

# CC2651R3SIPA SimpleLink™ マルチプロトコル 2.4GHz ワイヤレス・システム、 アンテナおよび 352KB メモリ内蔵パッケージ・モジュール

## 1 特長

### ワイヤレス・マイコン

- 強力な 48MHz Arm® Cortex®-M4 プロセッサ
- 352KB フラッシュ・プログラム・メモリ
- 32KB の超低リーク SRAM
- 8KB のキャッシュ SRAM (汎用 RAM としても使用可能)
- プログラマブルな無線機能には、2-(G)FSK、4-(G)FSK、MSK、*Bluetooth®* 5.2 Low Energy、IEEE 802.15.4 PHY、MAC のサポートが含まれます。
- OTA (Over-The-Air) アップグレードに対応

### 低い消費電力

- MCU の消費電流:
  - 3.60mA (アクティブ・モード、CoreMark)
  - 61μA/MHz (CoreMark 実行中)
  - 0.8μA (スタンバイ・モード、RTC、32KB RAM)
  - 0.1μA (シャットダウン・モード、ウェークアップ・オン・ピン)
- 無線の消費電流:
  - 6.8mA (RX)
  - 7.1mA (TX, 0dBm)
  - 9.6mA (TX, +5dBm)

### 無線プロトコルのサポート

- Zigbee®*
- Bluetooth®* 5.2 Low Energy
- SimpleLink™ TI 15.4 スタック
- 独自システム

### 高性能の無線

- 104dBm (*Bluetooth®* Low Energy、125kbps)
- 温度補償付きで最大 +5dBm の出力電力

### 法規制の順守

- 世界各国の無線周波数で規制適合認証:
  - ETSI RED (欧州) / RER (英国)
  - ISED (カナダ)
  - FCC (米国)

### MCU のペリフェラル

- デジタル・ペリフェラルを任意の GPIO に接続可能
- 4 つの 32 ビットまたは 8 つの 16 ビット汎用タイマ
- 12 ビット ADC、200k サンプル/秒、8 チャネル
- 8 ビット DAC
- 2 つのコンパレータ

- プログラマブル電流ソース
- UART、SSI、I<sup>2</sup>C、I<sup>2</sup>S
- リアルタイム・クロック (RTC)
- 温度およびバッテリー・モニタを内蔵

### セキュリティを実現する機能

- AES 128 ビット暗号化アクセラレータ
- 真性乱数生成器 (TRNG)
- その他の暗号化ドライバをソフトウェア開発キット (SDK) で利用可能

### 開発ツールとソフトウェア

- LP-CC2651R3SIPA 開発キット
- SimpleLink™ CC13xx および CC26xx ソフトウェア開発キット (SDK)
- SmartRF™ Studio による容易な無線構成
- SysConfig システム・コンフィギュレーション・ツール

### 動作範囲

- オンチップの降圧型 DC/DC コンバータ
- 1.8V~3.8V のシングル電源電圧
- T<sub>j</sub>: -40~+105°C

### パッケージ

- 7mm × 7mm MOU (32 GPIO)
- RoHS 準拠のパッケージ



## 2 アプリケーション

- 2400～2480MHz の ISM および SRD システム<sup>1</sup>
- ビル・オートメーション
  - ビルディングのセキュリティ・システム - モーション検出器、電子スマート・ロック、ドアおよび窓センサ、ガラス・ドア・システム、ゲートウェイ
  - HVAC - サーモスタット、ワイヤレス環境センサ、HVAC システム・コントローラ、ゲートウェイ
  - 防火システム - 煙および熱感知器、火災警報制御パネル (FACP)
  - ビデオ監視 - IP ネットワーク・カメラ
  - エレベータとエスカレータ - エレベータとエスカレータのエレベータ・メイン制御パネル
- 産業用輸送 - アセット・トラッキング
- ファクトリ・オートメーションおよび制御
- 医療用

- 電子 POS (EPOS) - 電子棚札 (ESL)
- 通信機器
  - 有線ネットワーク - 無線 LAN または Wi-Fi アクセス・ポイント、エッジ・ルータ、小規模企業向けルータ
- 個人用電子機器
  - 携帯型電子機器 - RF スマート遠隔制御
  - ホーム・シアターおよびエンターテインメント - スマート・スピーカ、スマート・ディスプレイ、セット・トップ・ボックス
  - ネットワーク接続の周辺機器 - 民生用ワイヤレス・モジュール、ポインティング・デバイス、キーボードとキーパッド
  - ゲーム - 電子玩具とロボット玩具
  - ウェアラブル (非医療用) - スマート・トラッカー、スマート衣料

## 3 概要

SimpleLink™ CC2651R3SIPA デバイスは、Zigbee®、Bluetooth® 5.2 Low Energy、IEEE 802.15.4g、TI 15.4 スタック (2.4 GHz) をサポートするマルチプロトコル 2.4GHz ワイヤレス・マイクロコントローラ (MCU) です。CC2651R3SIPA は、Arm® Cortex® M4 メイン・プロセッサをベースにしており、グリッド・インフラストラクチャ、ビル・オートメーション、リテール・オートメーション、パーソナル・エレクトロニクス、医療用アプリケーションの低消費電力の無線通信および高度なセンシングに最適化されています。

CC2651R3SIPA は、アンテナ、DCDC コンポーネント、バラン、高周波水晶発振器を内蔵した 7mm × 7mm の超小型認証済みワイヤレス・モジュール (2.4GHz) です。

CC2651R3SIPA は、Arm® Cortex® M0 で実行するソフトウェア無線を内蔵しているため、各種の物理層と RF 規格をサポートできます。本デバイスは、2360～2500MHz の周波数帯域での動作をサポートしています。CC2651R3SIPA は、2.4GHz 帯で +5dBm TX (9.6mA) をサポートしています。CC2651R3SIPA は -104dBm (125kbps の Bluetooth® Low Energy Coded PHY) の受信感度を実現しています。

CC2651R3SIPA は 0.9μA という低いスリープ電流 (RTC 動作、32KB RAM を保持) を実現しています。

テキサス・インスツルメンツでは、製品ライフ・サイクル・ポリシーに従って、製品の耐用期間と供給の継続性を約束しています。

CC2651R3SIPA デバイスは、SimpleLink™ MCU プラットフォームの一部です。このプラットフォームは、Wi-Fi®、Bluetooth® Low Energy、Thread、Zigbee、Wi-SUN®, Amazon Sidewalk、mioty、Sub-1 GHz MCU、およびホスト MCU で構成されています。CC2651R3SIPA は、32KB～704KB のフラッシュ・サイズに対応し、ピン互換パッケージ・オプションを備えたスケーラブルなポートフォリオの一部です。共通の SimpleLink™ CC13xx および CC26xx ソフトウェア開発キット (SDK) と SysConfig システム・コンフィギュレーション・ツールは、ポートフォリオ内のデバイス間の移行を支援します。多数のソフトウェア・スタック、アプリケーション例、SimpleLink™ Academy トレーニング・セッションが本 SDK に含まれます。詳細については、ワイヤレス・コネクティビティ製品をご覧ください。

### 製品情報

| 部品番号 <sup>(1)</sup> | パッケージ    | 本体サイズ (公称)      |
|---------------------|----------|-----------------|
| CC2651R3SIPAT0MOUR  | QFM (59) | 7.00mm × 7.00mm |

- (1) 提供中の全デバイスに関する最新の製品、パッケージ、および注文情報については、セクション 13 のパッケージ・オプションに関する付録、またはテキサス・インスツルメンツの Web サイトを参照してください。

<sup>1</sup> (サポートしているプロトコル規格、変調フォーマット、データ・レートの詳細については、RF コアを参照してください。)

## 4 機能ブロック図

CC2651R3SIPA モジュールの機能ブロック図を、[図 4-1](#) に示します。

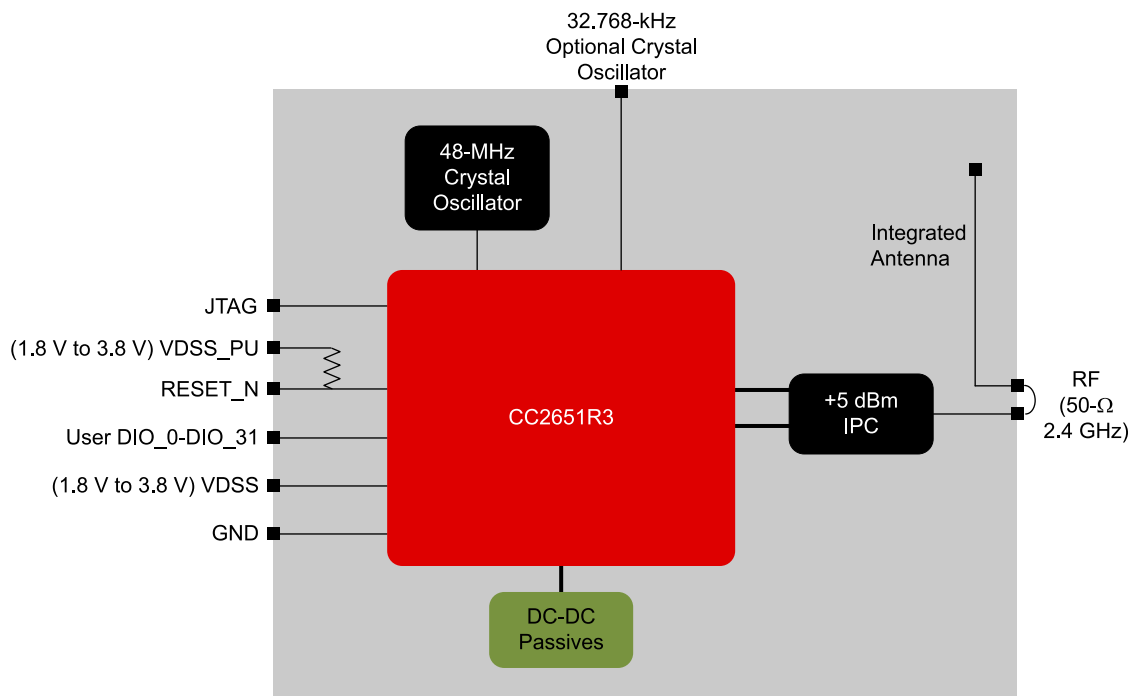


図 4-1. CC2651R3SIPA ブロック図

CC2651R3SIPA ハードウェアの概要を、[図 4-2](#) に示します。

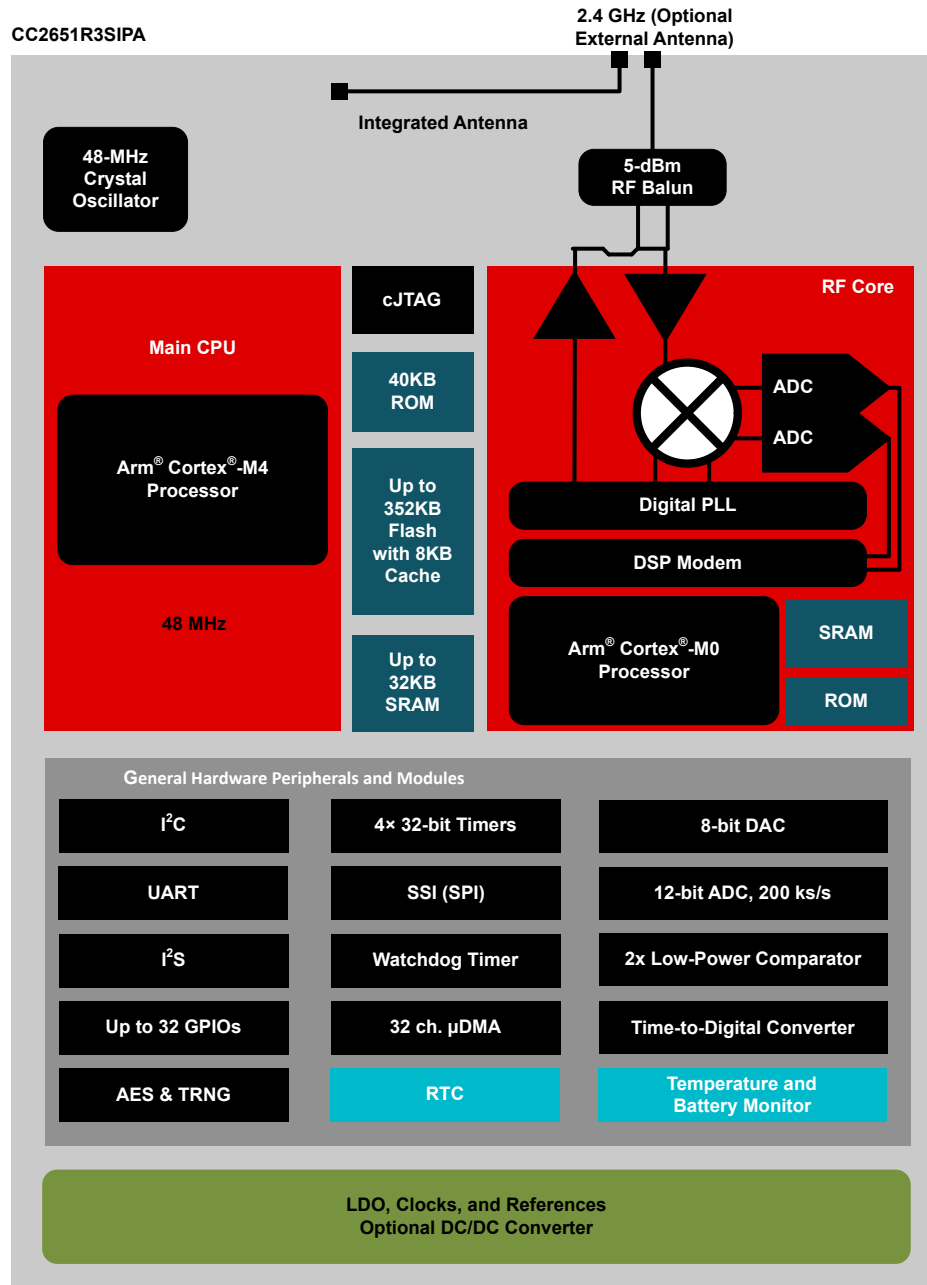


図 4-2. CC2651R3SIPA ハードウェアの概要

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## 5 Revision History

資料番号末尾の英字は改訂を表しています。その改訂履歴は英語版に準じています。

| Changes from Revision A (June 2022) to Revision B (August 2023) | Page      |
|-----------------------------------------------------------------|-----------|
| • Added RER (UK) to module comparison table.....                | <b>6</b>  |
| • Corrected pin diagram to properly represent Top View .....    | <b>7</b>  |
| • Added セクション 8.10; Antenna Characteristics, to セクション 8 .....   | <b>10</b> |
| • List of certifications updated to include RER (UK).....       | <b>46</b> |
| • FCC ID corrected to ZAT-2651R3SIPA.....                       | <b>46</b> |
| • Added Korea, Japan, and Taiwan certifications.....            | <b>46</b> |
| • Added MIC (Japan) certification section.....                  | <b>47</b> |
| • Added Korea certification section.....                        | <b>47</b> |
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| • Module layout guidelines updated.....                         | <b>56</b> |

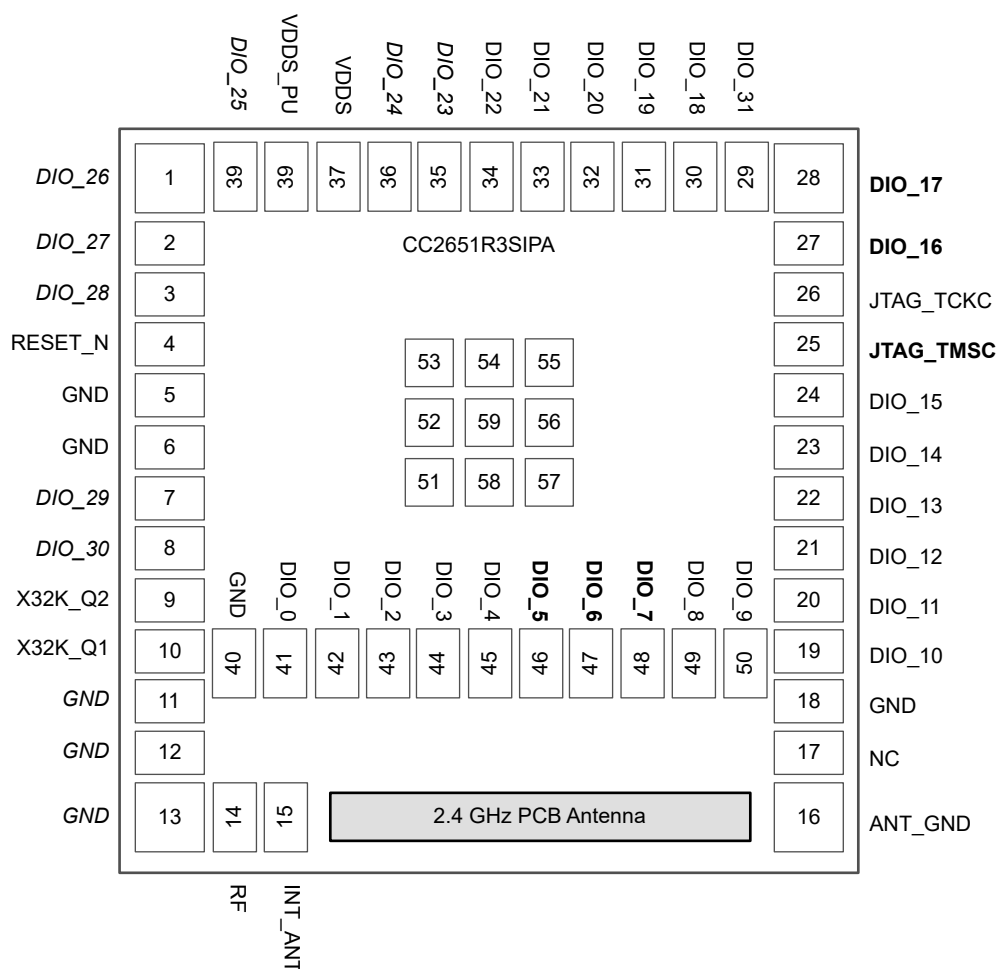
## 6 Device Comparison

| Device     | RADIO SUPPORT   |               |                |         |          |               |        |        |               |            | FLASH (KB) | RAM + Cache (KB) | GPIO  | PACKAGE SIZE       |                    |                    |                    |
|------------|-----------------|---------------|----------------|---------|----------|---------------|--------|--------|---------------|------------|------------|------------------|-------|--------------------|--------------------|--------------------|--------------------|
|            | Sub-1 GHz Prop. | 2.4 GHz Prop. | Wireless M-Bus | Wi-SUN® | Sidewalk | Bluetooth® LE | ZigBee | Thread | Multiprotocol | +20 dBm PA |            |                  |       | 4 x 4 mm VQFN (32) | 5 x 5 mm VQFN (32) | 5 x 5 mm VQFN (40) | 7 x 7 mm VQFN (48) |
| CC1310     | X               |               | X              |         |          |               |        |        |               |            | 32-128     | 16-20 + 8        | 10-30 | X                  | X                  |                    | X                  |
| CC1311R3   | X               |               | X              |         |          |               |        |        |               |            | 352        | 32 + 8           | 22-30 |                    |                    | X                  | X                  |
| CC1311P3   | X               |               | X              |         |          |               |        |        |               | X          | 352        | 32 + 8           | 26    |                    |                    |                    | X                  |
| CC1312R    | X               |               | X              | X       |          |               |        |        |               |            | 352        | 80 + 8           | 30    |                    |                    |                    | X                  |
| CC1312R7   | X               |               | X              | X       | X        |               |        |        | X             |            | 704        | 144 + 8          | 30    |                    |                    |                    | X                  |
| CC1352R    | X               | X             | X              | X       |          | X             | X      | X      | X             |            | 352        | 80 + 8           | 28    |                    |                    |                    | X                  |
| CC1352P    | X               | X             | X              | X       |          | X             | X      | X      | X             | X          | 352        | 80 + 8           | 26    |                    |                    |                    | X                  |
| CC1352P7   | X               | X             | X              | X       | X        | X             | X      | X      | X             | X          | 704        | 144 + 8          | 26    |                    |                    |                    | X                  |
| CC2640R2F  |                 |               |                |         |          | X             |        |        |               |            | 128        | 20 + 8           | 10-31 | X                  | X                  |                    | X                  |
| CC2642R    |                 |               |                |         |          | X             |        |        |               |            | 352        | 80 + 8           | 31    |                    |                    |                    | X                  |
| CC2642R-Q1 |                 |               |                |         |          | X             |        |        |               |            | 352        | 80 + 8           | 31    |                    |                    |                    | X                  |
| CC2651R3   |                 | X             |                |         |          | X             | X      |        |               |            | 352        | 32 + 8           | 23-31 |                    |                    | X                  | X                  |
| CC2651P3   |                 | X             |                |         |          | X             | X      |        |               | X          | 352        | 32 + 8           | 22-26 |                    |                    | X                  | X                  |
| CC2652R    |                 | X             |                |         |          | X             | X      | X      | X             |            | 352        | 80 + 8           | 31    |                    |                    |                    | X                  |
| CC2652RB   |                 | X             |                |         |          | X             | X      | X      | X             |            | 352        | 80 + 8           | 31    |                    |                    |                    | X                  |
| CC2652R7   |                 | X             |                |         |          | X             | X      | X      | X             |            | 704        | 144 + 8          | 31    |                    |                    |                    | X                  |
| CC2652P    |                 | X             |                |         |          | X             | X      | X      | X             | X          | 352        | 80 + 8           | 26    |                    |                    |                    | X                  |
| CC2652P7   |                 | X             |                |         |          | X             | X      | X      | X             | X          | 704        | 144 + 8          | 26    |                    |                    |                    | X                  |

| Module       | ANTENNA  |            | RADIO SUPPORT |        |            | CERTIFICATIONS |    |          |       |       |        | FLASH (KB) | RAM + Cache (KB) | GPIO | PACKAGE SIZE   |                |                      |
|--------------|----------|------------|---------------|--------|------------|----------------|----|----------|-------|-------|--------|------------|------------------|------|----------------|----------------|----------------------|
|              | External | Integrated | Bluetooth® LE | ZigBee | +10 dBm PA | FCC/IC         | CE | RER (UK) | Japan | Korea | Taiwan |            |                  |      | 7 x 7 QFM (73) | 7 x 7 QFM (59) | 16.9 x 11.0 QFM (29) |
| CC2650MODA   |          | X          | X             | X      |            | X              | X  |          | X     |       |        | 128        | 20+8             | 15   |                |                | X                    |
| CC2651R3SIPA | X        | X          | X             | X      |            | X              | X  | X        | X     | X     | X      | 352        | 32 + 8           | 32   |                | X              |                      |
| CC2652RSIP   | X        |            | X             | X      |            | X              | X  | X        |       |       |        | 352        | 80 + 8           | 32   | X              |                |                      |
| CC2652PSIP   | X        |            | X             | X      | X          | X              | X  | X        |       |       |        | 352        | 80 + 8           | 30   | X              |                |                      |

## 7 Terminal Configuration and Functions

### 7.1 Pin Diagram



**7-1. MOU (7-mm x 7-mm) Pinout, 0.5-mm Pitch (Top View)**

The following I/O pins marked in **7-1** in **bold** have high-drive capabilities:

- Pin 25, JTAG\_TMSC
- Pin 27, DIO\_16
- Pin 28, DIO\_17
- Pin 46, DIO\_5
- Pin 47, DIO\_6
- Pin 48, DIO\_7

The following I/O pins marked in **7-1** in *italics* have analog capabilities:

- Pin 1, DIO\_26
- Pin 2, DIO\_27
- Pin 3, DIO\_28
- Pin 7, DIO\_29
- Pin 8, DIO\_30
- Pin 35, DIO\_23
- Pin 36, DIO\_24
- Pin 39, DIO\_25

## 7.2 Signal Descriptions – SIPA Package

表 7-1. Signal Descriptions – SIPA Package

| PIN                   |       | I/O | TYPE              | DESCRIPTION                                                                                 |
|-----------------------|-------|-----|-------------------|---------------------------------------------------------------------------------------------|
| NAME                  | NO.   |     |                   |                                                                                             |
| ANT_GND               | 16    | —   | —                 | Antenna GND                                                                                 |
| DIO_0                 | 41    | I/O | Digital           | GPIO                                                                                        |
| DIO_1                 | 42    | I/O | Digital           | GPIO                                                                                        |
| DIO_10                | 19    | I/O | Digital           | GPIO                                                                                        |
| DIO_11                | 20    | I/O | Digital           | GPIO                                                                                        |
| DIO_12                | 21    | I/O | Digital           | GPIO                                                                                        |
| DIO_13                | 22    | I/O | Digital           | GPIO                                                                                        |
| DIO_14                | 23    | I/O | Digital           | GPIO                                                                                        |
| DIO_15                | 24    | I/O | Digital           | GPIO                                                                                        |
| DIO_16                | 27    | I/O | Digital           | GPIO, JTAG_TDO, high-drive capability                                                       |
| DIO_17                | 28    | I/O | Digital           | GPIO, JTAG_TDI, high-drive capability                                                       |
| DIO_18                | 30    | I/O | Digital           | GPIO                                                                                        |
| DIO_19                | 31    | I/O | Digital           | GPIO                                                                                        |
| DIO_2                 | 43    | I/O | Digital           | GPIO                                                                                        |
| DIO_20                | 32    | I/O | Digital           | GPIO                                                                                        |
| DIO_21                | 33    | I/O | Digital           | GPIO                                                                                        |
| DIO_22                | 34    | I/O | Digital           | GPIO                                                                                        |
| DIO_23                | 35    | I/O | Digital or Analog | GPIO, analog capability                                                                     |
| DIO_24                | 36    | I/O | Digital or Analog | GPIO, analog capability                                                                     |
| DIO_25                | 39    | I/O | Digital or Analog | GPIO, analog capability                                                                     |
| DIO_26                | 1     | I/O | Digital or Analog | GPIO, analog capability                                                                     |
| DIO_27                | 2     | I/O | Digital or Analog | GPIO, analog capability                                                                     |
| DIO_28                | 3     | I/O | Digital or Analog | GPIO, analog capability                                                                     |
| DIO_29                | 7     | I/O | Digital or Analog | GPIO, analog capability                                                                     |
| DIO_3                 | 44    | I/O | Digital           | GPIO                                                                                        |
| DIO_30                | 8     | I/O | Digital or Analog | GPIO, analog capability                                                                     |
| DIO_31 <sup>(1)</sup> | 29    | I/O | Digital           | Supports only peripheral functionality. Does not support general purpose I/O functionality. |
| DIO_4                 | 45    | I/O | Digital           | GPIO                                                                                        |
| DIO_5                 | 46    | I/O | Digital           | GPIO, high-drive capability                                                                 |
| DIO_6                 | 47    | I/O | Digital           | GPIO, high-drive capability                                                                 |
| DIO_7                 | 48    | I/O | Digital           | GPIO, high-drive capability                                                                 |
| DIO_8                 | 49    | I/O | Digital           | GPIO                                                                                        |
| DIO_9                 | 50    | I/O | Digital           | GPIO                                                                                        |
| GND                   | 5     | —   | —                 | GND                                                                                         |
| GND                   | 6     | —   | —                 | GND                                                                                         |
| GND                   | 11    | —   | —                 | GND                                                                                         |
| GND                   | 12    | —   | —                 | GND                                                                                         |
| GND                   | 13    | —   | —                 | GND                                                                                         |
| GND                   | 18    | —   | —                 | GND                                                                                         |
| GND                   | 40    | —   | —                 | GND                                                                                         |
| GND                   | 51-59 | —   | —                 | GND                                                                                         |
| INT_ANT               | 15    |     | RF                | RF connection to integral PCB antenna                                                       |

**表 7-1. Signal Descriptions – SIPA Package (continued)**

| PIN       |     | I/O | TYPE    | DESCRIPTION                                            |
|-----------|-----|-----|---------|--------------------------------------------------------|
| NAME      | NO. |     |         |                                                        |
| JTAG_TCKC | 26  | I/O | Digital | JTAG_TCKC                                              |
| JTAG_TM5C | 25  | I/O | Digital | JTAG_TM5C, high-drive capability                       |
| NC        | 17  | —   | —       | No Connect                                             |
| RESET_N   | 4   | I   | Digital | Reset, active low. Internal pullup resistor to VDD5_PU |
| RF        | 14  | —   | RF      | 50 ohm RF port                                         |
| VDD5      | 37  | I/O | Digital | 1.8-V to 3.8-V main SIP supply                         |
| VDD5_PU   | 38  | —   | Power   | Power to reset internal pullup resistor                |
| X32K_Q1   | 10  | —   | —       | 32-kHz crystal oscillator pin 1                        |
| X32K_Q2   | 9   | —   | —       | 32-kHz crystal oscillator pin 2                        |

(1) PORT\_ID = 0x00 is not supported. See the [SimpleLink™ CC13x1x3, CC26x1x3 Wireless MCU Technical Reference Manual](#) for further details.

