 0 and CLKPHA = 1.
2. Measurement done with 8 pF output loading at 10% and 90% of the I/O supply.
3. t<sub>PCLK</sub> is one period of the selected PCLK.

#### 4.19 USART SPI Secondary Timing

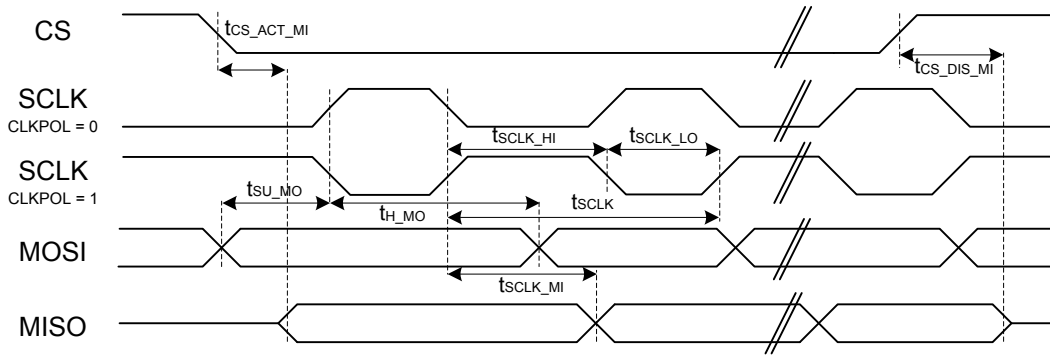


Figure 4.3. SPI Secondary Timing (SSSEARLY = 0)

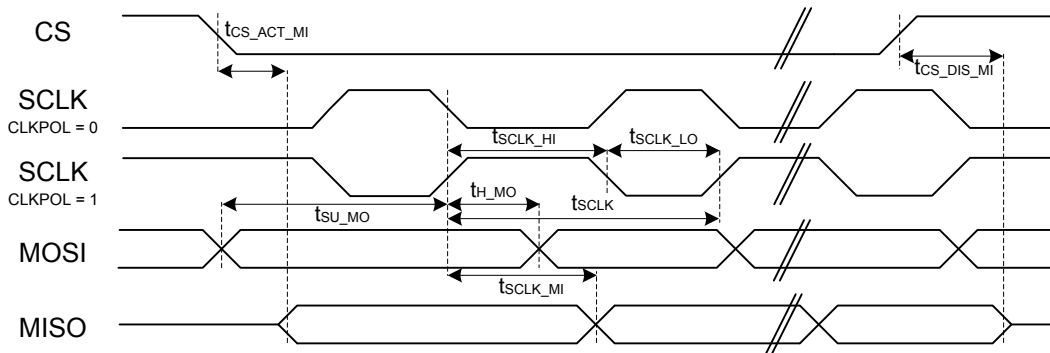


Figure 4.4. SPI Secondary Timing (SSSEARLY = 1)

#### 4.19.1 USART SPI Secondary Timing, Voltage Scaling = VSCALE2

Timing specifications are for all SPI signals routed to the same DBUS (DBUSAB or DBUSCD). All GPIO set to slew rate = 6.

**Table 4.42. USART SPI Secondary Timing, Voltage Scaling = VSCALE2**

| Parameter                         | Symbol                 | Test Condition | Min                           | Typ | Max                           | Unit |
|-----------------------------------|------------------------|----------------|-------------------------------|-----|-------------------------------|------|
| SCLK period <sup>1 2 3</sup>      | t <sub>SCLK</sub>      |                | 6*t <sub>PCLK</sub>           | —   | —                             | ns   |
| SCLK high time <sup>1 2 3</sup>   | t <sub>SCLK_HI</sub>   |                | 2.5*t <sub>PCLK</sub>         | —   | —                             | ns   |
| SCLK low time <sup>1 2 3</sup>    | t <sub>SCLK_LO</sub>   |                | 2.5*t <sub>PCLK</sub>         | —   | —                             | ns   |
| CS active to MISO <sup>1 2</sup>  | t <sub>CS_ACT_MI</sub> |                | 19                            | —   | 67                            | ns   |
| CS disable to MISO <sup>1 2</sup> | t <sub>CS_DIS_MI</sub> |                | 24                            | —   | 89                            | ns   |
| MOSI setup time <sup>1 2</sup>    | t <sub>SU_MO</sub>     |                | 12                            | —   | —                             | ns   |
| MOSI hold time <sup>1 2 3</sup>   | t <sub>H_MO</sub>      |                | 13                            | —   | —                             | ns   |
| SCLK to MISO <sup>1 2 3</sup>     | t <sub>SCLK_MI</sub>   |                | 14 +<br>1.5*t <sub>PCLK</sub> | —   | 24 +<br>2.5*t <sub>PCLK</sub> | ns   |

**Note:**

1. Applies for both CLKPHA = 0 and CLKPHA = 1 (figure only shows CLKPHA = 0).
2. Measurement done with 8 pF output loading at 10% and 90% of the I/O supply (figure shows 50%).
3. t<sub>PCLK</sub> is one period of the selected PCLK.

#### 4.19.2 USART SPI Secondary Timing, Voltage Scaling = VSCALE1

Timing specifications are for all SPI signals routed to the same DBUS (DBUSAB or DBUSCD). All GPIO set to slew rate = 6.

**Table 4.43. USART SPI Secondary Timing, Voltage Scaling = VSCALE1**

| Parameter                         | Symbol                 | Test Condition | Min                           | Typ | Max                           | Unit |
|-----------------------------------|------------------------|----------------|-------------------------------|-----|-------------------------------|------|
| SCLK period <sup>1 2 3</sup>      | t <sub>SCLK</sub>      |                | 6*t <sub>PCLK</sub>           | —   | —                             | ns   |
| SCLK high time <sup>1 2 3</sup>   | t <sub>SCLK_HI</sub>   |                | 2.5*t <sub>PCLK</sub>         | —   | —                             | ns   |
| SCLK low time <sup>1 2 3</sup>    | t <sub>SCLK_LO</sub>   |                | 2.5*t <sub>PCLK</sub>         | —   | —                             | ns   |
| CS active to MISO <sup>1 2</sup>  | t <sub>CS_ACT_MI</sub> |                | 25                            | —   | 96                            | ns   |
| CS disable to MISO <sup>1 2</sup> | t <sub>CS_DIS_MI</sub> |                | 24                            | —   | 87                            | ns   |
| MOSI setup time <sup>1 2</sup>    | t <sub>SU_MO</sub>     |                | 13                            | —   | —                             | ns   |
| MOSI hold time <sup>1 2 3</sup>   | t <sub>H_MO</sub>      |                | 14                            | —   | —                             | ns   |
| SCLK to MISO <sup>1 2 3</sup>     | t <sub>SCLK_MI</sub>   |                | 17 +<br>1.5*t <sub>PCLK</sub> | —   | 33 +<br>2.5*t <sub>PCLK</sub> | ns   |

**Note:**

1. Applies for both CLKPHA = 0 and CLKPHA = 1 (figure only shows CLKPHA = 0).
2. Measurement done with 8 pF output loading at 10% and 90% of the I/O supply (figure shows 50%).
3. t<sub>PCLK</sub> is one period of the selected PCLK.

## 4.20 EUSART SPI Main Timing

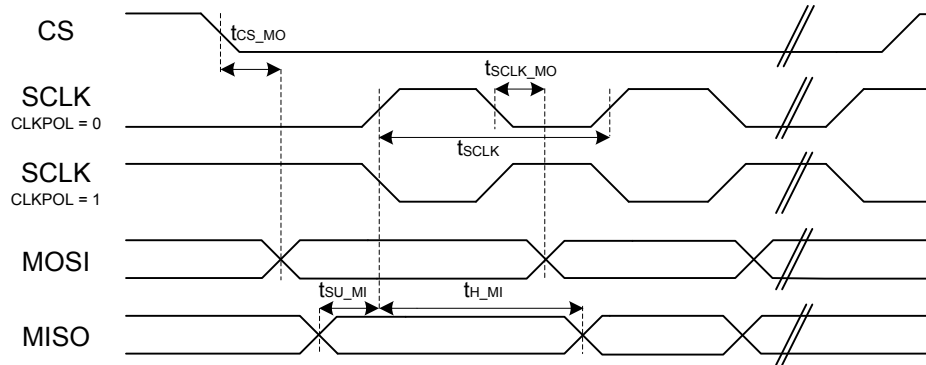


Figure 4.5. SPI Main Timing

### 4.20.1 EUSART SPI Main Timing, Voltage Scaling = VSCALE2

Timing specifications are for all SPI signals routed to the same DBUS (DBUSAB or DBUSCD) on consecutive pins. All GPIO set to slew rate = 6.

Table 4.44. EUSART SPI Main Timing, Voltage Scaling = VSCALE2

| Parameter                      | Symbol         | Test Condition | Min       | Typ | Max | Unit |
|--------------------------------|----------------|----------------|-----------|-----|-----|------|
| SCLK period <sup>1 2 3</sup>   | $t_{SCLK}$     |                | $t_{CLK}$ | —   | —   | ns   |
| CS to MOSI <sup>1 2</sup>      | $t_{CS\_MO}$   |                | -10       | —   | 9   | ns   |
| SCLK to MOSI <sup>1 2</sup>    | $t_{SCLK\_MO}$ |                | -3        | —   | 8   | ns   |
| MISO setup time <sup>1 2</sup> | $t_{SU\_MI}$   |                | 6         | —   | —   | ns   |
| MISO hold time <sup>1 2</sup>  | $t_{H\_MI}$    |                | -21       | —   | —   | ns   |

**Note:**

1. Applies for both CLKPHA = 0 and CLKPHA = 1.
2. Measurement done with 15 pF output loading at 10% and 90% of  $V_{DD}$ .
3.  $t_{CLK}$  is one period of the selected peripheral clock: EM01GRPCCLK for EUSART1/2, EUSART0CLK for EUSART0.

#### 4.20.2 EUSART SPI Main Timing, Voltage Scaling = VSCALE1

Timing specifications are for all SPI signals routed to the same DBUS (DBUSAB or DBUSCD) on consecutive pins. All GPIO set to slew rate = 6.

**Table 4.45. EUSART SPI Main Timing, Voltage Scaling = VSCALE1**

| Parameter                      | Symbol               | Test Condition | Min   | Typ | Max | Unit |
|--------------------------------|----------------------|----------------|-------|-----|-----|------|
| SCLK period <sup>1 2 3</sup>   | t <sub>SCLK</sub>    |                | t_CLK | —   | —   | ns   |
| CS to MOSI <sup>1 2</sup>      | t <sub>CS_MO</sub>   |                | -19   | —   | 15  | ns   |
| SCLK to MOSI <sup>1 2</sup>    | t <sub>SCLK_MO</sub> |                | -6    | —   | 13  | ns   |
| MISO setup time <sup>1 2</sup> | t <sub>SU_MI</sub>   |                | 10    | —   | —   | ns   |
| MISO hold time <sup>1 2</sup>  | t <sub>H_MI</sub>    |                | -13   | —   | —   | ns   |

**Note:**

1. Applies for both CLKPHA = 0 and CLKPHA = 1.
2. Measurement done with 15 pF output loading at 10% and 90% of V<sub>DD</sub>.
3. t<sub>CLK</sub> is one period of the selected peripheral clock: EM01GRPCCLK for EUSART1/2, EUSART0CLK for EUSART0.

#### 4.21 EUSART SPI Secondary Timing

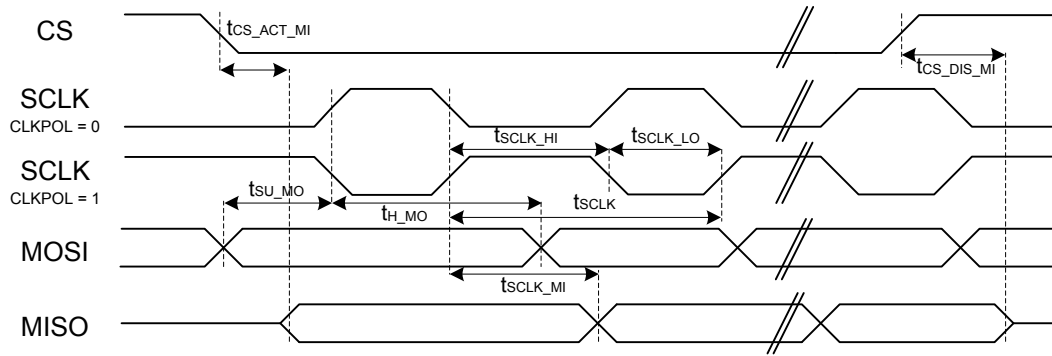


Figure 4.6. SPI Secondary Timing

##### 4.21.1 EUSART SPI Secondary Timing, Voltage Scaling = VSCALE2

Timing specifications are for all SPI signals routed to the same DBUS (DBUSAB or DBUSCD) on consecutive pins. All GPIO set to slew rate = 6.

Table 4.46. EUSART SPI Secondary Timing, Voltage Scaling = VSCALE2

| Parameter                         | Symbol            | Test Condition | Min | Typ | Max | Unit |
|-----------------------------------|-------------------|----------------|-----|-----|-----|------|
| SCLK high time <sup>1 2</sup>     | $t_{SCLK\_HI}$    |                | 50  | —   | —   | ns   |
| SCLK low time <sup>1 2</sup>      | $t_{SCLK\_LO}$    |                | 50  | —   | —   | ns   |
| CS active to MISO <sup>1 2</sup>  | $t_{CS\_ACT\_MI}$ |                | 4   | —   | 49  | ns   |
| CS disable to MISO <sup>1 2</sup> | $t_{CS\_DIS\_MI}$ |                | 5   | —   | 34  | ns   |
| MOSI setup time <sup>1 2</sup>    | $t_{SU\_MO}$      |                | 5   | —   | —   | ns   |
| MOSI hold time <sup>1 2</sup>     | $t_{H\_MO}$       |                | 6   | —   | —   | ns   |
| SCLK to MISO <sup>1 2</sup>       | $t_{SCLK\_MI}$    | IOVDD = 1.8 V  | 8   | —   | 40  | ns   |
|                                   |                   | IOVDD = 3.0 V  | 8   | —   | 30  | ns   |

**Note:**

1. Applies for both CLKPHA = 0 and CLKPHA = 1 (figure only shows CLKPHA = 0).
2. Measurement done with 15 pF output loading at 10% and 90% of  $V_{DD}$  (figure shows 50% of  $V_{DD}$ ).

#### 4.21.2 EUSART SPI Secondary Timing, Voltage Scaling = VSCALE1

Timing specifications are for all SPI signals routed to the same DBUS (DBUSAB or DBUSCD) on consecutive pins. All GPIO set to slew rate = 6.

**Table 4.47. EUSART SPI Secondary Timing, Voltage Scaling = VSCALE1**

| Parameter   | Symbol                 | Test Condition | Min | Typ | Max | Unit |
|---|------------------------|----------------|-----|-----|-----|------|
| SCLK high time <sup>1 2</sup>   | t <sub>SCLK_HI</sub>   |                | 50  | —   | —   | ns   |
| SCLK low time <sup>1 2</sup>  | t <sub>SCLK_LO</sub>   |                | 50  | —   | —   | ns   |
| CS active to MISO <sup>1 2</sup>  | t <sub>CS_ACT_MI</sub> |                | 6   | —   | 75  | ns   |
| CS disable to MISO <sup>1 2</sup>   | t <sub>CS_DIS_MI</sub> |                | 5   | —   | 56  | ns   |
| MOSI setup time <sup>1 2</sup>  | t <sub>SU_MO</sub>     |                | 4   | —   | —   | ns   |
| MOSI hold time <sup>1 2</sup>   | t <sub>H_MO</sub>      |                | 6   | —   | —   | ns   |
| SCLK to MISO <sup>1 2</sup>   | t <sub>SCLK_MI</sub>   | IOVDD = 1.8 V  | 9   | —   | 49  | ns   |
|   |                        | IOVDD = 3.0 V  | 9   | —   | 41  | ns   |
| <b>Note:</b>  |                        |                |     |     |     |      |
| 1. Applies for both CLKPHA = 0 and CLKPHA = 1 (figure only shows CLKPHA = 0).   |                        |                |     |     |     |      |
| 2. Measurement done with 15 pF output loading at 10% and 90% of V <sub>DD</sub> (figure shows 50% of V <sub>DD</sub> ). |                        |                |     |     |     |      |

#### 4.21.3 EUSART SPI Secondary Timing, Voltage Scaling = VSCALE0

Timing specifications at VSCALE0 apply to EUSART0 only, routed to DBUSAB on consecutive pins. All GPIO set to slew rate = 6.