## 7.3 Connections for Unused Pins and Modules

**表 7-2. Connections for Unused Pins – SIPA Package**

| FUNCTION           | SIGNAL NAME | PIN NUMBER | ACCEPTABLE PRACTICE <sup>(1)</sup> | PREFERRED PRACTICE <sup>(1)</sup> |
|--------------------|-------------|------------|------------------------------------|-----------------------------------|
| GPIO               | DIO_n       | 1-3        | NC or GND                          | NC                                |
|                    |             | 7-8        |                                    |                                   |
|                    |             | 19-24      |                                    |                                   |
|                    |             | 27-36      |                                    |                                   |
|                    |             | 39         |                                    |                                   |
|                    |             | 41-50      |                                    |                                   |
| 32.768-kHz crystal | X32K_Q2     | 9          | NC                                 | NC                                |
|                    | X32K_Q1     | 10         |                                    |                                   |
| No Connects        | NC          | 17         | NC                                 | NC                                |

(1) NC = No connect

## 8 Specifications

### 8.1 Absolute Maximum Ratings

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

|                                 |                                                      |                                                         | MIN  | MAX                              | UNIT |
|---------------------------------|------------------------------------------------------|---------------------------------------------------------|------|----------------------------------|------|
| V <sub>DDS</sub> <sup>(3)</sup> | Supply voltage                                       |                                                         | −0.3 | 4.1                              | V    |
|                                 | Voltage on any digital pin <sup>(4) (5)</sup>        |                                                         | −0.3 | V <sub>DDS</sub> + 0.3, max 4.1  | V    |
|                                 | Voltage on crystal oscillator pins, X32K_Q1, X32K_Q2 |                                                         | −0.3 | V <sub>DDR</sub> + 0.3, max 2.25 | V    |
| V <sub>in</sub>                 | Voltage on ADC input                                 | Voltage scaling enabled                                 | −0.3 | V <sub>DDS</sub>                 | V    |
|                                 |                                                      | Voltage scaling disabled, internal reference            | −0.3 | 1.49                             |      |
|                                 |                                                      | Voltage scaling disabled, V <sub>DDS</sub> as reference | −0.3 | V <sub>DDS</sub> / 2.9           |      |
|                                 | Input level, RF pin                                  |                                                         |      | 5                                | dBm  |
| T <sub>stg</sub>                | Storage temperature                                  |                                                         | −40  | 150                              | °C   |

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) All voltage values are with respect to ground, unless otherwise noted.
- (3) V<sub>DDS\_DCDC</sub>, V<sub>DDS2</sub> and V<sub>DDS3</sub> must be at the same potential as V<sub>DDS</sub>.
- (4) Including analog capable DIOs.
- (5) Injection current is not supported on any GPIO pin

### 8.2 ESD Ratings

|                  |                         |                                                                       |          | VALUE | UNIT |
|------------------|-------------------------|-----------------------------------------------------------------------|----------|-------|------|
| V <sub>ESD</sub> | Electrostatic discharge | Human body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>     | All pins | ±2000 | V    |
|                  |                         | Charged device model (CDM), per ANSI/ESDA/JEDEC JS-002 <sup>(2)</sup> | All pins | ±500  | V    |

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process

### 8.3 Recommended Operating Conditions

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

|                                              | MIN | MAX | UNIT  |
|----------------------------------------------|-----|-----|-------|
| Operating ambient temperature <sup>(1)</sup> | −40 | 105 | °C    |
| Operating supply voltage (V <sub>DDS</sub> ) | 1.8 | 3.8 | V     |
| Rising supply voltage slew rate              | 0   | 100 | mV/μs |
| Falling supply voltage slew rate             | 0   | 20  | mV/μs |

- (1) For thermal resistance characteristics refer to [セクション 8.8](#).

### 8.4 Power Supply and Modules

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

| PARAMETER                                                                     |                   | MIN        | TYP | MAX | UNIT |
|-------------------------------------------------------------------------------|-------------------|------------|-----|-----|------|
| V <sub>DDS</sub> Power-on-Reset (POR) threshold                               |                   | 1.1 - 1.55 |     |     | V    |
| V <sub>DDS</sub> Brown-out Detector (BOD)                                     | Rising threshold  | 1.77       |     |     | V    |
| V <sub>DDS</sub> Brown-out Detector (BOD), before initial boot <sup>(1)</sup> | Rising threshold  | 1.70       |     |     | V    |
| V <sub>DDS</sub> Brown-out Detector (BOD)                                     | Falling threshold | 1.75       |     |     | V    |

- (1) Brown-out Detector is trimmed at initial boot, value is kept until device is reset by a POR reset or the RESET\_N pin

## 8.5 Power Consumption - Power Modes

When measured on the [CC2651RSIPA-EM](#) reference design with  $T_c = 25\text{ }^\circ\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$  with DC/DC enabled unless otherwise noted.

| PARAMETER                             |                                 | TEST CONDITIONS                                                       | TYP  | UNIT          |
|---------------------------------------|---------------------------------|-----------------------------------------------------------------------|------|---------------|
| <b>Core Current Consumption</b>       |                                 |                                                                       |      |               |
| $I_{core}$                            | Reset and Shutdown              | Reset. RESET_N pin asserted or VDD5 below power-on-reset threshold    | 150  | nA            |
|                                       |                                 | Shutdown. No clocks running, no retention                             | 100  |               |
|                                       | Standby without cache retention | RTC running, CPU, 32KB RAM and (partial) register retention. RCOSC_LF | 0.8  | $\mu\text{A}$ |
|                                       |                                 | RTC running, CPU, 32KB RAM and (partial) register retention. XOSC_LF  | 0.9  |               |
|                                       | Standby with cache retention    | RTC running, CPU, 32KB RAM and (partial) register retention. RCOSC_LF | 2.4  | $\mu\text{A}$ |
|                                       |                                 | RTC running, CPU, 32KB RAM and (partial) register retention. XOSC_LF  | 2.6  |               |
|                                       | Idle                            | Supply Systems and RAM powered. RCOSC_HF                              | 650  | $\mu\text{A}$ |
|                                       | Active                          | MCU running CoreMark at 48 MHz. RCOSC_HF                              | 2.91 | mA            |
| <b>Peripheral Current Consumption</b> |                                 |                                                                       |      |               |
| $I_{peri}$                            | Peripheral power domain         | Delta current with domain enabled                                     | 56   | $\mu\text{A}$ |
|                                       | Serial power domain             | Delta current with domain enabled                                     | 5.0  |               |
|                                       | RF Core                         | Delta current with power domain enabled, clock enabled, RF core idle  | 144  |               |
|                                       | $\mu\text{DMA}$                 | Delta current with clock enabled, module is idle                      | 68.6 |               |
|                                       | Timers                          | Delta current with clock enabled, module is idle <sup>(3)</sup>       | 102  |               |
|                                       | I2C                             | Delta current with clock enabled, module is idle                      | 12.1 |               |
|                                       | I2S                             | Delta current with clock enabled, module is idle                      | 30.8 |               |
|                                       | SSI                             | Delta current with clock enabled, module is idle                      | 71.7 |               |
|                                       | UART                            | Delta current with clock enabled, module is idle <sup>(1)</sup>       | 147  |               |
|                                       | CRYPTO (AES)                    | Delta current with clock enabled, module is idle <sup>(2)</sup>       | 28.1 |               |
|                                       | TRNG                            | Delta current with clock enabled, module is idle                      | 27.1 |               |

- (1) Only one UART running  
 (2) Only one SSI running  
 (3) Only one GPTimer running

## 8.6 Power Consumption - Radio Modes

When measured on the [CC2651RSIPA-EM](#) reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$  with DC/DC enabled unless otherwise noted.

| PARAMETER                                                   | TEST CONDITIONS                         | TYP | UNIT |
|-------------------------------------------------------------|-----------------------------------------|-----|------|
| Radio receive current                                       | 2440 MHz                                | 6.7 | mA   |
| Radio transmit current<br>2.4 GHz PA (Bluetooth Low Energy) | 0 dBm output power setting<br>2440 MHz  | 7.7 | mA   |
|                                                             | +5 dBm output power setting<br>2440 MHz | 10  | mA   |

## 8.7 Nonvolatile (Flash) Memory Characteristics

Over operating free-air temperature range and  $V_{\text{DD5}} = 3.0\text{ V}$  (unless otherwise noted)

| PARAMETER                                                                     | TEST CONDITIONS                          | MIN  | TYP  | MAX  | UNIT             |
|-------------------------------------------------------------------------------|------------------------------------------|------|------|------|------------------|
| Flash sector size                                                             |                                          |      | 8    |      | KB               |
| Supported flash erase cycles before failure, full bank <sup>(1) (5)</sup>     |                                          | 30   |      |      | k Cycles         |
| Supported flash erase cycles before failure, single sector <sup>(2)</sup>     |                                          | 60   |      |      | k Cycles         |
| Maximum number of write operations per row before sector erase <sup>(3)</sup> |                                          |      |      | 83   | Write Operations |
| Flash retention                                                               | 105 °C                                   | 11.4 |      |      | Years            |
| Flash sector erase current                                                    | Average delta current                    |      | 10.7 |      | mA               |
| Flash sector erase time <sup>(4)</sup>                                        | Zero cycles                              |      | 10   |      | ms               |
|                                                                               | 30k cycles                               |      |      | 4000 | ms               |
| Flash write current                                                           | Average delta current, 4 bytes at a time |      | 6.2  |      | mA               |
| Flash write time <sup>(4)</sup>                                               | 4 bytes at a time                        |      | 21.6 |      | ms               |

(1) A full bank erase is counted as a single erase cycle on each sector

(2) Up to 4 customer-designated sectors can be individually erased an additional 30k times beyond the baseline bank limitation of 30k cycles

(3) Each wordline is 2048 bits (or 256 bytes) wide. This limitation corresponds to sequential memory writes of 4 (3.1) bytes minimum per write over a whole wordline. If additional writes to the same wordline are required, a sector erase is required once the maximum number of write operations per row is reached.

(4) This number is dependent on Flash aging and increases over time and erase cycles

(5) Aborting flash during erase or program modes is not a safe operation.

## 8.8 Thermal Resistance Characteristics

| THERMAL METRIC <sup>(1)</sup> |                                              | PACKAGE   | UNIT                |
|-------------------------------|----------------------------------------------|-----------|---------------------|
|                               |                                              | MOU (SIP) |                     |
|                               |                                              | 59 PINS   |                     |
| R <sub>θJA</sub>              | Junction-to-ambient thermal resistance       | 48.7      | °C/W <sup>(2)</sup> |
| R <sub>θJC(top)</sub>         | Junction-to-case (top) thermal resistance    | 12.4      | °C/W <sup>(2)</sup> |
| R <sub>θJB</sub>              | Junction-to-board thermal resistance         | 32.2      | °C/W <sup>(2)</sup> |
| ψ <sub>JT</sub>               | Junction-to-top characterization parameter   | 0.40      | °C/W <sup>(2)</sup> |
| ψ <sub>JB</sub>               | Junction-to-board characterization parameter | 32.0      | °C/W <sup>(2)</sup> |

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

(2)  $^{\circ}\text{C/W}$  = degrees Celsius per watt.

## 8.9 RF Frequency Bands

Over operating free-air temperature range (unless otherwise noted).

| PARAMETER       | MIN  | TYP | MAX  | UNIT |
|-----------------|------|-----|------|------|
| Frequency bands | 2360 |     | 2500 | MHz  |

## 8.10 Antenna Characteristics

When measured on the [LP-CC2651R3SIPA](#) LaunchPad design with  $T_c = 25\text{ }^{\circ}\text{C}$ .

| PARAMETER    | TEST CONDITIONS | MIN    | TYP | MAX | UNIT |
|--------------|-----------------|--------|-----|-----|------|
| Polarization |                 | Linear |     |     |      |
| Peak Gain    | 2.4 GHz Band    |        |     | 3.5 | dBi  |
| Efficiency   | 2.4 GHz Band    |        | 70% |     | dBi  |

## 8.11 Bluetooth Low Energy - Receive (RX)

When measured on the [CC2651RSIPA-EM](#) reference design with  $T_c = 25\text{ }^{\circ}\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ ,  $f_{RF} = 2440\text{ MHz}$  with DC/DC enabled unless otherwise noted. All measurements are performed conducted.

| PARAMETER                                                      | TEST CONDITIONS                                                                                                                                                          | MIN | TYP                     | MAX | UNIT |
|----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-------------------------|-----|------|
| <b>125 kbps (LE Coded)</b>                                     |                                                                                                                                                                          |     |                         |     |      |
| Receiver sensitivity                                           | Differential mode. BER = $10^{-3}$                                                                                                                                       |     | -103                    |     | dBm  |
| Receiver saturation                                            | Differential mode. BER = $10^{-3}$                                                                                                                                       |     | >5                      |     | dBm  |
| Frequency error tolerance                                      | Difference between the incoming carrier frequency and the internally generated carrier frequency                                                                         |     | > (-300 / 300)          |     | kHz  |
| Data rate error tolerance                                      | Difference between incoming data rate and the internally generated data rate (37-byte packets)                                                                           |     | > (-320 / 240)          |     | ppm  |
| Data rate error tolerance                                      | Difference between incoming data rate and the internally generated data rate (255-byte packets)                                                                          |     | > (-125 / 125)          |     | ppm  |
| Co-channel rejection <sup>(1)</sup>                            | Wanted signal at -79 dBm, modulated interferer in channel, BER = $10^{-3}$                                                                                               |     | -1.5                    |     | dB   |
| Selectivity, $\pm 1\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at -79 dBm, modulated interferer at $\pm 1\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 8 / 4.5 <sup>(2)</sup>  |     | dB   |
| Selectivity, $\pm 2\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at -79 dBm, modulated interferer at $\pm 2\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 44 / 39 <sup>(2)</sup>  |     | dB   |
| Selectivity, $\pm 3\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at -79 dBm, modulated interferer at $\pm 3\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 46 / 44 <sup>(2)</sup>  |     | dB   |
| Selectivity, $\pm 4\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at -79 dBm, modulated interferer at $\pm 4\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 44 / 46 <sup>(2)</sup>  |     | dB   |
| Selectivity, $\pm 6\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at -79 dBm, modulated interferer at $\geq \pm 6\text{ MHz}$ , BER = $10^{-3}$                                                                              |     | 48 / 44 <sup>(2)</sup>  |     | dB   |
| Selectivity, $\pm 7\text{ MHz}$                                | Wanted signal at -79 dBm, modulated interferer at $\geq \pm 7\text{ MHz}$ , BER = $10^{-3}$                                                                              |     | 51 / 45 <sup>(2)</sup>  |     | dB   |
| Selectivity, Image frequency <sup>(1)</sup>                    | Wanted signal at -79 dBm, modulated interferer at image frequency, BER = $10^{-3}$                                                                                       |     | 39                      |     | dB   |
| Selectivity, Image frequency $\pm 1\text{ MHz}$ <sup>(1)</sup> | Note that Image frequency + 1 MHz is the Co- channel - 1 MHz. Wanted signal at -79 dBm, modulated interferer at $\pm 1\text{ MHz}$ from image frequency, BER = $10^{-3}$ |     | 4.5 / 44 <sup>(2)</sup> |     | dB   |
| <b>500 kbps (LE Coded)</b>                                     |                                                                                                                                                                          |     |                         |     |      |
| Receiver sensitivity                                           | Differential mode. BER = $10^{-3}$                                                                                                                                       |     | -99                     |     | dBm  |
| Receiver saturation                                            | Differential mode. BER = $10^{-3}$                                                                                                                                       |     | > 5                     |     | dBm  |
| Frequency error tolerance                                      | Difference between the incoming carrier frequency and the internally generated carrier frequency                                                                         |     | > (-300 / 300)          |     | kHz  |
| Data rate error tolerance                                      | Difference between incoming data rate and the internally generated data rate (37-byte packets)                                                                           |     | > (-450 / 450)          |     | ppm  |
| Data rate error tolerance                                      | Difference between incoming data rate and the internally generated data rate (255-byte packets)                                                                          |     | > (-175 / 175)          |     | ppm  |
| Co-channel rejection <sup>(1)</sup>                            | Wanted signal at -72 dBm, modulated interferer in channel, BER = $10^{-3}$                                                                                               |     | -3.5                    |     | dB   |
| Selectivity, $\pm 1\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at -72 dBm, modulated interferer at $\pm 1\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 8 / 4 <sup>(2)</sup>    |     | dB   |
| Selectivity, $\pm 2\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at -72 dBm, modulated interferer at $\pm 2\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 44 / 37 <sup>(2)</sup>  |     | dB   |
| Selectivity, $\pm 3\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at -72 dBm, modulated interferer at $\pm 3\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 46 / 42 <sup>(2)</sup>  |     | dB   |
| Selectivity, $\pm 4\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at -72 dBm, modulated interferer at $\pm 4\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 45 / 43 <sup>(2)</sup>  |     | dB   |
| Selectivity, $\pm 6\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at -72 dBm, modulated interferer at $\geq \pm 6\text{ MHz}$ , BER = $10^{-3}$                                                                              |     | 46 / 45 <sup>(2)</sup>  |     | dB   |
| Selectivity, $\pm 7\text{ MHz}$                                | Wanted signal at -72 dBm, modulated interferer at $\geq \pm 7\text{ MHz}$ , BER = $10^{-3}$                                                                              |     | 49 / 45 <sup>(2)</sup>  |     | dB   |
| Selectivity, Image frequency <sup>(1)</sup>                    | Wanted signal at -72 dBm, modulated interferer at image frequency, BER = $10^{-3}$                                                                                       |     | 37                      |     | dB   |

When measured on the [CC2651RSIPA-EM](#) reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ ,  $f_{RF} = 2440\text{ MHz}$  with DC/DC enabled unless otherwise noted. All measurements are performed conducted.

| PARAMETER                                                      | TEST CONDITIONS                                                                                                                                                          | MIN | TYP                    | MAX | UNIT |
|----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|------------------------|-----|------|
| Selectivity, Image frequency $\pm 1\text{ MHz}$ <sup>(1)</sup> | Note that Image frequency + 1 MHz is the Co- channel – 1 MHz. Wanted signal at –72 dBm, modulated interferer at $\pm 1\text{ MHz}$ from image frequency, BER = $10^{-3}$ |     | 4 / 46 <sup>(2)</sup>  |     | dB   |
| <b>1 Mbps (LE 1M)</b>                                          |                                                                                                                                                                          |     |                        |     |      |
| Receiver sensitivity                                           | Differential mode. BER = $10^{-3}$                                                                                                                                       |     | –96                    |     | dBm  |
| Receiver saturation                                            | Differential mode. BER = $10^{-3}$                                                                                                                                       |     | > 5                    |     | dBm  |
| Frequency error tolerance                                      | Difference between the incoming carrier frequency and the internally generated carrier frequency                                                                         |     | > (–350 / 350)         |     | kHz  |
| Data rate error tolerance                                      | Difference between incoming data rate and the internally generated data rate (37-byte packets)                                                                           |     | > (–750 / 750)         |     | ppm  |
| Co-channel rejection <sup>(1)</sup>                            | Wanted signal at –67 dBm, modulated interferer in channel, BER = $10^{-3}$                                                                                               |     | –6                     |     | dB   |
| Selectivity, $\pm 1\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at –67 dBm, modulated interferer at $\pm 1\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 7 / 4 <sup>(2)</sup>   |     | dB   |
| Selectivity, $\pm 2\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at –67 dBm, modulated interferer at $\pm 2\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 40 / 33 <sup>(2)</sup> |     | dB   |
| Selectivity, $\pm 3\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at –67 dBm, modulated interferer at $\pm 3\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 36 / 41 <sup>(2)</sup> |     | dB   |
| Selectivity, $\pm 4\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at –67 dBm, modulated interferer at $\pm 4\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 40 / 45 <sup>(2)</sup> |     | dB   |
| Selectivity, $\pm 5\text{ MHz}$ or more <sup>(1)</sup>         | Wanted signal at –67 dBm, modulated interferer at $\pm 5\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 40                     |     | dB   |
| Selectivity, image frequency <sup>(1)</sup>                    | Wanted signal at –67 dBm, modulated interferer at image frequency, BER = $10^{-3}$                                                                                       |     | 33                     |     | dB   |
| Selectivity, image frequency $\pm 1\text{ MHz}$ <sup>(1)</sup> | Note that Image frequency + 1 MHz is the Co- channel – 1 MHz. Wanted signal at –67 dBm, modulated interferer at $\pm 1\text{ MHz}$ from image frequency, BER = $10^{-3}$ |     | 4 / 41 <sup>(2)</sup>  |     | dB   |
| Out-of-band blocking <sup>(3)</sup>                            | 30 MHz to 2000 MHz                                                                                                                                                       |     | –10                    |     | dBm  |
| Out-of-band blocking                                           | 2003 MHz to 2399 MHz                                                                                                                                                     |     | –18                    |     | dBm  |
| Out-of-band blocking                                           | 2484 MHz to 2997 MHz                                                                                                                                                     |     | –12                    |     | dBm  |
| Out-of-band blocking                                           | 3000 MHz to 12.75 GHz                                                                                                                                                    |     | –2                     |     | dBm  |
| Intermodulation                                                | Wanted signal at 2402 MHz, –64 dBm. Two interferers at 2405 and 2408 MHz respectively, at the given power level                                                          |     | –42                    |     | dBm  |
| Spurious emissions, 30 to 1000 MHz                             | Measurement in a 50- $\Omega$ single-ended load.                                                                                                                         |     | < –59                  |     | dBm  |
| Spurious emissions, 1 to 12.75 GHz                             | Measurement in a 50- $\Omega$ single-ended load.                                                                                                                         |     | < –47                  |     | dBm  |
| RSSI dynamic range                                             |                                                                                                                                                                          |     | 70                     |     | dB   |
| RSSI accuracy                                                  |                                                                                                                                                                          |     | $\pm 4$                |     | dB   |
| <b>2 Mbps (LE 2M)</b>                                          |                                                                                                                                                                          |     |                        |     |      |
| Receiver sensitivity                                           | Differential mode. Measured at SMA connector, BER = $10^{-3}$                                                                                                            |     | –91                    |     | dBm  |
| Receiver saturation                                            | Differential mode. Measured at SMA connector, BER = $10^{-3}$                                                                                                            |     | > 5                    |     | dBm  |
| Frequency error tolerance                                      | Difference between the incoming carrier frequency and the internally generated carrier frequency                                                                         |     | > (–500 / 500)         |     | kHz  |
| Data rate error tolerance                                      | Difference between incoming data rate and the internally generated data rate (37-byte packets)                                                                           |     | > (–700 / 750)         |     | ppm  |
| Co-channel rejection <sup>(1)</sup>                            | Wanted signal at –67 dBm, modulated interferer in channel, BER = $10^{-3}$                                                                                               |     | –7                     |     | dB   |
| Selectivity, $\pm 2\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at –67 dBm, modulated interferer at $\pm 2\text{ MHz}$ , Image frequency is at –2 MHz, BER = $10^{-3}$                                                     |     | 8 / 4 <sup>(2)</sup>   |     | dB   |
| Selectivity, $\pm 4\text{ MHz}$ <sup>(1)</sup>                 | Wanted signal at –67 dBm, modulated interferer at $\pm 4\text{ MHz}$ , BER = $10^{-3}$                                                                                   |     | 36 / 36 <sup>(2)</sup> |     | dB   |

When measured on the [CC2651RSIPA-EM](#) reference design with  $T_c = 25\text{ }^{\circ}\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ ,  $f_{RF} = 2440\text{ MHz}$  with DC/DC enabled unless otherwise noted. All measurements are performed conducted.

| PARAMETER                                             | TEST CONDITIONS                                                                                                                                                                  | MIN | TYP                    | MAX | UNIT |
|-------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|------------------------|-----|------|
| Selectivity, $\pm 6\text{ MHz}^{(1)}$                 | Wanted signal at $-67\text{ dBm}$ , modulated interferer at $\pm 6\text{ MHz}$ , $\text{BER} = 10^{-3}$                                                                          |     | 37 / 36 <sup>(2)</sup> |     | dB   |
| Selectivity, image frequency <sup>(1)</sup>           | Wanted signal at $-67\text{ dBm}$ , modulated interferer at image frequency, $\text{BER} = 10^{-3}$                                                                              |     | 4                      |     | dB   |
| Selectivity, image frequency $\pm 2\text{ MHz}^{(1)}$ | Note that Image frequency + 2 MHz is the Co-channel. Wanted signal at $-67\text{ dBm}$ , modulated interferer at $\pm 2\text{ MHz}$ from image frequency, $\text{BER} = 10^{-3}$ |     | -7 / 36 <sup>(2)</sup> |     | dB   |
| Out-of-band blocking <sup>(3)</sup>                   | 30 MHz to 2000 MHz                                                                                                                                                               |     | -16                    |     | dBm  |
| Out-of-band blocking                                  | 2003 MHz to 2399 MHz                                                                                                                                                             |     | -21                    |     | dBm  |
| Out-of-band blocking                                  | 2484 MHz to 2997 MHz                                                                                                                                                             |     | -15                    |     | dBm  |
| Out-of-band blocking                                  | 3000 MHz to 12.75 GHz                                                                                                                                                            |     | -12                    |     | dBm  |
| Intermodulation                                       | Wanted signal at 2402 MHz, $-64\text{ dBm}$ . Two interferers at 2408 and 2414 MHz respectively, at the given power level                                                        |     | -38                    |     | dBm  |

(1) Numbers given as I/C dB

(2) X / Y, where X is +N MHz and Y is -N MHz

(3) Excluding one exception at  $F_{\text{wanted}} / 2$ , per Bluetooth Specification

## 8.12 Bluetooth Low Energy - Transmit (TX)

When measured on the [CC2651R3SIPA-EM](#) reference design with  $T_c = 25\text{ }^{\circ}\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ ,  $f_{RF} = 2440\text{ MHz}$  with DC/DC enabled unless otherwise noted. All measurements are performed conducted.

| PARAMETER                               | TEST CONDITIONS                                                                 | MIN            | TYP   | MAX | UNIT |
|-----------------------------------------|---------------------------------------------------------------------------------|----------------|-------|-----|------|
| <b>General Parameters</b>               |                                                                                 |                |       |     |      |
| Max output power                        | Differential mode, delivered to a single-ended 50 $\Omega$ load through a balun |                | 5     |     | dBm  |
| Output power programmable range         | Differential mode, delivered to a single-ended 50 $\Omega$ load through a balun |                | 26    |     | dB   |
| <b>Spurious emissions and harmonics</b> |                                                                                 |                |       |     |      |
| Spurious emissions                      | f < 1 GHz, outside restricted bands                                             | +5 dBm setting | < -36 |     | dBm  |
|                                         | f < 1 GHz, restricted bands ETSI                                                |                | < -54 |     | dBm  |
|                                         | f < 1 GHz, restricted bands FCC                                                 |                | < -55 |     | dBm  |
|                                         | f > 1 GHz, including harmonics                                                  |                | < -42 |     | dBm  |
| Harmonics                               | Second harmonic                                                                 |                | < -42 |     | dBm  |
|                                         | Third harmonic                                                                  |                | < -42 |     | dBm  |

### 8.13 Zigbee - IEEE 802.15.4-2006 2.4 GHz (OQPSK DSSS1:8, 250 kbps) - RX

When measured on the [CC2651RSIPA-EM](#) reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ ,  $f_{RF} = 2440\text{ MHz}$  with DC/DC enabled unless otherwise noted. All measurements are performed conducted.

| PARAMETER                                                  | TEST CONDITIONS                                                                                                                        | MIN | TYP     | MAX | UNIT |
|------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|-----|---------|-----|------|
| <b>General Parameters</b>                                  |                                                                                                                                        |     |         |     |      |
| Receiver sensitivity                                       | PER = 1%                                                                                                                               |     | -99     |     | dBm  |
| Receiver saturation                                        | PER = 1%                                                                                                                               |     | > 5     |     | dBm  |
| Adjacent channel rejection                                 | Wanted signal at -82 dBm, modulated interferer at $\pm 5\text{ MHz}$ , PER = 1%                                                        |     | 36      |     | dB   |
| Alternate channel rejection                                | Wanted signal at -82 dBm, modulated interferer at $\pm 10\text{ MHz}$ , PER = 1%                                                       |     | 57      |     | dB   |
| Channel rejection, $\pm 15\text{ MHz}$ or more             | Wanted signal at -82 dBm, undesired signal is IEEE 802.15.4 modulated channel, stepped through all channels 2405 to 2480 MHz, PER = 1% |     | 59      |     | dB   |
| Blocking and desensitization, 5 MHz from upper band edge   | Wanted signal at -97 dBm (3 dB above the sensitivity level), CW jammer, PER = 1%                                                       |     | 57      |     | dB   |
| Blocking and desensitization, 10 MHz from upper band edge  | Wanted signal at -97 dBm (3 dB above the sensitivity level), CW jammer, PER = 1%                                                       |     | 63      |     | dB   |
| Blocking and desensitization, 20 MHz from upper band edge  | Wanted signal at -97 dBm (3 dB above the sensitivity level), CW jammer, PER = 1%                                                       |     | 63      |     | dB   |
| Blocking and desensitization, 50 MHz from upper band edge  | Wanted signal at -97 dBm (3 dB above the sensitivity level), CW jammer, PER = 1%                                                       |     | 66      |     | dB   |
| Blocking and desensitization, -5 MHz from lower band edge  | Wanted signal at -97 dBm (3 dB above the sensitivity level), CW jammer, PER = 1%                                                       |     | 60      |     | dB   |
| Blocking and desensitization, -10 MHz from lower band edge | Wanted signal at -97 dBm (3 dB above the sensitivity level), CW jammer, PER = 1%                                                       |     | 60      |     | dB   |
| Blocking and desensitization, -20 MHz from lower band edge | Wanted signal at -97 dBm (3 dB above the sensitivity level), CW jammer, PER = 1%                                                       |     | 63      |     | dB   |
| Blocking and desensitization, -50 MHz from lower band edge | Wanted signal at -97 dBm (3 dB above the sensitivity level), CW jammer, PER = 1%                                                       |     | 65      |     | dB   |
| Spurious emissions, 30 MHz to 1000 MHz                     | Measurement in a 50- $\Omega$ single-ended load                                                                                        |     | -66     |     | dBm  |
| Spurious emissions, 1 GHz to 12.75 GHz                     | Measurement in a 50- $\Omega$ single-ended load                                                                                        |     | -53     |     | dBm  |
| Frequency error tolerance                                  | Difference between the incoming carrier frequency and the internally generated carrier frequency                                       |     | > 350   |     | ppm  |
| Symbol rate error tolerance                                | Difference between incoming symbol rate and the internally generated symbol rate                                                       |     | > 1000  |     | ppm  |
| RSSI dynamic range                                         |                                                                                                                                        |     | 95      |     | dB   |
| RSSI accuracy                                              |                                                                                                                                        |     | $\pm 4$ |     | dB   |

## 8.14 Zigbee - IEEE 802.15.4-2006 2.4 GHz (OQPSK DSSS1:8, 250 kbps) - TX

When measured on the [CC2651RSIPA-EM](#) reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ ,  $f_{\text{RF}} = 2440\text{ MHz}$  with DC/DC enabled unless otherwise noted. All measurements are performed conducted.

| PARAMETER                                            | TEST CONDITIONS                                                          |                | MIN   | TYP | MAX | UNIT |
|------------------------------------------------------|--------------------------------------------------------------------------|----------------|-------|-----|-----|------|
| General Parameters                                   |                                                                          |                |       |     |     |      |
| Max output power                                     | Differential mode, delivered to a single-ended 50-Ω load through a balun |                | 5     |     |     | dBm  |
| Output power programmable range                      | Differential mode, delivered to a single-ended 50-Ω load through a balun |                | 25    |     |     | dB   |
| Spurious emissions and harmonics                     |                                                                          |                |       |     |     |      |
| Spurious emissions <sup>(1)</sup>                    | f < 1 GHz, outside restricted bands                                      | +5 dBm setting | < -36 |     |     | dBm  |
|                                                      | f < 1 GHz, restricted bands ETSI                                         |                | < -47 |     |     | dBm  |
|                                                      | f < 1 GHz, restricted bands FCC                                          |                | < -55 |     |     | dBm  |
|                                                      | f > 1 GHz, including harmonics                                           |                | < -42 |     |     | dBm  |
| Harmonics                                            | Second harmonic                                                          |                | < -42 |     |     | dBm  |
|                                                      | Third harmonic                                                           |                | < -42 |     |     | dBm  |
| IEEE 802.15.4-2006 2.4 GHz (OQPSK DSSS1:8, 250 kbps) |                                                                          |                |       |     |     |      |
| Error vector magnitude                               | +5 dBm setting                                                           |                | 2     |     |     | %    |

- (1) To meet the FCC 15.247 Part 15 (US) Band Edge requirement, Channel 26 is reduced by 3 dBm when using the integrated antenna. When using the external antenna option, Channel 26 output power is reducing by 4 dBm, with a max allowable antenna gain of 3.3 dBi.

## 8.15 Timing and Switching Characteristics

### 8.15.1 Reset Timing

| PARAMETER            | MIN | TYP | MAX | UNIT |
|----------------------|-----|-----|-----|------|
| RESET_N low duration | 1   |     |     | μs   |

### 8.15.2 Wakeup Timing

Measured over operating free-air temperature with  $V_{\text{DD5}} = 3.0\text{ V}$  (unless otherwise noted). The times listed here do not include software overhead.

| PARAMETER                              | TEST CONDITIONS | MIN | TYP  | MAX | UNIT |
|----------------------------------------|-----------------|-----|------|-----|------|
| MCU, Reset to Active <sup>(1)</sup>    |                 | 850 | 3000 |     | μs   |
| MCU, Shutdown to Active <sup>(1)</sup> |                 | 850 | 3000 |     | μs   |
| MCU, Standby to Active                 |                 |     | 160  |     | μs   |
| MCU, Active to Standby                 |                 |     | 36   |     | μs   |
| MCU, Idle to Active                    |                 |     | 14   |     | μs   |

- (1) The wakeup time is dependent on remaining charge on VDDR capacitor when starting the device, and thus how long the device has been in Reset or Shutdown before starting up again.

### 8.15.3 Clock Specifications

#### 8.15.3.1 48 MHz Crystal Oscillator (XOSC\_HF)

Measured on a Texas Instruments reference design with integrated 48 MHz crystal including parameters based on external manufacturer's crystal specification at  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$  at initial time, unless otherwise noted.

|  | PARAMETER                                  | MIN | TYP | MAX | UNIT          |
|--|--------------------------------------------|-----|-----|-----|---------------|
|  | Crystal frequency                          |     | 48  |     | MHz           |
|  | Start-up time <sup>(1)</sup>               |     | 200 |     | $\mu\text{s}$ |
|  | Crystal frequency tolerance <sup>(2)</sup> | -16 |     | 18  | ppm           |
|  | Crystal aging <sup>(2)</sup>               | -4  |     | 2   | ppm/year      |

(1) Start-up time using the TI-provided power driver. Start-up time may increase if driver is not used.

(2) External manufacturer's crystal specification

#### 8.15.3.2 48 MHz RC Oscillator (RCOSC\_HF)

Measured on a Texas Instruments reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ , unless otherwise noted.

|                                              | MIN | TYP        | MAX | UNIT          |
|----------------------------------------------|-----|------------|-----|---------------|
| Frequency                                    |     | 48         |     | MHz           |
| Uncalibrated frequency accuracy              |     | $\pm 1$    |     | %             |
| Calibrated frequency accuracy <sup>(1)</sup> |     | $\pm 0.25$ |     | %             |
| Start-up time                                |     | 5          |     | $\mu\text{s}$ |

(1) Accuracy relative to the calibration source (XOSC\_HF)

#### 8.15.3.3 32.768 kHz Crystal Oscillator (XOSC\_LF)

Measured on a Texas Instruments reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ , unless otherwise noted.

|                   | MIN | TYP              | MAX | UNIT             |
|-------------------|-----|------------------|-----|------------------|
| Crystal frequency |     | 32.768           |     | kHz              |
| ESR               |     | 30               | 100 | $\text{k}\Omega$ |
| $C_L$             | 6   | 7 <sup>(1)</sup> | 12  | pF               |

(1) Default load capacitance using TI reference designs including parasitic capacitance. Crystals with different load capacitance may be used.

#### 8.15.3.4 32 kHz RC Oscillator (RCOSC\_LF)

Measured on a Texas Instruments reference design with  $T_c = 25^\circ\text{C}$ ,  $V_{\text{DD5}} = 3.0\text{ V}$ , unless otherwise noted.

|                                         | MIN | TYP                      | MAX | UNIT                  |
|-----------------------------------------|-----|--------------------------|-----|-----------------------|
| Frequency                               |     | 32.8                     |     | kHz                   |
| Calibrated RTC variation <sup>(1)</sup> |     | $\pm 600$ <sup>(3)</sup> |     | ppm                   |
| Temperature coefficient.                |     | 50                       |     | ppm/ $^\circ\text{C}$ |

(1) When using RCOSC\_LF as source for the low frequency system clock (SCLK\_LF), the accuracy of the SCLK\_LF-derived Real Time Clock (RTC) can be improved by measuring RCOSC\_LF relative to XOSC\_HF and compensating for the RTC tick speed. This functionality is available through the TI-provided Power driver.

(2) TI driver software calibrates the RTC every time XOSC\_HF is enabled.

(3) Some device's variation can exceed 1000 ppm. Further calibration will not improve variation.

## 8.15.4 Synchronous Serial Interface (SSI) Characteristics

### 8.15.4.1 Synchronous Serial Interface (SSI) Characteristics

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

| PARAMETER NO.     | PARAMETER              |                   | MIN | TYP | MAX   | UNIT                         |
|-------------------|------------------------|-------------------|-----|-----|-------|------------------------------|
| S1                | $t_{\text{clk\_per}}$  | SSIClk cycle time | 12  |     | 65024 | System Clocks <sup>(2)</sup> |
| S2 <sup>(1)</sup> | $t_{\text{clk\_high}}$ | SSIClk high time  |     | 0.5 |       | $t_{\text{clk\_per}}$        |
| S3 <sup>(1)</sup> | $t_{\text{clk\_low}}$  | SSIClk low time   |     | 0.5 |       | $t_{\text{clk\_per}}$        |

- (1) Refer to SSI timing diagrams Figure 8-1, Figure 8-2, and Figure 8-3.  
(2) When using the TI-provided Power driver, the SSI system clock is always 48 MHz.

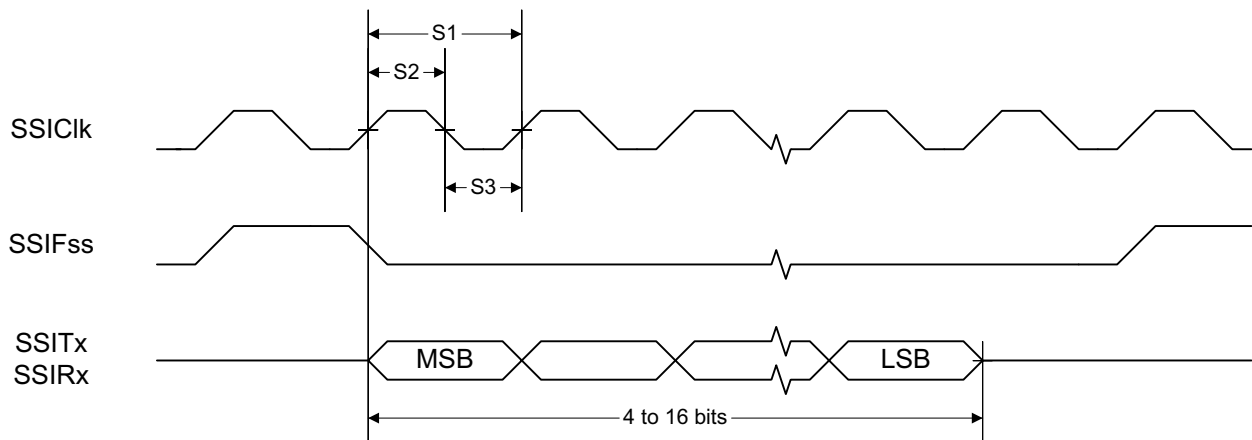


FIG 8-1. SSI Timing for TI Frame Format (FRF = 01), Single Transfer Timing Measurement

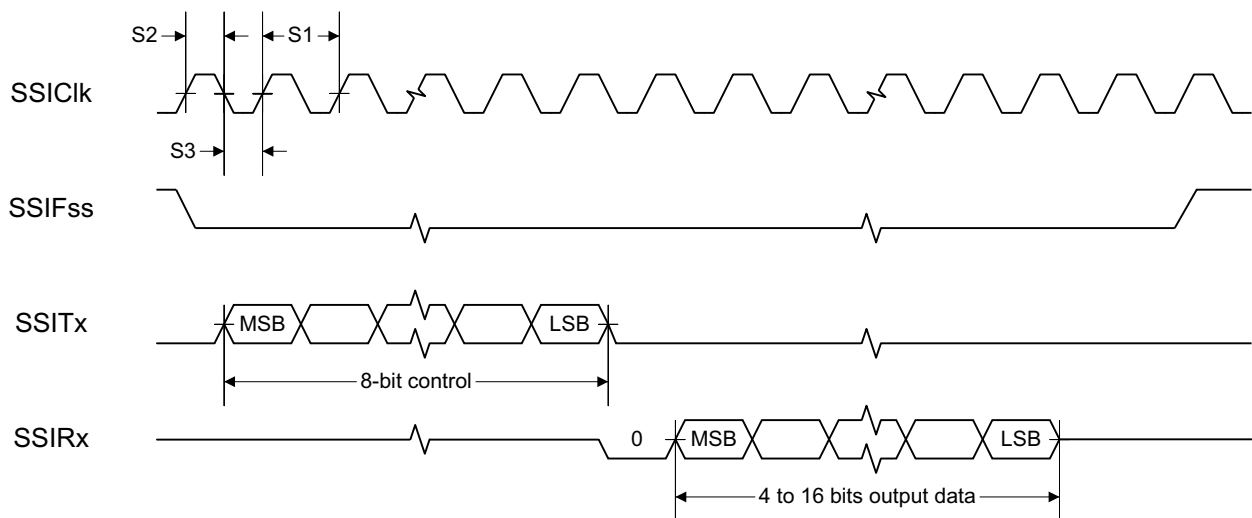
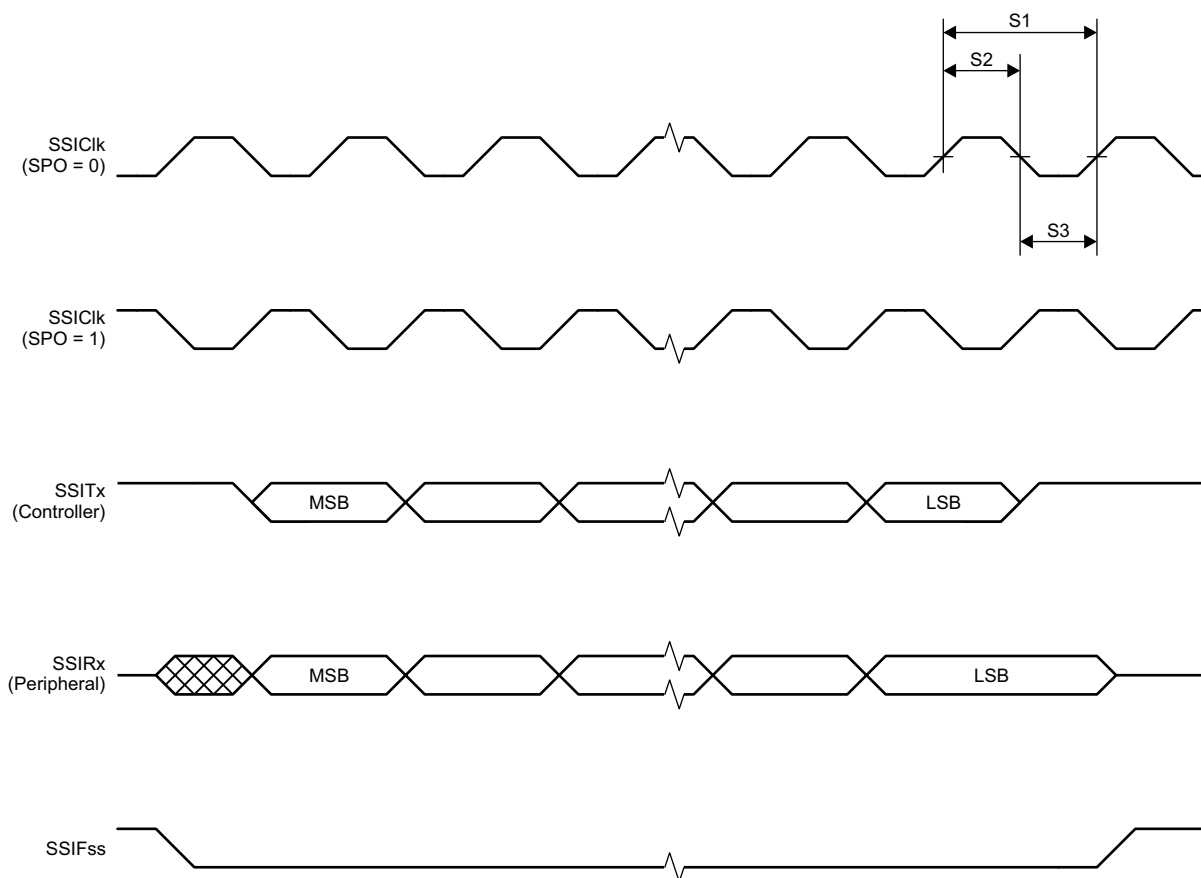


FIG 8-2. SSI Timing for MICROWIRE Frame Format (FRF = 10), Single Transfer



**8-3. SSI Timing for SPI Frame Format (FRF = 00), With SPH = 1**

## 8.15.5 UART

### 8.15.5.1 UART Characteristics

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

| PARAMETER | MIN | TYP | MAX | UNIT  |
|-----------|-----|-----|-----|-------|
| UART rate |     |     | 3   | MBaud |

## 8.16 Peripheral Characteristics

### 8.16.1 ADC

#### 8.16.1.1 Analog-to-Digital Converter (ADC) Characteristics

$T_c = 25^\circ\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$  and voltage scaling enabled, unless otherwise noted.<sup>(1)</sup>

Performance numbers require use of offset and gain adjustments in software by TI-provided ADC drivers.

| PARAMETER          |                                      | TEST CONDITIONS                                                                                                                                                                                                                                                                                                                       | MIN | TYP                               | MAX  | UNIT         |
|--------------------|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----------------------------------|------|--------------|
|                    | Input voltage range                  |                                                                                                                                                                                                                                                                                                                                       | 0   |                                   | VDD5 | V            |
|                    | Resolution                           |                                                                                                                                                                                                                                                                                                                                       |     | 12                                |      | Bits         |
|                    | Sample Rate                          |                                                                                                                                                                                                                                                                                                                                       |     |                                   | 200  | ksps         |
|                    | Offset                               | Internal 4.3 V equivalent reference <sup>(2)</sup>                                                                                                                                                                                                                                                                                    |     | −0.24                             |      | LSB          |
|                    | Gain error                           | Internal 4.3 V equivalent reference <sup>(2)</sup>                                                                                                                                                                                                                                                                                    |     | 7.14                              |      | LSB          |
| DNL <sup>(4)</sup> | Differential nonlinearity            |                                                                                                                                                                                                                                                                                                                                       |     | >−1                               |      | LSB          |
| INL                | Integral nonlinearity                |                                                                                                                                                                                                                                                                                                                                       |     | ±4                                |      | LSB          |
| ENOB               | Effective number of bits             | Internal 4.3 V equivalent reference <sup>(2)</sup> , 200 kSamples/s, 9.6 kHz input tone                                                                                                                                                                                                                                               |     | 9.8                               |      | Bits         |
|                    |                                      | Internal 4.3 V equivalent reference <sup>(2)</sup> , 200 kSamples/s, 9.6 kHz input tone, DC/DC enabled                                                                                                                                                                                                                                |     | 9.8                               |      |              |
|                    |                                      | VDD5 as reference, 200 kSamples/s, 9.6 kHz input tone                                                                                                                                                                                                                                                                                 |     | 10.1                              |      |              |
|                    |                                      | Internal reference, voltage scaling disabled, 32 samples average, 200 kSamples/s, 300 Hz input tone                                                                                                                                                                                                                                   |     | 11.1                              |      |              |
|                    |                                      | Internal reference, voltage scaling disabled, 14-bit mode, 200 kSamples/s, 300 Hz input tone <sup>(5)</sup>                                                                                                                                                                                                                           |     | 11.3                              |      |              |
|                    |                                      | Internal reference, voltage scaling disabled, 15-bit mode, 200 kSamples/s, 300 Hz input tone <sup>(5)</sup>                                                                                                                                                                                                                           |     | 11.6                              |      |              |
| THD                | Total harmonic distortion            | Internal 4.3 V equivalent reference <sup>(2)</sup> , 200 kSamples/s, 9.6 kHz input tone                                                                                                                                                                                                                                               |     | −65                               |      | dB           |
|                    |                                      | VDD5 as reference, 200 kSamples/s, 9.6 kHz input tone                                                                                                                                                                                                                                                                                 |     | −70                               |      |              |
|                    |                                      | Internal reference, voltage scaling disabled, 32 samples average, 200 kSamples/s, 300 Hz input tone                                                                                                                                                                                                                                   |     | −72                               |      |              |
| SINAD, SNDR        | Signal-to-noise and distortion ratio | Internal 4.3 V equivalent reference <sup>(2)</sup> , 200 kSamples/s, 9.6 kHz input tone                                                                                                                                                                                                                                               |     | 60                                |      | dB           |
|                    |                                      | VDD5 as reference, 200 kSamples/s, 9.6 kHz input tone                                                                                                                                                                                                                                                                                 |     | 63                                |      |              |
|                    |                                      | Internal reference, voltage scaling disabled, 32 samples average, 200 kSamples/s, 300 Hz input tone                                                                                                                                                                                                                                   |     | 68                                |      |              |
| SFDR               | Spurious-free dynamic range          | Internal 4.3 V equivalent reference <sup>(2)</sup> , 200 kSamples/s, 9.6 kHz input tone                                                                                                                                                                                                                                               |     | 70                                |      | dB           |
|                    |                                      | VDD5 as reference, 200 kSamples/s, 9.6 kHz input tone                                                                                                                                                                                                                                                                                 |     | 73                                |      |              |
|                    |                                      | Internal reference, voltage scaling disabled, 32 samples average, 200 kSamples/s, 300 Hz input tone                                                                                                                                                                                                                                   |     | 75                                |      |              |
|                    | Conversion time                      | Serial conversion, time-to-output, 24 MHz clock                                                                                                                                                                                                                                                                                       |     | 50                                |      | Clock Cycles |
|                    | Current consumption                  | Internal 4.3 V equivalent reference <sup>(2)</sup>                                                                                                                                                                                                                                                                                    |     | 0.42                              |      | mA           |
|                    | Current consumption                  | VDD5 as reference                                                                                                                                                                                                                                                                                                                     |     | 0.6                               |      | mA           |
|                    | Reference voltage                    | Equivalent fixed internal reference (input voltage scaling enabled). For best accuracy, the ADC conversion should be initiated through the TI-RTOS API in order to include the gain/offset compensation factors stored in FCFG1                                                                                                       |     | 4.3 <sup>(2)</sup> <sup>(3)</sup> |      | V            |
|                    | Reference voltage                    | Fixed internal reference (input voltage scaling disabled). For best accuracy, the ADC conversion should be initiated through the TI-RTOS API in order to include the gain/offset compensation factors stored in FCFG1. This value is derived from the scaled value (4.3 V) as follows:<br>$V_{ref} = 4.3\text{ V} \times 1408 / 4095$ |     | 1.48                              |      | V            |
|                    | Reference voltage                    | VDD5 as reference, input voltage scaling enabled                                                                                                                                                                                                                                                                                      |     | VDD5                              |      | V            |
|                    | Reference voltage                    | VDD5 as reference, input voltage scaling disabled                                                                                                                                                                                                                                                                                     |     | VDD5 / 2.82 <sup>(3)</sup>        |      | V            |

$T_c = 25\text{ }^{\circ}\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$  and voltage scaling enabled, unless otherwise noted.<sup>(1)</sup>

Performance numbers require use of offset and gain adjustments in software by TI-provided ADC drivers.

| PARAMETER |                 | TEST CONDITIONS                                                                                                            | MIN | TYP | MAX | UNIT |
|-----------|-----------------|----------------------------------------------------------------------------------------------------------------------------|-----|-----|-----|------|
|           | Input impedance | 200 kSamples/s, voltage scaling enabled. Capacitive input, Input impedance depends on sampling frequency and sampling time |     | >1  |     | MΩ   |

- (1) Using IEEE Std 1241-2010 for terminology and test methods
- (2) Input signal scaled down internally before conversion, as if voltage range was 0 to 4.3 V
- (3) Applied voltage must be within Absolute Maximum Ratings (see [セクション 8.1](#)) at all times
- (4) No missing codes
- (5)  $\text{ADC\_output} = \Sigma(4^n \text{ samples}) \gg n$ ,  $n$  = desired extra bits

## 8.16.2 DAC

### 8.16.2.1 Digital-to-Analog Converter (DAC) Characteristics

$T_c = 25^\circ\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ , unless otherwise noted.

| PARAMETER                                                                 |                                                                                       | TEST CONDITIONS                                                                                                          | MIN   | TYP | MAX  | UNIT                 |
|---------------------------------------------------------------------------|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|-------|-----|------|----------------------|
| General Parameters                                                        |                                                                                       |                                                                                                                          |       |     |      |                      |
|                                                                           | Resolution                                                                            |                                                                                                                          | 8     |     |      | Bits                 |
| V <sub>DD5</sub>                                                          | Supply voltage                                                                        | Any load, any V <sub>REF</sub> , pre-charge OFF, DAC charge-pump ON                                                      | 1.8   |     | 3.8  | V                    |
|                                                                           |                                                                                       | External Load <sup>(4)</sup> , any V <sub>REF</sub> , pre-charge OFF, DAC charge-pump OFF                                | 2.0   |     | 3.8  |                      |
|                                                                           |                                                                                       | Any load, V <sub>REF</sub> = DCOUPL, pre-charge ON                                                                       | 2.6   |     | 3.8  |                      |
| F <sub>DAC</sub>                                                          | Clock frequency                                                                       | Buffer ON (recommended for external load)                                                                                | 16    |     | 250  | kHz                  |
|                                                                           |                                                                                       | Buffer OFF (internal load)                                                                                               | 16    |     | 1000 |                      |
|                                                                           | Voltage output settling time                                                          | V <sub>REF</sub> = VDD5, buffer OFF, internal load                                                                       | 13    |     |      | 1 / F <sub>DAC</sub> |
|                                                                           |                                                                                       | V <sub>REF</sub> = VDD5, buffer ON, external capacitive load = 20 pF <sup>(3)</sup>                                      | 13.8  |     |      |                      |
|                                                                           | External capacitive load                                                              |                                                                                                                          |       | 20  | 200  | pF                   |
|                                                                           | External resistive load                                                               |                                                                                                                          | 10    |     |      | MΩ                   |
|                                                                           | Short circuit current                                                                 |                                                                                                                          |       |     | 400  | μA                   |
| Z <sub>MAX</sub>                                                          | Max output impedance Vref = VDD5, buffer ON, CLK 250 kHz                              | VDD5 = 3.8 V, DAC charge-pump OFF                                                                                        | 50.8  |     |      | kΩ                   |
|                                                                           |                                                                                       | VDD5 = 3.0 V, DAC charge-pump ON                                                                                         | 51.7  |     |      |                      |
|                                                                           |                                                                                       | VDD5 = 3.0 V, DAC charge-pump OFF                                                                                        | 53.2  |     |      |                      |
|                                                                           |                                                                                       | VDD5 = 2.0 V, DAC charge-pump ON                                                                                         | 48.7  |     |      |                      |
|                                                                           |                                                                                       | VDD5 = 2.0 V, DAC charge-pump OFF                                                                                        | 70.2  |     |      |                      |
|                                                                           |                                                                                       | VDD5 = 1.8 V, DAC charge-pump ON                                                                                         | 46.3  |     |      |                      |
|                                                                           |                                                                                       | VDD5 = 1.8 V, DAC charge-pump OFF                                                                                        | 88.9  |     |      |                      |
| Internal Load - Continuous Time Comparator / Low Power Clocked Comparator |                                                                                       |                                                                                                                          |       |     |      |                      |
| DNL                                                                       | Differential nonlinearity                                                             | V <sub>REF</sub> = VDD5, load = Continuous Time Comparator or Low Power Clocked Comparator<br>F <sub>DAC</sub> = 250 kHz | ±1    |     |      | LSB <sup>(1)</sup>   |
|                                                                           | Differential nonlinearity                                                             | V <sub>REF</sub> = VDD5, load = Continuous Time Comparator or Low Power Clocked Comparator<br>F <sub>DAC</sub> = 16 kHz  | ±1.2  |     |      |                      |
|                                                                           | Offset error <sup>(2)</sup><br>Load = Continuous Time Comparator                      | V <sub>REF</sub> = VDD5 = 3.8 V                                                                                          | ±0.64 |     |      | LSB <sup>(1)</sup>   |
|                                                                           |                                                                                       | V <sub>REF</sub> = VDD5= 3.0 V                                                                                           | ±0.81 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = VDD5 = 1.8 V                                                                                          | ±1.27 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = DCOUPL, pre-charge ON                                                                                 | ±3.43 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = DCOUPL, pre-charge OFF                                                                                | ±2.88 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = ADCREF                                                                                                | ±2.37 |     |      |                      |
|                                                                           | Offset error <sup>(2)</sup><br>Load = Low Power Clocked Comparator                    | V <sub>REF</sub> = VDD5= 3.8 V                                                                                           | ±0.78 |     |      | LSB <sup>(1)</sup>   |
|                                                                           |                                                                                       | V <sub>REF</sub> = VDD5 = 3.0 V                                                                                          | ±0.77 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = VDD5= 1.8 V                                                                                           | ±3.46 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = DCOUPL, pre-charge ON                                                                                 | ±3.44 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = DCOUPL, pre-charge OFF                                                                                | ±4.70 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = ADCREF                                                                                                | ±4.11 |     |      |                      |
|                                                                           | Max code output voltage variation <sup>(2)</sup><br>Load = Continuous Time Comparator | V <sub>REF</sub> = VDD5 = 3.8 V                                                                                          | ±1.53 |     |      | LSB <sup>(1)</sup>   |
|                                                                           |                                                                                       | V <sub>REF</sub> = VDD5 = 3.0 V                                                                                          | ±1.71 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = VDD5= 1.8 V                                                                                           | ±2.10 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = DCOUPL, pre-charge ON                                                                                 | ±6.00 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = DCOUPL, pre-charge OFF                                                                                | ±3.85 |     |      |                      |
|                                                                           |                                                                                       | V <sub>REF</sub> = ADCREF                                                                                                | ±5.84 |     |      |                      |