**Table 4.48. EUSART SPI Secondary Timing, Voltage Scaling = VSCALE0**

| Parameter   | Symbol                 | Test Condition | Min | Typ | Max | Unit |
|---|------------------------|----------------|-----|-----|-----|------|
| SCLK high time <sup>1 2</sup>   | t <sub>SCLK_HI</sub>   |                | 100 | —   | —   | ns   |
| SCLK low time <sup>1 2</sup>  | t <sub>SCLK_LO</sub>   |                | 100 | —   | —   | ns   |
| CS active to MISO <sup>1 2</sup>  | t <sub>CS_ACT_MI</sub> |                | 8   | —   | 100 | ns   |
| CS disable to MISO <sup>1 2</sup>   | t <sub>CS_DIS_MI</sub> |                | 7   | —   | 70  | ns   |
| MOSI setup time <sup>1 2</sup>  | t <sub>SU_MO</sub>     |                | 9   | —   | —   | ns   |
| MOSI hold time <sup>1 2</sup>   | t <sub>H_MO</sub>      |                | 32  | —   | —   | ns   |
| SCLK to MISO <sup>1 2</sup>   | t <sub>SCLK_MI</sub>   | IOVDD = 1.8 V  | 11  | —   | 86  | ns   |
|   |                        | IOVDD = 3.0 V  | 11  | —   | 78  | ns   |
| <b>Note:</b>  |                        |                |     |     |     |      |
| 1. Applies for both CLKPHA = 0 and CLKPHA = 1 (figure only shows CLKPHA = 0).   |                        |                |     |     |     |      |
| 2. Measurement done with 15 pF output loading at 10% and 90% of V <sub>DD</sub> (figure shows 50% of V <sub>DD</sub> ). |                        |                |     |     |     |      |

## 4.22 I2C Electrical Specifications

### 4.22.1 I2C Standard-mode (Sm)

CLHR set to 0 in the I2Cn\_CTRL register.

Table 4.49. I2C Standard-mode (Sm)

| Parameter  | Symbol        | Test Condition | Min | Typ | Max | Unit    |
|--|---------------|----------------|-----|-----|-----|---------|
| SCL clock frequency <sup>1</sup>                 | $f_{SCL}$     |                | 0   | —   | 100 | kHz     |
| SCL clock low time                               | $t_{LOW}$     |                | 4.7 | —   | —   | $\mu$ s |
| SCL clock high time                              | $t_{HIGH}$    |                | 4   | —   | —   | $\mu$ s |
| SDA set-up time                                  | $t_{SU\_DAT}$ |                | 250 | —   | —   | ns      |
| SDA hold time                                    | $t_{HD\_DAT}$ |                | 0   | —   | —   | ns      |
| Repeated START condition set-up time             | $t_{SU\_STA}$ |                | 4.7 | —   | —   | $\mu$ s |
| Repeated START condition hold time               | $t_{HD\_STA}$ |                | 4.0 | —   | —   | $\mu$ s |
| STOP condition set-up time                       | $t_{SU\_STO}$ |                | 4.0 | —   | —   | $\mu$ s |
| Bus free time between a STOP and START condition | $t_{BUF}$     |                | 4.7 | —   | —   | $\mu$ s |

**Note:**

1. The maximum SCL clock frequency listed is assuming that an arbitrary clock frequency is available. The maximum attainable SCL clock frequency may be slightly less using the HFXO or HFRCO due to the limited frequencies available. The CLKDIV should be set to a value that keeps the SCL clock frequency below the max value listed.

**4.22.2 I2C Fast-mode (Fm)**

CLHR set to 1 in the I2Cn\_CTRL register.

**Table 4.50. I2C Fast-mode (Fm)**

| Parameter  | Symbol              | Test Condition | Min | Typ | Max | Unit |
|--|---------------------|----------------|-----|-----|-----|------|
| SCL clock frequency <sup>1</sup>                 | f <sub>SCL</sub>    |                | 0   | —   | 400 | kHz  |
| SCL clock low time                               | t <sub>LOW</sub>    |                | 1.3 | —   | —   | μs   |
| SCL clock high time                              | t <sub>HIGH</sub>   |                | 0.6 | —   | —   | μs   |
| SDA set-up time                                  | t <sub>SU_DAT</sub> |                | 100 | —   | —   | ns   |
| SDA hold time                                    | t <sub>HD_DAT</sub> |                | 0   | —   | —   | ns   |
| Repeated START condition set-up time             | t <sub>SU_STA</sub> |                | 0.6 | —   | —   | μs   |
| Repeated START condition hold time               | t <sub>HD_STA</sub> |                | 0.6 | —   | —   | μs   |
| STOP condition set-up time                       | t <sub>SU_STO</sub> |                | 0.6 | —   | —   | μs   |
| Bus free time between a STOP and START condition | t <sub>BUF</sub>    |                | 1.3 | —   | —   | μs   |

**Note:**

1. The maximum SCL clock frequency listed is assuming that an arbitrary clock frequency is available. The maximum attainable SCL clock frequency may be slightly less using the HFXO or HFRCO due to the limited frequencies available. The CLKDIV should be set to a value that keeps the SCL clock frequency below the max value listed.

### 4.22.3 I2C Fast-mode Plus (Fm+)

CLHR set to 1 in the I2Cn\_CTRL register.

**Table 4.51. I2C Fast-mode Plus (Fm+)**

| Parameter  | Symbol              | Test Condition | Min  | Typ | Max  | Unit |
|--|---------------------|----------------|------|-----|------|------|
| SCL clock frequency <sup>1</sup>                 | f <sub>SCL</sub>    |                | 0    | —   | 1000 | kHz  |
| SCL clock low time                               | t <sub>LOW</sub>    |                | 0.5  | —   | —    | μs   |
| SCL clock high time                              | t <sub>HIGH</sub>   |                | 0.26 | —   | —    | μs   |
| SDA set-up time                                  | t <sub>SU_DAT</sub> |                | 50   | —   | —    | ns   |
| SDA hold time                                    | t <sub>HD_DAT</sub> |                | 0    | —   | —    | ns   |
| Repeated START condition set-up time             | t <sub>SU_STA</sub> |                | 0.26 | —   | —    | μs   |
| Repeated START condition hold time               | t <sub>HD_STA</sub> |                | 0.26 | —   | —    | μs   |
| STOP condition set-up time                       | t <sub>SU_STO</sub> |                | 0.26 | —   | —    | μs   |
| Bus free time between a STOP and START condition | t <sub>BUF</sub>    |                | 0.5  | —   | —    | μs   |

**Note:**

1. The maximum SCL clock frequency listed is assuming that an arbitrary clock frequency is available. The maximum attainable SCL clock frequency may be slightly less using the HF XO or HFRCO due to the limited frequencies available. The CLKDIV should be set to a value that keeps the SCL clock frequency below the max value listed.

### 4.23 Boot Timing

Secure boot impacts the recovery time from all sources of device reset. In addition to the root code authentication process, which cannot be disabled or bypassed, the root code can authenticate a bootloader, and the bootloader can authenticate the application. In projects that include only an application and no bootloader, the root code can authenticate the application directly. The duration of each authentication operation depends on two factors: the computation of the associated image hash, which is proportional to the size of the image, and the verification of the image signature, which is independent of image size.

The duration for the root code to authenticate the bootloader will depend on the SE firmware version as well as on the size of the bootloader.

The duration for the bootloader to authenticate the application can depend on the size of the application.

The configurations below assume that the associated bootloader and application code images do not contain a bootloader certificate or an application certificate. Authenticating a bootloader certificate or an application certificate will extend the boot time by an additional 6 to 7 ms.

The table below provides the durations from the termination of reset until the completion of the secure boot process (start of main() function in the application image) under various conditions.

Conditions:

- SE firmware version 2.1.5
- Gecko Bootloader size 10.2 KB

Timing is expected to be similar for subsequent SE firmware versions. Refer to SE firmware release notes for any significant changes.

**Table 4.52. Boot Timing**

| Parameter | Symbol     | Test Condition  | Min | Typ  | Max | Unit |
|-----------|------------|---|-----|------|-----|------|
| Boot time | $t_{BOOT}$ | Secure boot application check disabled, no bootloader   | —   | 30.5 | —   | ms   |
|           |            | Secure boot application check disabled, second stage bootloader check enabled, 50 kB application size | —   | 37.7 | —   | ms   |
|           |            | Secure boot application check enabled, second stage bootloader check enabled, 50 kB application size  | —   | 48.3 | —   | ms   |
|           |            | Secure boot application check enabled, second stage bootloader check enabled, 150 kB application size | —   | 51.0 | —   | ms   |
|           |            | Secure boot application check enabled, second stage bootloader check enabled, 350 kB application size | —   | 56.4 | —   | ms   |

#### 4.24 Crypto Operation Timing for SE Manager API

Values in this table represent timing from SE Manager API call to return. The Cortex-M33 HCLK frequency is 39.0 MHz. The timing specifications below are measured at the SE Manager function call API. Each duration in the table contains some portion that is influenced by SE Manager build compilation and Cortex-M33 operating frequency and some portion that is influenced by the Hardware Secure Engine's firmware version and its operating speed (typically 80 MHz). The contributions of the Cortex-M33 properties to the overall specification timing are most pronounced for the shorter operations such as AES and hash when operating on small payloads. The overhead of command processing at the mailbox interface can also dominate the timing for shorter operations.

Conditions:

- SE firmware version 2.1.5
- GSDK version 3.2

Timing is expected to be similar for subsequent SE firmware versions. Refer to SE firmware release notes for any significant changes.

**Table 4.53. Crypto Operation Timing for SE Manager API**

| Parameter                     | Symbol          | Test Condition                   | Min | Typ  | Max | Unit    |
|-------------------------------|-----------------|----------------------------------|-----|------|-----|---------|
| AES-128 timing                | $t_{AES128}$    | AES-128 CCM encryption, PT 1 kB  | —   | 571  | —   | $\mu s$ |
|                               |                 | AES-128 CCM encryption, PT 32 kB | —   | 1751 | —   | $\mu s$ |
|                               |                 | AES-128 CTR encryption, PT 1 kB  | —   | 474  | —   | $\mu s$ |
|                               |                 | AES-128 CTR encryption, PT 32 kB | —   | 1043 | —   | $\mu s$ |
|                               |                 | AES-128 GCM encryption, PT 1 kB  | —   | 522  | —   | $\mu s$ |
|                               |                 | AES-128 GCM encryption, PT 32 kB | —   | 1087 | —   | $\mu s$ |
| AES-256 timing                | $t_{AES256}$    | AES-256 CCM encryption, PT 1 kB  | —   | 585  | —   | $\mu s$ |
|                               |                 | AES-256 CCM encryption, PT 32 kB | —   | 2184 | —   | $\mu s$ |
|                               |                 | AES-256 CTR encryption, PT 1 kB  | —   | 482  | —   | $\mu s$ |
|                               |                 | AES-256 CTR encryption, PT 32 kB | —   | 1255 | —   | $\mu s$ |
|                               |                 | AES-256 GCM encryption, PT 1 kB  | —   | 529  | —   | $\mu s$ |
|                               |                 | AES-256 GCM encryption, PT 32 kB | —   | 1306 | —   | $\mu s$ |
| ECC P-256 timing              | $t_{ECC\_P256}$ | ECC key generation, P-256        | —   | 5.5  | —   | ms      |
|                               |                 | ECC signing, P-256               | —   | 5.9  | —   | ms      |
|                               |                 | ECC verification, P-256          | —   | 6.2  | —   | ms      |
| ECC P-521 timing <sup>1</sup> | $t_{ECC\_P521}$ | ECC key generation, P-521        | —   | 30.2 | —   | ms      |
|                               |                 | ECC signing, P-521               | —   | 31.0 | —   | ms      |
|                               |                 | ECC verification, P-521          | —   | 36.2 | —   | ms      |

| Parameter                       | Symbol                  | Test Condition                            | Min | Typ  | Max | Unit |
|---------------------------------|-------------------------|---|-----|------|-----|------|
| ECC P-25519 timing <sup>2</sup> | t <sub>ECC_P25519</sub> | ECC key generation, P-25519               | —   | 4.5  | —   | ms   |
|                                 |                         | ECC signing, P-25519                      | —   | 8.9  | —   | ms   |
|                                 |                         | ECC verification, P-25519                 | —   | 6.3  | —   | ms   |
| ECDH compute secret timing      | t <sub>ECDH</sub>       | ECDH compute secret, P-521 <sup>1</sup>   | —   | 30.5 | —   | ms   |
|                                 |                         | ECDH compute secret, P-25519 <sup>2</sup> | —   | 4.5  | —   | ms   |
|                                 |                         | ECDH compute secret, P-256                | —   | 5.6  | —   | ms   |
| ECJPAKE client timing           | t <sub>ECJPAKE_C</sub>  | ECJPAKE client write round one            | —   | 21.4 | —   | ms   |
|                                 |                         | ECJPAKE client read round one             | —   | 11.7 | —   | ms   |
|                                 |                         | ECJPAKE client write round two            | —   | 15.2 | —   | ms   |
|                                 |                         | ECJPAKE client read round two             | —   | 6.3  | —   | ms   |
|                                 |                         | ECJPAKE client derive secret              | —   | 8.8  | —   | ms   |
| ECJPAKE server timing           | t <sub>ECJPAKE_S</sub>  | ECJPAKE server write round one            | —   | 21.4 | —   | ms   |
|                                 |                         | ECJPAKE server read round one             | —   | 11.7 | —   | ms   |
|                                 |                         | ECJPAKE server write round two            | —   | 15.3 | —   | ms   |
|                                 |                         | ECJPAKE server read round two             | —   | 6.4  | —   | ms   |
|                                 |                         | ECJPAKE server derive secret              | —   | 8.8  | —   | ms   |
| POLY-1305 timing <sup>1</sup>   | t <sub>POLY1305</sub>   | POLY-1305, PT 1 kB                        | —   | 514  | —   | μs   |
|                                 |                         | POLY-1305, PT 32 kB                       | —   | 1177 | —   | μs   |
| SHA-256 timing                  | t <sub>SHA256</sub>     | SHA-256, PT 1 kB                          | —   | 308  | —   | μs   |
|                                 |                         | SHA-256, PT 32 kB                         | —   | 737  | —   | μs   |
| SHA-512 timing <sup>1</sup>     | t <sub>SHA512</sub>     | SHA-512, PT 1 kB                          | —   | 305  | —   | μs   |
|                                 |                         | SHA-512, PT 32 kB                         | —   | 620  | —   | μs   |

**Note:**

- Option is only available on OPNs with Secure Vault High feature set.
- Option is not available on Secure Vault Mid devices with SE firmware earlier than v2.1.7.

#### 4.25 Crypto Operation Average Current for SE Manager API

Values in this table represent current consumed by security core during the operation, and represent additions to the current consumed by the Cortex-M33 application CPU due to the Hardware Secure Engine CPU and its associated crypto accelerators. The current measurements below represent the average value of the current for the duration of the crypto operation. Instantaneous peak currents may be higher.

Conditions:

- SE firmware version 2.1.5
- GSDK version 3.2

Current consumption is expected to be similar for subsequent SE firmware versions. Refer to SE firmware release notes for any significant changes.

**Table 4.54. Crypto Operation Average Current for SE Manager API**

| Parameter                      | Symbol               | Test Condition                   | Min | Typ | Max | Unit |
|--------------------------------|----------------------|----------------------------------|-----|-----|-----|------|
| AES-128 current                | I <sub>AES128</sub>  | AES-128 CCM encryption, PT 1 kB  | —   | 0.9 | —   | mA   |
|                                |                      | AES-128 CCM encryption, PT 32 kB | —   | 3.9 | —   | mA   |
|                                |                      | AES-128 CTR encryption, PT 1 kB  | —   | 0.8 | —   | mA   |
|                                |                      | AES-128 CTR encryption, PT 32 kB | —   | 3.8 | —   | mA   |
|                                |                      | AES-128 GCM encryption, PT 1 kB  | —   | 0.8 | —   | mA   |
|                                |                      | AES-128 GCM encryption, PT 32 kB | —   | 3.8 | —   | mA   |
| AES-256 current                | I <sub>AES256</sub>  | AES-256 CCM encryption, PT 1 kB  | —   | 1.0 | —   | mA   |
|                                |                      | AES-256 CCM encryption, PT 32 kB | —   | 4.0 | —   | mA   |
|                                |                      | AES-256 CTR encryption, PT 1 kB  | —   | 0.8 | —   | mA   |
|                                |                      | AES-256 CTR encryption, PT 32 kB | —   | 4.0 | —   | mA   |
|                                |                      | AES-256 GCM encryption, PT 1 kB  | —   | 0.8 | —   | mA   |
|                                |                      | AES-256 GCM encryption, PT 32 kB | —   | 3.9 | —   | mA   |
| ECC P-256 current              | I <sub>ECCP256</sub> | ECC key generation, P-256        | —   | 1.7 | —   | mA   |
|                                |                      | ECC signing, P-256               | —   | 1.6 | —   | mA   |
|                                |                      | ECC verification, P-256          | —   | 1.7 | —   | mA   |
| ECC P-521 current <sup>1</sup> | I <sub>ECCP521</sub> | ECC key generation, P-521        | —   | 1.8 | —   | mA   |
|                                |                      | ECC signing, P-521               | —   | 1.8 | —   | mA   |
|                                |                      | ECC verification, P-521          | —   | 1.8 | —   | mA   |

| Parameter                        | Symbol                 | Test Condition                            | Min | Typ | Max | Unit |
|----------------------------------|------------------------|---|-----|-----|-----|------|
| ECC P-25519 current <sup>2</sup> | I <sub>ECCP25519</sub> | ECC key generation, P-25519               | —   | 1.6 | —   | mA   |
|                                  |                        | ECC signing, P-25519                      | —   | 1.6 | —   | mA   |
|                                  |                        | ECC verification, P-25519                 | —   | 1.6 | —   | mA   |
| ECDH compute secret current      | I <sub>ECDH</sub>      | ECDH compute secret, P-521 <sup>1</sup>   | —   | 1.8 | —   | mA   |
|                                  |                        | ECDH compute secret, P-25519 <sup>2</sup> | —   | 1.5 | —   | mA   |
|                                  |                        | ECDH compute secret, P-256                | —   | 1.6 | —   | mA   |
| ECJPAKE client current           | I <sub>ECJPAKE_C</sub> | ECJPAKE client write round one            | —   | 1.7 | —   | mA   |
|                                  |                        | ECJPAKE client read round one             | —   | 1.7 | —   | mA   |
|                                  |                        | ECJPAKE client write round two            | —   | 1.7 | —   | mA   |
|                                  |                        | ECJPAKE client read round two             | —   | 1.7 | —   | mA   |
|                                  |                        | ECJPAKE client derive secret              | —   | 1.7 | —   | mA   |
| ECJPAKE server current           | I <sub>ECJPAKE_S</sub> | ECJPAKE server write round one            | —   | 1.7 | —   | mA   |
|                                  |                        | ECJPAKE server read round one             | —   | 1.7 | —   | mA   |
|                                  |                        | ECJPAKE server write round two            | —   | 1.7 | —   | mA   |
|                                  |                        | ECJPAKE server read round two             | —   | 1.6 | —   | mA   |
|                                  |                        | ECJPAKE server derive secret              | —   | 1.7 | —   | mA   |
| POLY-1305 current <sup>1</sup>   | I <sub>POLY1305</sub>  | POLY-1305, PT 1 kB                        | —   | 0.6 | —   | mA   |
|                                  |                        | POLY-1305, PT 32 kB                       | —   | 1.6 | —   | mA   |
| SHA-256 current                  | I <sub>SHA256</sub>    | SHA-256, PT 1 kB                          | —   | 0.7 | —   | mA   |
|                                  |                        | SHA-256, PT 32 kB                         | —   | 2.3 | —   | mA   |
| SHA-512 current <sup>1</sup>     | I <sub>SHA512</sub>    | SHA-512, PT 1 kB                          | —   | 0.7 | —   | mA   |
|                                  |                        | SHA-512, PT 32 kB                         | —   | 1.9 | —   | mA   |

**Note:**

- Option is only available on OPNs with Secure Vault High feature set.
- Option is not available on Secure Vault Mid devices with SE firmware earlier than v2.1.7.