$T_c = 25\text{ }^{\circ}\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ , unless otherwise noted.

| PARAMETER     |                                                                                         | TEST CONDITIONS                                                  | MIN | TYP   | MAX | UNIT               |
|---------------|-----------------------------------------------------------------------------------------|------------------------------------------------------------------|-----|-------|-----|--------------------|
|               | Max code output voltage variation <sup>(2)</sup><br>Load = Low Power Clocked Comparator | V <sub>REF</sub> = V <sub>DDS</sub> = 3.8 V                      |     | ±2.92 |     | LSB <sup>(1)</sup> |
|               |                                                                                         | V <sub>REF</sub> =V <sub>DDS</sub> = 3.0 V                       |     | ±3.06 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 1.8 V                      |     | ±3.91 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge ON                         |     | ±7.84 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge OFF                        |     | ±4.06 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = ADCREF                                        |     | ±6.94 |     |                    |
|               | Output voltage range <sup>(2)</sup><br>Load = Continuous Time Comparator                | V <sub>REF</sub> = V <sub>DDS</sub> = 3.8 V, code 1              |     | 0.03  |     | V                  |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 3.8 V, code 255            |     | 3.62  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 3.0 V, code 1              |     | 0.02  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 3.0 V, code 255            |     | 2.86  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 1.8 V, code 1              |     | 0.01  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 1.8 V, code 255            |     | 1.71  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge OFF, code 1                |     | 0.01  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge OFF, code 255              |     | 1.21  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge ON, code 1                 |     | 1.27  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge ON, code 255               |     | 2.46  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = ADCREF, code 1                                |     | 0.01  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = ADCREF, code 255                              |     | 1.41  |     |                    |
|               | Output voltage range <sup>(2)</sup><br>Load = Low Power Clocked Comparator              | V <sub>REF</sub> = V <sub>DDS</sub> = 3.8 V, code 1              |     | 0.03  |     | V                  |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 3.8 V, code 255            |     | 3.61  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 3.0 V, code 1              |     | 0.02  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 3.0 V, code 255            |     | 2.85  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 1.8 V, code 1              |     | 0.01  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 1.8 V, code 255            |     | 1.71  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge OFF, code 1                |     | 0.01  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge OFF, code 255              |     | 1.21  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge ON, code 1                 |     | 1.27  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge ON, code 255               |     | 2.46  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = ADCREF, code 1                                |     | 0.01  |     |                    |
|               |                                                                                         | V <sub>REF</sub> = ADCREF, code 255                              |     | 1.41  |     |                    |
| External Load |                                                                                         |                                                                  |     |       |     |                    |
| INL           | Integral nonlinearity                                                                   | V <sub>REF</sub> = V <sub>DDS</sub> , F <sub>DAC</sub> = 250 kHz |     | ±1    |     | LSB <sup>(1)</sup> |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, F <sub>DAC</sub> = 250 kHz            |     | ±1    |     |                    |
|               |                                                                                         | V <sub>REF</sub> = ADCREF, F <sub>DAC</sub> = 250 kHz            |     | ±1    |     |                    |
| DNL           | Differential nonlinearity                                                               | V <sub>REF</sub> = V <sub>DDS</sub> , F <sub>DAC</sub> = 250 kHz |     | ±1    |     | LSB <sup>(1)</sup> |
|               | Offset error                                                                            | V <sub>REF</sub> = V <sub>DDS</sub> = 3.8 V                      |     | ±0.20 |     | LSB <sup>(1)</sup> |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 3.0 V                      |     | ±0.25 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 1.8 V                      |     | ±0.45 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge ON                         |     | ±1.55 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge OFF                        |     | ±1.30 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = ADCREF                                        |     | ±1.10 |     |                    |
|               | Max code output voltage variation                                                       | V <sub>REF</sub> = V <sub>DDS</sub> = 3.8 V                      |     | ±0.60 |     | LSB <sup>(1)</sup> |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 3.0 V                      |     | ±0.55 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = V <sub>DDS</sub> = 1.8 V                      |     | ±0.60 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge ON                         |     | ±3.45 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = DCOUPL, pre-charge OFF                        |     | ±2.10 |     |                    |
|               |                                                                                         | V <sub>REF</sub> = ADCREF                                        |     | ±1.90 |     |                    |

$T_c = 25\text{ }^{\circ}\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ , unless otherwise noted.

| PARAMETER                                                      |  | TEST CONDITIONS                                     | MIN | TYP  | MAX | UNIT |
|----------------------------------------------------------------|--|-----------------------------------------------------|-----|------|-----|------|
| Output voltage range<br>Load = Low Power Clocked<br>Comparator |  | $V_{REF} = V_{DD5} = 3.8\text{ V}$ , code 1         |     | 0.03 |     | V    |
|                                                                |  | $V_{REF} = V_{DD5} = 3.8\text{ V}$ , code 255       |     | 3.61 |     |      |
|                                                                |  | $V_{REF} = V_{DD5} = 3.0\text{ V}$ , code 1         |     | 0.02 |     |      |
|                                                                |  | $V_{REF} = V_{DD5} = 3.0\text{ V}$ , code 255       |     | 2.85 |     |      |
|                                                                |  | $V_{REF} = V_{DD5} = 1.8\text{ V}$ , code 1         |     | 0.02 |     |      |
|                                                                |  | $V_{REF} = V_{DD5} = 1.8\text{ V}$ , code 255       |     | 1.71 |     |      |
|                                                                |  | $V_{REF} = \text{DCOUP}$ , pre-charge OFF, code 1   |     | 0.02 |     |      |
|                                                                |  | $V_{REF} = \text{DCOUP}$ , pre-charge OFF, code 255 |     | 1.20 |     |      |
|                                                                |  | $V_{REF} = \text{DCOUP}$ , pre-charge ON, code 1    |     | 1.27 |     |      |
|                                                                |  | $V_{REF} = \text{DCOUP}$ , pre-charge ON, code 255  |     | 2.46 |     |      |
|                                                                |  | $V_{REF} = \text{ADCRE}$ , code 1                   |     | 0.02 |     |      |
|                                                                |  | $V_{REF} = \text{ADCRE}$ , code 255                 |     | 1.42 |     |      |

(1) 1 LSB ( $V_{REF} 3.8\text{ V}/3.0\text{ V}/1.8\text{ V}/\text{DCOUP}/\text{ADCRE}$ ) = 14.10 mV/11.13 mV/6.68 mV/4.67 mV/5.48 mV

(2) Includes comparator offset

(3) A load > 20 pF will increase the settling time

(4) Keysight 34401A Multimeter

### 8.16.3 Temperature and Battery Monitor

#### 8.16.3.1 Temperature Sensor

Measured on a Texas Instruments reference design with  $T_c = 25\text{ }^{\circ}\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ , unless otherwise noted.

| PARAMETER                                 | TEST CONDITIONS                                              | MIN | TYP       | MAX | UNIT                 |
|-------------------------------------------|--------------------------------------------------------------|-----|-----------|-----|----------------------|
| Resolution                                |                                                              |     | 2         |     | $^{\circ}\text{C}$   |
| Accuracy                                  | $-40\text{ }^{\circ}\text{C}$ to $0\text{ }^{\circ}\text{C}$ |     | $\pm 5.0$ |     | $^{\circ}\text{C}$   |
| Accuracy                                  | $0\text{ }^{\circ}\text{C}$ to $105\text{ }^{\circ}\text{C}$ |     | $\pm 2.5$ |     | $^{\circ}\text{C}$   |
| Supply voltage coefficient <sup>(1)</sup> |                                                              |     | 3.6       |     | $^{\circ}\text{C/V}$ |

(1) The temperature sensor is automatically compensated for  $V_{DD5}$  variation when using the TI-provided driver.

#### 8.16.3.2 Battery Monitor

Measured on a Texas Instruments reference design with  $T_c = 25\text{ }^{\circ}\text{C}$ , unless otherwise noted.

| PARAMETER                   | TEST CONDITIONS          | MIN | TYP  | MAX | UNIT |
|-----------------------------|--------------------------|-----|------|-----|------|
| Resolution                  |                          |     | 25   |     | mV   |
| Range                       |                          | 1.8 |      | 3.8 | V    |
| Integral nonlinearity (max) |                          |     | 23   |     | mV   |
| Accuracy                    | $V_{DD5} = 3.0\text{ V}$ |     | 22.5 |     | mV   |
| Offset error                |                          |     | -32  |     | mV   |
| Gain error                  |                          |     | -1   |     | %    |

## 8.16.4 Comparators

### 8.16.4.1 Continuous Time Comparator

$T_c = 25^\circ\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ , unless otherwise noted.

| PARAMETER                          | TEST CONDITIONS                             | MIN | TYP     | MAX       | UNIT          |
|------------------------------------|---------------------------------------------|-----|---------|-----------|---------------|
| Input voltage range <sup>(1)</sup> |                                             | 0   |         | $V_{DD5}$ | V             |
| Offset                             | Measured at $V_{DD5} / 2$                   |     | $\pm 5$ |           | mV            |
| Decision time                      | Step from $-10\text{ mV}$ to $10\text{ mV}$ |     | 0.78    |           | $\mu\text{s}$ |
| Current consumption                | Internal reference                          |     | 8.6     |           | $\mu\text{A}$ |

(1) The input voltages can be generated externally and connected throughout I/Os or an internal reference voltage can be generated using the DAC

## 8.16.5 Current Source

### 8.16.5.1 Programmable Current Source

$T_c = 25^\circ\text{C}$ ,  $V_{DD5} = 3.0\text{ V}$ , unless otherwise noted.

| PARAMETER                                                    | TEST CONDITIONS | MIN | TYP       | MAX | UNIT          |
|--------------------------------------------------------------|-----------------|-----|-----------|-----|---------------|
| Current source programmable output range (logarithmic range) |                 |     | 0.25 - 20 |     | $\mu\text{A}$ |
| Resolution                                                   |                 |     | 0.25      |     | $\mu\text{A}$ |

## 8.16.6 GPIO

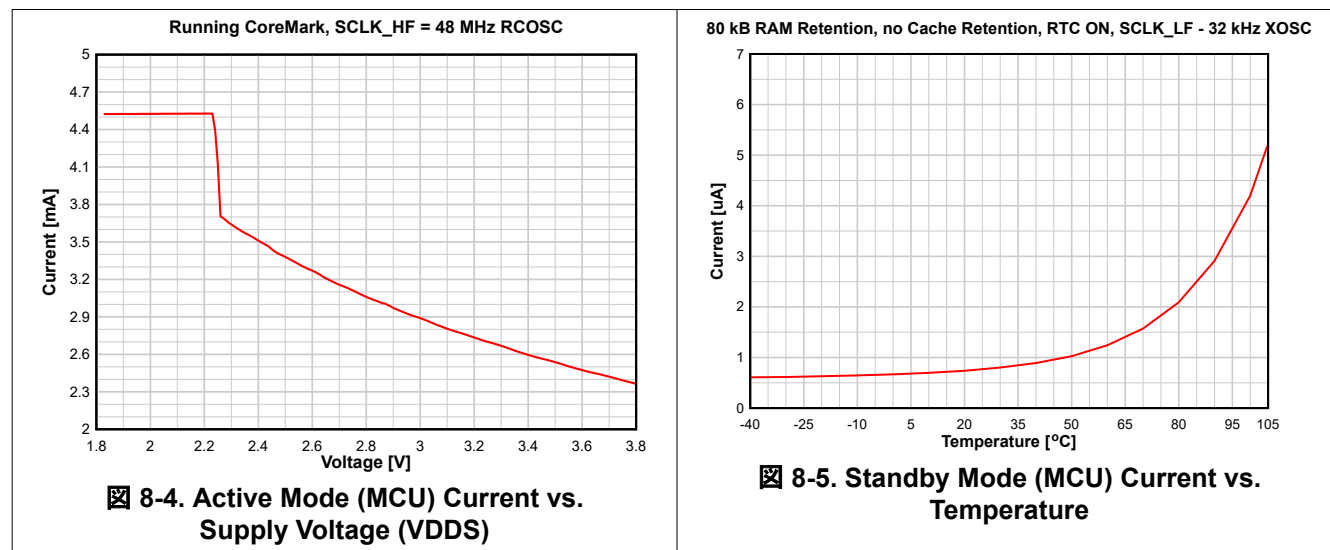
### 8.16.6.1 GPIO DC Characteristics

| PARAMETER                                             | TEST CONDITIONS                                                 | MIN                  | TYP                  | MAX | UNIT |
|-------------------------------------------------------|-----------------------------------------------------------------|----------------------|----------------------|-----|------|
| <b>T<sub>A</sub> = 25 °C, V<sub>DDs</sub> = 1.8 V</b> |                                                                 |                      |                      |     |      |
| GPIO VOH at 8 mA load                                 | IOCURR = 2, high-drive GPIOs only                               |                      | 1.56                 |     | V    |
| GPIO VOL at 8 mA load                                 | IOCURR = 2, high-drive GPIOs only                               |                      | 0.24                 |     | V    |
| GPIO VOH at 4 mA load                                 | IOCURR = 1                                                      |                      | 1.59                 |     | V    |
| GPIO VOL at 4 mA load                                 | IOCURR = 1                                                      |                      | 0.21                 |     | V    |
| GPIO pullup current                                   | Input mode, pullup enabled, Vpad = 0 V                          |                      | 73                   |     | μA   |
| GPIO pulldown current                                 | Input mode, pulldown enabled, Vpad = VDDs                       |                      | 19                   |     | μA   |
| GPIO low-to-high input transition, with hysteresis    | IH = 1, transition voltage for input read as 0 → 1              |                      | 1.08                 |     | V    |
| GPIO high-to-low input transition, with hysteresis    | IH = 1, transition voltage for input read as 1 → 0              |                      | 0.73                 |     | V    |
| GPIO input hysteresis                                 | IH = 1, difference between 0 → 1 and 1 → 0 points               |                      | 0.35                 |     | V    |
| <b>T<sub>A</sub> = 25 °C, V<sub>DDs</sub> = 3.0 V</b> |                                                                 |                      |                      |     |      |
| GPIO VOH at 8 mA load                                 | IOCURR = 2, high-drive GPIOs only                               |                      | 2.59                 |     | V    |
| GPIO VOL at 8 mA load                                 | IOCURR = 2, high-drive GPIOs only                               |                      | 0.42                 |     | V    |
| GPIO VOH at 4 mA load                                 | IOCURR = 1                                                      |                      | 2.63                 |     | V    |
| GPIO VOL at 4 mA load                                 | IOCURR = 1                                                      |                      | 0.40                 |     | V    |
| <b>T<sub>A</sub> = 25 °C, V<sub>DDs</sub> = 3.8 V</b> |                                                                 |                      |                      |     |      |
| GPIO pullup current                                   | Input mode, pullup enabled, Vpad = 0 V                          |                      | 282                  |     | μA   |
| GPIO pulldown current                                 | Input mode, pulldown enabled, Vpad = VDDs                       |                      | 110                  |     | μA   |
| GPIO low-to-high input transition, with hysteresis    | IH = 1, transition voltage for input read as 0 → 1              |                      | 1.97                 |     | V    |
| GPIO high-to-low input transition, with hysteresis    | IH = 1, transition voltage for input read as 1 → 0              |                      | 1.55                 |     | V    |
| GPIO input hysteresis                                 | IH = 1, difference between 0 → 1 and 1 → 0 points               |                      | 0.42                 |     | V    |
| <b>T<sub>A</sub> = 25 °C</b>                          |                                                                 |                      |                      |     |      |
| VIH                                                   | Lowest GPIO input voltage reliably interpreted as a <i>High</i> | 0.8*V <sub>DDs</sub> |                      |     | V    |
| VIL                                                   | Highest GPIO input voltage reliably interpreted as a <i>Low</i> |                      | 0.2*V <sub>DDs</sub> |     | V    |

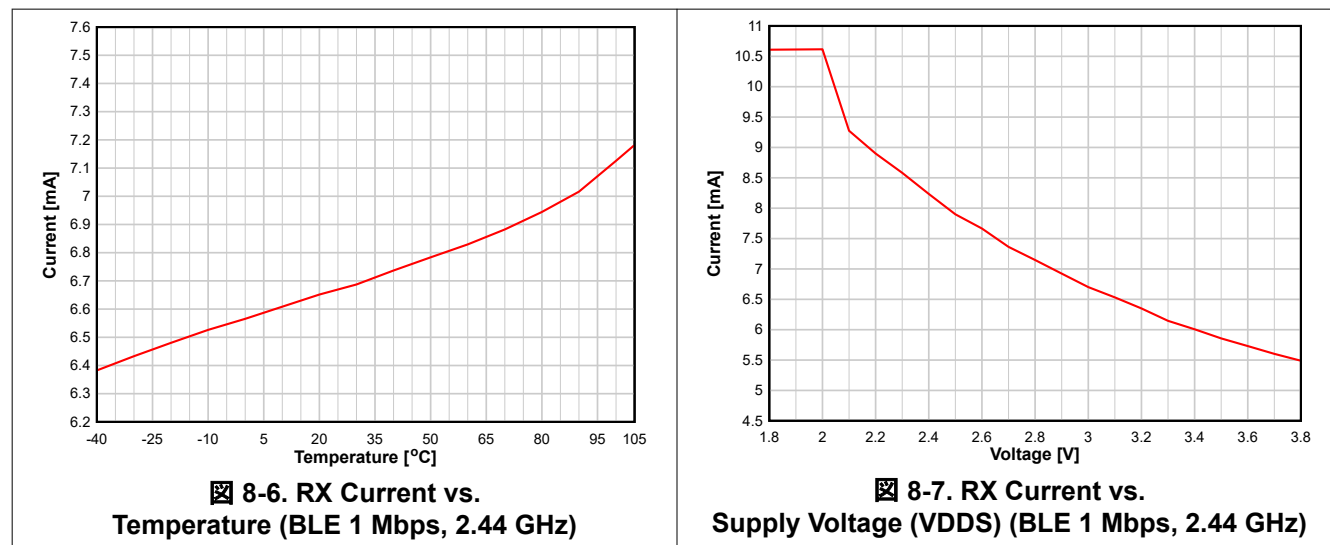
## 8.17 Typical Characteristics

All measurements in this section are done with  $T_c = 25^\circ\text{C}$  and  $V_{DD5} = 3.0\text{ V}$ , unless otherwise noted. See *Recommended Operating Conditions*, セクション 8.3, for device limits. Values exceeding these limits are for reference only.

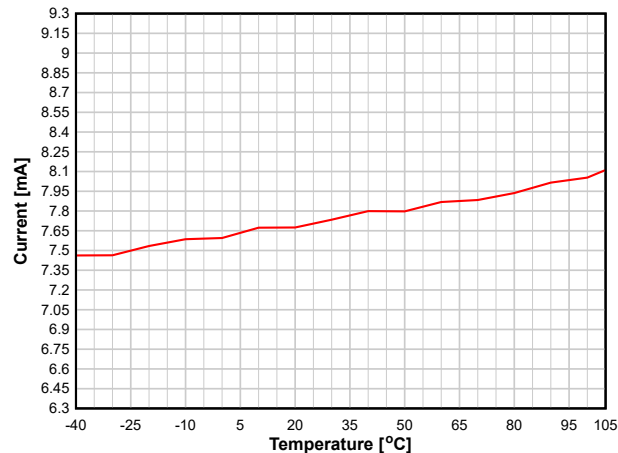
### 8.17.1 MCU Current



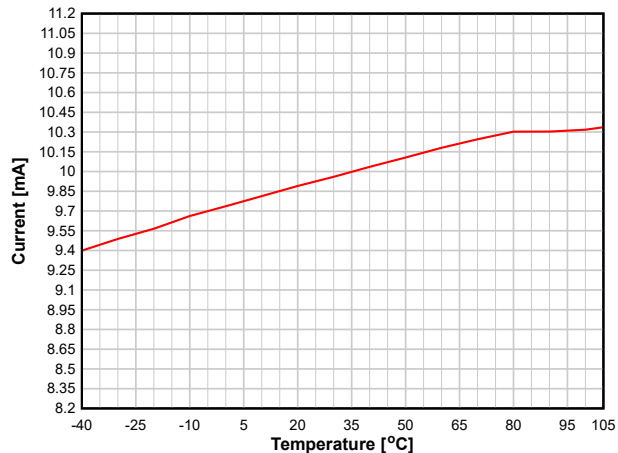
### 8.17.2 RX Current



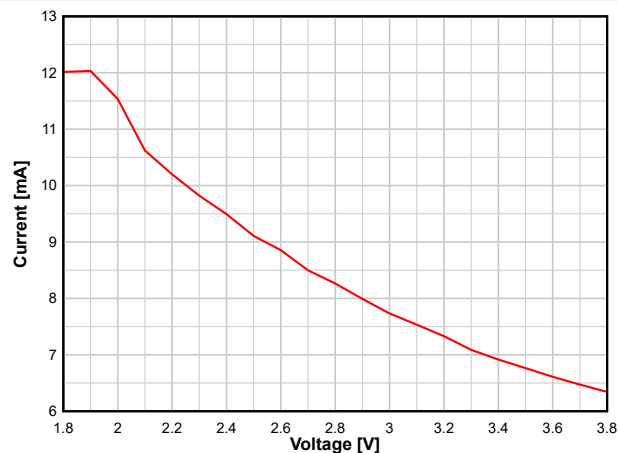
### 8.17.3 TX Current



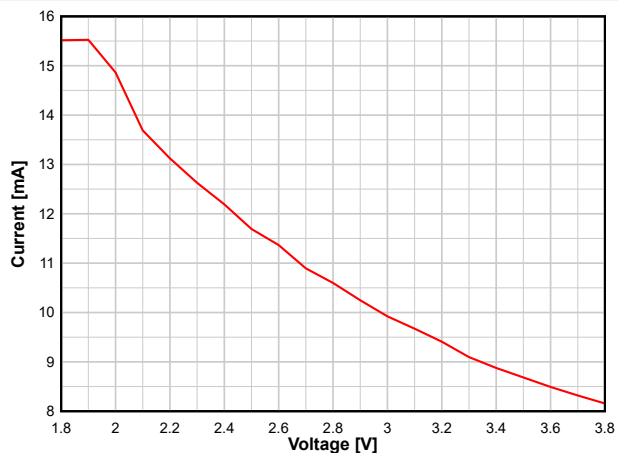
8-8. TX Current vs. Temperature  
(BLE 1 Mbps, 2.44 GHz, 0 dBm)



8-9. TX Current vs. Temperature  
(BLE 1 Mbps, 2.44 GHz, +5 dBm)



8-10. TX Current vs. Supply Voltage  
(VDD5) (BLE 1 Mbps, 2.44 GHz, 0 dBm)



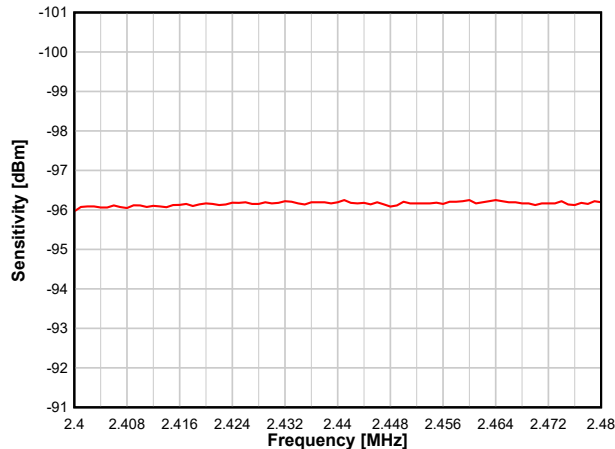
8-11. TX Current vs. Supply Voltage  
(VDD5) (BLE 1 Mbps, 2.44 GHz, +5 dBm)

表 8-1 shows the typical TX current and output power for different output power settings.

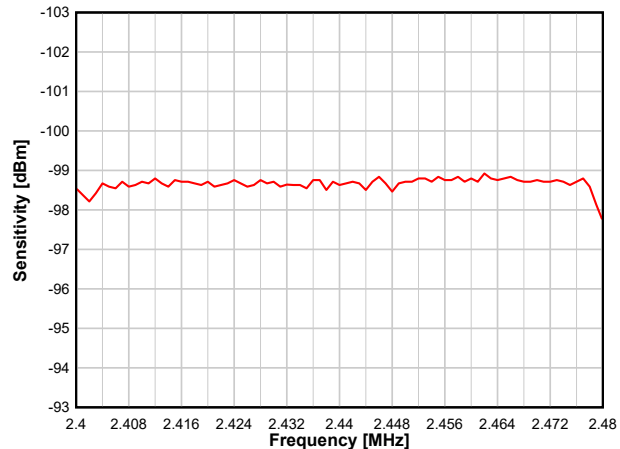
**表 8-1. Typical TX Current and Output Power**

| CC2651R3SIPA at 2.4 GHz, VDD5 = 3.0 V (Measured on CC2651RSIPA-EM) |                                   |                            |                                  |
|--------------------------------------------------------------------|-----------------------------------|----------------------------|----------------------------------|
| txPower                                                            | TX Power Setting (SmartRF Studio) | Typical Output Power [dBm] | Typical Current Consumption [mA] |
| 0xA42E                                                             | 5                                 | 4.4                        | 9.9                              |
| 0x601E                                                             | 4                                 | 3.3                        | 9.2                              |
| 0x246A                                                             | 3                                 | 2.5                        | 8.8                              |
| 0x2E64                                                             | 2                                 | 1.7                        | 8.4                              |
| 0x20A5                                                             | 1                                 | 0.7                        | 8.0                              |
| 0x20A2                                                             | 0                                 | 0.1                        | 7.7                              |
| 0x08DC                                                             | -5                                | -4.6                       | 6.4                              |
| 0x00D2                                                             | -10                               | -9.0                       | 5.6                              |
| 0x00CD                                                             | -15                               | -12.7                      | 5.2                              |
| 0x00C8                                                             | -20                               | -18.2                      | 4.8                              |

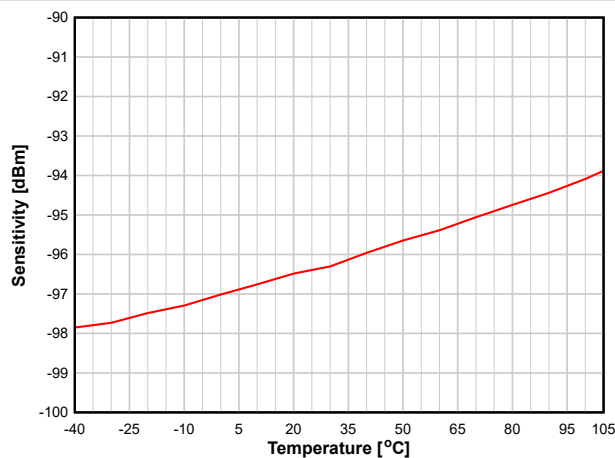
## 8.17.4 RX Performance



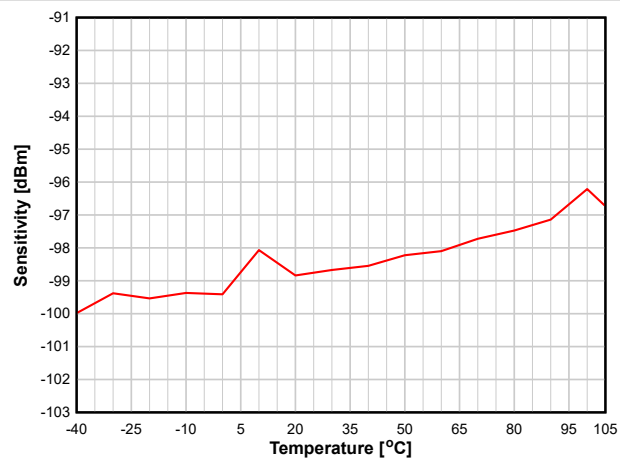
8-12. Sensitivity vs.  
Frequency (BLE 1 Mbps, 2.44 GHz)



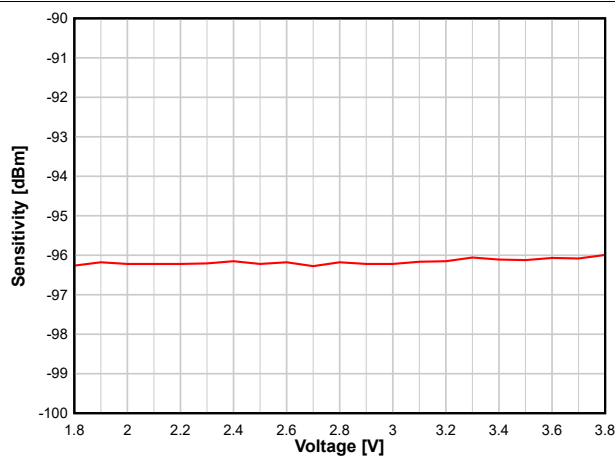
8-13. Sensitivity vs.  
Frequency (250 kbps, 2.44 GHz)



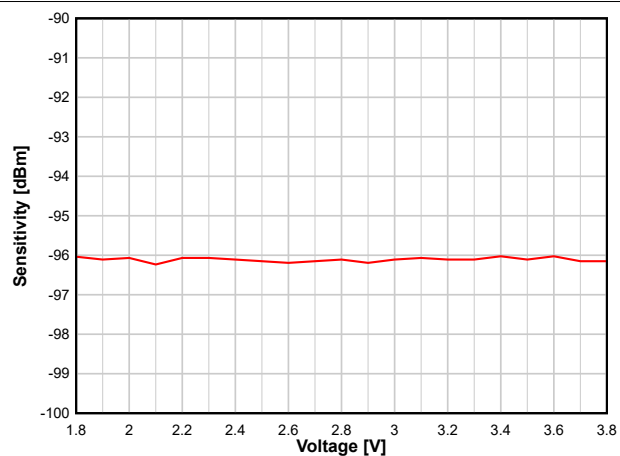
8-14. Sensitivity vs.  
Temperature (BLE 1 Mbps, 2.44 GHz)



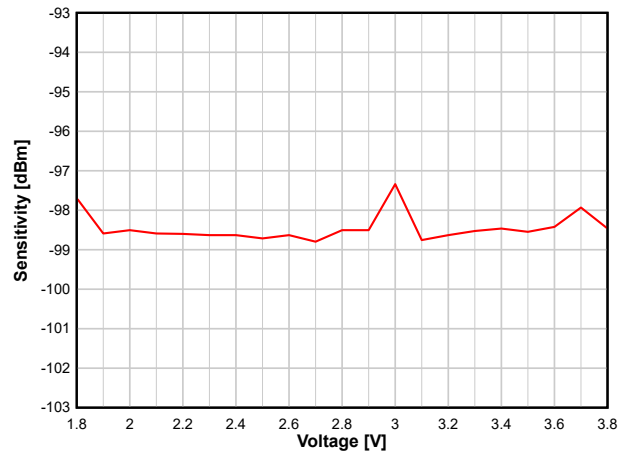
8-15. Sensitivity vs.  
Temperature (250 kbps, 2.44 GHz)



8-16. Sensitivity vs.  
Supply Voltage (VDDS) (BLE 1 Mbps, 2.44 GHz)

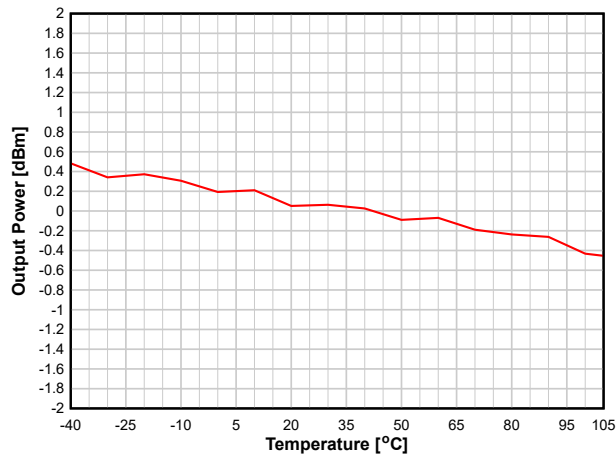


8-17. Sensitivity vs.  
Supply Voltage (VDDS) (BLE 1 Mbps, 2.44 GHz,  
DCDC Off)

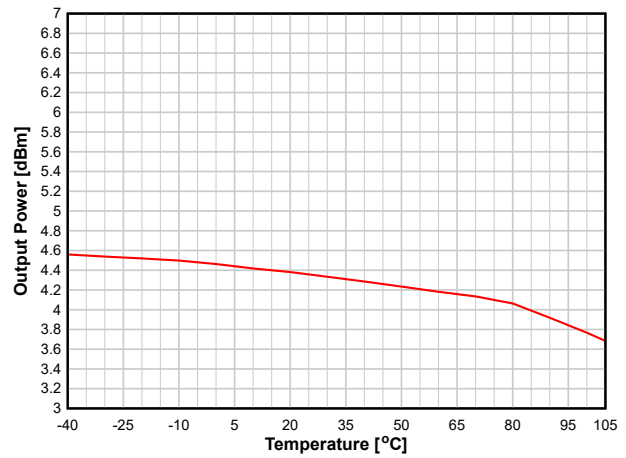


**8-18. Sensitivity vs.  
Supply Voltage (VDDS) (250 kbps, 2.44 GHz)**

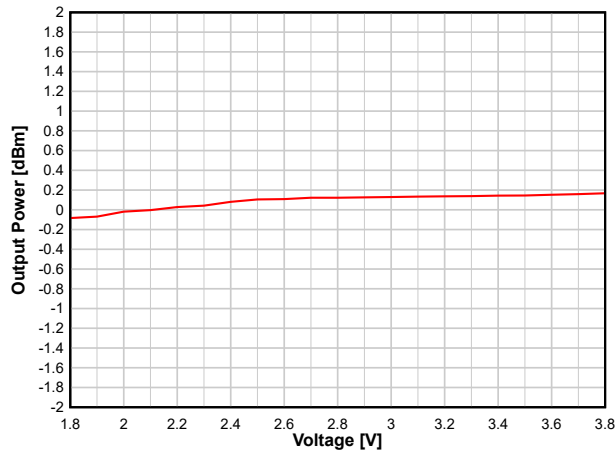
### 8.17.5 TX Performance



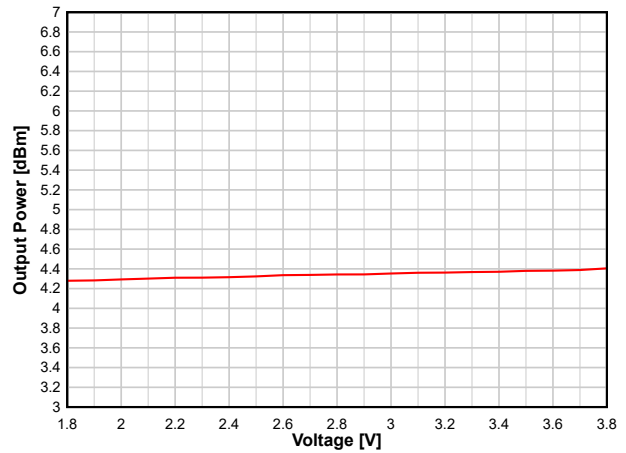
8-19. Output Power vs. Temperature  
(BLE 1 Mbps, 2.44 GHz, 0 dBm)



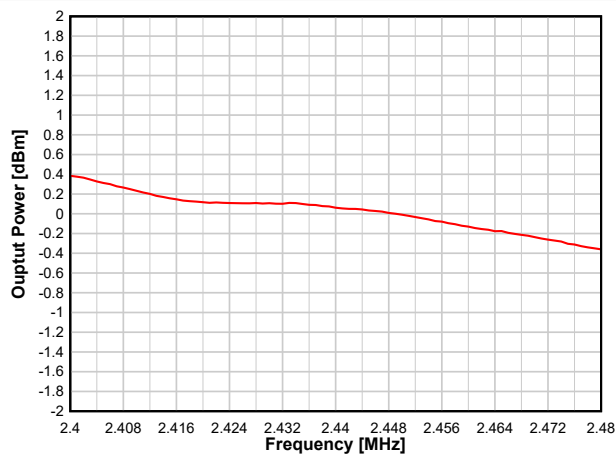
8-20. Output Power vs. Temperature  
(BLE 1 Mbps, 2.44 GHz, +5 dBm)



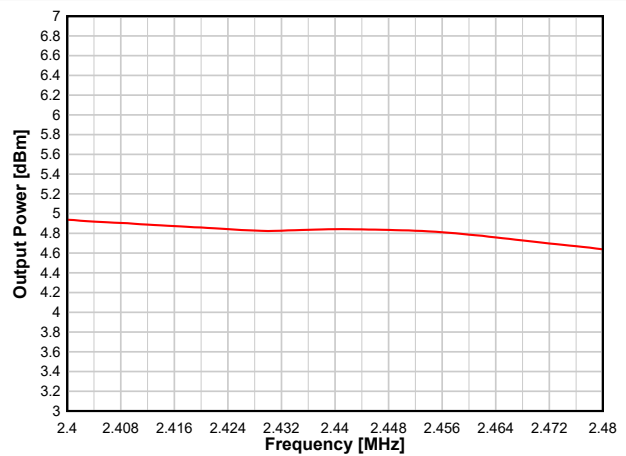
8-21. Output Power vs. Supply Voltage  
(VDD5) (BLE 1 Mbps, 2.44 GHz, 0 dBm)



8-22. Output Power vs. Supply Voltage  
(VDD5) (BLE 1 Mbps, 2.44 GHz, +5 dBm)

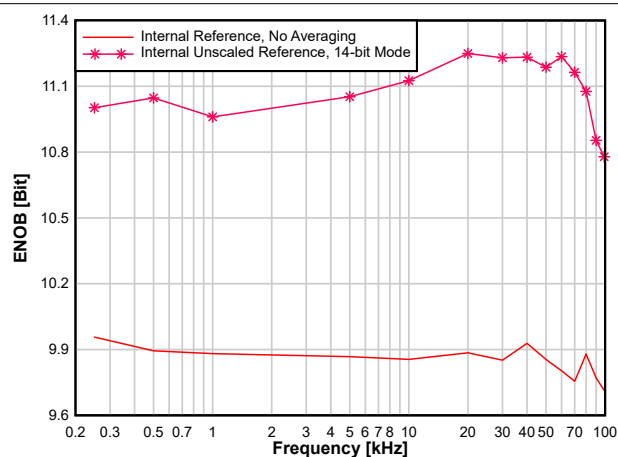


8-23. Output Power vs. Frequency  
(BLE 1 Mbps, 2.44 GHz, 0 dBm)

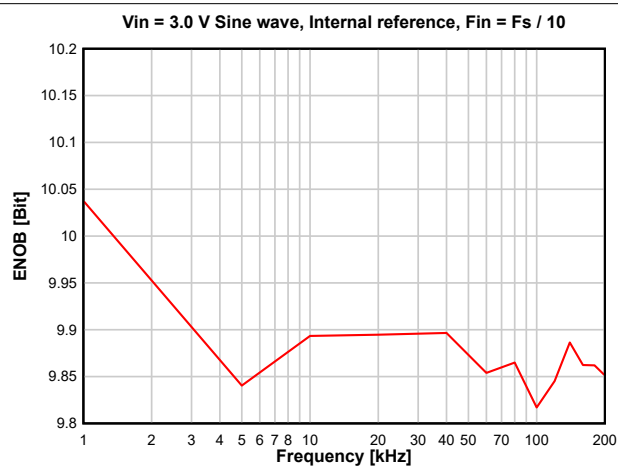


8-24. Output Power vs. Frequency  
(BLE 1 Mbps, 2.44 GHz, +5 dBm)

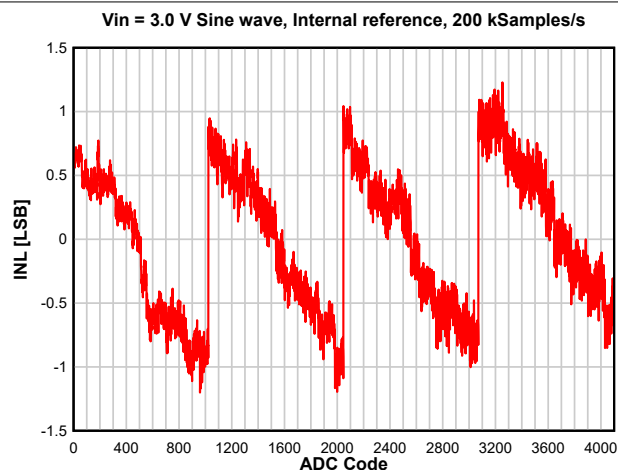
## 8.17.6 ADC Performance



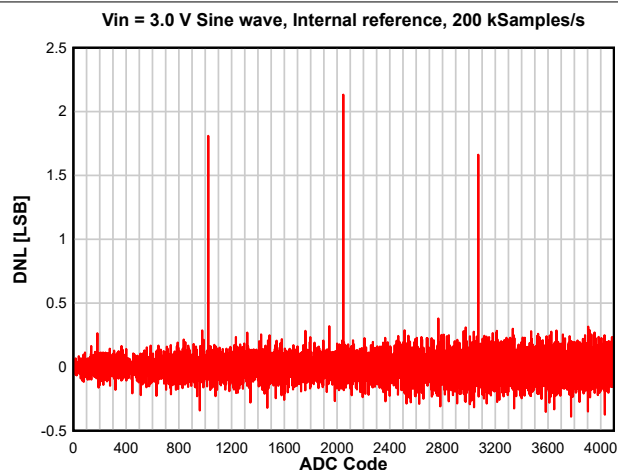
**8-25. ENOB vs.  
Input Frequency**



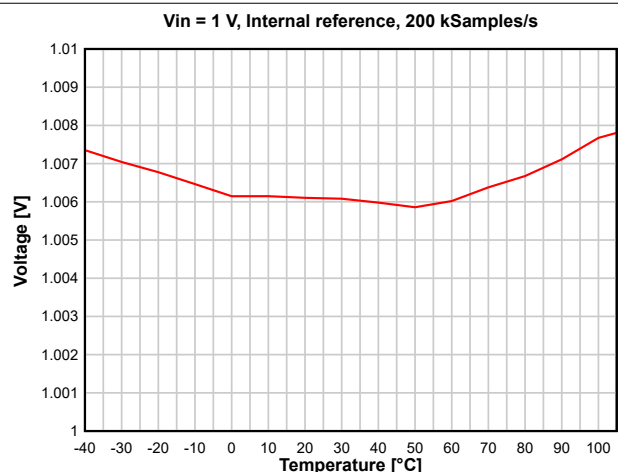
**8-26. ENOB vs.  
Sampling Frequency**



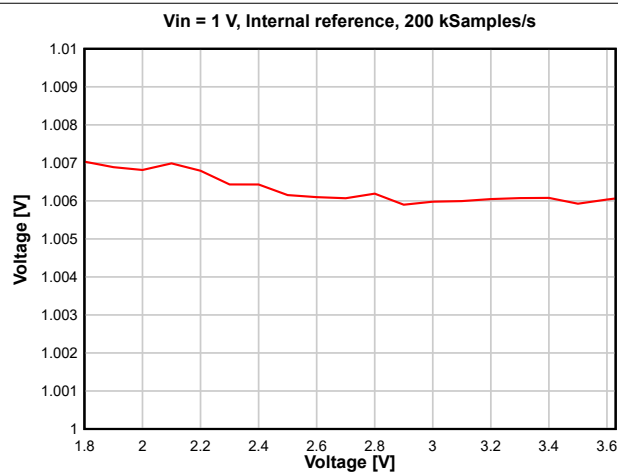
**8-27. INL vs.  
ADC Code**



**8-28. DNL vs.  
ADC Code**



**8-29. ADC Accuracy vs.  
Temperature**



**8-30. ADC Accuracy vs.  
Supply Voltage (VDDS)**

## 9 Detailed Description

### 9.1 Overview

[セクション 4](#) shows the core modules of the CC2651R3SIPA device.

### 9.2 System CPU

The CC2651R3SIPA SimpleLink™ Wireless MCU contains an Arm® Cortex®-M4 system CPU, which runs the application and the higher layers of radio protocol stacks.

The system CPU is the foundation of a high-performance, low-cost platform that meets the system requirements of minimal memory implementation, and low-power consumption, while delivering outstanding computational performance and exceptional system response to interrupts.

Its features include the following:

- ARMv7-M architecture optimized for small-footprint embedded applications
- Arm Thumb®-2 mixed 16- and 32-bit instruction set delivers the high performance expected of a 32-bit Arm core in a compact memory size
- Fast code execution permits increased sleep mode time
- Deterministic, high-performance interrupt handling for time-critical applications
- Single-cycle multiply instruction and hardware divide
- Hardware division and fast digital-signal-processing oriented multiply accumulate
- Saturating arithmetic for signal processing
- Full debug with data matching for watchpoint generation
  - Data Watchpoint and Trace Unit (DWT)
  - JTAG Debug Access Port (DAP)
  - Flash Patch and Breakpoint Unit (FPB)
- Trace support reduces the number of pins required for debugging and tracing
  - Instrumentation Trace Macrocell Unit (ITM)
  - Trace Port Interface Unit (TPIU) with asynchronous serial wire output (SWO)
- Optimized for single-cycle flash memory access
- Tightly connected to 8-KB 4-way random replacement cache for minimal active power consumption and wait states
- Ultra-low-power consumption with integrated sleep modes
- 48 MHz operation
- 1.25 DMIPS per MHz

## 9.3 Radio (RF Core)

The RF Core is a highly flexible and future proof radio module which contains an Arm Cortex-M0 processor that interfaces the analog RF and base-band circuitry, handles data to and from the system CPU side, and assembles the information bits in a given packet structure. The RF core offers a high level, command-based API to the main CPU that configurations and data are passed through. The Arm Cortex-M0 processor is not programmable by customers and is interfaced through the TI-provided RF driver that is included with the SimpleLink Software Development Kit (SDK).

The RF core can autonomously handle the time-critical aspects of the radio protocols, thus offloading the main CPU, which reduces power and leaves more resources for the user application. Several signals are also available to control external circuitry such as RF switches or range extenders autonomously.

The various physical layer radio formats are partly built as a software defined radio where the radio behavior is either defined by radio ROM contents or by non-ROM radio formats delivered in form of firmware patches with the SimpleLink SDKs. This allows the radio platform to be updated for support of future versions of standards even with over-the-air (OTA) updates while still using the same silicon.

### 9.3.1 Bluetooth 5.2 Low Energy

The RF Core offers full support for Bluetooth 5.2 Low Energy, including the high-speed 2-Mbps physical layer and the 500-kbps and 125-kbps long range PHYs (Coded PHY) through the TI provided Bluetooth 5.2 stack or through a high-level Bluetooth API. The Bluetooth 5.2 PHY and part of the controller are in radio and system ROM, providing significant savings in memory usage and more space available for applications.

The new high-speed mode allows data transfers up to 2 Mbps, twice the speed of Bluetooth 4.2 and five times the speed of Bluetooth 4.0, without increasing power consumption. In addition to faster speeds, this mode offers significant improvements for energy efficiency and wireless coexistence with reduced radio communication time.

Bluetooth 5.2 also enables unparalleled flexibility for adjustment of speed and range based on application needs, which capitalizes on the high-speed or long-range modes respectively. Data transfers are now possible at 2 Mbps, enabling development of applications using voice, audio, imaging, and data logging that were not previously an option using Bluetooth low energy. With high-speed mode, existing applications deliver faster responses, richer engagement, and longer battery life. Bluetooth 5.2 enables fast, reliable firmware updates.

### 9.3.2 802.15.4 (Zigbee)

Through a dedicated IEEE radio API, the RF Core supports the 2.4-GHz IEEE 802.15.4-2011 physical layer (2 Mcps per second Offset-QPSK with DSSS 1:8), used in the Zigbee protocol. The 802.15.4 PHY and MAC are in radio and system ROM. TI also provides royalty-free protocol stacks for Zigbee as part of the SimpleLink SDK, enabling a robust end-to-end solution.

## 9.4 Memory

The up to 352-KB nonvolatile (Flash) memory provides storage for code and data. The flash memory is in-system programmable and erasable. The last flash memory sector must contain a Customer Configuration section (CCFG) that is used by boot ROM and TI provided drivers to configure the device. This configuration is done through the `ccfg.c` source file that is included in all TI provided examples.

The ultra-low leakage system static RAM (SRAM) is a single 32-KB block and can be used for both storage of data and execution of code. Retention of SRAM contents in Standby power mode is enabled by default and included in Standby mode power consumption numbers.

To improve code execution speed and lower power when executing code from nonvolatile memory, a 4-way nonassociative 8-KB cache is enabled by default to cache and prefetch instructions read by the system CPU. The cache can be used as a general-purpose RAM by enabling this feature in the Customer Configuration Area (CCFG).

The ROM contains a serial (SPI and UART) bootloader that can be used for initial programming of the device.

## 9.5 Cryptography

The CC2651R3SIPA device comes with a wide set of cryptography-related hardware accelerators, reducing code footprint and execution time for cryptographic operations. It also has the benefit of being lower power and improves availability and responsiveness of the system because the cryptography operations run in a background hardware thread. The hardware accelerator modules are:

- **True Random Number Generator (TRNG)** module provides a true, nondeterministic noise source for the purpose of generating keys, initialization vectors (IVs), and other random number requirements. The TRNG is built on 24 ring oscillators that create unpredictable output to feed a complex nonlinear-combinatorial circuit.
- **Advanced Encryption Standard (AES)** with 128 bit key lengths

Together with the hardware accelerator module, a large selection of open-source cryptography libraries provided with the Software Development Kit (SDK), this allows for secure and future proof IoT applications to be easily built on top of the platform. The TI provided cryptography drivers are:

- **Key Agreement Schemes**
  - Elliptic curve Diffie-Hellman with static or ephemeral keys (ECDH and ECDHE)
  - Elliptic curve Password Authenticated Key Exchange by Juggling (ECJ-PAKE)
- **Signature Generation**
  - Elliptic curve Diffie-Hellman Digital Signature Algorithm (ECDSA)
- **Curve Support**
  - Short Weierstrass form (full hardware support), such as:
    - NIST-P224, NIST-P256, NIST-P384, NIST-P521
    - Brainpool-256R1, Brainpool-384R1, Brainpool-512R1
    - secp256r1
  - Montgomery form (hardware support for multiplication), such as:
    - Curve25519
- **SHA2 based MACs**
  - HMAC with SHA224, SHA256, SHA384, or SHA512
- Block cipher mode of operation
  - AESCCM
  - AESGCM
  - AESECB
  - AESCBC
  - AESCBC-MAC
- **True random number generation**

Other capabilities, such as RSA encryption and signatures as well as Edwards type of elliptic curves such as Curve1174 or Ed25519, are a provided part of the TI SimpleLink SDK for the CC2651R3SIPA device.

## 9.6 Timers

A large selection of timers are available as part of the CC2651R3SIPA device. These timers are:

- **Real-Time Clock (RTC)**

A 70-bit 3-channel timer running on the 32 kHz low frequency system clock (SCLK\_LF)

This timer is available in all power modes except Shutdown. The timer can be calibrated to compensate for frequency drift when using the LF RCOSC as the low frequency system clock. If an external LF clock with frequency different from 32.768 kHz is used, the RTC tick speed can be adjusted to compensate for this. When using TI-RTOS, the RTC is used as the base timer in the operating system and should thus only be accessed through the kernel APIs such as the Clock module. By default, the RTC halts when a debugger halts the device.

- **General Purpose Timers (GPTIMER)**

The four flexible GPTIMERS can be used as either 4× 32 bit timers or 8× 16 bit timers, all running on up to 48 MHz. Each of the 16- or 32-bit timers support a wide range of features such as one-shot or periodic counting, pulse width modulation (PWM), time counting between edges and edge counting. The inputs and outputs of the timer are connected to the device event fabric, which allows the timers to interact with signals such as GPIO inputs, other timers, DMA and ADC. The GPTIMERS are available in Active and Idle power modes.

- **Radio Timer**

A multichannel 32-bit timer running at 4 MHz is available as part of the device radio. The radio timer is typically used as the timing base in wireless network communication using the 32-bit timing word as the network time. The radio timer is synchronized with the RTC by using a dedicated radio API when the device radio is turned on or off. This ensures that for a network stack, the radio timer seems to always be running when the radio is enabled. The radio timer is in most cases used indirectly through the trigger time fields in the radio APIs and should only be used when running the accurate 48 MHz high frequency crystal is the source of SCLK\_HF.

- **Watchdog timer**

The watchdog timer is used to regain control if the system operates incorrectly due to software errors. It is typically used to generate an interrupt to and reset of the device for the case where periodic monitoring of the system components and tasks fails to verify proper functionality. The watchdog timer runs on a 1.5 MHz clock rate and cannot be stopped once enabled. The watchdog timer pauses to run in Standby power mode and when a debugger halts the device.

## 9.7 Serial Peripherals and I/O

The SSI is a synchronous serial interfaces that are compatible with SPI, MICROWIRE, and TI's synchronous serial interfaces. The SSIs support both SPI controller and peripheral up to 4 MHz. The SSI modules support configurable phase and polarity.

The UARTs implement universal asynchronous receiver and transmitter functions. They support flexible baud-rate generation up to a maximum of 3 Mbps.

The I<sup>2</sup>S interface is used to handle digital audio and can also be used to interface pulse-density modulation microphones (PDM).

The I<sup>2</sup>C interface is also used to communicate with devices compatible with the I<sup>2</sup>C standard. The I<sup>2</sup>C interface can handle 100 kHz and 400 kHz operation, and can serve as both controller and peripheral.

The I/O controller (IOC) controls the digital I/O pins and contains multiplexer circuitry to allow a set of peripherals to be assigned to I/O pins in a flexible manner. All digital I/Os are interrupt and wake-up capable, have a programmable pullup and pulldown function, and can generate an interrupt on a negative or positive edge (configurable). When configured as an output, pins can function as either push-pull or open-drain. Five GPIOs have high-drive capabilities, which are marked in **bold** in [セクション 7](#). All digital peripherals can be connected to any digital pin on the device.

For more information, see the [CC13x1x2, CC26x1x2 SimpleLink™ Wireless MCU Technical Reference Manual](#).

## 9.8 Battery and Temperature Monitor

A combined temperature and battery voltage monitor is available in the CC2651R3SIPA device. The battery and temperature monitor allows an application to continuously monitor on-chip temperature and supply voltage and respond to changes in environmental conditions as needed. The module contains window comparators to interrupt the system CPU when temperature or supply voltage go outside defined windows. These events can also be used to wake up the device from Standby mode through the Always-On (AON) event fabric.

## 9.9 $\mu$ DMA

The device includes a direct memory access ( $\mu$ DMA) controller. The  $\mu$ DMA controller provides a way to offload data-transfer tasks from the system CPU, thus allowing for more efficient use of the processor and the available bus bandwidth. The  $\mu$ DMA controller can perform a transfer between memory and peripherals. The  $\mu$ DMA controller has dedicated channels for each supported on-chip module and can be programmed to automatically perform transfers between peripherals and memory when the peripheral is ready to transfer more data.

Some features of the  $\mu$ DMA controller include the following (this is not an exhaustive list):

- Highly flexible and configurable channel operation of up to 32 channels
- Transfer modes: memory-to-memory, memory-to-peripheral, peripheral-to-memory, and peripheral-to-peripheral
- Data sizes of 8, 16, and 32 bits
- Ping-pong mode for continuous streaming of data

## 9.10 Debug

The on-chip debug support is done through a dedicated cJTAG (IEEE 1149.7) or JTAG (IEEE 1149.1) interface. The device boots by default into cJTAG mode and must be reconfigured to use 4-pin JTAG.

## 9.11 Power Management

To minimize power consumption, the CC2651R3SIPA supports a number of power modes and power management features (see 表 9-1).