#### 4.26 Matrix Vector Processor (MVP)

All measurements are in comparison to EM1 baseline current at given VSCALE and Clock settings. Matrix dimensions are X = 24 x 32, Y = 32 x 24 and Z = 24 x 24.

**Table 4.55. Matrix Vector Processor (MVP)**

| Parameter   | Symbol                    | Test Condition   | Min | Typ   | Max | Unit   |
|---|---------------------------|--|-----|-------|-----|--------|
| MVP Enable Current                                | I <sub>EN</sub>           | VSCALE1, HFXO @ 39 MHz   | —   | 16.8  | —   | μA     |
|   |                           | VSCALE2, HFRCO w/ DPLL @ 78 MHz  | —   | 41.2  | —   | μA     |
| Matrix Multiplication Duration using MVP Hardware | T <sub>MVP_MULTIPLY</sub> | 16-bit complex numbers, fully banked memory, VSCALE1, HFXO @ 39 MHz          | —   | 504.0 | —   | μs     |
|   |                           | 16-bit complex numbers, fully banked memory, VSCALE2, HFRCO w/ DPLL @ 78 MHz | —   | 252.0 | —   | μs     |
|   |                           | 16-bit complex numbers, interleaved memory, VSCALE1, HFXO @ 39 MHz           | —   | 596.2 | —   | μs     |
|   |                           | 16-bit complex numbers, interleaved memory, VSCALE2, HFRCO w/ DPLL @ 78 MHz  | —   | 298.2 | —   | μs     |
| Matrix Multiplication Duration using Software     | T <sub>SW_MULTIPLY</sub>  | 16-bit complex numbers, interleaved memory, VSCALE1, HFXO @ 39 MHz           | —   | 41.0  | —   | ms     |
|   |                           | 16-bit complex numbers, interleaved memory, VSCALE2, HFRCO w/ DPLL @ 78 MHz  | —   | 20.5  | —   | ms     |
|   |                           | 32-bit complex numbers, interleaved memory, VSCALE1, HFXO @ 39 MHz           | —   | 19.7  | —   | ms     |
|   |                           | 32-bit complex numbers, interleaved memory, VSCALE2, HFRCO w/ DPLL @ 78 MHz  | —   | 9.9   | —   | ms     |
| Matrix Multiplication Current using MVP Hardware  | I <sub>MVP_MULTIPLY</sub> | 16-bit complex numbers, fully banked memory, VSCALE1, HFXO @ 39 MHz          | —   | 61.3  | —   | μA/MHz |
|   |                           | 16-bit complex numbers, fully banked memory, VSCALE2, HFRCO w/ DPLL @ 78 MHz | —   | 62.4  | —   | μA/MHz |
|   |                           | 16-bit complex numbers, interleaved memory, VSCALE1, HFXO @ 39 MHz           | —   | 53.2  | —   | μA/MHz |
|   |                           | 16-bit complex numbers, interleaved memory, VSCALE2, HFRCO w/ DPLL @ 78 MHz  | —   | 53.8  | —   | μA/MHz |

| Parameter                                    | Symbol                    | Test Condition  | Min | Typ  | Max | Unit   |
|--|---------------------------|---|-----|------|-----|--------|
| Matrix Multiplication Current using Software | I <sub>SW_MULTIPPLY</sub> | 16-bit complex numbers, interleaved memory, VSCALE1, HFXO @ 39 MHz          | —   | 41.7 | —   | μA/MHz |
|  |                           | 16-bit complex numbers, interleaved memory, VSCALE2, HFRCO w/ DPLL @ 78 MHz | —   | 44.7 | —   | μA/MHz |
|  |                           | 32-bit complex numbers, interleaved memory, VSCALE1, HFXO @ 39 MHz          | —   | 31.9 | —   | μA/MHz |
|  |                           | 32-bit complex numbers, interleaved memory, VSCALE2, HFRCO w/ DPLL @ 78 MHz | —   | 33.8 | —   | μA/MHz |

#### 4.27 Typical Performance Curves

Typical performance curves indicate typical characterized performance under the stated conditions.

4.27.1 Supply Current

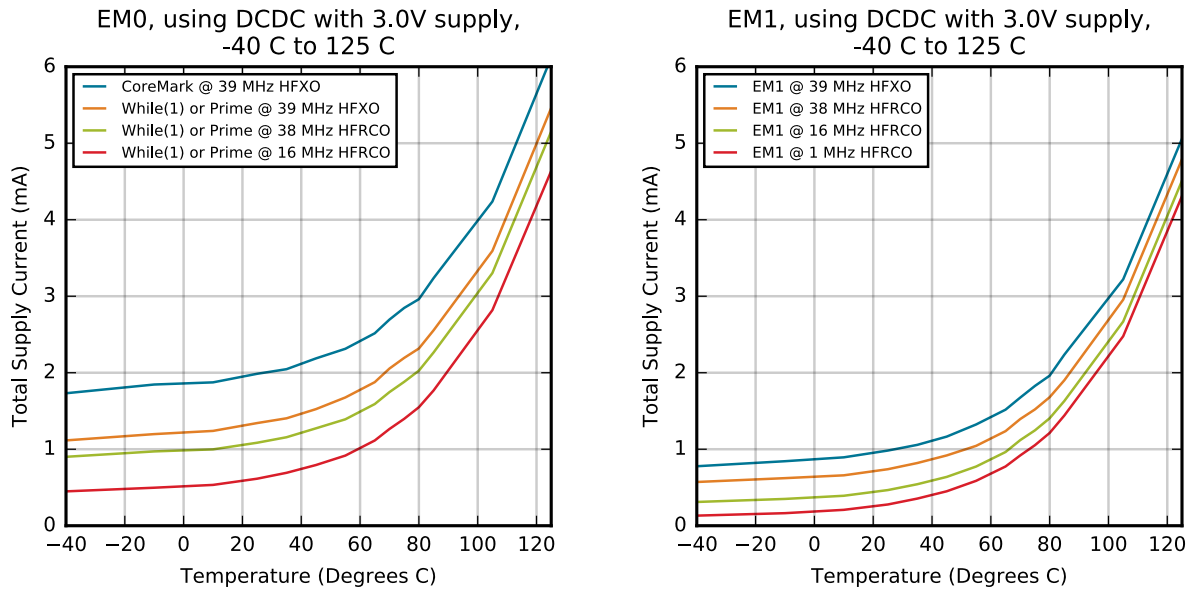


Figure 4.7. EM0 and EM1 Typical Supply Current vs. Temperature

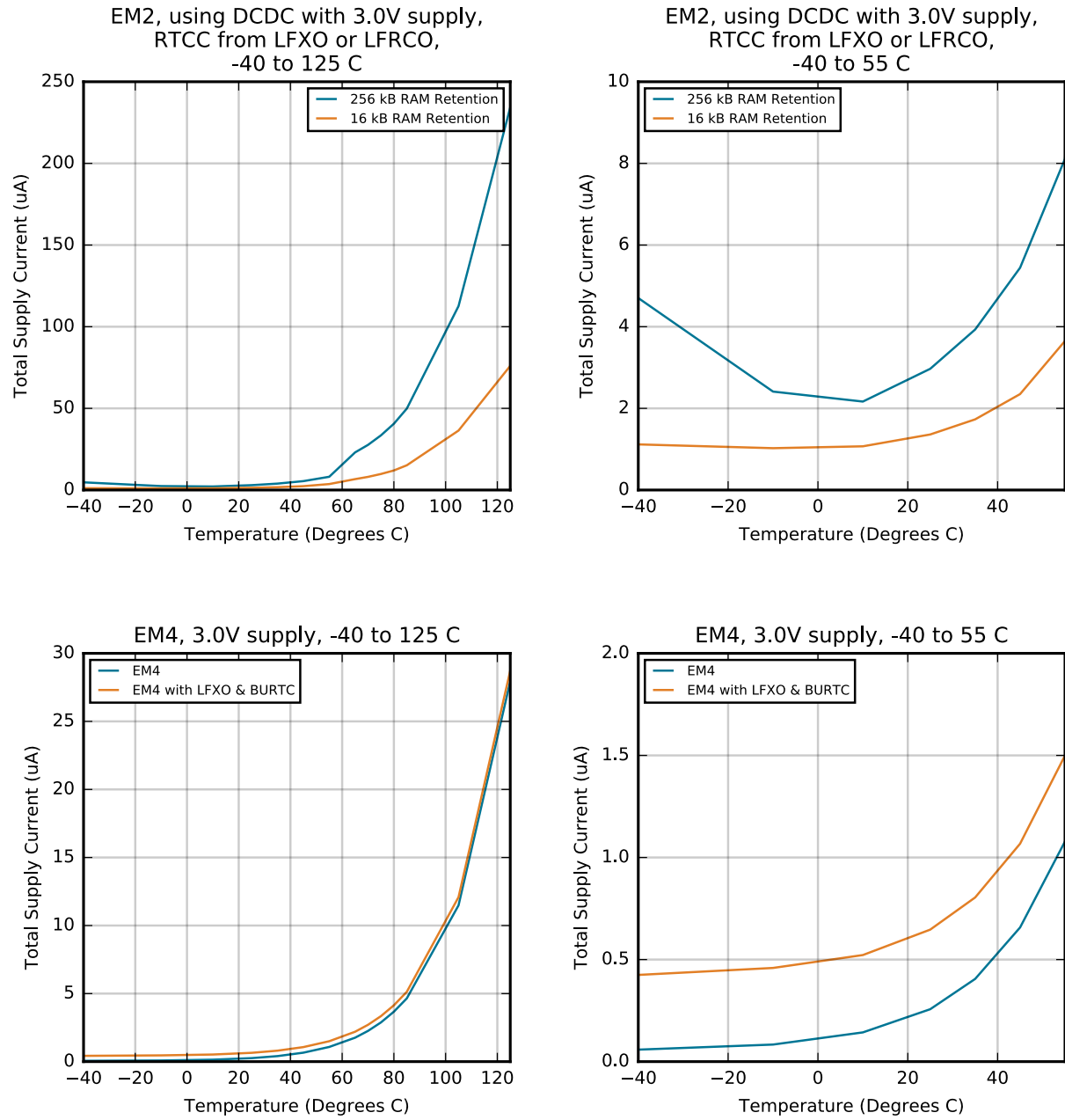


Figure 4.8. EM2 and EM4 Typical Supply Current vs. Temperature

4.27.2 RF Characteristics

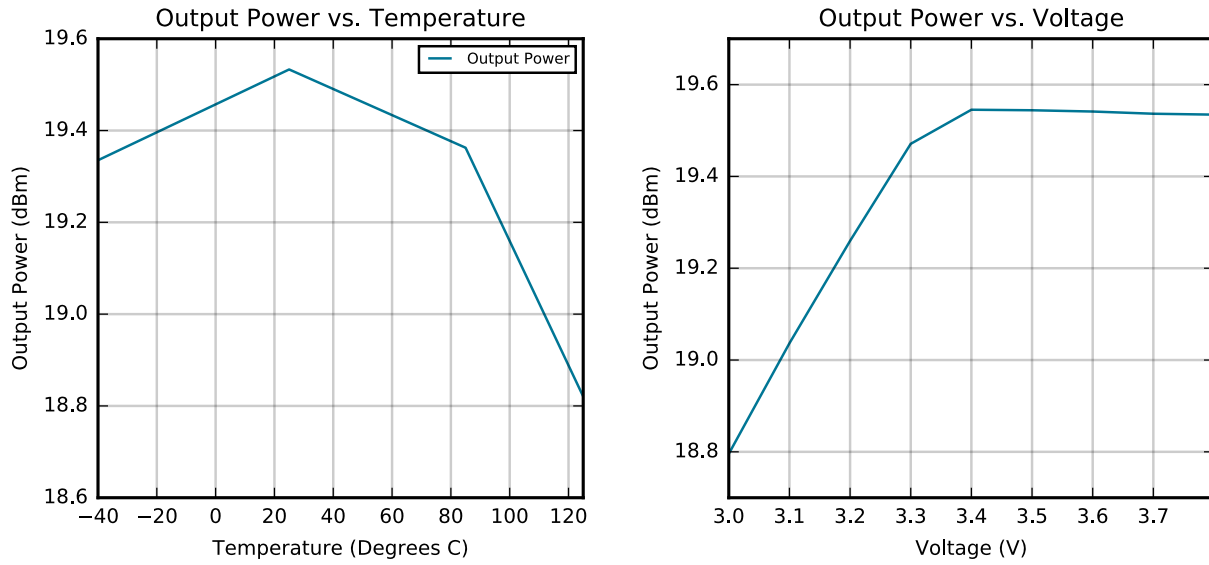


Figure 4.9. 2.4 GHz 20 dBm PA RF Transmitter Output Power (Pout=19.5 dBm)

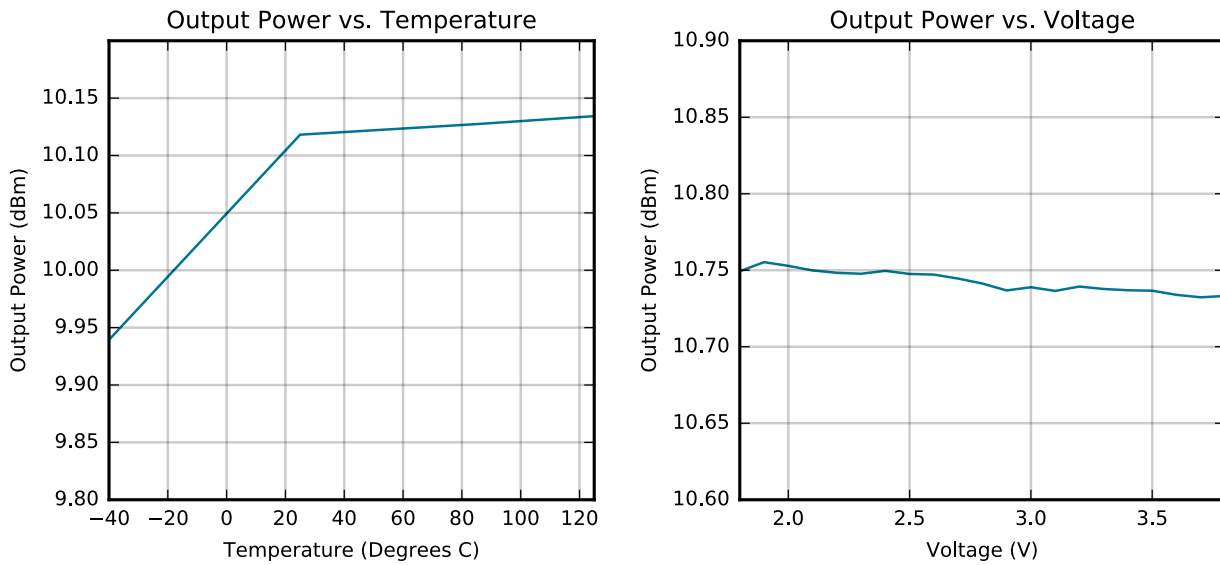


Figure 4.10. 2.4 GHz 10 dBm PA RF Transmitter Output Power (Pout=10 dBm)