表 9-1. Power Modes

| MODE                              | SOFTWARE CONFIGURABLE POWER MODES |                     |                     |           | RESET PIN<br>HELD |
|-----------------------------------|-----------------------------------|---------------------|---------------------|-----------|-------------------|
|                                   | ACTIVE                            | IDLE                | STANDBY             | SHUTDOWN  |                   |
| <b>CPU</b>                        | Active                            | Off                 | Off                 | Off       | Off               |
| <b>Flash</b>                      | On                                | Available           | Off                 | Off       | Off               |
| <b>SRAM</b>                       | On                                | On                  | Retention           | Off       | Off               |
| <b>Supply System</b>              | On                                | On                  | Duty Cycled         | Off       | Off               |
| Register and CPU retention        | Full                              | Full                | Partial             | No        | No                |
| SRAM retention                    | Full                              | Full                | Full                | No        | No                |
| 48 MHz high-speed clock (SCLK_HF) | XOSC_HF or RCOSC_HF               | XOSC_HF or RCOSC_HF | Off                 | Off       | Off               |
| 32 kHz low-speed clock (SCLK_LF)  | XOSC_LF or RCOSC_LF               | XOSC_LF or RCOSC_LF | XOSC_LF or RCOSC_LF | Off       | Off               |
| Peripherals                       | Available                         | Available           | Off                 | Off       | Off               |
| Wake-up on RTC                    | Available                         | Available           | Available           | Off       | Off               |
| Wake-up on pin edge               | Available                         | Available           | Available           | Available | Off               |
| Wake-up on reset pin              | On                                | On                  | On                  | On        | On                |
| Brownout detector (BOD)           | On                                | On                  | Duty Cycled         | Off       | Off               |
| Power-on reset (POR)              | On                                | On                  | On                  | Off       | Off               |
| Watchdog timer (WDT)              | Available                         | Available           | Paused              | Off       | Off               |

In **Active** mode, the application system CPU is actively executing code. Active mode provides normal operation of the processor and all of the peripherals that are currently enabled. The system clock can be any available clock source (see 表 9-1).

In **Idle** mode, all active peripherals can be clocked, but the Application CPU core and memory are not clocked and no code is executed. Any interrupt event brings the processor back into active mode.

In **Standby** mode, only the always-on (AON) domain is active. An external wake-up event or RTC event is required to bring the device back to active mode. MCU peripherals with retention do not need to be reconfigured when waking up again, and the CPU continues execution from where it went into standby mode. All GPIOs are latched in standby mode.

In **Shutdown** mode, the device is entirely turned off (including the AON domain), and the I/Os are latched with the value they had before entering shutdown mode. A change of state on any I/O pin defined as a *wake from shutdown pin* wakes up the device and functions as a reset trigger. The CPU can differentiate between reset in this way and reset-by-reset pin or power-on reset by reading the reset status register. The only state retained in this mode is the latched I/O state and the flash memory contents.

### 注

The power, RF and clock management for the CC2651R3SIPA device require specific configuration and handling by software for optimized performance. This configuration and handling is implemented in the TI-provided drivers that are part of the CC2651R3SIPA software development kit (SDK). Therefore, TI highly recommends using this software framework for all application development on the device. The complete [SDK](#) with TI-RTOS (optional), device drivers, and examples are offered free of charge in source code.

## 9.12 Clock Systems

The CC2651R3SIPA device has several internal system clocks.

The 48 MHz SCLK\_HF is used as the main system (MCU and peripherals) clock. This can be driven by the internal 48 MHz RC Oscillator (RCOSC\_HF) or in-package 48 MHz crystal (XOSC\_HF). Note that the radio operation runs off the included, in-package 48 MHz crystal within the module.

SCLK\_LF is the 32.768 kHz internal low-frequency system clock. It can be used for the RTC and to synchronize the radio timer before or after Standby power mode. SCLK\_LF can be driven by the internal 32.8 kHz RC Oscillator (RCOSC\_LF), a 32.768 kHz watch-type crystal, or a clock input on any digital IO.

When using a crystal or the internal RC oscillator, the device can output the 32 kHz SCLK\_LF signal to other devices, thereby reducing the overall system cost.

## 9.13 Network Processor

Depending on the product configuration, the CC2651R3SIPA device can function as a wireless network processor (WNP - a device running the wireless protocol stack with the application running on a separate host MCU), or as a system-on-chip (SoC) with the application and protocol stack running on the system CPU inside the device.

In the first case, the external host MCU communicates with the device using SPI or UART. In the second case, the application must be written according to the application framework supplied with the wireless protocol stack.

## 9.14 Device Certification and Qualification

The CC2651R3SIPA module from TI is certified for FCC, IC/ISED, ETSI/CE, RER (UK), Korea, MIC (Japan), and Taiwan as listed in 表 9-2. Moreover, the module is a Bluetooth Qualified Design by the Bluetooth Special Interest Group (Bluetooth SIG). TI Customers that build products based on the TI CC2651R3SIPA module can save in testing cost and time per product family.

### 注

The FCC, IC, Korea, Japan, and Taiwan IDs, as well as the CE, UK, Korea, and Japan markings, must be located in both the user manual and on the packaging. Due to the small size of the module (7 mm x 7 mm), placing the IDs and markings in a type size large enough to be legible without the aid of magnification is impractical.

**表 9-2. CC2651R3SIPA List of Certifications**

| Regulatory Body             | Specification                              | ID (IF APPLICABLE) |
|-----------------------------|--------------------------------------------|--------------------|
| FCC (USA)                   | Part 15C + MPE FCC RF Exposure (Bluetooth) | ZAT-2651R3SIPA     |
|                             | Part 15C + MPE FCC RF Exposure (802.15.4)  |                    |
| IC/ISED (Canada)            | RSS-102 (MPE) and RSS-247 (Bluetooth)      | 451H-2651R3SIPA    |
|                             | RSS-102 (MPE) and RSS-247 (802.15.4)       |                    |
| ETSI/CE (Europe) & RER (UK) | EN 300328 v2.2.2 (2019-07) (Bluetooth)     | —                  |
|                             | EN 300328 v2.2.2 (2019-07) (802.15.4)      | —                  |
|                             | EN 62311:2020 and EN 50655:2017 (MPE)      | —                  |
|                             | EN 301 489-1 v2.2.3 (2019-11)              | —                  |
|                             | EN 301489-17 v3.2.4 (2020-09)              | —                  |
|                             | EN 62368-1:2020/A11:2020                   | —                  |
| Korea                       | Clause 2, Article 58-2 of Radio Waves Act. | R-C-T3P-2651R3SIPA |
| MIC (Japan)                 | Article 49-20 of ORRE                      | 201-230017         |
| Taiwan                      | NCC LP002 (2020-07-01)                     | CCAF23Y10010T2     |

### 9.14.1 FCC Certification and Statement

#### 注意

#### FCC RF Radiation Exposure Statement:

This equipment complies with FCC radiation exposure limits set forth for an uncontrolled environment. End users must follow the specific operating instructions for satisfying RF exposure limits. This transmitter must not be co-located or operating with any other antenna or transmitter.

The CC2651R3SIPAT0MOUR module from TI is certified for the FCC as a single-modular transmitter. The module is an FCC-certified radio module that carries a modular grant.

You are cautioned that changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This device is planned to comply with Part 15 of the FCC Rules. Operation is subject to the following two conditions:

- This device may not cause harmful interference.
- This device must accept any interference received, including interference that may cause undesired operation of the device.

### 9.14.2 IC/ISED Certification and Statement

#### 注意

##### IC RF Radiation Exposure Statement:

To comply with IC RF exposure requirements, this device and its antenna must not be co-located or operating in conjunction with any other antenna or transmitter.

Pour se conformer aux exigences de conformité RF canadienne l'exposition, cet appareil et son antenne ne doivent pas être co-localisés ou fonctionnant en conjonction avec une autre antenne ou transmetteur.

The CC2651R3SIPAT0MOUR module from TI is certified for IC as a single-modular transmitter. The CC2651R3SIPA module from TI meets IC modular approval and labeling requirements. The IC follows the same testing and rules as the FCC regarding certified modules in authorized equipment.

This device complies with Industry Canada licence-exempt RSS standards.

Operation is subject to the following two conditions:

- This device may not cause interference.
- This device must accept any interference, including interference that may cause undesired operation of the device.

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence.

L'exploitation est autorisée aux deux conditions suivantes:

- L'appareil ne doit pas produire de brouillage
- L'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

### 9.14.3 ETSI/CE Certification

The CC2651R3SIPAT0MOUR module from TI is CE certified with certifications to the appropriate EU radio and EMC directives summarized in the Declaration of Conformity and evidenced by the CE mark. The module is tested and certified against the Radio Equipment Directive (RED).

See the full text of the for the [EU Declaration of Conformity](#) for the CC2651R3SIPAT0MOU device.

### 9.14.4 UK Certification

The CC2651R3SIPAT0MOUR module from TI is UK certified with certifications to the appropriate UK radio and EMC directives summarized in the Declaration of Conformity and evidenced by the UK mark. The module is tested and certified against the Radio Equipment Regulations 2017.

See the full text of the for the [UK Declaration of Conformity](#) for the CC2651R3SIPAT0MOU device.

### 9.14.5 MIC Certification

The CC2651R3SIPAT0MOUR modules from TI is MIC certified against article 49-20 and the relevant articles of the Ordinance Regulating Radio Equipment.

Operation is subject to the following condition:

- The host system does not contain a wireless wide area network (WWAN) device.

### 9.14.6 Korea Certification

The CC2651R3SIPAT0MOUR modules from TI is Korea certified against article 58-2 and the relevant articles of the Radio Waves Act. In addition it is the responsibility of the OEM to ensure the Korea device, label, and user manual requirements are met per [表 9-3](#)

表 9-3. KCC Label and User Manual Requirements for EOM

| KCC Label Requirements <sup>(1)</sup> | Information                                                                                                              | Device <sup>(2) (3)</sup> | Package <sup>(2) (3)</sup> | User Manual <sup>(2) (3)</sup> |
|---------------------------------------|--------------------------------------------------------------------------------------------------------------------------|---------------------------|----------------------------|--------------------------------|
| KC Mark                               |                                         | M                         | M                          |                                |
| KC ID                                 | R-C-T3P2651R3SIPA                                                                                                        | M                         | M                          |                                |
| Applicant Name                        | Texas Instruments                                                                                                        | M, E                      | M, E                       | M, E                           |
| Product Name                          | CC2651R3SIPA SimpleLink™ Multiprotocol 2.4-GHz Wireless System-in-Package Module with Integrated Antenna & 352-KB Memory | M, E                      | M, E                       | M, E                           |
| Model Name                            | CC2651R3SIPAT0MOUR                                                                                                       | M, E                      | M, E                       | M, E                           |
| Manufacturer name                     | Texas Instruments Inc.                                                                                                   | M, E                      | M, E                       | M, E                           |
| Manufacturing country                 | Taiwan                                                                                                                   | M, E                      | M, E                       | M, E                           |
| Manufacturing year                    | 2023                                                                                                                     | M, E                      | M, E                       | M, E                           |

(1) For small products with a maximum area of 400 mm<sup>2</sup> or less, and where a label cannot be marked, the label can be attached to the product packaging or only a basic design, or identification code can be marked on the product.

(2) M = Mandatory

(3) E = OEM integrator can choose to where to place the information

#### 9.14.7 NCC Certification and Statement

The CC2651R3SIPAT0MOUR modules from TI is NCC certified against NCC LP002.

Operation is subject to the following condition:

- 「取得審驗證明之低功率射頻器材，非經核准，公司、商號或使用者均不得擅自變更頻率、加大功率或變更原設計之特性及功能。低功率射頻器材之使用不得影響飛航安全及干擾合法通信；經發現有干擾現象時，應立即停用，並改善至無干擾時方得繼續使用。前述合法通信，指依電信管理法規定作業之無線電信。低功率射頻器材須忍受合法通信或工業、科學及醫療用電波輻射性電機設備之干擾。」

"A company, a trade name or an operator may not change frequency, increase power or change the characteristics and functions of the original design without approval for lowpower RF equipment as verified." The use of low-power RF equipment shall not affect the safety of flight and interfere with lawful communication, and shall be immediately deactivated if interference is found and shall be improved to non-interference. The aforementioned legal communication refers to radio communications operating in accordance with the provisions of the Telecommunications Administration Act. Low-power RF equipment is subject to interference from legitimate communications or industrial, scientific and medical radiowave radio-motor equipment."

- 「本公司於說明書中提供所有必要資訊以指導使用者/安裝者正確的安裝及操作」。

"The Company provides all necessary information in the instructions to guide the correct installation and operation of the user/installer."

- 「平台商應於最終產品本體明顯處標示 本產品內含射頻模組 (CCAF23Y10010T2) 」。

"The platform provider shall mark it clearly on the body of the final product:

This product contains RF module (CCAF23Y10010T2"

## 9.15 Module Markings

図 9-1 shows the top-side marking for the CC2651R3SIPA module.



図 9-1. Top-Side Marking

表 9-4 lists the CC2651R3SIPA module markings.

表 9-4. Module Descriptions

| MARKING  | DESCRIPTION                         |
|----------|-------------------------------------|
| CC2651   | Generic Part Number                 |
| R        | Model                               |
| SIPA     | SIPA = Module type, X = pre-release |
| NNN NNNN | LTC (Lot Trace Code)                |

## 9.16 End Product Labeling

The CC2651R3SIPAT0MOUR module complies with the FCC single modular FCC grant, FCC ID: **ZAT-2651R3SIPA**. The host system using this module must display a visible label indicating the following text:

- Contains FCC ID: **ZAT-2651R3SIPA**

The CC2651R3SIPAT0MOUR module complies with the IC single modular IC grant, IC: **451H-2651R3SIPA**. The host system using this module must display a visible label indicating the following text:

- Contains IC: **451H-2651R3SIPA**

The CC2651R3SIPAT0MOUR module complies with the EU Directive 2014/53/EU and with the UK Radio Equipment Regulations 2017. The host system using this module must display a visible label with the CE and UKCA markings.

The CC2651R3SIPAT0MOUR module is designed to comply with the JP statement, **201-230017**. The host system using this module must display a visible label indicating the following text:

- Contains transmitter module with certificate number: **201-230017**

The CC2651R3SIPAT0MOUR module is designed to comply with Taiwan NCC,  **CCAF23Y10010T2**. The host system using this module must display a visible label indicating the following text:

- 本產品內含射頻模組:  **CCAF23Y10010T2**

The CC2651R3SIPAT0MOUR module is designed to comply with Korea statement, **R-C-T3P-2651R3SIPA**. The host system using this module must display a visible label indicating the following text in addition to the KC marking:

- R-C-T3P-2651R3SIPA**

For more information on end product labeling and a sample label, please see section 4 of the [OEM Integrators Guide](#)

### 9.17 Manual Information to the End User

The OEM integrator must be aware not to provide information to the end user regarding how to install or remove this RF module in the user's manual of the end product which integrates this module.

The end user manual must include all required regulatory information and warnings as shown in this manual.

## 10 Application, Implementation, and Layout

### 注

以下のアプリケーション情報は、TI の製品仕様に含まれるものではなく、TI ではその正確性または完全性を保証いたしません。個々の目的に対する製品の適合性については、お客様の責任で判断していただくことになります。お客様は自身の設計実装を検証しテストすることで、システムの機能を確認する必要があります。

### 10.1 Typical Application Circuit

図 10-1 shows the typical application schematic using the CC2651R3SIPA module. Note that C15 should be assembled when using the integrated antenna option within the module and when the layout design guidelines in セクション 10.4.2 are strictly followed. If the layout guidelines described in セクション 10.4.2 cannot be followed, it is recommended to implement the alternate application circuit schematic in セクション 10.2 and follow the alternate layout guidelines in セクション 10.4.4.

If using the external antenna option, C14 should be assembled. In addition, Pin 15 of the module should be connected to GND as shown in 図 10-2. For the full reference schematic, download the [LP-CC2651R3SIPA Design Files](#).

### 注

The following guidelines are recommended for implementation of the RF design when using an external antenna on the RF path, pin 14:

- Ensure an RF path is designed with an impedance of 50  $\Omega$ .
- Tuning of the antenna impedance  $\pi$  matching network is recommended after manufacturing of the PCB to account for PCB parasitics.
- $\pi$  or L matching and tuning may be required between RF out path, pin 14, and the external connection as shown in 図 10-2.

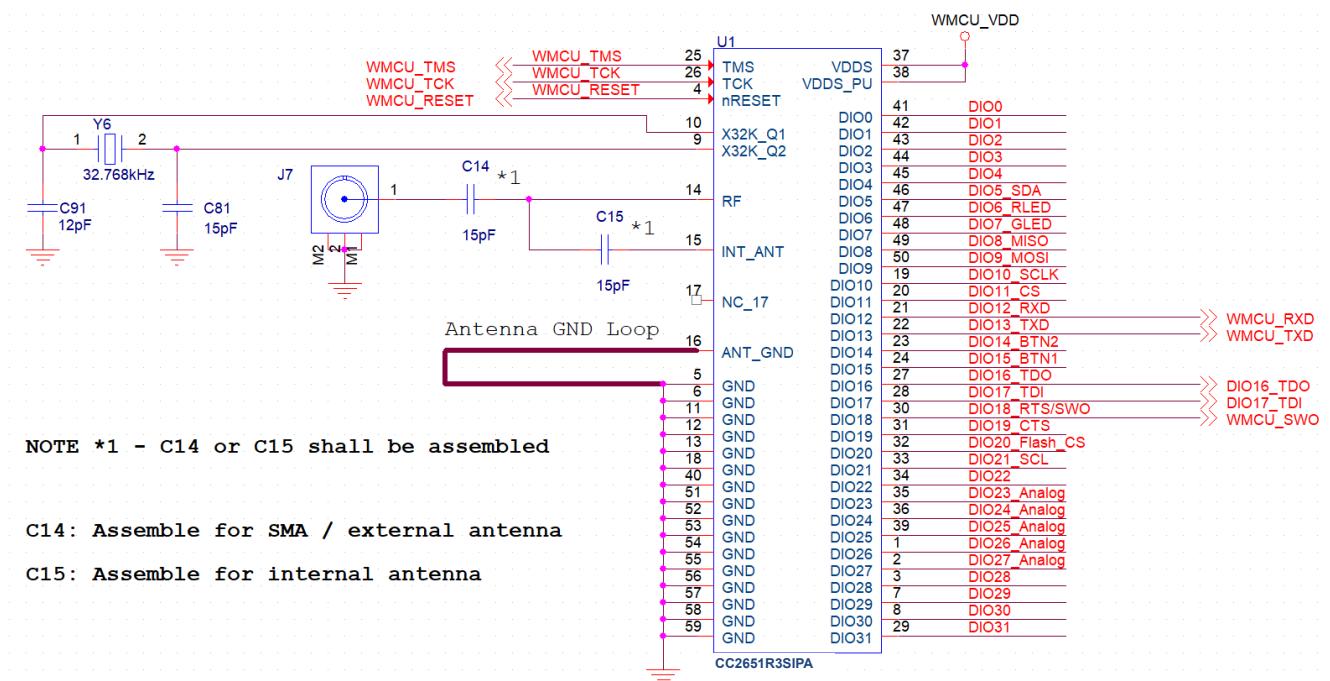
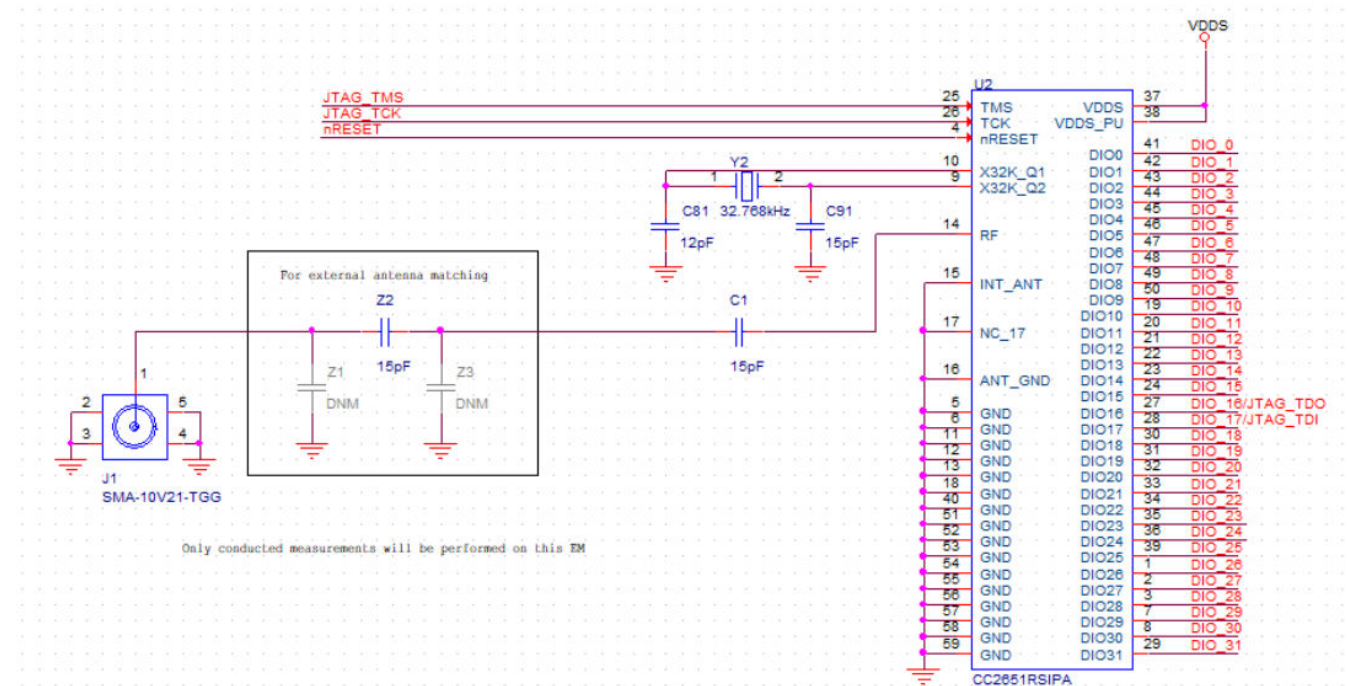


図 10-1. CC2651R3SIPA Typical Application Schematic



10-2. CC2651R3SIPA Typical Application Schematic for External Antenna Connection

表 10-1 provides the bill of materials for a typical application using the CC2651R3SIPA module with the internal antenna as shown in 図 10-1, while 表 10-2 provides the bill of materials for a typical application using the CC2651R3SIPA module with an external antenna as shown in 図 10-2

**表 10-1. Bill of Materials for Internal Antenna Configuration**

| PART REFERENCE               | VALUE        | MANUFACTURER      | PART NUMBER        | DESCRIPTION                                                                                |
|------------------------------|--------------|-------------------|--------------------|--------------------------------------------------------------------------------------------|
| C14, C15, C91 <sup>(1)</sup> | 15 pF        | Murata            | GRM0335C1E150JA01D | Capacitor, ceramic, 15 pF, 50 V, ±5%, C0G/NP0, 0201                                        |
| C81                          | 12 pF        | Murata            | GRT0335C1H120JA02D | Capacitor, ceramic, 12 pF, 50 V, ±5%, C0G/NP0, 0201                                        |
| J7                           | U.FL         | Hirose            | U.FL-R-SMT-1(01)   | U.FL (UMCC) connector receptacle, male pin 50 Ω, surface mount solder                      |
| U1                           | CC2651R3SIPA | Texas Instruments | CC2651R3SIPAT0MOUR | SimpleLink™ multiprotocol 2.4-GHz wireless MCU with integrated power amplifier and Antenna |
| Y6                           | 32.768kHz    | TAI-SAW           | TZ1166C            | Crystal, resonator, 32.768kHz, -40°C / +125°C, SMD                                         |

(1) C15 is placed when using the integrated antenna. C14 is placed when using an external antenna

**表 10-2. Bill of Materials for External Antenna Configuration**

| PART REFERENCE    | VALUE        | MANUFACTURER      | PART NUMBER        | DESCRIPTION                                                                                |
|-------------------|--------------|-------------------|--------------------|--------------------------------------------------------------------------------------------|
| C1, C91           | 15 pF        | Murata            | GRM0335C1E150JA01D | Capacitor, ceramic, 15 pF, 50 V, ±5%, C0G/NP0, 0201                                        |
| C81               | 12 pF        | Murata            | GRT0335C1H120JA02D | Capacitor, ceramic, 12 pF, 50 V, ±5%, C0G/NP0, 0201                                        |
| J1                | SMA          | HUS-TSAN          | SMA-10V21-TGG      | Connector, coax, RF, female, Straight, 1 pin, SMD                                          |
| U2                | CC2651R3SIPA | Texas Instruments | CC2651R3SIPAT0MOUR | SimpleLink™ multiprotocol 2.4-GHz wireless MCU with integrated power amplifier and Antenna |
| Y6                | 32.768kHz    | TAI-SAW           | TZ1166C            | Crystal, resonator, 32.768kHz, -40°C / +125°C, SMD                                         |
| Z2 <sup>(1)</sup> | 15 pF        | Murata            | GRM0335C1E150JA01D | Capacitor, ceramic, 15 pF, 50 V, ±5%, C0G/NP0, 0201                                        |

(1) Z2 is the recommended series matching component to use when using connecting to an SMA connector. Additional Shunt components Z1 and Z3 can be used for additional tuning for external antenna performance.

## 10.2 Alternate Application Circuit

図 10-3 shows the alternate application schematic using the CC2651R3SIPA module. This circuit implementation should be used when the 4-layer stackup and layout recommendations in セクション 10.4.2 cannot be followed, and thus the alternate layout guidelines in セクション 10.4.4 should be followed. Note that C15 should be assembled when using the integrated antenna option within the module. C14 should be assembled if the module is to be used with an external antenna, in which case its recommended to follow the typical application circuit as outlined in セクション 10.1. For the full reference schematic, download the [LP-CC2651R3SIPA Design Files](#).

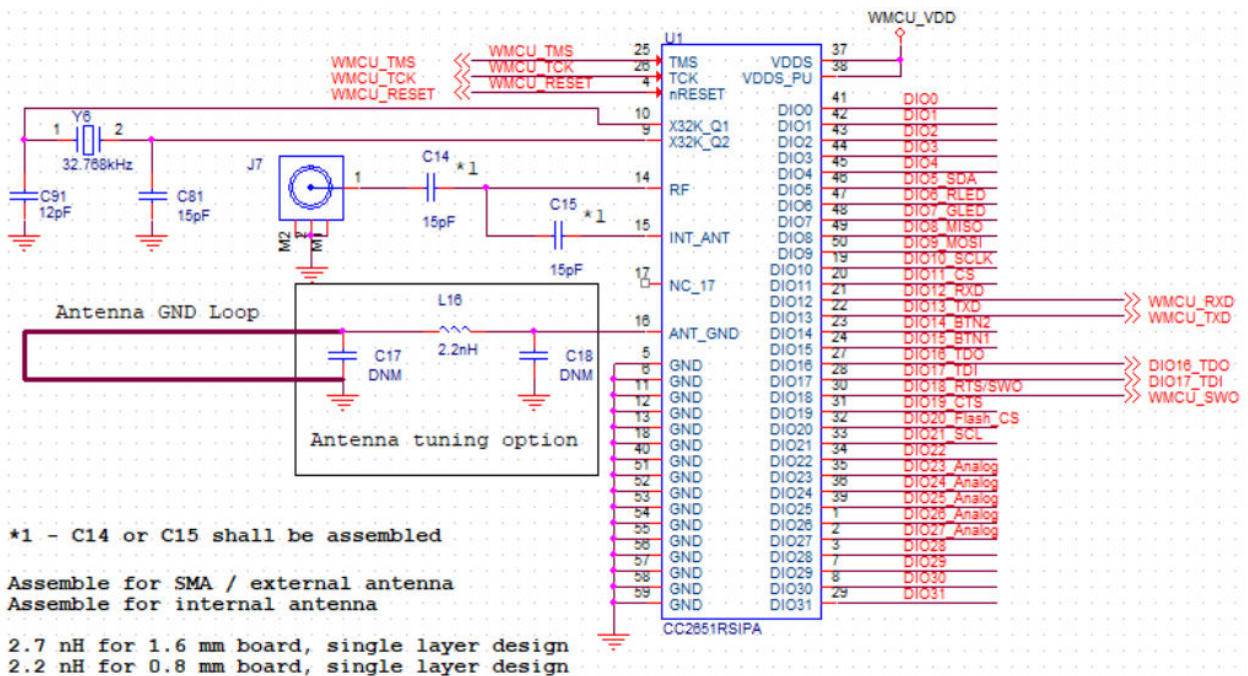


图 10-3. CC2651R3SIPA Alternate Application Schematic

表 10-3 provides the bill of materials for the alternate application circuit using the CC2651R3SIPA module in [セクション 10.2](#).

For full operation reference design, see the [LP-CC2651R3SIPA Design Files](#).