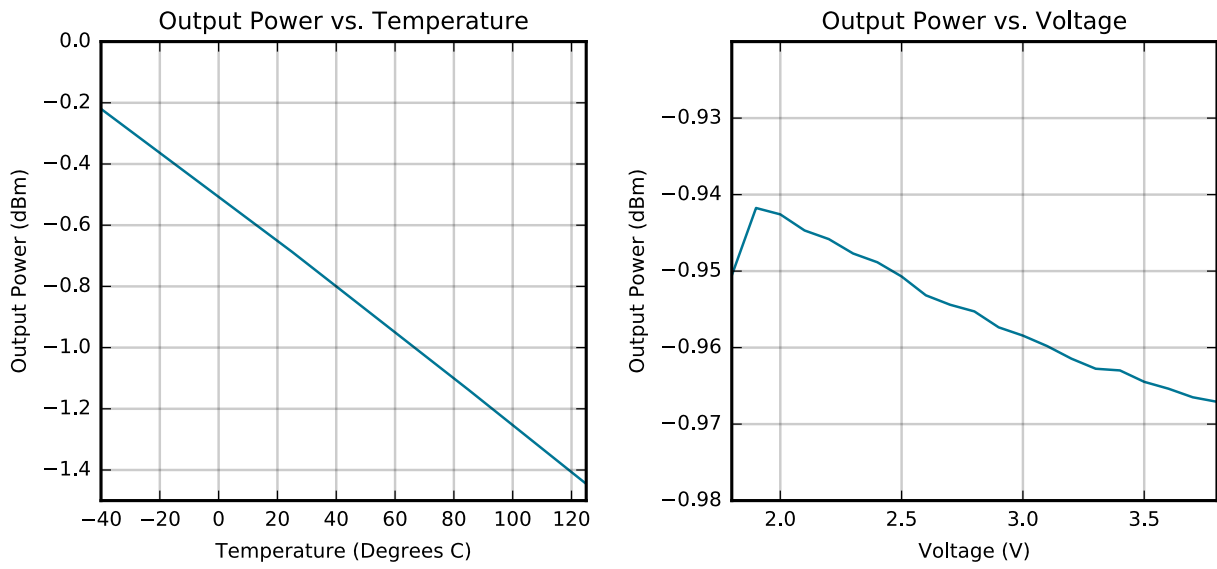


Figure 4.11. 2.4 GHz 0 dBm PA RF Transmitter Output Power (Pout=0 dBm)

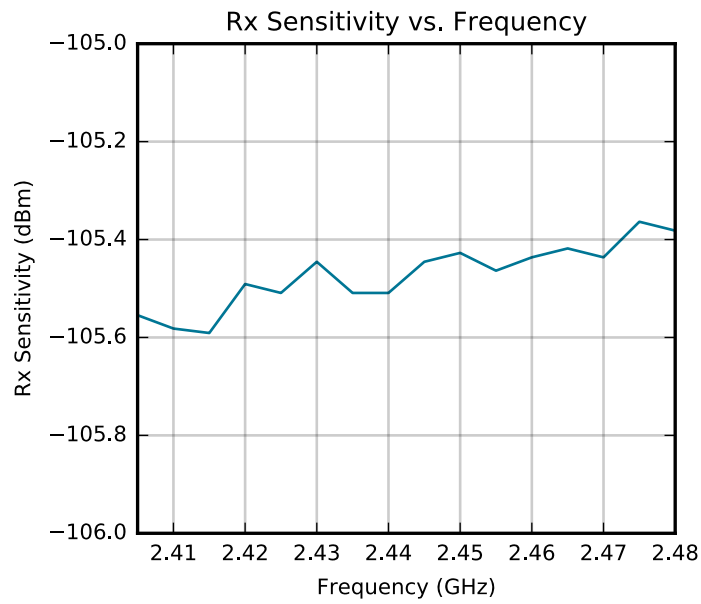


Figure 4.12. 2.4 GHz 802.15.4 RF Receiver Sensitivity

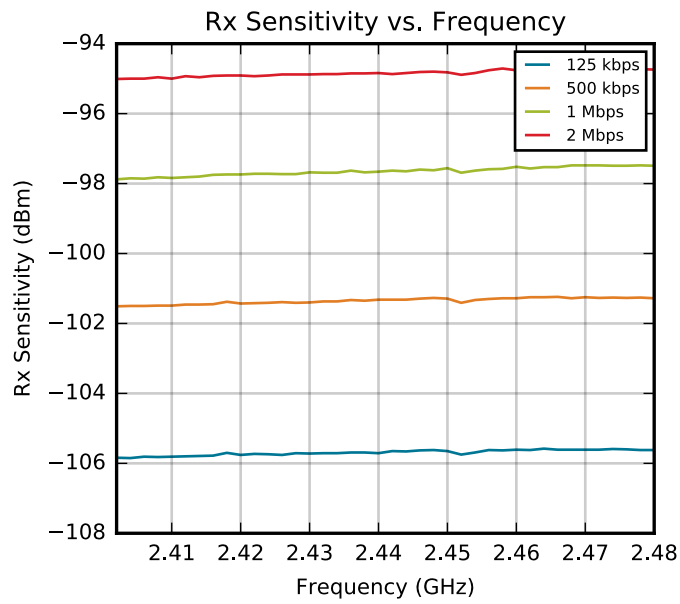


Figure 4.13. 2.4 GHz BLE RF Receiver Sensitivity

#### 4.27.3 DC-DC Converter

Performance characterized with Murata DFE2HCAH2R2MJ0 ( $L_{DCDC} = 2.2 \mu\text{H}$ ) and TDK CGA5L3X8R1C475K160AB ( $C_{DCDC} = 4.7 \mu\text{F}$ )

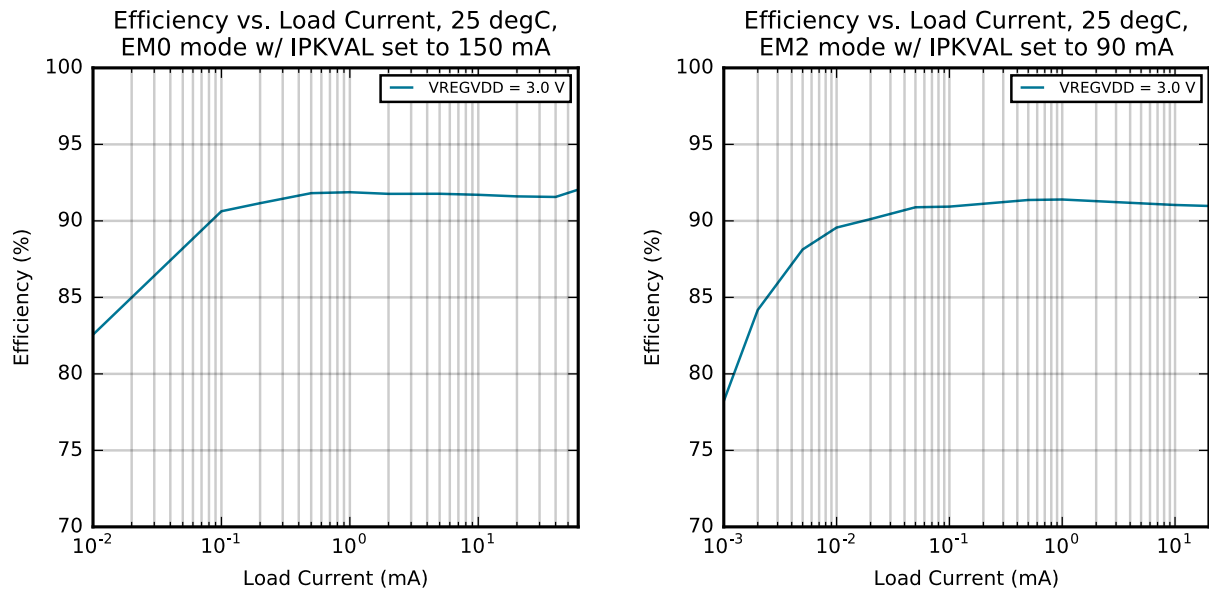


Figure 4.14. DC-DC Efficiency

4.27.4 IADC

Typical performance is shown using 10 MHz ADC clock for fastest sampling speed and adjusting oversampling ratio (OSR).

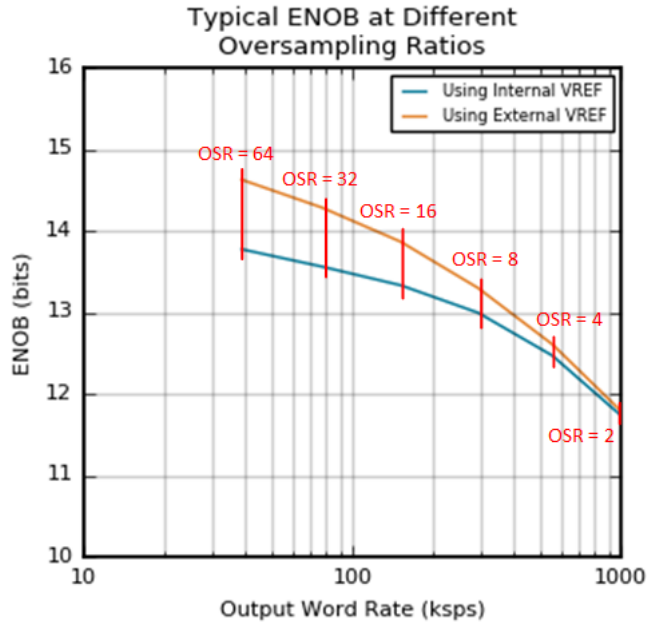


Figure 4.15. Typical ENOB vs. Oversampling Ratio

4.27.5 GPIO

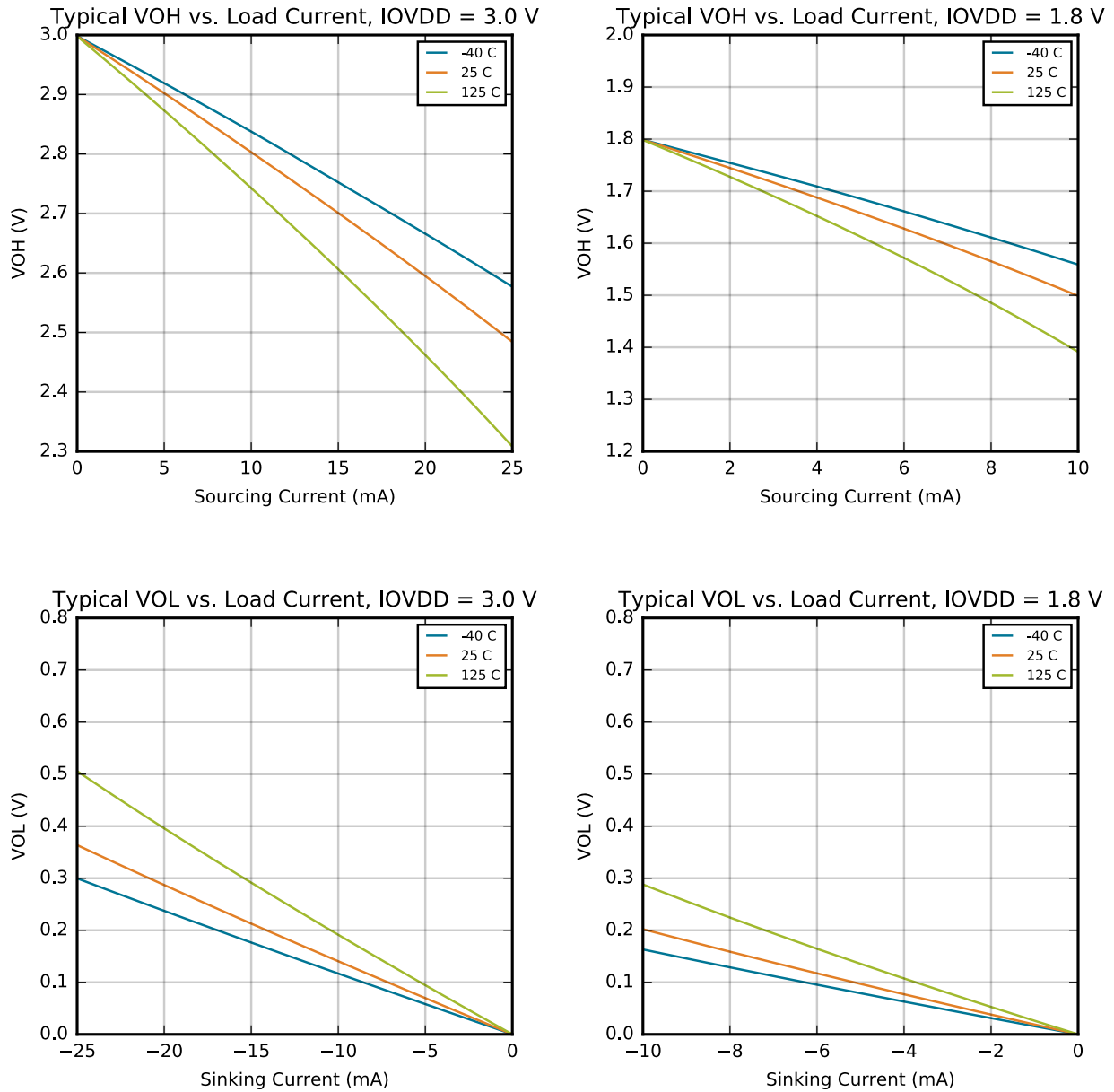


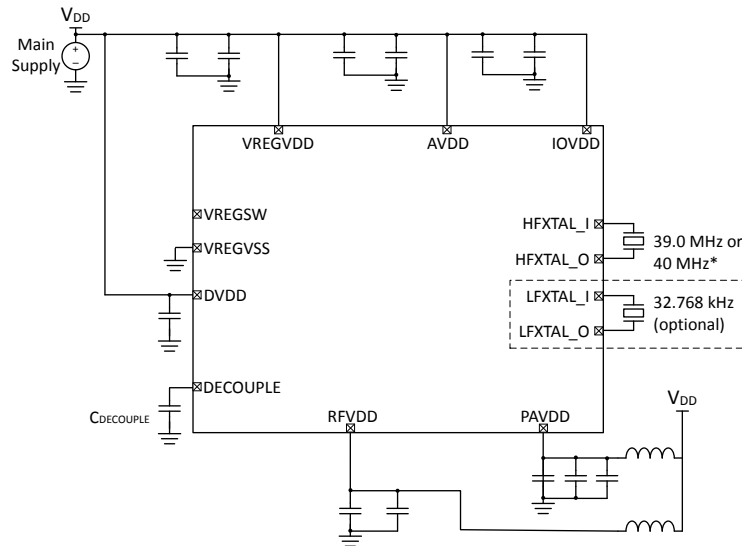
Figure 4.16. VOH and VOL vs. Load Current

## 5. Typical Connections

### 5.1 Power

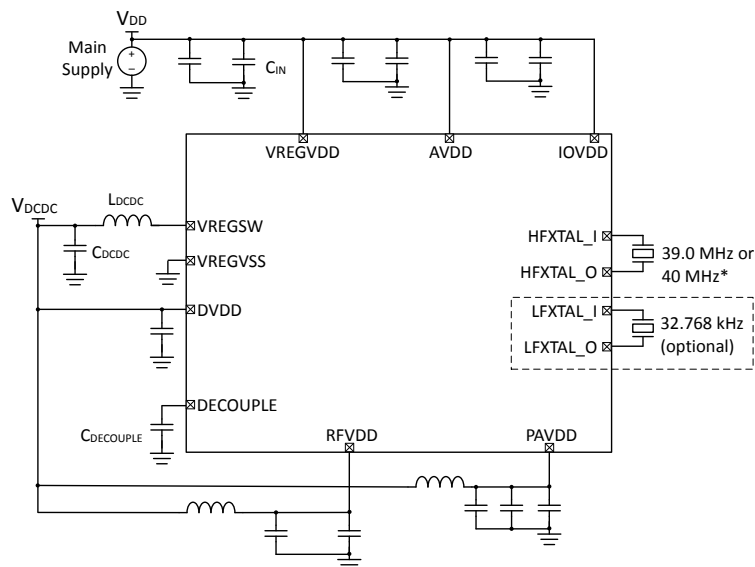
Typical power supply connections are shown in the following figures.

**Note:** PAVDD, RFVDD, AVDD, and IOVDD supply connections are flexible. They may be connected in other configurations or to external supplies as long as the supply limits described in 4.1 Electrical Characteristics are met.



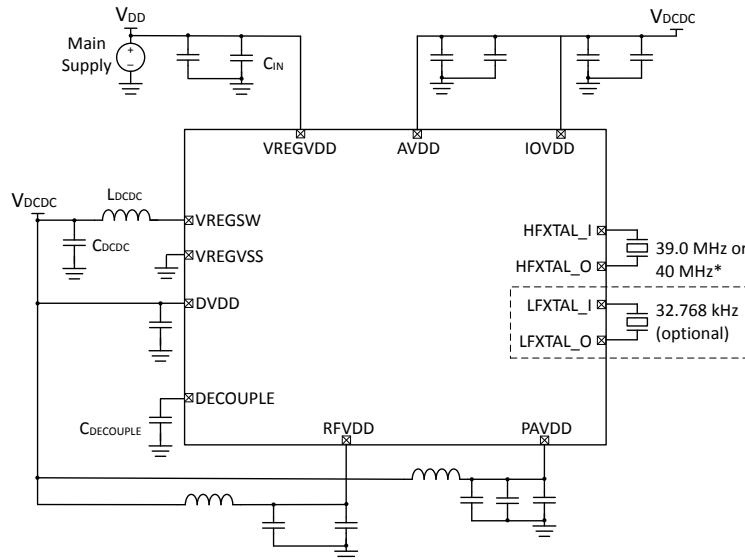
\*40 MHz required for applications using Channel Sounding

**Figure 5.1. EFR32MG24 Typical Application Circuit: Direct Supply Configuration without DCDC**



\*40 MHz required for applications using Channel Sounding

**Figure 5.2. EFR32MG24 Typical Application Circuit: DCDC Configuration, PAVDD and RFVDD from DCDC output, AVDD and IOVDD from main supply**



\*40 MHz required for applications using Channel Sounding

**Figure 5.3. EFR32MG24 Typical Application Circuit: DCDC Configuration with PAVDD, RFVDD, AVDD, and IOVDD from DCDC output**

## 5.2 Other Connections

Other components or connections may be required to meet the system-level requirements. Application Note AN0002.2: "EFR32 Wireless Gecko Series 2 Hardware Design Considerations" contains detailed information on these connections. Application Notes can be accessed on the Silicon Labs website ([www.silabs.com/32bit-appnotes](http://www.silabs.com/32bit-appnotes)).

## 6. Pin Definitions

### 6.1 QFN48 / Standard Device Pinout

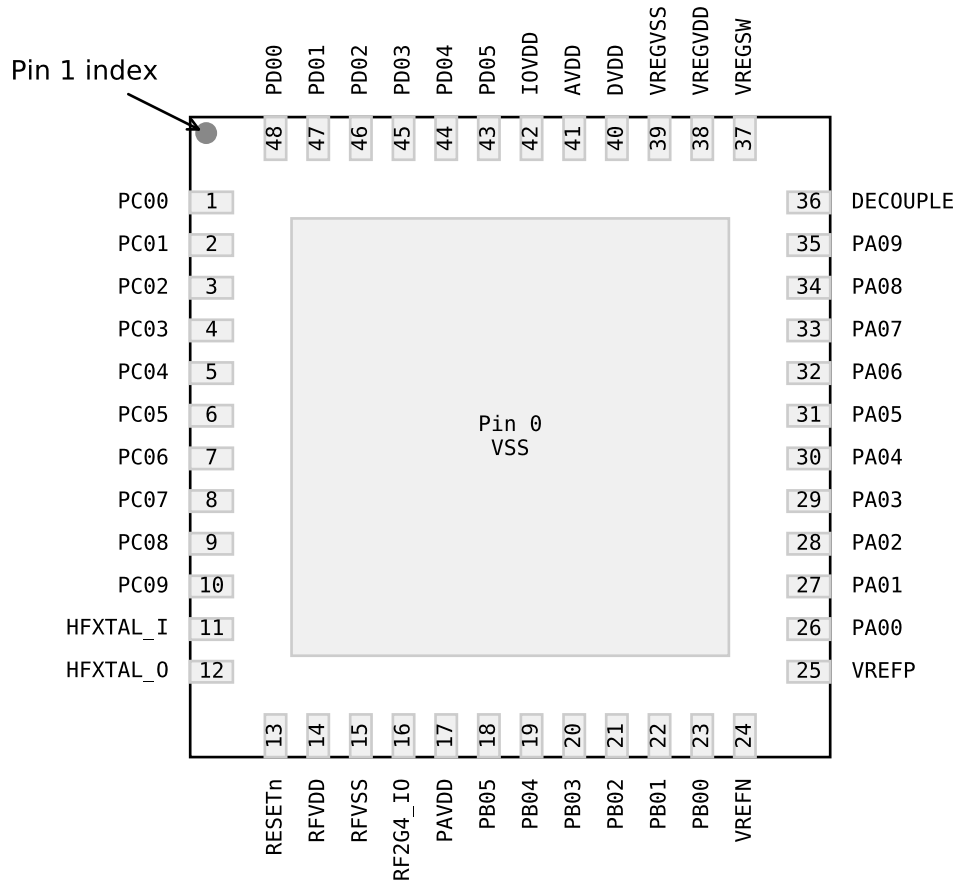


Figure 6.1. QFN48 / Standard Device Pinout

The following table provides package pin connections and general descriptions of pin functionality. For detailed information on the supported features for each GPIO pin, see [6.5 Alternate Function Table](#), [6.6 Analog Peripheral Connectivity](#), and [6.7 Digital Peripheral Connectivity](#).

Table 6.1. QFN48 / Standard Device Pinout

| Pin Name | Pin(s) | Description | Pin Name | Pin(s) | Description |
|----------|--------|-------------|----------|--------|-------------|
| PC00     | 1      | GPIO        | PC01     | 2      | GPIO        |
| PC02     | 3      | GPIO        | PC03     | 4      | GPIO        |
| PC04     | 5      | GPIO        | PC05     | 6      | GPIO        |
| PC06     | 7      | GPIO        | PC07     | 8      | GPIO        |
| PC08     | 9      | GPIO        | PC09     | 10     | GPIO        |

| Pin Name | Pin(s) | Description  | Pin Name | Pin(s) | Description  |
|----------|--------|--|----------|--------|--|
| HFXTAL_I | 11     | High Frequency Crystal Input                               | HFXTAL_O | 12     | High Frequency Crystal Output  |
| RESETn   | 13     | Reset Pin. The RESETn pin is internally pulled up to DVDD. | RFVDD    | 14     | Radio power supply   |
| RFVSS    | 15     | Radio Ground   | RF2G4_IO | 16     | 2.4 GHz RF input/output  |
| PAVDD    | 17     | Power Amplifier (PA) power supply                          | PB05     | 18     | GPIO   |
| PB04     | 19     | GPIO   | PB03     | 20     | GPIO   |
| PB02     | 21     | GPIO   | PB01     | 22     | GPIO   |
| PB00     | 23     | GPIO   | VREFN    | 24     | Dedicated ADC VREF Negative Input  |
| VREFP    | 25     | Dedicated ADC VREF Positive Input                          | PA00     | 26     | GPIO   |
| PA01     | 27     | GPIO   | PA02     | 28     | GPIO   |
| PA03     | 29     | GPIO   | PA04     | 30     | GPIO   |
| PA05     | 31     | GPIO   | PA06     | 32     | GPIO   |
| PA07     | 33     | GPIO   | PA08     | 34     | GPIO   |
| PA09     | 35     | GPIO   | DECOUPLE | 36     | Decouple output for on-chip voltage regulator. An external decoupling capacitor is required at this pin. |
| VREGSW   | 37     | DCDC regulator switching node                              | VREGVDD  | 38     | DCDC regulator input supply  |
| VREGVSS  | 39     | DCDC ground  | DVDD     | 40     | Digital power supply   |
| AVDD     | 41     | Analog power supply  | IOVDD    | 42     | I/O power supply   |
| PD05     | 43     | GPIO   | PD04     | 44     | GPIO   |
| PD03     | 45     | GPIO   | PD02     | 46     | GPIO   |
| PD01     | 47     | GPIO   | PD00     | 48     | GPIO   |

## 6.2 QFN48 / ADC Device Pinout

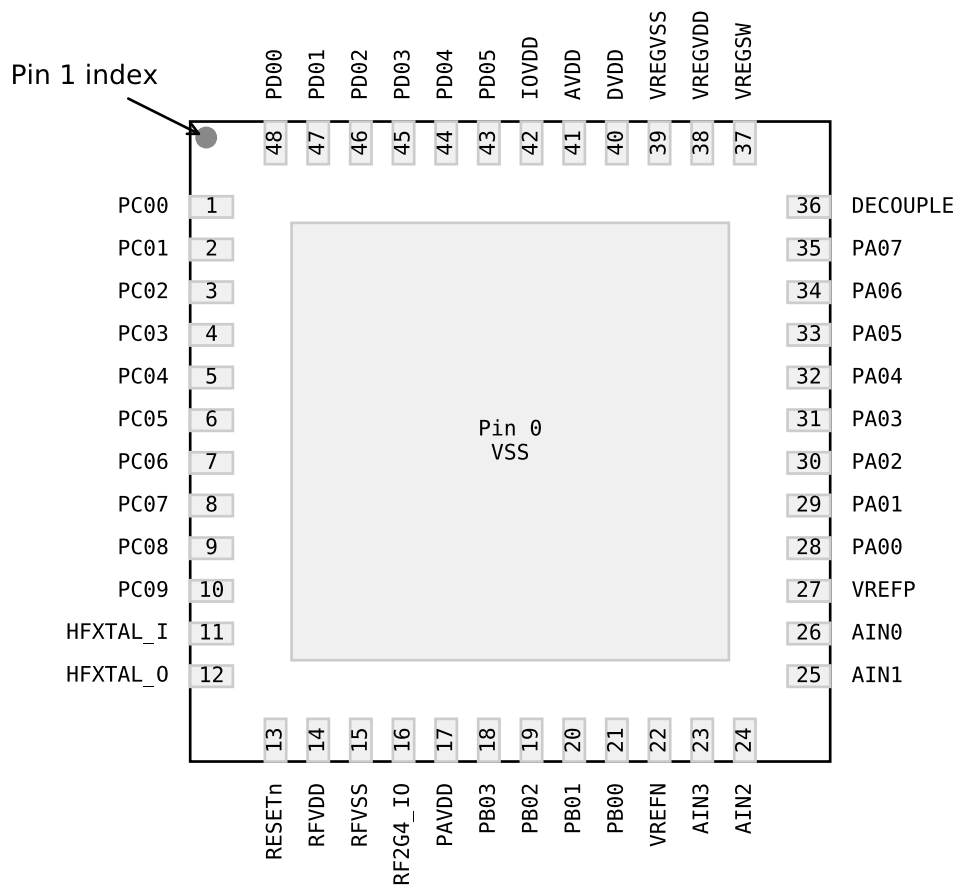


Figure 6.2. QFN48 / ADC Device Pinout

The following table provides package pin connections and general descriptions of pin functionality. For detailed information on the supported features for each GPIO pin, see [6.5 Alternate Function Table](#), [6.6 Analog Peripheral Connectivity](#), and [6.7 Digital Peripheral Connectivity](#).

Table 6.2. QFN48 / ADC Device Pinout

| Pin Name | Pin(s) | Description                  | Pin Name | Pin(s) | Description                   |
|----------|--------|------------------------------|----------|--------|-------------------------------|
| PC00     | 1      | GPIO                         | PC01     | 2      | GPIO                          |
| PC02     | 3      | GPIO                         | PC03     | 4      | GPIO                          |
| PC04     | 5      | GPIO                         | PC05     | 6      | GPIO                          |
| PC06     | 7      | GPIO                         | PC07     | 8      | GPIO                          |
| PC08     | 9      | GPIO                         | PC09     | 10     | GPIO                          |
| HFXTAL_I | 11     | High Frequency Crystal Input | HFXTAL_O | 12     | High Frequency Crystal Output |

| Pin Name | Pin(s) | Description  | Pin Name | Pin(s) | Description  |
|----------|--------|--|----------|--------|--|
| RESETn   | 13     | Reset Pin. The RESETn pin is internally pulled up to DVDD. | RFVDD    | 14     | Radio power supply   |
| RFVSS    | 15     | Radio Ground   | RF2G4_IO | 16     | 2.4 GHz RF input/output  |
| PAVDD    | 17     | Power Amplifier (PA) power supply                          | PB03     | 18     | GPIO   |
| PB02     | 19     | GPIO   | PB01     | 20     | GPIO   |
| PB00     | 21     | GPIO   | VREFN    | 22     | Dedicated ADC VREF Negative Input  |
| AIN3     | 23     | Dedicated ADC Input 3                                      | AIN2     | 24     | Dedicated ADC Input 2  |
| AIN1     | 25     | Dedicated ADC Input 1                                      | AIN0     | 26     | Dedicated ADC Input 0  |
| VREFP    | 27     | Dedicated ADC VREF Positive Input                          | PA00     | 28     | GPIO   |
| PA01     | 29     | GPIO   | PA02     | 30     | GPIO   |
| PA03     | 31     | GPIO   | PA04     | 32     | GPIO   |
| PA05     | 33     | GPIO   | PA06     | 34     | GPIO   |
| PA07     | 35     | GPIO   | DECOUPLE | 36     | Decouple output for on-chip voltage regulator. An external decoupling capacitor is required at this pin. |
| VREGSW   | 37     | DCDC regulator switching node                              | VREGVDD  | 38     | DCDC regulator input supply  |
| VREGVSS  | 39     | DCDC ground  | DVDD     | 40     | Digital power supply   |
| AVDD     | 41     | Analog power supply  | IOVDD    | 42     | I/O power supply   |
| PD05     | 43     | GPIO   | PD04     | 44     | GPIO   |
| PD03     | 45     | GPIO   | PD02     | 46     | GPIO   |
| PD01     | 47     | GPIO   | PD00     | 48     | GPIO   |

### 6.3 QFN40 / Standard Device Pinout

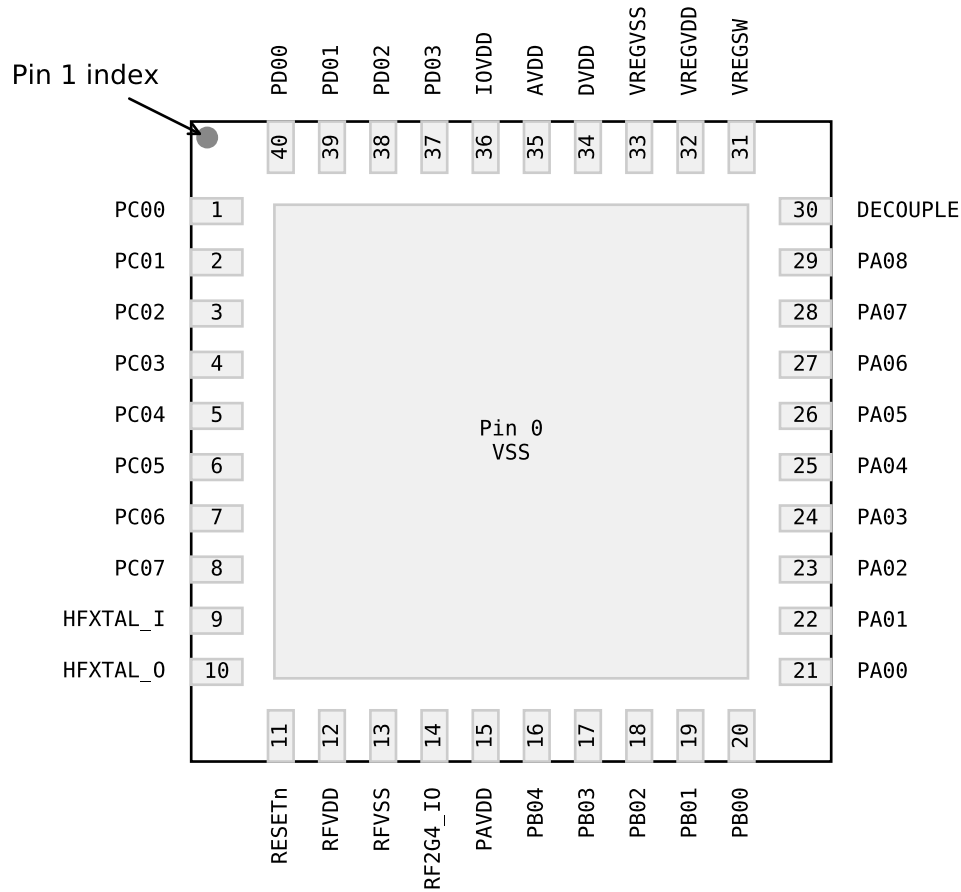


Figure 6.3. QFN40 / Standard Device Pinout

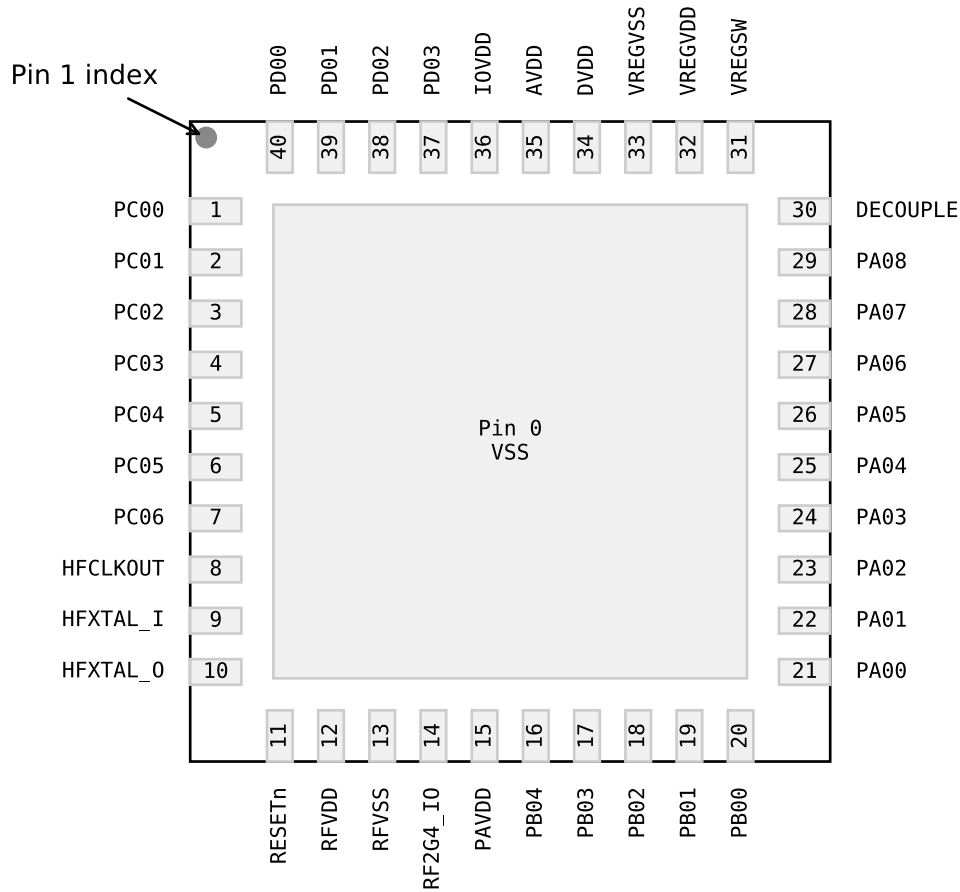
The following table provides package pin connections and general descriptions of pin functionality. For detailed information on the supported features for each GPIO pin, see [6.5 Alternate Function Table](#), [6.6 Analog Peripheral Connectivity](#), and [6.7 Digital Peripheral Connectivity](#).