**表 10-3. Bill of Materials for Alternate Application Schematic**

| PART REFERENCE               | VALUE        | MANUFACTURER      | PART NUMBER        | DESCRIPTION                                                                                |
|------------------------------|--------------|-------------------|--------------------|--------------------------------------------------------------------------------------------|
| C14, C15, C91 <sup>(1)</sup> | 15 pF        | Murata            | GRM0335C1E150JA01D | Capacitor, ceramic, 15 pF, 50 V, ±5%, C0G/NP0, 0201                                        |
| C81                          | 12 pF        | Murata            | GRT0335C1H120JA02D | Capacitor, ceramic, 12 pF, 50 V, ±5%, C0G/NP0, 0201                                        |
| C17, C18 <sup>(2)</sup>      | Do Not Mount |                   |                    |                                                                                            |
| L16 <sup>(3)</sup>           | 2.7 nH       | Murata            | LQP03TN2N7B02      | Inductor, thick film, 2.7 nH, 500 mA, 200 mOhm, ±0.1 nH, 0201                              |
|                              | 2.2 nH       | Murata            | LQP03TG2N2B02      | Inductor, thick film, 2.2 nH, 500 mA, 200 mOhm, ±0.1 nH, 0201                              |
| J7                           | U.FL         | Hirose            | U.FL-R-SMT-1(01)   | U.FL (UMCC) connector receptacle, male pin 50 Ω, surface mount solder                      |
| U1                           | CC2651R3SIPA | Texas Instruments | CC2651R3SIPAT0MOUR | SimpleLink™ multiprotocol 2.4-GHz wireless MCU with integrated power amplifier and Antenna |
| Y6                           | 32.768kHz    | TAI-SAW           | TZ1166C            | Crystal, resonator, 32.768kHz, -40°C / +125°C, SMD                                         |

(1) C15 is placed when using the integrated antenna. C14 is placed when using an external antenna

(2) C17 and C18 are optional, but should be placed in the design as it allows for additional tuning of the resonance frequency

(3) L16 is mounted when using the integrated antenna. The recommended starting value when following the layout recommendation in [セクション 10.4.4](#) is 2.7 nH for a 1.6 mm board and 2.2 nH for a 0.8 mm board.

## 10.3 Device Connections

### 10.3.1 Reset

In order to meet the module power-on-reset requirements, VDDS (Pin 37) and VDDS\_PU (Pin 38) should be connected together. If the reset signal is not based upon a power-on-reset and is derived from an external MCU, then VDDS\_PU (Pin 38) should be No Connect (NC). Please refer to [図 10-1](#) for the recommended circuit implementation.

### 10.3.2 Unused Pins

All unused pins can be left unconnected without the concern of having leakage current.

## 10.4 PCB Layout Guidelines

This section details the PCB guidelines to speed up the PCB design using the CC2651R3SIPA module. The integrator of the CC2651R3SIPA modules must comply with the PCB layout recommendations described in the following subsections to minimize the risk with regulatory certifications for the FCC, IC/ISED, ETSI/CE, and RAR (UK). Moreover, TI recommends customers to follow the guidelines described in this section to achieve similar performance to that obtained with the TI reference design.

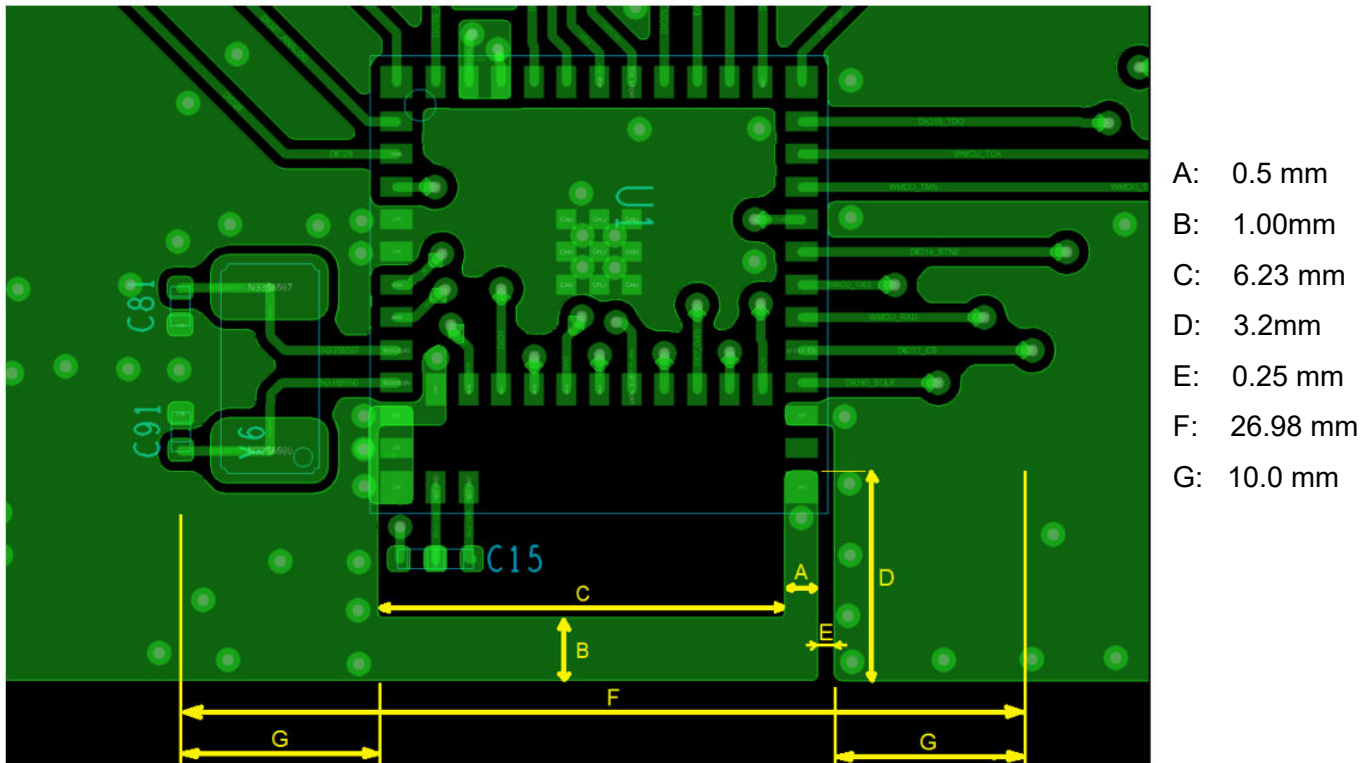
### 10.4.1 General Layout Recommendations

Ensure that the following general layout recommendations are followed:

- Have a solid ground plane and ground vias under the module for stable system and thermal dissipation.
- Do not run signal traces underneath the module on a layer where the module is mounted.

### 10.4.2 Typical RF Layout Recommendations with Integrated Antenna

It is critical that the RF section be laid out correctly to ensure optimal module performance. A poor layout can cause low-output power and sensitivity degradation. [Figure 10-4](#) shows the RF placement and routing of the CC2651R3SIPA module with the 2.4-GHz integrated antenna.



**Figure 10-4. Module Layout Guidelines**

Follow these RF layout recommendations for the CC2651R3SIPA module when using the integrated Antenna:

- Dimensions A thru G in [Figure 10-4](#) must be strictly adhered to for optimal RF performance
- The module must have a minimum 10-mm ground plane on either side of the module on all layers as shown with dimension G in [Figure 10-4](#)
- There must be at least one ground-reference plane under the module on the main PCB

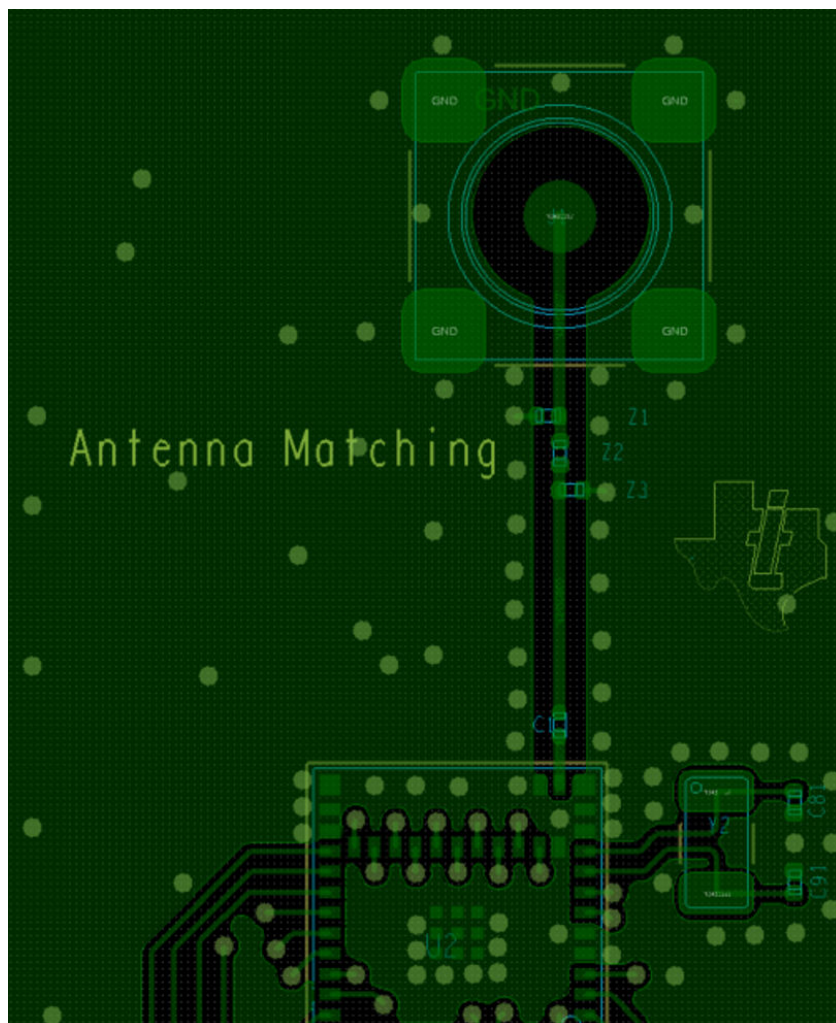
For the CC2651R3SIPA it is recommended to use 4-layer PCB board with the dimensions A thru G copied on all 4 layers. This will provide for the best antenna bandwidth in the 2.4GHz band. In addition, it is recommended for optimal antenna RF performance that:

- L1 to L2 layer thickness of 0.175 mm,
- Overall 4-layer board thickness of 1.6 mm as per the reference design
- The 4-layer dielectric constant of 4.0 +/- 0.2.

Deviation from this will cause a potential detuning of the integrated antenna.

### 10.4.3 RF Layout Recommendations with External Antenna

When using the external antenna option, it is critical that the RF section be laid out correctly to ensure optimal module performance. A poor layout can cause low-output power and sensitivity degradation. [Figure 10-5](#) shows the RF placement and routing of the CC2651R3SIPA module routed for use with an external SMA connector.



**Figure 10-5. Module Layout Guidelines with External Antenna**

Follow these RF layout recommendations for the CC2651R3SIPA module when connecting to an external antenna:

- RF traces must have 50- $\Omega$  impedance.
- RF trace bends must be made with gradual curves, and 90° bends must be avoided.
- RF traces must not have sharp corners.
- There must be no traces or ground under the antenna section.
- RF traces must have via stitching on the ground plane beside the RF trace on both sides.
- RF traces must be as short as possible.
- The module must be as close to the PCB edge in consideration of the product enclosure and type of antenna being used.

### 10.4.3.1 External Antenna Placement and Routing

The antenna is the element used to convert the guided waves on the PCB traces to the free space electromagnetic radiation. The placement and layout of the antenna are the keys to increased range and data rates. 表 10-4 provides a summary of the antenna guidelines to follow with the CC2651R3SIPA module when using the module with an external antenna.

**表 10-4. External Antenna Guidelines**

| SR NO. | GUIDELINES                                                                                                                                                                                                                                                              |
|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1      | Place the antenna on an edge of the PCB.                                                                                                                                                                                                                                |
| 2      | Ensure that no signals are routed across the antenna elements on any PCB layer.                                                                                                                                                                                         |
| 3      | Most antennas, including the PCB antenna used on the LaunchPad™, require ground clearance on all the layers of the PCB. Ensure that the ground is cleared on inner layers as well.                                                                                      |
| 4      | Ensure that there is provision to place matching components for the antenna. These must be tuned for best return loss when the complete board is assembled. Any plastics or casing must also be mounted while tuning the antenna because this can impact the impedance. |
| 5      | Ensure that the antenna impedance is 50 $\Omega$ because the module is rated to work only with a 50- $\Omega$ system.                                                                                                                                                   |
| 6      | In case of printed antenna, ensure that the simulation is performed with the solder mask in consideration.                                                                                                                                                              |
| 7      | Ensure that the antenna has a near omnidirectional pattern.                                                                                                                                                                                                             |

表 10-5 lists the recommended external antennas to use with the CC2651R3SIPA module. Other external antennas may be available for use with the CC2651R3SIPA module.

**表 10-5. Recommended Components**

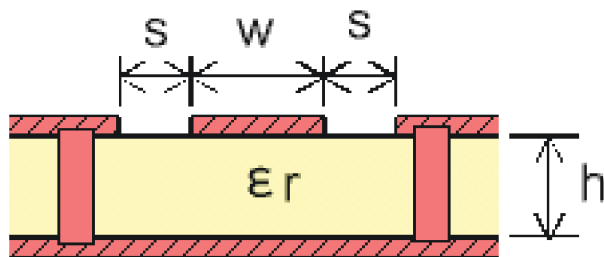
| CHOICE | ANTENNA                    | MANUFACTURER      | NOTES                                                                                                               |
|--------|----------------------------|-------------------|---------------------------------------------------------------------------------------------------------------------|
| 1      | 2.4-GHz Inverted F Antenna | Texas Instruments | Refer to <a href="#">2.4-GHz Inverted F Antenna</a> for details of the antenna implementation and PCB requirements. |

### 10.4.3.2 Transmission Line Considerations

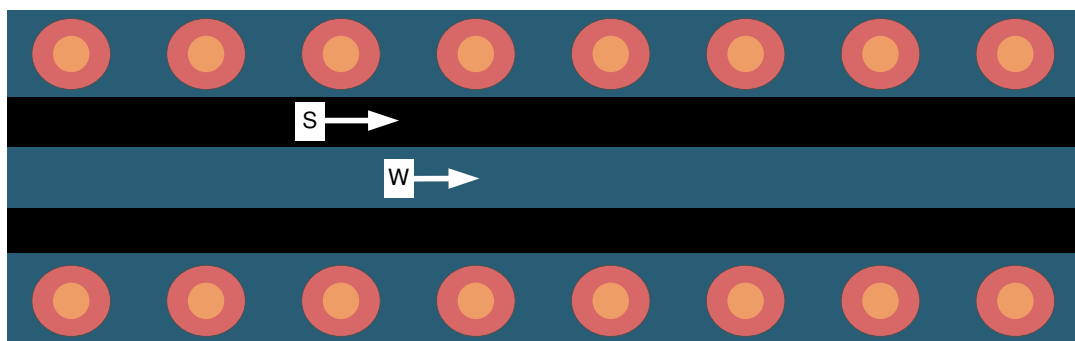
The RF signal from the module is routed to the antenna using a Coplanar Waveguide with ground (CPW-G) structure. CPW-G structure offers the maximum amount of isolation and the best possible shielding to the RF lines. In addition to the ground on the L1 layer, placing GND vias along the line also provides additional shielding.

✎ 10-6 shows a cross section of the coplanar waveguide with the critical dimensions.

✎ 10-7 shows the top view of the coplanar waveguide with GND and via stitching.



✎ 10-6. Coplanar Waveguide (Cross Section)



✎ 10-7. CPW With GND and Via Stitching (Top View)

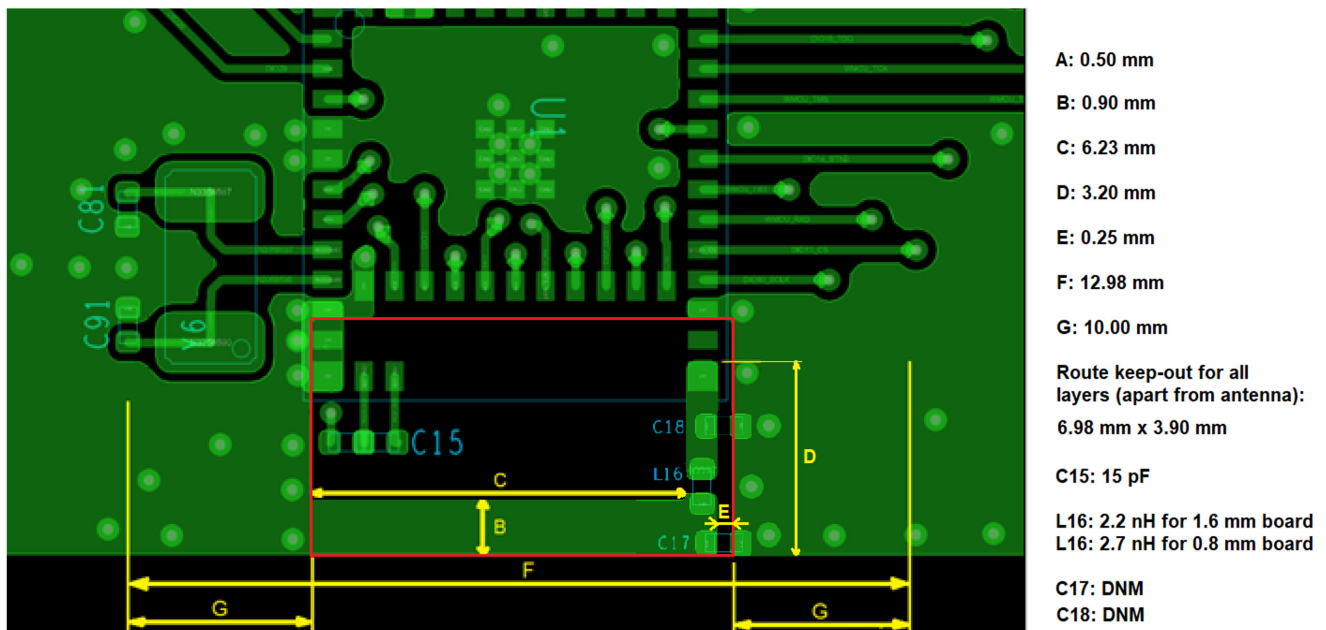
The recommended values for a 4-layer PCB board is provided in 表 10-6.

**表 10-6. Recommended PCB Values for 4-Layer Board (L1 to L2 = 0.175 mm)**

| PARAMETER           | VALUE | UNITS |
|---------------------|-------|-------|
| W                   | 0.300 | mm    |
| S                   | 0.500 | mm    |
| H                   | 0.175 | mm    |
| Er (FR-4 substrate) | 4.4   | F/m   |

#### 10.4.4 Alternate PCB Layout Guidelines

The PCB layout guidelines recommended in this section are to be used when the PCB requirements of セクション 10.4.2 cannot be strictly followed. This would include deviation from the recommended 4-layer PCB stackup, dielectric constant, and outlined design rules. 図 10-8 shows the RF placement and routing of the CC2651R3SIPA module with the 2.4-GHz integrated antenna.



**図 10-8. Alternate Module Layout Guidelines**

Follow these RF layout recommendations for the CC2651R3SIPA module when using the integrated Antenna:

- Dimensions A thru F in 図 10-8 must be strictly adhered to for optimal RF performance
- For optimal efficiency of the antenna, its best to have a minimum 10-mm ground plane on either side of the module on all layers as shown with dimension G in 図 10-8
- There must be at least on ground-reference plane under the module on the main PCB
- The ground loop should only be on the top layer of the board and not on all 4-layers.
- A  $\pi$  matching network implementation in the ground loop allowing for tuning of the integrated antenna for optimal performance.

## 10.5 Reference Designs

The following reference designs should be followed closely when implementing designs using the CC2651R3SIPA device.

Special attention must be paid to RF component placement, decoupling capacitors and DCDC regulator components, as well as ground connections for all of these.

### [CC2651RSIPA-EM Design Files](#)

The CC2651RSIPA-EM reference design provides schematic, layout and production files for the characterization board used for deriving the performance number found in this document.

### [LP-CC2651R3SIPA Design Files](#)

The CC2651R3SIPA LaunchPad Design Files contain detailed schematics and layouts to build application specific boards using the CC2651R3SIPA device.

### [Sub-1 GHz and 2.4 GHz Antenna Kit for LaunchPad™ Development Kit and SensorTag](#)

The antenna kit allows real-life testing to identify the optimal antenna for your application. The antenna kit includes 16 antennas for frequencies from 169 MHz to 2.4 GHz, including:

- PCB antennas
- Helical antennas
- Chip antennas
- Dual-band antennas for 868 MHz and 915 MHz combined with 2.4 GHz

The antenna kit includes a JSC cable to connect to the Wireless MCU LaunchPad Development Kits and SensorTags.

## 10.6 Junction Temperature Calculation

This section shows the different techniques for calculating the junction temperature under various operating conditions. For more details, see [Semiconductor and IC Package Thermal Metrics](#).

There are three recommended ways to derive the junction temperature from other measured temperatures:

1. From package temperature:

$$T_J = \psi_{JT} \times P + T_{\text{case}} \quad (1)$$

2. From board temperature:

$$T_J = \psi_{JB} \times P + T_{\text{board}} \quad (2)$$

3. From ambient temperature:

$$T_J = R_{\theta JA} \times P + T_A \quad (3)$$

P is the power dissipated from the device and can be calculated by multiplying current consumption with supply voltage. Thermal resistance coefficients are found in [セクション 8.8](#).

### Example:

Using [式 3](#), the temperature difference between ambient temperature and junction temperature is calculated. In this example, we assume a simple use case where the radio is transmitting continuously at 0 dBm output power. Let us assume the ambient temperature is 85 °C and the supply voltage is 3 V. To calculate P, we need to look up the current consumption for Tx at 85 °C in. From the plot, we see that the current consumption is 7.8 mA. This means that P is 7.95 mA × 3 V = 23.85 mW.

The junction temperature is then calculated as:

$$T_J = 48.7^{\circ}\text{C}/\text{W} \times 23.85\text{mW} + T_A = 1.2^{\circ}\text{C} + T_A$$

As can be seen from the example, the junction temperature is 1.2°C higher than the ambient temperature when running continuous Tx at 85 °C and, thus, well within the recommended operating conditions.

For various application use cases current consumption for other modules may have to be added to calculate the appropriate power dissipation. For example, the MCU may be running simultaneously as the radio, peripheral modules may be enabled, etc. Typically, the easiest way to find the peak current consumption, and thus the peak power dissipation in the device, is to measure as described in [Measuring CC13xx and CC26xx current consumption](#).

## **11 Environmental Requirements and SMT Specifications**

### **11.1 PCB Bending**

The PCB follows IPC-A-600J for PCB twist and warpage < 0.75% or 7.5 mil per inch.

### **11.2 Handling Environment**

#### **11.2.1 Terminals**

The product is mounted with motherboard through land-grid array (LGA). To prevent poor soldering, do not make skin contact with the LGA portion.

#### **11.2.2 Falling**

The mounted components will be damaged if the product falls or is dropped. Such damage may cause the product to malfunction.

### **11.3 Storage Condition**

#### **11.3.1 Moisture Barrier Bag Before Opened**

A moisture barrier bag must be stored in a temperature of less than 30°C with humidity under 85% RH. The calculated shelf life for the dry-packed product will be 24 months from the date the bag is sealed.

#### **11.3.2 Moisture Barrier Bag Open**

Humidity indicator cards must be blue, < 30%.

### **11.4 PCB Assembly Guide**

The wireless MCU modules are packaged in a substrate base Leadless Quad Flatpack (QFM) package. The modules are designed with pull back leads for easy PCB layout and board mounting.

#### **11.4.1 PCB Land Pattern & Thermal Vias**

We recommended a solder mask defined land pattern to provide a consistent soldering pad dimension in order to obtain better solder balancing and solder joint reliability. PCB land pattern are 1:1 to module soldering pad dimension. Thermal vias on PCB connected to other metal plane are for thermal dissipation purpose. It is critical to have sufficient thermal vias to avoid device thermal shutdown. Recommended vias size are 0.2mm and position not directly under solder paste to avoid solder dripping into the vias.

#### **11.4.2 SMT Assembly Recommendations**

The module surface mount assembly operations include:

- Screen printing the solder paste on the PCB
- Monitor the solder paste volume (uniformity)
- Package placement using standard SMT placement equipment
- X-ray pre-reflow check - paste bridging
- Reflow
- X-ray post-reflow check - solder bridging and voids

### 11.4.3 PCB Surface Finish Requirements

A uniform PCB plating thickness is key for high assembly yield. For an electroless nickel immersion gold finish, the gold thickness should range from 0.05  $\mu\text{m}$  to 0.20  $\mu\text{m}$  to avoid solder joint embrittlement. Using a PCB with Organic Solderability Preservative (OSP) coating finish is also recommended as an alternative to Ni-Au.

### 11.4.4 Solder Stencil

Solder paste deposition using a stencil-printing process involves the transfer of the solder paste through pre-defined apertures with the application of pressure. Stencil parameters such as aperture area ratio and the fabrication process have a significant impact on paste deposition. Inspection of the stencil prior to placement of package is highly recommended to improve board assembly yields.

### 11.4.5 Package Placement

Packages can be placed using standard pick and place equipment with an accuracy of  $\pm 0.05$  mm. Component pick and place systems are composed of a vision system that recognizes and positions the component and a mechanical system that physically performs the pick and place operation. Two commonly used types of vision systems are:

- A vision system that locates a package silhouette
- A vision system that locates individual pads on the interconnect pattern

The second type renders more accurate placements but tends to be more expensive and time consuming. Both methods are acceptable since the parts align due to a self-centering features of the solder joint during solder reflow. It is recommended to avoid solder bridging to 2 mils into the solder paste or with minimum force to avoid causing any possible damage to the thinner packages.

### 11.4.6 Solder Joint Inspection

After surface mount assembly, transmission X-ray should be used for sample monitoring of the solder attachment process. This identifies defects such as solder bridging, shorts, opens, and voids. It is also recommended to use side view inspection in addition to X-rays to determine if there are "Hour Glass" shaped solder and package tilting existing. The "Hour Glass" solder shape is not a reliable joint. 90° mirror projection can be used for side view inspection.

### 11.4.7 Rework and Replacement

TI recommends removal of modules by rework station applying a profile similar to the mounting process. Using a heat gun can sometimes cause damage to the module by overheating.

### 11.4.8 Solder Joint Voiding

TI recommends to control solder joint voiding to be less than 30% (per IPC-7093). Solder joint voids could be reduced by baking of components and PCB, minimized solder paste exposure duration, and reflow profile optimization.

## 11.5 Baking Conditions

Products require baking before mounting if:

- Humidity indicator cards read  $> 30\%$
- Temp  $< 30^\circ\text{C}$ , humidity  $< 70\%$  RH, over 96 hours

Baking condition:  $90^\circ\text{C}$ , 12 to 24 hours

Baking times: 1 time

## 11.6 Soldering and Reflow Condition

- Heating method: Conventional convection or IR convection
- Temperature measurement: Thermocouple d = 0.1 mm to 0.2 mm CA (K) or CC (T) at soldering portion or equivalent method
- Solder paste composition: SAC305
- Allowable reflow soldering times: 2 times based on the reflow soldering profile (see 図 11-1)
- Temperature profile: Reflow soldering will be done according to the temperature profile (see 図 11-1)
- Peak temperature: 260°C

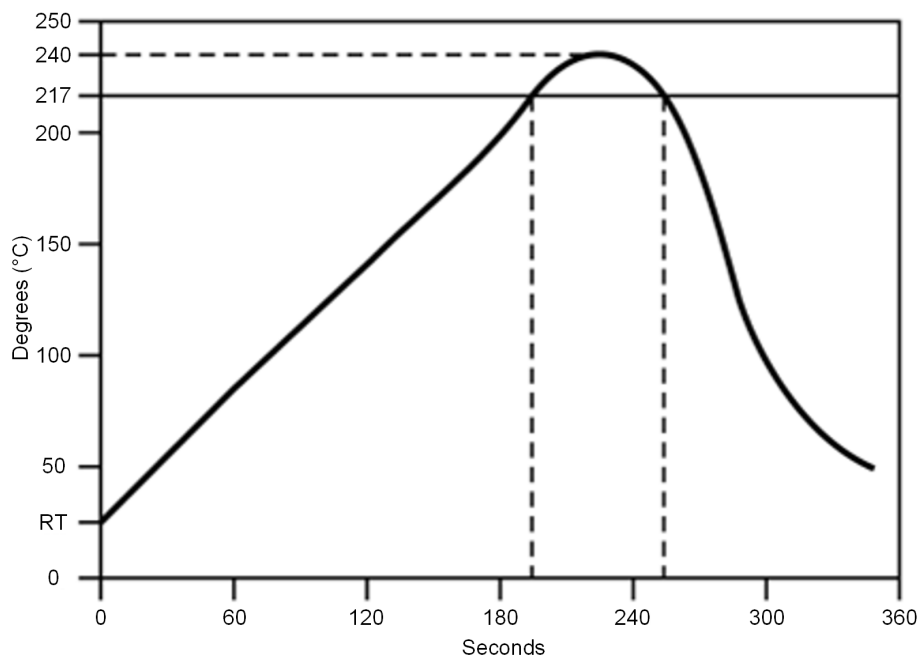


図 11-1. Temperature Profile for Evaluation of Solder Heat Resistance of a Component (at Solder Joint)

表 11-1. Temperature Profile

| Profile Elements                  | Convection or IR <sup>(1)</sup>      |
|-----------------------------------|--------------------------------------|
| Peak temperature range            | 235 to 240°C typical (260°C maximum) |
| Pre-heat / soaking (150 to 200°C) | 60 to 120 seconds                    |
| Time above melting point          | 60 to 90 seconds                     |
| Time with 5°C to peak             | 30 seconds maximum                   |
| Ramp up                           | < 3°C / second                       |
| Ramp down                         | < -6°C / second                      |

(1) For details, refer to the solder paste manufacturer's recommendation.