Table 6.3. QFN40 / Standard Device Pinout

| Pin Name | Pin(s) | Description  | Pin Name | Pin(s) | Description                   |
|----------|--------|--|----------|--------|-------------------------------|
| PC00     | 1      | GPIO   | PC01     | 2      | GPIO                          |
| PC02     | 3      | GPIO   | PC03     | 4      | GPIO                          |
| PC04     | 5      | GPIO   | PC05     | 6      | GPIO                          |
| PC06     | 7      | GPIO   | PC07     | 8      | GPIO                          |
| HFXTAL_I | 9      | High Frequency Crystal Input                               | HFXTAL_O | 10     | High Frequency Crystal Output |
| RESETh   | 11     | Reset Pin. The RESETh pin is internally pulled up to DVDD. | RFVDD    | 12     | Radio power supply            |

| Pin Name | Pin(s) | Description                       | Pin Name | Pin(s) | Description  |
|----------|--------|-----------------------------------|----------|--------|--|
| RFVSS    | 13     | Radio Ground                      | RF2G4_IO | 14     | 2.4 GHz RF input/output  |
| PAVDD    | 15     | Power Amplifier (PA) power supply | PB04     | 16     | GPIO   |
| PB03     | 17     | GPIO                              | PB02     | 18     | GPIO   |
| PB01     | 19     | GPIO                              | PB00     | 20     | GPIO   |
| PA00     | 21     | GPIO                              | PA01     | 22     | GPIO   |
| PA02     | 23     | GPIO                              | PA03     | 24     | GPIO   |
| PA04     | 25     | GPIO                              | PA05     | 26     | GPIO   |
| PA06     | 27     | GPIO                              | PA07     | 28     | GPIO   |
| PA08     | 29     | GPIO                              | DECOUPLE | 30     | Decouple output for on-chip voltage regulator. An external decoupling capacitor is required at this pin. |
| VREGSW   | 31     | DCDC regulator switching node     | VREGVDD  | 32     | DCDC regulator input supply  |
| VREGVSS  | 33     | DCDC ground                       | DVDD     | 34     | Digital power supply   |
| AVDD     | 35     | Analog power supply               | IOVDD    | 36     | I/O power supply   |
| PD03     | 37     | GPIO                              | PD02     | 38     | GPIO   |
| PD01     | 39     | GPIO                              | PD00     | 40     | GPIO   |

### 6.4 QFN40 / HFCLKOUT Device Pinout



**Figure 6.4. QFN40 / HFCLKOUT Device Pinout**

The following table provides package pin connections and general descriptions of pin functionality. For detailed information on the supported features for each GPIO pin, see [6.5 Alternate Function Table](#), [6.6 Analog Peripheral Connectivity](#), and [6.7 Digital Peripheral Connectivity](#).

**Table 6.4. QFN40 / HFCLKOUT Device Pinout**

| Pin Name | Pin(s) | Description  | Pin Name | Pin(s) | Description                   |
|----------|--------|--|----------|--------|-------------------------------|
| PC00     | 1      | GPIO   | PC01     | 2      | GPIO                          |
| PC02     | 3      | GPIO   | PC03     | 4      | GPIO                          |
| PC04     | 5      | GPIO   | PC05     | 6      | GPIO                          |
| PC06     | 7      | GPIO   | HFCLKOUT | 8      | High Frequency Clock Output   |
| HFXTAL_I | 9      | High Frequency Crystal Input                               | HFXTAL_O | 10     | High Frequency Crystal Output |
| RESETn   | 11     | Reset Pin. The RESETn pin is internally pulled up to DVDD. | RFVDD    | 12     | Radio power supply            |

| Pin Name | Pin(s) | Description                       | Pin Name | Pin(s) | Description  |
|----------|--------|-----------------------------------|----------|--------|--|
| RFVSS    | 13     | Radio Ground                      | RF2G4_IO | 14     | 2.4 GHz RF input/output  |
| PAVDD    | 15     | Power Amplifier (PA) power supply | PB04     | 16     | GPIO   |
| PB03     | 17     | GPIO                              | PB02     | 18     | GPIO   |
| PB01     | 19     | GPIO                              | PB00     | 20     | GPIO   |
| PA00     | 21     | GPIO                              | PA01     | 22     | GPIO   |
| PA02     | 23     | GPIO                              | PA03     | 24     | GPIO   |
| PA04     | 25     | GPIO                              | PA05     | 26     | GPIO   |
| PA06     | 27     | GPIO                              | PA07     | 28     | GPIO   |
| PA08     | 29     | GPIO                              | DECOUPLE | 30     | Decouple output for on-chip voltage regulator. An external decoupling capacitor is required at this pin. |
| VREGSW   | 31     | DCDC regulator switching node     | VREGVDD  | 32     | DCDC regulator input supply  |
| VREGVSS  | 33     | DCDC ground                       | DVDD     | 34     | Digital power supply   |
| AVDD     | 35     | Analog power supply               | IOVDD    | 36     | I/O power supply   |
| PD03     | 37     | GPIO                              | PD02     | 38     | GPIO   |
| PD01     | 39     | GPIO                              | PD00     | 40     | GPIO   |

## 6.5 Alternate Function Table

A wide selection of alternate functionality is available for multiplexing to various pins. The following table shows GPIO pins with support for dedicated functions across the different package options.

**Table 6.5. GPIO Alternate Function Table**

| GPIO | Alternate Functions        | QFN48 / Standard Package <sup>1</sup> | QFN48 / ADC Package <sup>2</sup> | QFN40 / Standard Package <sup>3</sup> | QFN40 / HFCLKOUT Package <sup>4</sup> |
|------|----------------------------|---------------------------------------|----------------------------------|---------------------------------------|---------------------------------------|
| PA00 | IADC0.VREFFP               |                                       |                                  | Yes                                   | Yes                                   |
| PA01 | GPIO.SWCLK                 | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PA02 | GPIO.SWDIO                 | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PA03 | GPIO.SWV                   | Yes                                   | Yes                              | Yes                                   | Yes                                   |
|      | GPIO.TDO                   | Yes                                   | Yes                              | Yes                                   | Yes                                   |
|      | GPIO.TRACEDATA0            | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PA04 | GPIO.TDI                   | Yes                                   | Yes                              | Yes                                   | Yes                                   |
|      | GPIO.TRACECLK              | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PA05 | GPIO.TRACEDATA1            | Yes                                   | Yes                              | Yes                                   | Yes                                   |
|      | GPIO.EM4WU0                | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PA06 | GPIO.TRACEDATA2            | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PA07 | GPIO.TRACEDATA3            | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PB00 | VDAC0.VDAC_CH0_MAIN_OUTPUT | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PB01 | GPIO.EM4WU3                | Yes                                   | Yes                              | Yes                                   | Yes                                   |
|      | VDAC0.VDAC_CH1_MAIN_OUTPUT | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PB02 | VDAC1.VDAC_CH0_MAIN_OUTPUT | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PB03 | GPIO.EM4WU4                | Yes                                   | Yes                              | Yes                                   | Yes                                   |
|      | VDAC1.VDAC_CH1_MAIN_OUTPUT | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PC00 | GPIO.EM4WU6                | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PC01 | GPIO.EFP_TX_SDA            | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PC02 | GPIO.EFP_TX_SCL            | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PC05 | GPIO.EFP_INT               | Yes                                   | Yes                              | Yes                                   | Yes                                   |
|      | GPIO.EM4WU7                | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PC06 | GPIO.THMSW_EN              |                                       |                                  |                                       | Yes                                   |
|      | GPIO.THMSW_HALFSWITCH      |                                       |                                  |                                       | Yes                                   |
| PC07 | GPIO.EM4WU8                | Yes                                   | Yes                              | Yes                                   |                                       |
|      | GPIO.THMSW_EN              |                                       |                                  | Yes                                   |                                       |
|      | GPIO.THMSW_HALFSWITCH      |                                       |                                  | Yes                                   |                                       |
| PC09 | GPIO.THMSW_EN              | Yes                                   | Yes                              |                                       |                                       |
|      | GPIO.THMSW_HALFSWITCH      | Yes                                   | Yes                              |                                       |                                       |
| PD00 | LFXO.LFXTAL_O              | Yes                                   | Yes                              | Yes                                   | Yes                                   |

| GPIO | Alternate Functions | QFN48 / Standard Package <sup>1</sup> | QFN48 / ADC Package <sup>2</sup> | QFN40 / Standard Package <sup>3</sup> | QFN40 / HFCLKOUT Package <sup>4</sup> |
|------|---------------------|---------------------------------------|----------------------------------|---------------------------------------|---------------------------------------|
| PD01 | LFXO.LFXTAL_I       | Yes                                   | Yes                              | Yes                                   | Yes                                   |
|      | LFXO.LF_EXTCLK      | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PD02 | GPIO.EM4WU9         | Yes                                   | Yes                              | Yes                                   | Yes                                   |
| PD05 | GPIO.EM4WU10        | Yes                                   | Yes                              |                                       |                                       |

**Note:**

1. QFN48 / Standard Package includes OPNs EFR32MG24A010F1024IM48-B, EFR32MG24A010F1536IM48-B, EFR32MG24A020F1024IM48-B, EFR32MG24A020F1536IM48-B, EFR32MG24A410F1536IM48-B, EFR32MG24A420F1536IM48-B, EFR32MG24B010F1024IM48-B, EFR32MG24B010F1536IM48-B, EFR32MG24B020F1024IM48-B, EFR32MG24B020F1536IM48-B, EFR32MG24B210F1536IM48-B, and EFR32MG24B220F1536IM48-B
2. QFN48 / ADC Package includes OPNs EFR32MG24A110F1024IM48-B, EFR32MG24B110F1536IM48-B, EFR32MG24B120F1536IM48-B, and EFR32MG24B310F1536IM48-B
3. QFN40 / Standard Package includes OPNs EFR32MG24A010F1024IM40-B, EFR32MG24A010F1536IM40-B, EFR32MG24A020F1024IM40-B, EFR32MG24A020F1536IM40-B, EFR32MG24A410F1536IM40-B, EFR32MG24A420F1536IM40-B, EFR32MG24B010F1536IM40-B, and EFR32MG24B020F1536IM40-B
4. QFN40 / HFCLKOUT Package includes OPN EFR32MG24A021F1024IM40-B

## 6.6 Analog Peripheral Connectivity

Many analog resources are routable and can be connected to numerous GPIO's. The table below indicates which peripherals are available on each GPIO port. When a differential connection is being used Positive inputs are restricted to the EVEN pins and Negative inputs are restricted to the ODD pins. When a single ended connection is being used positive input is available on all pins. See the device Reference Manual for more details on the ABUS and analog peripherals. Note that some functions may not be available on all device variants.

**Table 6.6. ABUS Routing Table**

| Peripheral | Signal                | PA   |     | PB   |     | PC   |     | PD   |     |
|------------|-----------------------|------|-----|------|-----|------|-----|------|-----|
|            |                       | EVEN | ODD | EVEN | ODD | EVEN | ODD | EVEN | ODD |
| ACMP0      | ANA_NEG               | Yes  | Yes | Yes  | Yes | Yes  | Yes | Yes  | Yes |
|            | ANA_POS               | Yes  | Yes | Yes  | Yes | Yes  | Yes | Yes  | Yes |
| ACMP1      | ANA_NEG               | Yes  | Yes | Yes  | Yes | Yes  | Yes | Yes  | Yes |
|            | ANA_POS               | Yes  | Yes | Yes  | Yes | Yes  | Yes | Yes  | Yes |
| IADC0      | ANA_NEG               | Yes  | Yes | Yes  | Yes | Yes  | Yes | Yes  | Yes |
|            | ANA_POS               | Yes  | Yes | Yes  | Yes | Yes  | Yes | Yes  | Yes |
| VDAC0      | VDAC_CH0_ABUS_OUT-PUT | Yes  | Yes | Yes  | Yes | Yes  | Yes | Yes  | Yes |
|            | VDAC_CH1_ABUS_OUT     | Yes  | Yes | Yes  | Yes | Yes  | Yes | Yes  | Yes |
| VDAC1      | VDAC_CH0_ABUS_OUT-PUT | Yes  | Yes | Yes  | Yes | Yes  | Yes | Yes  | Yes |
|            | VDAC_CH1_ABUS_OUT     | Yes  | Yes | Yes  | Yes | Yes  | Yes | Yes  | Yes |

## 6.7 Digital Peripheral Connectivity

Many digital resources are routable and can be connected to numerous GPIO's. The table below indicates which peripherals are available on each GPIO port. Note that some functions may not be available on all device variants.

**Table 6.7. DBUS Routing Table**

| Peripheral.Resource       | PORT      |           |           |           |
|---------------------------|-----------|-----------|-----------|-----------|
|                           | PA        | PB        | PC        | PD        |
| ACMP0.DIGOUT              | Available | Available | Available | Available |
| ACMP1.DIGOUT              | Available | Available | Available | Available |
| CMU.CLKIN0                |           |           | Available | Available |
| CMU.CLKOUT0               |           |           | Available | Available |
| CMU.CLKOUT1               |           |           | Available | Available |
| CMU.CLKOUT2               | Available | Available |           |           |
| EUSART0.CS                | Available | Available |           |           |
| EUSART0.CTS               | Available | Available |           |           |
| EUSART0.RTS               | Available | Available |           |           |
| EUSART0.RX                | Available | Available |           |           |
| EUSART0.SCLK              | Available | Available |           |           |
| EUSART0.TX                | Available | Available |           |           |
| EUSART1.CS                | Available | Available | Available | Available |
| EUSART1.CTS               | Available | Available | Available | Available |
| EUSART1.RTS               | Available | Available | Available | Available |
| EUSART1.RX                | Available | Available | Available | Available |
| EUSART1.SCLK              | Available | Available | Available | Available |
| EUSART1.TX                | Available | Available | Available | Available |
| FRC.DCLK                  |           |           | Available | Available |
| FRC.DFRAME                |           |           | Available | Available |
| FRC.DOUT                  |           |           | Available | Available |
| HFXO0.BUFOUT_REQ_IN_ASYNC | Available | Available |           |           |
| I2C0.SCL                  | Available | Available | Available | Available |
| I2C0.SDA                  | Available | Available | Available | Available |
| I2C1.SCL                  |           |           | Available | Available |
| I2C1.SDA                  |           |           | Available | Available |
| KEYSCAN.COL_OUT_0         | Available | Available | Available | Available |
| KEYSCAN.COL_OUT_1         | Available | Available | Available | Available |
| KEYSCAN.COL_OUT_2         | Available | Available | Available | Available |
| KEYSCAN.COL_OUT_3         | Available | Available | Available | Available |
| KEYSCAN.COL_OUT_4         | Available | Available | Available | Available |

| Peripheral.Resource | PORT      |           |           |           |
|---------------------|-----------|-----------|-----------|-----------|
|                     | PA        | PB        | PC        | PD        |
| KEYSCAN.COL_OUT_5   | Available | Available | Available | Available |
| KEYSCAN.COL_OUT_6   | Available | Available | Available | Available |
| KEYSCAN.COL_OUT_7   | Available | Available | Available | Available |
| KEYSCAN.ROW_SENSE_0 | Available | Available |           |           |
| KEYSCAN.ROW_SENSE_1 | Available | Available |           |           |
| KEYSCAN.ROW_SENSE_2 | Available | Available |           |           |
| KEYSCAN.ROW_SENSE_3 | Available | Available |           |           |
| KEYSCAN.ROW_SENSE_4 | Available | Available |           |           |
| KEYSCAN.ROW_SENSE_5 | Available | Available |           |           |
| LETIMER0.OUT0       | Available | Available |           |           |
| LETIMER0.OUT1       | Available | Available |           |           |
| MODEM.ANT0          | Available | Available | Available | Available |
| MODEM.ANT1          | Available | Available | Available | Available |
| MODEM.ANT_ROLL_OVER |           |           | Available | Available |
| MODEM.ANT_RR0       |           |           | Available | Available |
| MODEM.ANT_RR1       |           |           | Available | Available |
| MODEM.ANT_RR2       |           |           | Available | Available |
| MODEM.ANT_RR3       |           |           | Available | Available |
| MODEM.ANT_RR4       |           |           | Available | Available |
| MODEM.ANT_RR5       |           |           | Available | Available |
| MODEM.ANT_SW_EN     |           |           | Available | Available |
| MODEM.ANT_SW_US     |           |           | Available | Available |
| MODEM.ANT_TRIG      |           |           | Available | Available |
| MODEM.ANT_TRIG_STOP |           |           | Available | Available |
| MODEM.DCLK          | Available | Available |           |           |
| MODEM.DIN           | Available | Available |           |           |
| MODEM.DOUT          | Available | Available |           |           |
| PCNT0.S0IN          | Available | Available |           |           |
| PCNT0.S1IN          | Available | Available |           |           |
| PRS.ASYNCH0         | Available | Available |           |           |
| PRS.ASYNCH1         | Available | Available |           |           |
| PRS.ASYNCH2         | Available | Available |           |           |
| PRS.ASYNCH3         | Available | Available |           |           |
| PRS.ASYNCH4         | Available | Available |           |           |
| PRS.ASYNCH5         | Available | Available |           |           |
| PRS.ASYNCH6         |           |           | Available | Available |

| Peripheral.Resource | PORT      |           |           |           |
|---------------------|-----------|-----------|-----------|-----------|
|                     | PA        | PB        | PC        | PD        |
| PRS.ASYNCH7         |           |           | Available | Available |
| PRS.ASYNCH8         |           |           | Available | Available |
| PRS.ASYNCH9         |           |           | Available | Available |
| PRS.ASYNCH10        |           |           | Available | Available |
| PRS.ASYNCH11        |           |           | Available | Available |
| PRS.ASYNCH12        | Available | Available |           |           |
| PRS.ASYNCH13        | Available | Available |           |           |
| PRS.ASYNCH14        | Available | Available |           |           |
| PRS.ASYNCH15        | Available | Available |           |           |
| PRS.SYNCH0          | Available | Available | Available | Available |
| PRS.SYNCH1          | Available | Available | Available | Available |
| PRS.SYNCH2          | Available | Available | Available | Available |
| PRS.SYNCH3          | Available | Available | Available | Available |
| RAC.LNAEN           | Available | Available | Available | Available |
| RAC.PAEN            | Available | Available | Available | Available |
| TIMER0.CC0          | Available | Available | Available | Available |
| TIMER0.CC1          | Available | Available | Available | Available |
| TIMER0.CC2          | Available | Available | Available | Available |
| TIMER0.CDTI0        | Available | Available | Available | Available |
| TIMER0.CDTI1        | Available | Available | Available | Available |
| TIMER0.CDTI2        | Available | Available | Available | Available |
| TIMER1.CC0          | Available | Available | Available | Available |
| TIMER1.CC1          | Available | Available | Available | Available |
| TIMER1.CC2          | Available | Available | Available | Available |
| TIMER1.CDTI0        | Available | Available | Available | Available |
| TIMER1.CDTI1        | Available | Available | Available | Available |
| TIMER1.CDTI2        | Available | Available | Available | Available |
| TIMER2.CC0          | Available | Available |           |           |
| TIMER2.CC1          | Available | Available |           |           |
| TIMER2.CC2          | Available | Available |           |           |
| TIMER2.CDTI0        | Available | Available |           |           |
| TIMER2.CDTI1        | Available | Available |           |           |
| TIMER2.CDTI2        | Available | Available |           |           |
| TIMER3.CC0          |           |           | Available | Available |
| TIMER3.CC1          |           |           | Available | Available |
| TIMER3.CC2          |           |           | Available | Available |

| Peripheral.Resource | PORT      |           |           |           |
|---------------------|-----------|-----------|-----------|-----------|
|                     | PA        | PB        | PC        | PD        |
| TIMER3.CDTI0        |           |           | Available | Available |
| TIMER3.CDTI1        |           |           | Available | Available |
| TIMER3.CDTI2        |           |           | Available | Available |
| TIMER4.CC0          | Available | Available |           |           |
| TIMER4.CC1          | Available | Available |           |           |
| TIMER4.CC2          | Available | Available |           |           |
| TIMER4.CDTI0        | Available | Available |           |           |
| TIMER4.CDTI1        | Available | Available |           |           |
| TIMER4.CDTI2        | Available | Available |           |           |
| USART0.CLK          | Available | Available | Available | Available |
| USART0.CS           | Available | Available | Available | Available |
| USART0.CTS          | Available | Available | Available | Available |
| USART0.RTS          | Available | Available | Available | Available |
| USART0.RX           | Available | Available | Available | Available |
| USART0.TX           | Available | Available | Available | Available |

## 7. QFN40 Package Specifications

### 7.1 QFN40 Package Dimensions

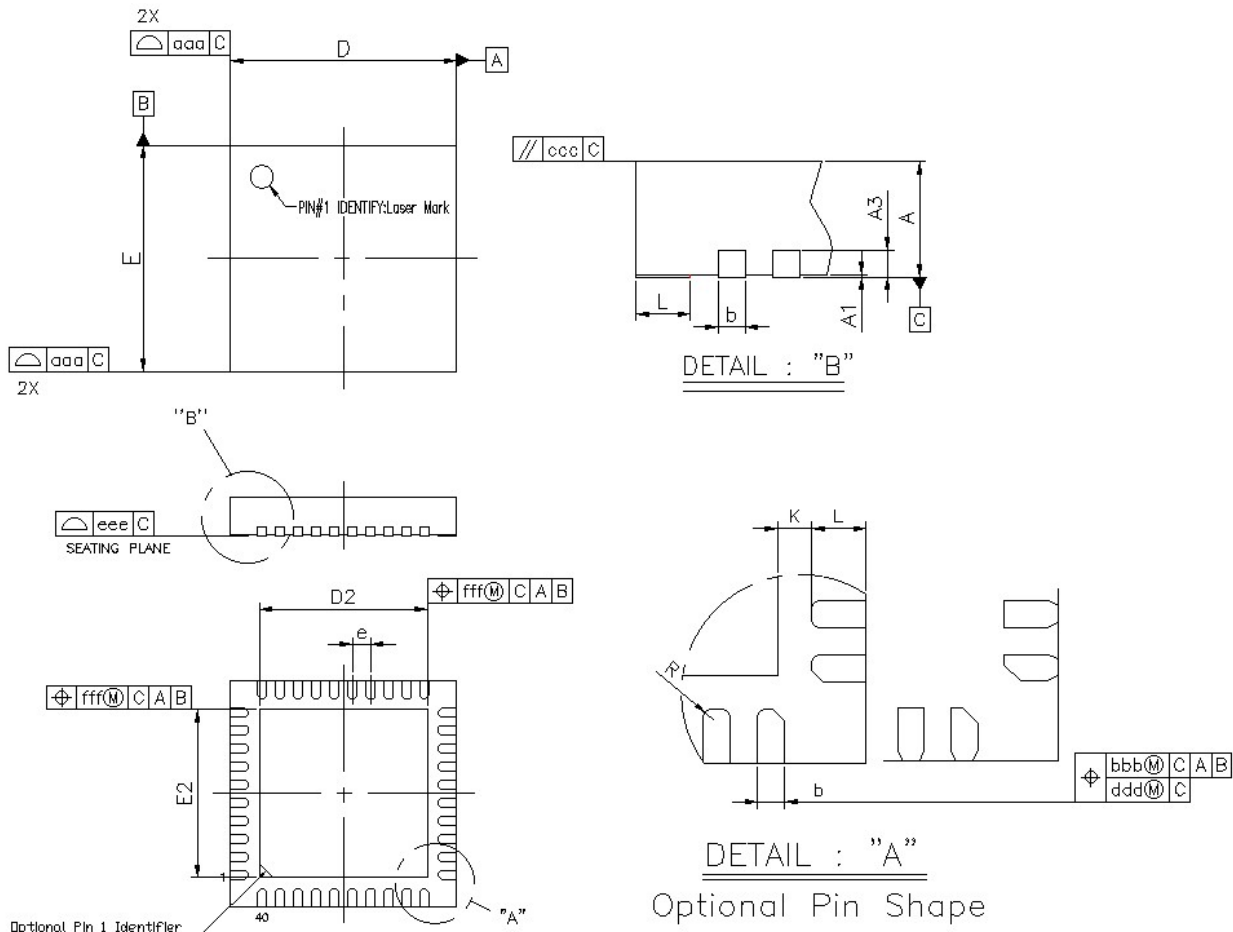


Figure 7.1. QFN40 Package Drawing

**Table 7.1. QFN40 Package Dimensions**

| Dimension | Min      | Typ  | Max  |
|-----------|----------|------|------|
| A         | 0.80     | 0.85 | 0.90 |
| A1        | 0.00     | 0.02 | 0.05 |
| A3        | 0.20 REF |      |      |
| b         | 0.15     | 0.20 | 0.25 |
| D         | 4.90     | 5.00 | 5.10 |
| E         | 4.90     | 5.00 | 5.10 |
| D2        | 3.55     | 3.70 | 3.85 |
| E2        | 3.55     | 3.70 | 3.85 |
| e         | 0.40 BSC |      |      |
| L         | 0.30     | 0.40 | 0.50 |
| K         | 0.20     | —    | —    |
| R         | 0.075    | —    | —    |
| aaa       | 0.10     |      |      |
| bbb       | 0.07     |      |      |
| ccc       | 0.10     |      |      |
| ddd       | 0.05     |      |      |
| eee       | 0.08     |      |      |
| fff       | 0.10     |      |      |

**Note:**

1. All dimensions shown are in millimeters (mm) unless otherwise noted.
2. Dimensioning and Tolerancing per ANSI Y14.5M-1994.
3. This drawing conforms to the JEDEC Solid State Outline MO-220, Variation VKKD-4.
4. Recommended card reflow profile is per the JEDEC/IPC J-STD-020 specification for Small Body Components.
5. Package external pad (epad) may have pin one chamfer.

7.2 QFN40 PCB Land Pattern

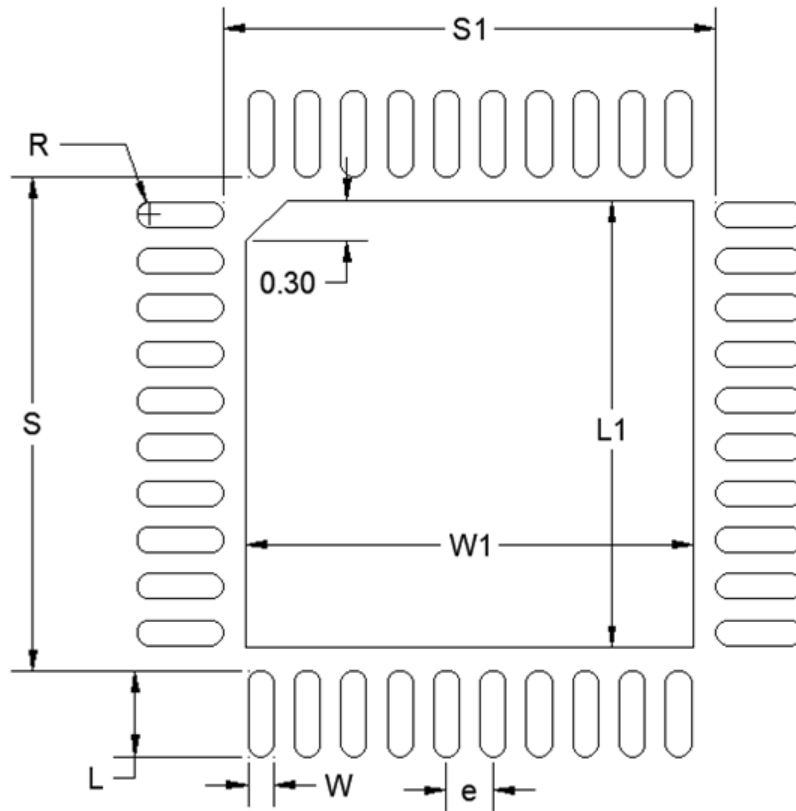


Figure 7.2. QFN40 PCB Land Pattern Drawing

Table 7.2. QFN40 PCB Land Pattern Dimensions

| Dimension | Typ  |
|-----------|------|
| S1        | 4.25 |
| S         | 4.25 |
| L1        | 3.85 |
| W1        | 3.85 |
| e         | 0.40 |
| W         | 0.22 |
| L         | 0.74 |
| R         | 0.11 |

| Dimension  | Typ |
|--|-----|
| <p><b>Note:</b></p> <ol style="list-style-type: none"> <li>1. All dimensions shown are in millimeters (mm) unless otherwise noted.</li> <li>2. This Land Pattern Design is based on the IPC-7351 guidelines.</li> <li>3. A stainless steel, laser-cut and electro-polished stencil with trapezoidal walls should be used to assure good solder paste release.</li> <li>4. The stencil thickness should be 0.101 mm (4 mils).</li> <li>5. The ratio of stencil aperture to land pad size can be 1:1 for all perimeter pads.</li> <li>6. A 3x3 array of 0.90 mm square openings on a 1.20 mm pitch can be used for the center ground pad.</li> <li>7. A No-Clean, Type-3 solder paste is recommended.</li> <li>8. The recommended card reflow profile is per the JEDEC/IPC J-STD-020 specification for Small Body Components.</li> <li>9. <b>Above notes and stencil design are shared as recommendations only. A customer or user may find it necessary to use different parameters and fine tune their SMT process as required for their application and tooling.</b></li> </ol> |     |

### 7.3 QFN40 Package Marking

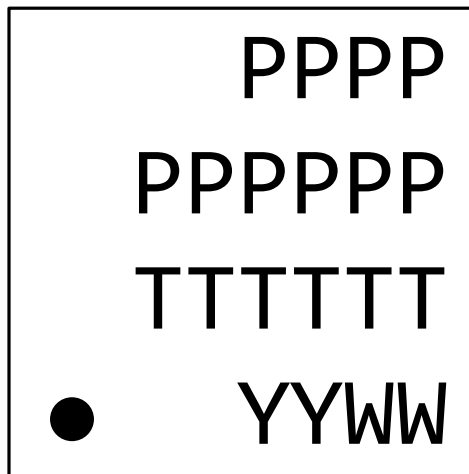


Figure 7.3. QFN40 Package Marking

The package marking consists of:

- Line 1: PPPP – The product family codes (BG24 | MG24)
- Line 2: PPPPPP – The product option codes:
  - 1) Security ( A = Secure Vault Mid | B = Secure Vault High )
  - 2-4) Product Feature Codes
  - 5) Flash ( S = 768k | J = 1024k | V = 1536k )
  - 6) Temperature grade (G = -40 to 85 °C | I = -40 to 125 °C )
- TTTTTT – A trace or manufacturing code. The first letter is the device revision.
- YY – The last 2 digits of the assembly year.
- WW – The 2-digit workweek when the device was assembled.