### 注

TI does not recommend the use of conformal coating or similar material on the SimpleLink™ module. This coating can lead to localized stress on the solder connections inside the module and impact the module reliability. Use caution during the module assembly process to the final PCB to avoid the presence of foreign material inside the module.

## 12 Device and Documentation Support

TI offers an extensive line of development tools. Tools and software to evaluate the performance of the device, generate code, and develop solutions are listed as follows.

### 12.1 Device Nomenclature

To designate the stages in the product development cycle, TI assigns prefixes to all part numbers and/or date-code. Each device has one of three prefixes/identifications: X, P, or null (no prefix) (for example, XCC2651R3SIPA is in preview; therefore, an X prefix/identification is assigned).

Device development evolutionary flow:

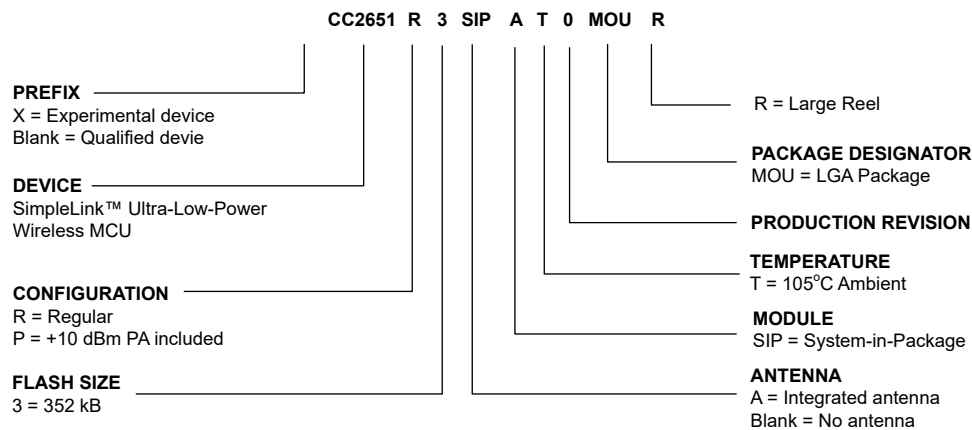
- X** Experimental device that is not necessarily representative of the final device's electrical specifications and may not use production assembly flow.
- P** Prototype device that is not necessarily the final silicon die and may not necessarily meet final electrical specifications.
- null** Production version of the silicon die that is fully qualified.

Production devices have been characterized fully, and the quality and reliability of the device have been demonstrated fully. TI's standard warranty applies.

Predictions show that prototype devices (X or P) have a greater failure rate than the standard production devices. Texas Instruments recommends that these devices not be used in any production system because their expected end-use failure rate still is undefined. Only qualified production devices are to be used.

TI device nomenclature also includes a suffix with the device family name. This suffix indicates the package type (for example, RGZ).

For orderable part numbers of CC2651R3SIPA devices in the RGZ (7-mm x 7-mm) package type, see the *Package Option Addendum* of this document, the Device Information in [セクション 3](#), the TI website ([www.ti.com](http://www.ti.com)), or contact your TI sales representative.



**12-1. Device Nomenclature**

### 12.2 Tools and Software

The CC2651R3SIPA device is supported by a variety of software and hardware development tools.

#### Development Kit

[CC2651R3SIPA  
LaunchPad™  
Development Kit](#)

The CC2651R3SIPA LaunchPad™ Development Kit enables development of high-performance wireless applications that benefit from low-power operation. The kit features the CC2651R3SIPA SimpleLink Wireless system-in-Package, which allows

you to quickly evaluate and prototype 2.4-GHz wireless applications such as Bluetooth 5 Low Energy and Zigbee, plus combinations of these. The kit works with the LaunchPad ecosystem, easily enabling additional functionality like sensors, display and more.

## Software

### SimpleLink™ CC13XX- CC26XX SDK

The SimpleLink CC13xx and CC26xx Software Development Kit (SDK) provides a complete package for the development of wireless applications on the CC13XX / CC26XX family of devices. The SDK includes a comprehensive software package for the CC2651R3SIPA module, including the following protocol stacks:

- Bluetooth Low Energy 4 and 5.2
- Thread (based on OpenThread)
- Zigbee 3.0
- TI 15.4-Stack - an IEEE 802.15.4-based star networking solution for Sub-1 GHz and 2.4 GHz

The SimpleLink CC13XX-CC26XX SDK is part of TI's SimpleLink MCU platform, offering a single development environment that delivers flexible hardware, software and tool options for customers developing wired and wireless applications. For more information about the SimpleLink MCU Platform, visit <http://www.ti.com/simplelink>.

**Code Composer  
Studio™ Integrated  
Development  
Environment (IDE)**

Code Composer Studio is an integrated development environment (IDE) that supports TI's Microcontroller and Embedded Processors portfolio. Code Composer Studio comprises a suite of tools used to develop and debug embedded applications. It includes an optimizing C/C++ compiler, source code editor, project build environment, debugger, profiler, and many other features. The intuitive IDE provides a single user interface taking you through each step of the application development flow. Familiar tools and interfaces allow users to get started faster than ever before. Code Composer Studio combines the advantages of the Eclipse® software framework with advanced embedded debug capabilities from TI resulting in a compelling feature-rich development environment for embedded developers.

CCS has support for all SimpleLink Wireless MCUs and includes support for EnergyTrace™ software (application energy usage profiling). A real-time object viewer plugin is available for TI-RTOS, part of the SimpleLink SDK.

Code Composer Studio is provided free of charge when used in conjunction with the XDS debuggers included on a LaunchPad Development Kit.

**Code Composer  
Studio™ Cloud  
IDE**

Code Composer Studio (CCS) Cloud is a web-based IDE that allows you to create, edit and build CCS and Energia™ projects. After you have successfully built your project, you can download and run on your connected LaunchPad. Basic debugging, including features like setting breakpoints and viewing variable values is now supported with CCS Cloud.

**IAR Embedded  
Workbench® for  
Arm®**

IAR Embedded Workbench® is a set of development tools for building and debugging embedded system applications using assembler, C and C++. It provides a completely integrated development environment that includes a project manager, editor, and build tools. IAR has support for all SimpleLink Wireless MCUs. It offers broad debugger support, including XDS110, IAR I-jet™ and Segger J-Link™. A real-time object viewer plugin is available for TI-RTOS, part of the SimpleLink SDK. IAR is also supported out-of-the-box on most software examples provided as part of the SimpleLink SDK.

A 30-day evaluation or a 32 KB size-limited version is available through [iar.com](http://iar.com).

**SmartRF™ Studio**

SmartRF™ Studio is a Windows® application that can be used to evaluate and configure SimpleLink Wireless MCUs from Texas Instruments. The application will help designers of RF systems to easily evaluate the radio at an early stage in the design process. It is especially useful for generation of configuration register values and for practical testing and debugging of the RF system. SmartRF Studio can be used either as a standalone application or together with applicable evaluation boards or debug probes for the RF device. Features of the SmartRF Studio include:

- Link tests - send and receive packets between nodes
- Antenna and radiation tests - set the radio in continuous wave TX and RX states
- Export radio configuration code for use with the TI SimpleLink SDK RF driver
- Custom GPIO configuration for signaling and control of external switches

### CCS UniFlash

CCS UniFlash is a standalone tool used to program on-chip flash memory on TI MCUs. UniFlash has a GUI, command line, and scripting interface. CCS UniFlash is available free of charge.

### 12.2.1 SimpleLink™ Microcontroller Platform

The SimpleLink microcontroller platform sets a new standard for developers with the broadest portfolio of wired and wireless Arm® MCUs (System-on-Chip) in a single software development environment. Delivering flexible hardware, software and tool options for your IoT applications. Invest once in the SimpleLink software development kit and use throughout your entire portfolio. Learn more on [ti.com/simplelink](http://ti.com/simplelink).

### 12.3 Documentation Support

To receive notification of documentation updates on data sheets, errata, application notes and similar, navigate to the device product folder on [ti.com/product/CC2651R3SIPA](http://ti.com/product/CC2651R3SIPA). In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

The current documentation that describes the MCU, related peripherals, and other technical collateral is listed as follows.

#### TI Resource Explorer

[TI Resource Explorer](#) Software examples, libraries, executables, and documentation are available for your device and development board.

#### Errata

##### [CC2651R3SIPA Silicon Errata](#)

The silicon errata describes the known exceptions to the functional specifications for each silicon revision of the device and description on how to recognize a device revision.

#### Application Reports

All application reports for the CC2651R3SIPA device are found on the device product folder at: [ti.com/product/CC2651R3SIPA/technicaldocuments](http://ti.com/product/CC2651R3SIPA/technicaldocuments).

#### Technical Reference Manual (TRM)

##### [CC13x1x3, CC26x1x3 SimpleLink™ Wireless MCU TRM](#)

The TRM provides a detailed description of all modules and peripherals available in the device family.

### 12.4 サポート・リソース

[TI E2E™ サポート・フォーラム](#)は、エンジニアが検証済みの回答と設計に関するヒントをエキスパートから迅速かつ直接得ることができる場所です。既存の回答を検索したり、独自の質問をしたりすることで、設計に必要な支援を迅速に得ることができます。

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### 12.5 Trademarks

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J-Link™ is a trademark of SEGGER Microcontroller Systeme GmbH.

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IAR Embedded Workbench® is a registered trademark of IAR Systems AB.

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## 12.6 静電気放電に関する注意事項



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ESD による破損は、わずかな性能低下からデバイスの完全な故障まで多岐にわたります。精密な IC の場合、パラメータがわずかに変化するだけで公表されている仕様から外れる可能性があるため、破損が発生しやすくなっています。

## 12.7 用語集

[テキサス・インスツルメンツ用語集](#)

この用語集には、用語や略語の一覧および定義が記載されています。

## 13 Mechanical, Packaging, and Orderable Information

The following pages include mechanical packaging and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

---

### 注

The total height of the module is 1.51 mm.

The weight of the CC2651R3SIPA module is typically 0.182 g.

---

## PACKAGING INFORMATION

| Orderable part number              | Status<br>(1) | Material type<br>(2) | Package   Pins | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|------------------------------------|---------------|----------------------|----------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">CC2651R3SIPAT0MOUR</a> | Active        | Production           | QFM (MOU)   50 | 2000   LARGE T&R      | Yes         | ENEPIG                               | Level-3-260C-168 HR               | -40 to 105   | CC2651<br>R SIPA    |
| CC2651R3SIPAT0MOUR.B               | Active        | Production           | QFM (MOU)   50 | 2000   LARGE T&R      | Yes         | ENEPIG                               | Level-3-260C-168 HR               | -40 to 105   | CC2651<br>R SIPA    |

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

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

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

<sup>(4)</sup> **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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

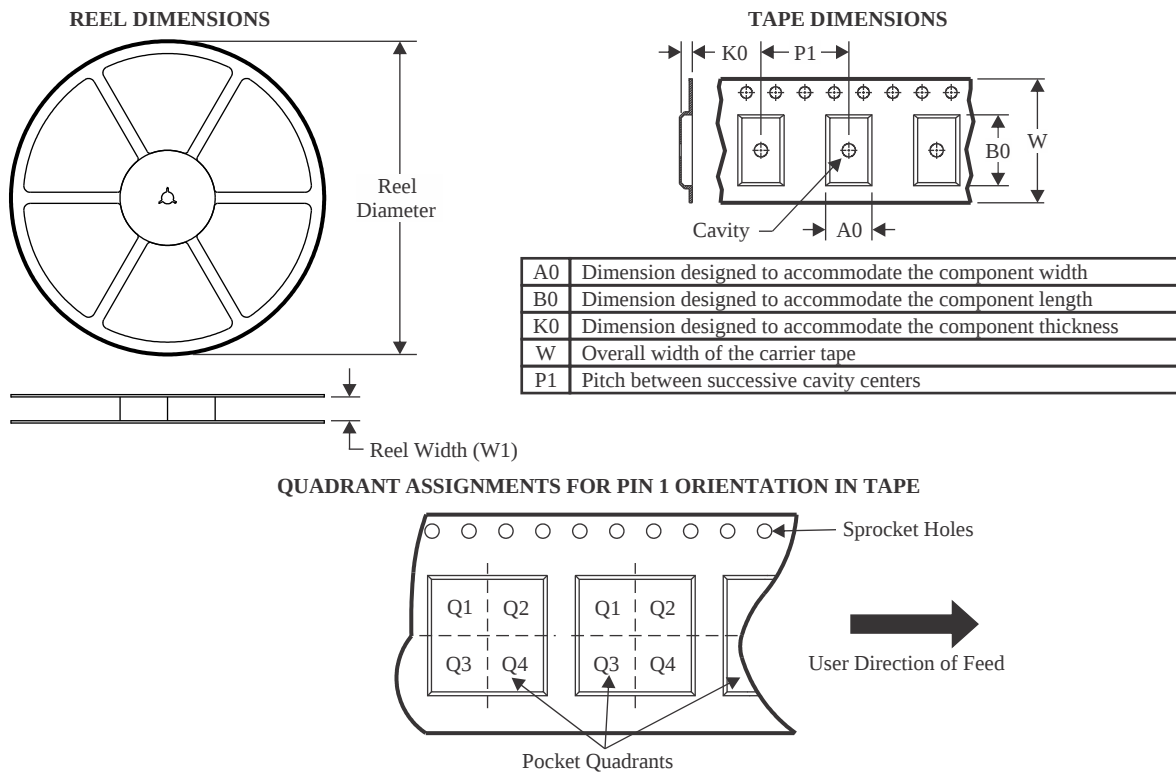
<sup>(6)</sup> **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

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

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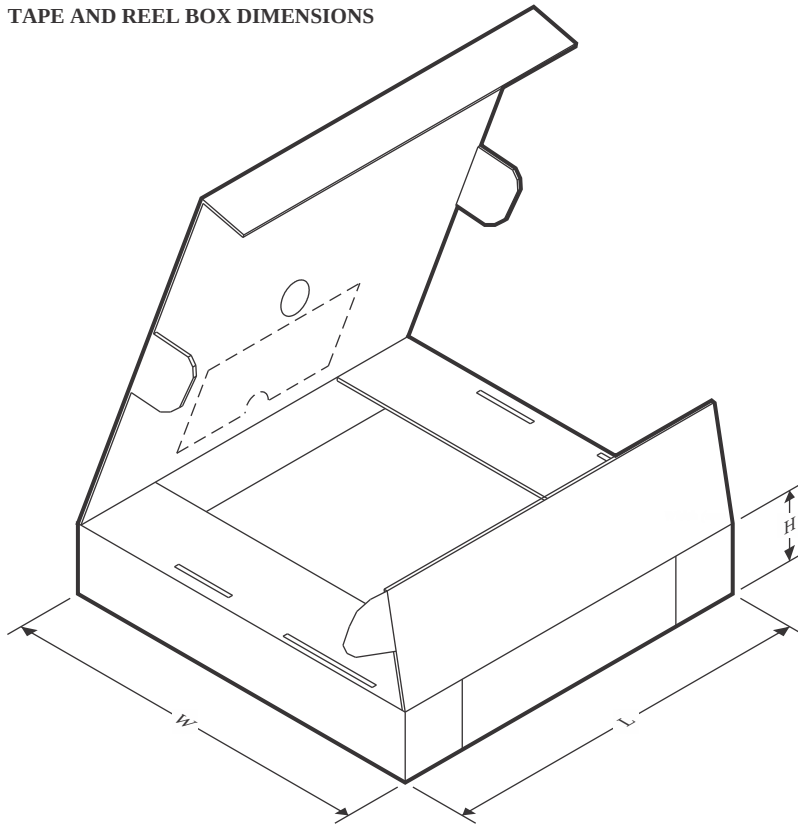
## TAPE AND REEL INFORMATION



\*All dimensions are nominal

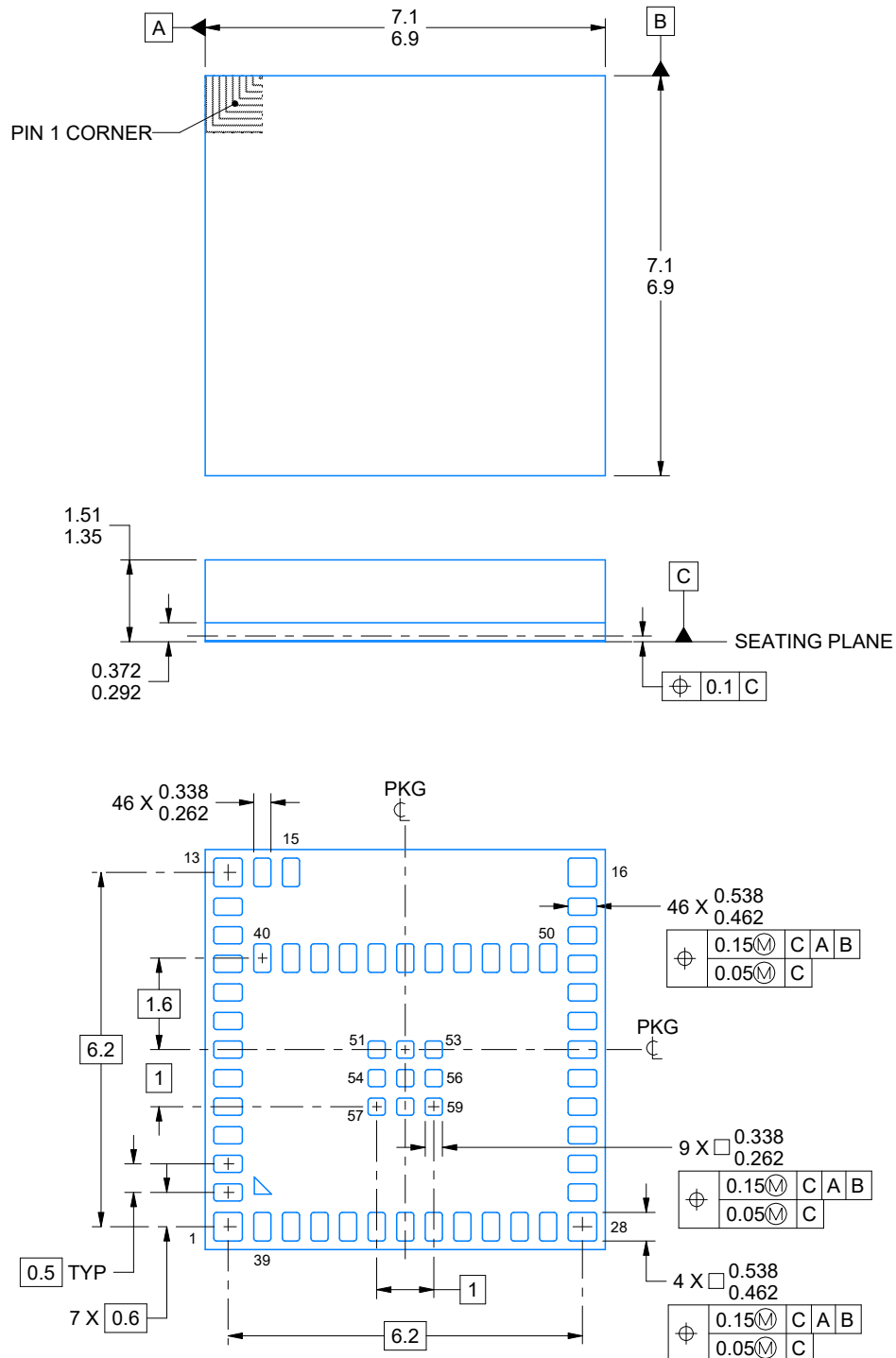
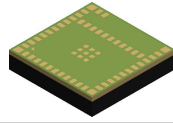
| Device             | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|--------------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| CC2651R3SIPAT0MOUR | QFM          | MOU             | 50   | 2000 | 330.0              | 16.4               | 7.4     | 7.4     | 1.88    | 12.0    | 16.0   | Q1            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device             | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|--------------------|--------------|-----------------|------|------|-------------|------------|-------------|
| CC2651R3SIPAT0MOUR | QFM          | MOU             | 50   | 2000 | 336.6       | 336.6      | 31.8        |



4226342/B 12/2020

NOTES:

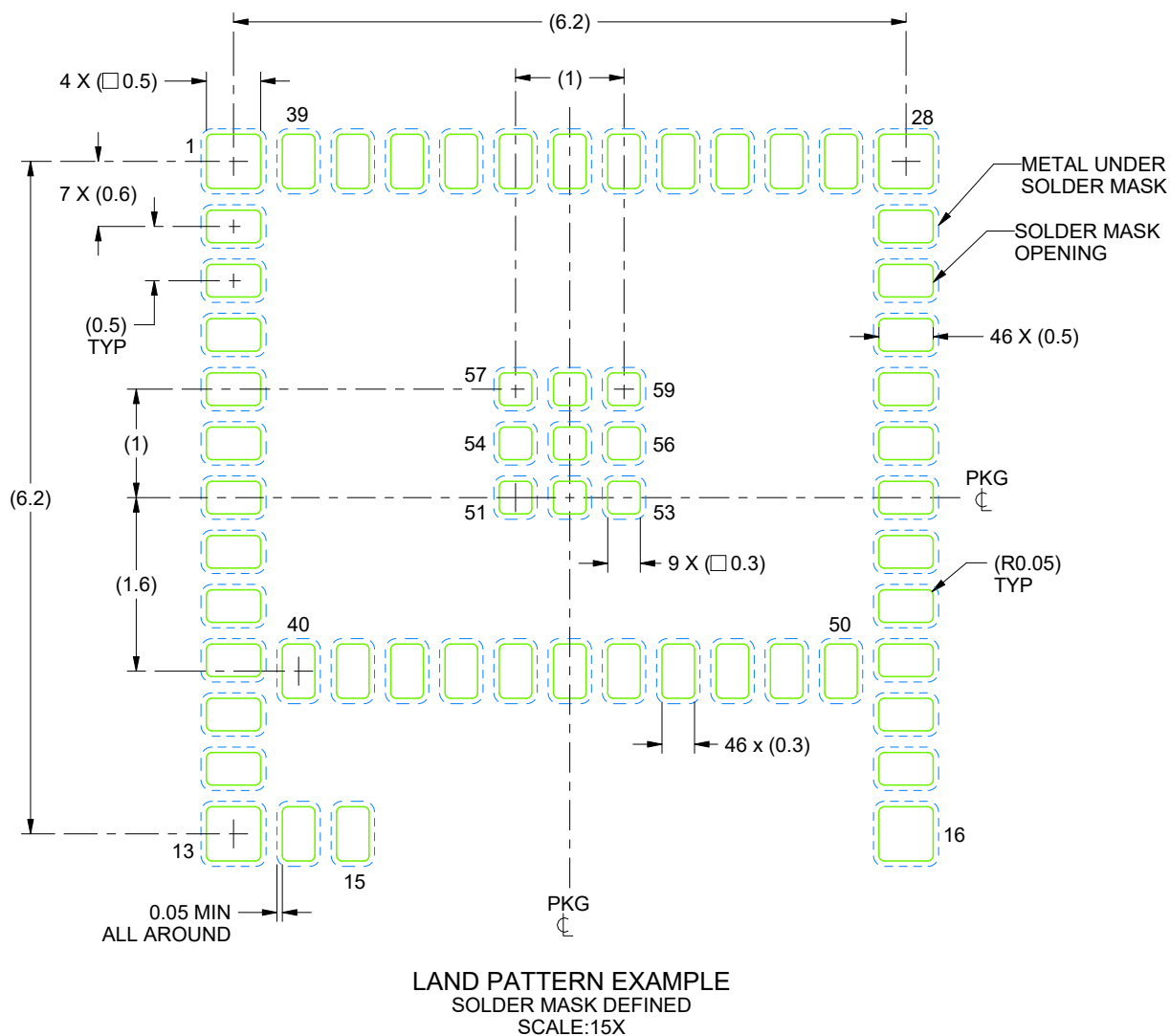
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.

# EXAMPLE BOARD LAYOUT

MOU0050A

QFM - 1.51 mm max height

QUAD FLAT MODULE



4226342/B 12/2020

NOTES: (continued)

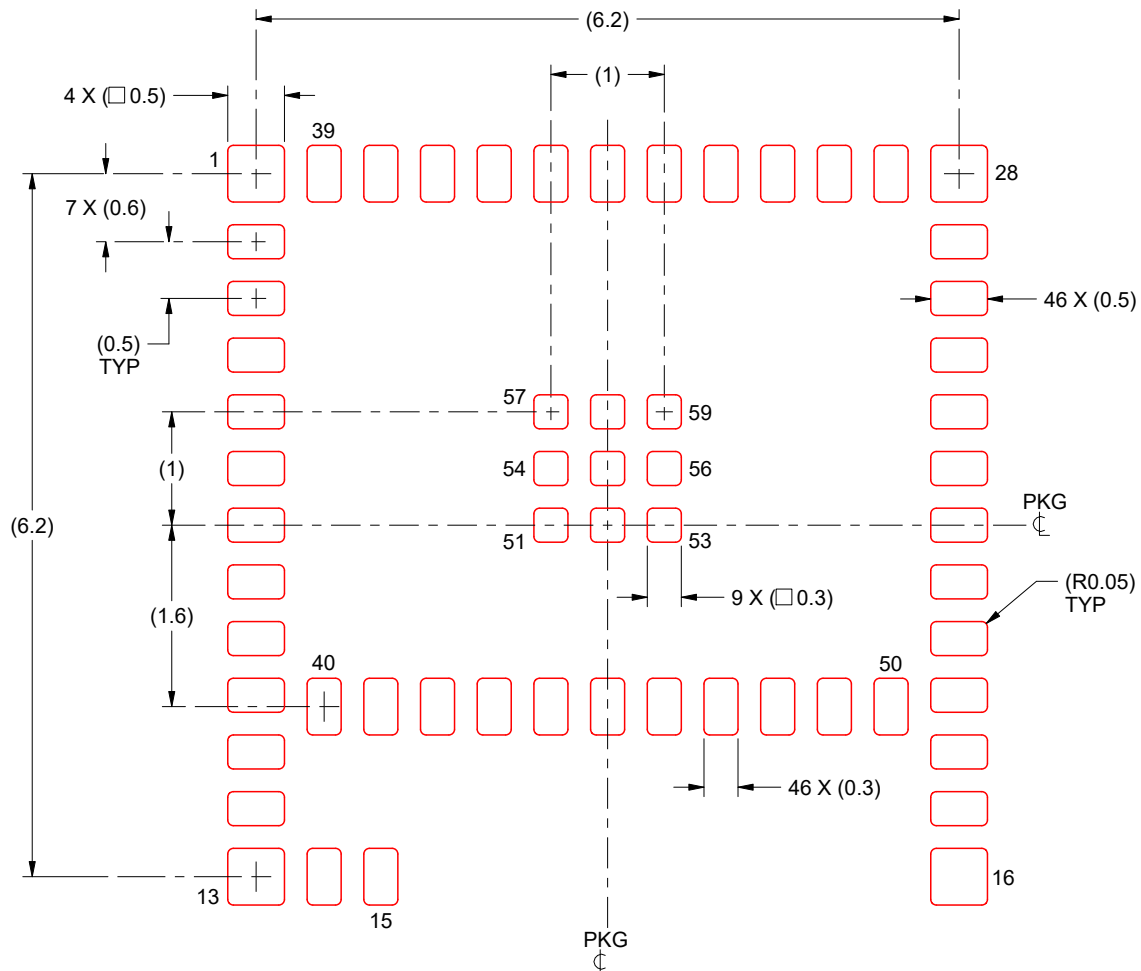
- This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/sluea271](http://www.ti.com/lit/sluea271)).

# EXAMPLE STENCIL DESIGN

MOU0050A

QFM - 1.51 mm max height

QUAD FLAT MODULE



SOLDER PASTE EXAMPLE  
 BASED ON 0.125 mm THICK STENCIL  
 SCALE:15X

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NOTES: (continued)

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

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