## 8. QFN48 Package Specifications

### 8.1 QFN48 Package Dimensions

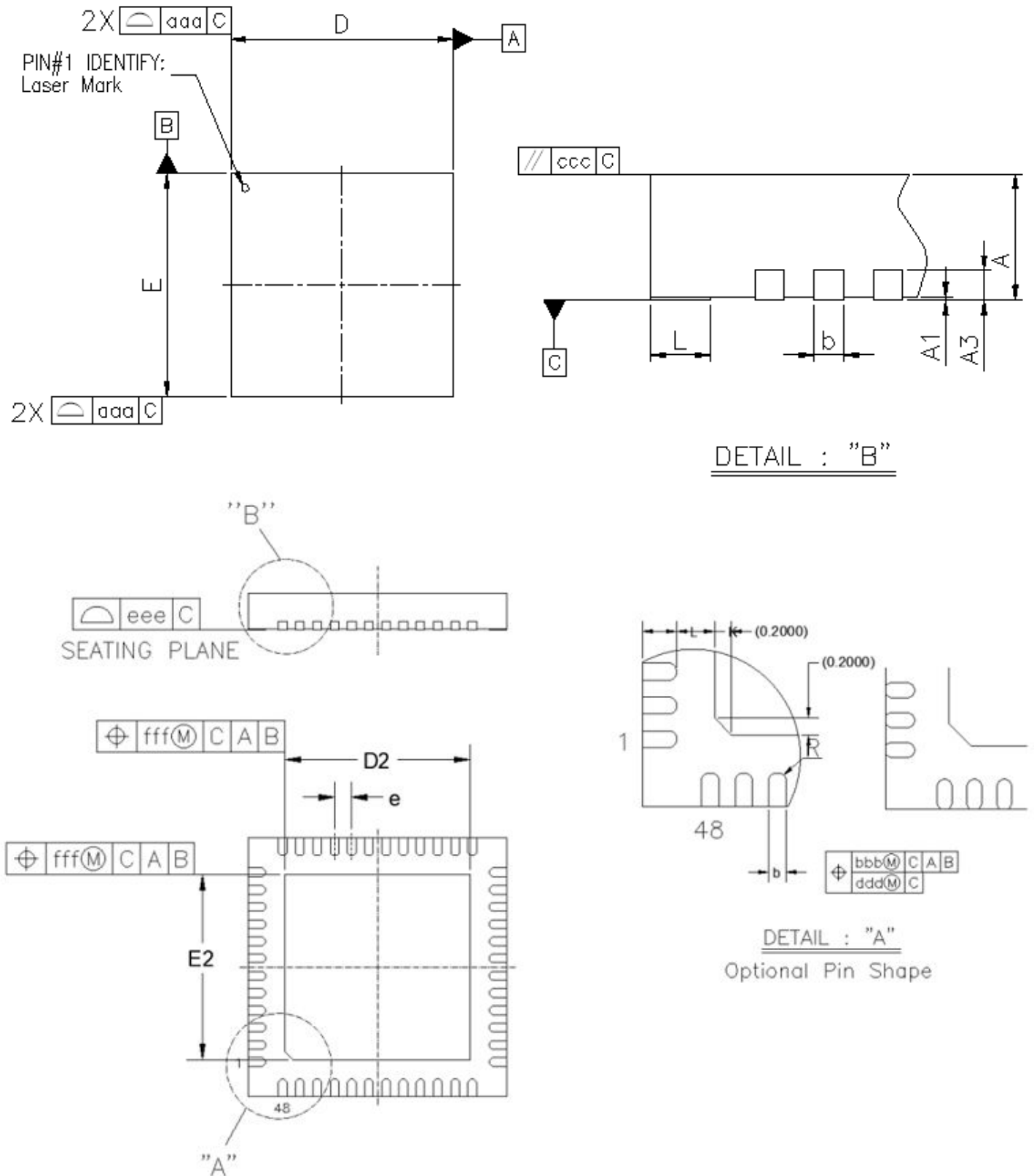


Figure 8.1. QFN48 Package Drawing

**Table 8.1. QFN48 Package Dimensions**

| Dimension | Min      | Typ  | Max  |
|-----------|----------|------|------|
| A         | 0.80     | 0.85 | 0.90 |
| A1        | 0.00     | 0.02 | 0.05 |
| A3        | 0.20 REF |      |      |
| b         | 0.15     | 0.2  | 0.25 |
| D         | 5.90     | 6.00 | 6.10 |
| E         | 5.90     | 6.00 | 6.10 |
| e         | 0.40 BSC |      |      |
| D2        | 4.15     | 4.30 | 4.45 |
| E2        | 4.15     | 4.30 | 4.45 |
| L         | 0.30     | 0.4  | 0.50 |
| K         | 0.20     | —    | —    |
| R         | 0.075    | —    | —    |
| aaa       | 0.10     |      |      |
| bbb       | 0.07     |      |      |
| ccc       | 0.10     |      |      |
| ddd       | 0.05     |      |      |
| eee       | 0.08     |      |      |
| fff       | 0.10     |      |      |

**Note:**

1. All dimensions shown are in millimeters (mm) unless otherwise noted.
2. Dimensioning and Tolerancing per ANSI Y14.5M-1994.
3. This drawing conforms to the JEDEC Outline MS-013, Variation AA.
4. Recommended reflow profile per JEDEC J-STD-020C specification for small body, lead-free components.

8.2 QFN48 PCB Land Pattern

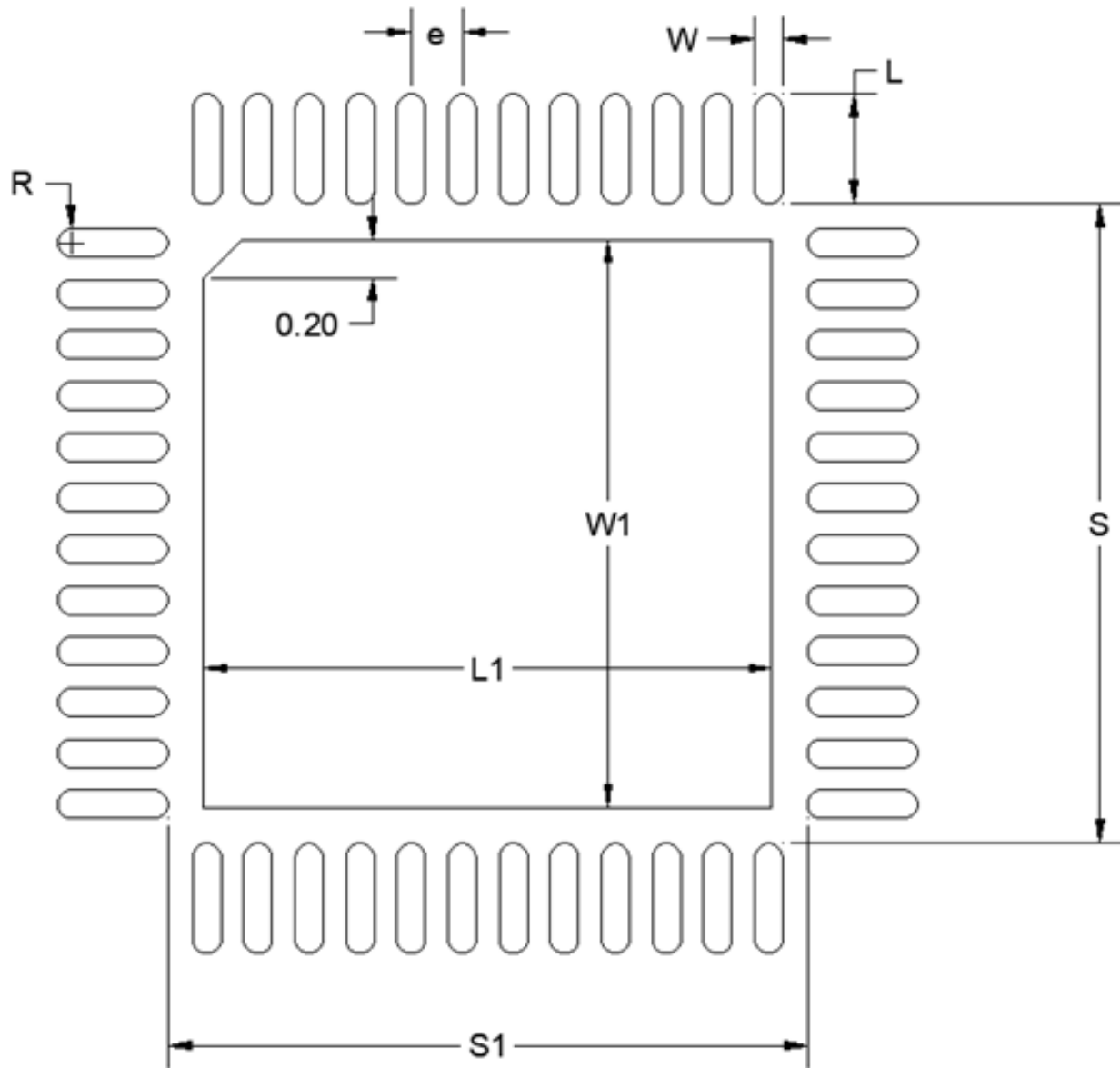


Figure 8.2. QFN48 PCB Land Pattern Drawing

Table 8.2. QFN48 PCB Land Pattern Dimensions

| Dimension | Typ  |
|-----------|------|
| L         | 0.86 |
| W         | 0.22 |
| e         | 0.40 |
| S         | 5.01 |
| S1        | 5.01 |
| L1        | 4.45 |
| W1        | 4.45 |
| R         | 0.11 |

| Dimension   | Typ |
|---|-----|
| <p><b>Note:</b></p> <ol style="list-style-type: none"> <li>1. All dimensions shown are in millimeters (mm) unless otherwise noted.</li> <li>2. This Land Pattern Design is based on the IPC-7351 guidelines.</li> <li>3. All metal pads are to be non-solder mask defined (NSMD). Clearance between the solder mask and the metal pad is to be 60 μm minimum, all the way around the pad.</li> <li>4. A stainless steel, laser-cut and electro-polished stencil with trapezoidal walls should be used to assure good solder paste release.</li> <li>5. The stencil thickness should be 0.101 mm (4 mils).</li> <li>6. The ratio of stencil aperture to land pad size can be 1:1 for all perimeter pads.</li> <li>7. A 3x3 array of 1.10mm x 1.10mm openings on 1.30mm pitch should be used for the center ground pad.</li> <li>8. A No-Clean, Type-3 solder paste is recommended.</li> <li>9. The recommended card reflow profile is per the JEDEC/IPC J-STD-020 specification for Small Body Components.</li> <li>10. <b>Above notes and stencil design are shared as recommendations only. A customer or user may find it necessary to use different parameters and fine tune their SMT process as required for their application and tooling.</b></li> </ol> |     |

### 8.3 QFN48 Package Marking

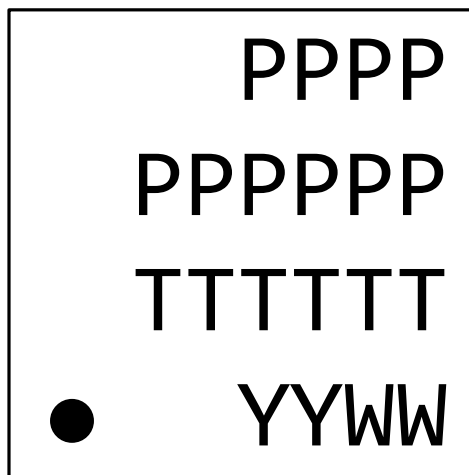


Figure 8.3. QFN48 Package Marking

The package marking consists of:

- Line 1: P P P P – The product family codes (BG24 | MG24)
- Line 2: P P P P P – The product option codes:
  - 1) Security ( A = Secure Vault Mid | B = Secure Vault High )
  - 2-4) Product Feature Codes
  - 5) Flash ( S = 768k | J = 1024k | V = 1536k )
  - 6) Temperature grade ( G = -40 to 85 °C | I = -40 to 125 °C )
- T T T T T – A trace or manufacturing code. The first letter is the device revision.
- Y Y – The last 2 digits of the assembly year.
- W W – The 2-digit workweek when the device was assembled.

## 9. Revision History

### Revision 1.2

October, 2024

- Added information to front page and key features.
- Added Channel Sounding and updated PRS channels in [Features](#) list.
- Added note for AEC-Q100 parts in [Table 2.1 Ordering Information on page 3](#).
- Updated Typical Connections diagrams in the [5.1 Power](#) section to add Channel Sounding note.

### Revision 1.1

March, 2023

- Updated front page diagram colors to indicate LFRCO works down to EM4
- Corrected diagram in [3.13 Memory Map](#)
- Clarified that Secure Debug is supported for both Secure Vault Mid and High in [3.8.4 Secure Debug with Lock/Unlock](#)
- Updated [Table 3.1 Secure Vault Features on page 13](#) comparison table to show that "Curve25519 (ECDH)" and "Ed25519 (Ed-SA)" are available for Public Key Encryption for Secure Vault Mid if using SE firmware v2.1.7 or higher.
- Added BURAM to [Table 3.2 Peripheral Power Subdomains on page 18](#) table
- [4.3 General Operating Conditions](#) table changes:
  - Added VREGVDD operating supply range specifications for "Bypass, 120mA load" case
  - Added HCLK and SYSCLK frequency specifications for "VSCALE1, WS0" and "VSCALE1, WS1"
  - Corrected condition for External Clock input specifications to add "IOVDD >= 2.7V"
- [Table 4.12 Energy Mode Wake-up and Entry Times on page 45](#) table changes:
  - Corrected EM4 Wakeup time TYP value from "21.7  $\mu$ s" to "21.7 ms"
- [4.9.2.2 RF Receiver Characteristics for 802.15.4 DSSS-OQPSK in the 2.4 GHz Band](#) table changes
  - Changed condition for "Max usable receiver input level, 1% PER" to "Rx Max Strong Signal Input Level for 1% PER"
- [4.9.2.3 RF Receiver Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 1 Mbps Data Rate](#) table changes
  - Changed condition for "Max usable receiver input level" to "Rx Max Strong Signal Input Level for 0.1% BER"
- [4.9.1.4 RF Transmitter Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 2 Mbps Data Rate](#) table changes
  - Changed condition for "Max usable receiver input level" to "Rx Max Strong Signal Input Level for 0.1% BER"
  - Corrected condition for In-band spurious emissions specification for  $P_{out_{MAX}}$  from "+/- 2 MHz" to "+/- 4 MHz"
- [4.9.2.5 RF Receiver Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 500 kbps Data Rate](#) table changes
  - Changed condition for "Max usable receiver input level" to "Rx Max Strong Signal Input Level for 0.1% BER"
- [4.9.2.6 RF Receiver Characteristics for Bluetooth Low Energy in the 2.4 GHz Band 125 kbps Data Rate](#) table changes
  - Changed condition for "Max usable receiver input level" to "Rx Max Strong Signal Input Level for 0.1% BER"
- [4.10.1 High Frequency Crystal Oscillator \(HFXO\)](#) table changes:
  - Updated footnotes to clarify that BLE and Zigbee can use either a 38.4 MHz or 39.0 MHz crystal.
  - Added new footnote to indicate that a Simplicity Studio component may need to be updated based on the crystal frequency
- [4.13 Analog Comparator \(ACMP\)](#) table changes:
  - Added specification for "Current consumption from VSENSEDIV in sample/hold mode"
- [4.12 Analog to Digital Converter \(IADC\)](#) table changes:
  - Corrected Input Sampling Frequency, High-Accuracy Mode Typical value from " $f_{ADC\_CLK} / 4$ " to " $f_{ADC\_CLK} / 5$ "
  - Added Gain Error, High-Accuracy Mode specs for all gain settings
  - Added Offset Error, High-Accuracy Mode specs for all gain settings
  - Added Spurious-Free Dynamic Range, High Accuracy Mode spec MIN value
  - Added Current from all supplies, Continuous operation, High Accuracy Mode TYP and MAX values
- [4.23 Boot Timing](#) table changes:
  - Added condition "Second stage bootloader check enabled" for all specifications
  - Added specification for "Secure boot application check disable, no bootloader"

**Revision 1.0**

August, 2022

- Updated "TBD" values in [4.1 Electrical Characteristics](#) tables
- Updates to System Overview [Table 3.3 Configuration Summary on page 21](#) table
- Added [4.27 Typical Performance Curves](#)
- Corrected DCDC output capacitor part number in [4.4 DC-DC Converter](#)
- Modified ACMP Electrical Specifications to show that hysteresis is only supported when BIAS  $\geq 3$  in [4.13 Analog Comparator \(ACMP\)](#)
- Added "T=25°C" condition to all timing specs in [4.7 Flash Characteristics](#)

**Revision 0.6**

April, 2022

- Updated values in [4.1 Electrical Characteristics](#) tables

**Revision 0.5**

March, 2022

- Updated front page block diagram
- Updated typical power consumption and performance numbers and Protocol Support in [1. Feature List](#)
- Updated values in [4.1 Electrical Characteristics](#) tables
- Updated [5. Typical Connections](#) Diagrams
- Updated Package Marking diagrams for 40QFN and 48QFN packages

**Revision 0.4**

Jan 2022

- Updated front page content
- Updated typical power consumption numbers and Protocol Support in [1. Feature List](#)
- Updated list of OPNs in table
- Removed -G temperature grade information from Electrical Specification tables
- Added typical EM2/3/4 current data to [4.6 Current Consumption](#) tables
- Revised EM2/3 spec format in [4.6 Current Consumption](#) tables
- Added Startup Time and Current Consumption data to [4.10.5 Precision Low Frequency RC Oscillator \(LFRCO\)](#) table

**Revision 0.3**

Oct 2021

- Updated typical power consumption numbers in [1. Feature List](#)
- Added IADC High Speed / High Accuracy information and Package Pinout information to table
- Updated IADC information in System Overview
- Corrected "RTCC" to "SYSRTC" in [1. Feature List](#)
- Added 20-bit ADC resolution and sampling rate to [1. Feature List](#)
- Added DALI function to EUSART in [1. Feature List](#)
- In [Table 3.2 Peripheral Power Subdomains on page 18](#) table
  - Removed "Tamper"
  - Corrected "LFRCO" cells
  - Removed "EUSART1"
  - Removed footnote from FSRCO suggesting it operates in EM4
  - Revised table to show PD0A and PDHV columns
  - Revised section text content
- Removed AVDD/DVDD power mux from [Figure 3.1 Detailed EFR32MG24 Block Diagram on page 9](#)

## **Revision 0.2**

June 2021

In Electrical Specifications section:

- Added EUSART timing and specifications
- Renamed USART specifications
- Added RX Sensitivity Specifications
- Removed Wi-Fi Notch Filter from Electrical Specifications

## **Revision 0.1**

March 2021

Initial release.

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