

## A USB-Enabled System-On-Chip Solution for 2.4-GHz IEEE 802.15.4 and ZigBee Applications

Check for Samples: [CC2531F128](#), [CC2531F256](#)

### FEATURES

- **RF/Layout**
  - 2.4-GHz IEEE 802.15.4 Compliant RF Transceiver
  - Excellent Receiver Sensitivity and Robustness to Interference
  - Programmable Output Power Up to 4.5 dBm
  - Few External Components
  - Only a Single Crystal Needed for Asynchronous Networks
  - 6-mm × 6-mm QFN40 Package
  - Suitable for Systems Targeting Compliance With Worldwide Radio-Frequency Regulations: ETSI EN 300 328 and EN 300 440 (Europe), FCC CFR47 Part 15 (US), and ARIB STD-T-66 (Japan)
- **USB**
  - USB 2.0 Certified Full Speed Device (12 Mbps)
  - 5 Highly Flexible Endpoints
  - 1-KB Dedicated FIFO
  - DMA Access to FIFO
  - No 48-MHz Crystal Required
- **Low Power**
  - Active Mode RX (CPU Idle): 24 mA
  - Active Mode TX at 1 dBm (CPU Idle): 29 mA
  - Power Mode 1 (4  $\mu$ s Wake-Up): 0.2 mA
  - Power Mode 2 (Sleep Timer Running): 1  $\mu$ A
  - Power Mode 3 (External Interrupts): 0.4  $\mu$ A
  - Wide Supply-Voltage Range (2 V–3.6 V)
- **Microcontroller**
  - High-Performance and Low-Power 8051 Microcontroller Core With Code Prefetch
  - 256-KB or 128-KB In-System-Programmable Flash
  - 8-KB RAM With Retention in All Power Modes
  - Hardware Debug Support
- **Peripherals**
  - Powerful Five-Channel DMA
  - IEEE 802.15.4 MAC Timer, General-Purpose Timers (One 16-Bit, Two 8-Bit)
  - IR Generation Circuitry
  - 32-kHz Sleep Timer With Capture
  - CSMA/CA Hardware Support
  - Accurate Digital RSSI/LQI Support
  - Battery Monitor and Temperature Sensor
  - 12-Bit ADC With Eight Channels and Configurable Resolution
  - AES Security Coprocessor
  - Two Powerful USARTs With Support for Several Serial Protocols
  - 21 General-Purpose I/O Pins (19 × 4 mA, 2 × 20 mA)
  - Watchdog Timer
- **Development Tools**
  - CC2531 Development Kit
  - Certified CC2531 USB Dongle Reference Design
  - SmartRF™ Software
  - Packet Sniffer
  - IAR Embedded Workbench® Software Available



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## APPLICATIONS

- **USB Upgradable 2.4-GHz IEEE 802.15.4 Systems**
- **RF4CE Remote Control Target for TV or STB**
- **PC Peripherals**
- **ZigBee® Systems**
- **Home/Building Automation**
- **Lighting Systems**
- **Industrial Control and Monitoring**
- **Low-Power Wireless Sensor Networks**
- **Consumer Electronics**
- **Health Care**



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

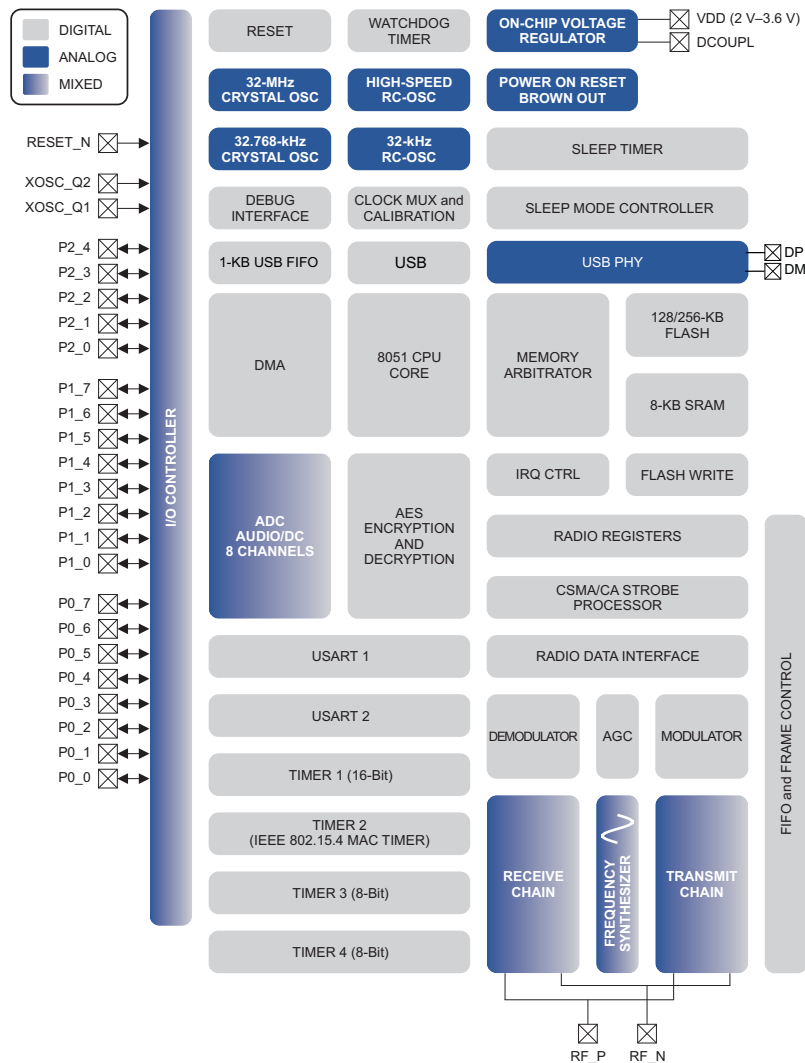
ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

## DESCRIPTION

The CC2531 is a USB enabled true system-on-chip (SoC) solution for IEEE 802.15.4, ZigBee and RF4CE applications. It enables USB dongles or USB upgradable network nodes to be built with low total bill-of-material costs. The CC2531 combines the performance of a leading RF transceiver with an industry-standard enhanced 8051 MCU, in-system programmable flash memory, 8-KB RAM, and many other powerful features. The CC2531 has various operating modes, making it suited for systems where ultralow power consumption is required. Short transition times between operating modes further ensure low energy consumption. Source code for USB HID and CDC libraries and examples are downloadable from the CC2531 product page on [www.ti.com](http://www.ti.com).

Combined with the industry-leading and golden-unit-status ZigBee protocol stack ( Z-Stack™) from Texas Instruments, the CC2531 provides a robust and complete ZigBee USB dongle or firmware upgradable network node.

Combined with the golden-unit-status RemoTI™ stack from Texas Instruments, the CC2531 provides a robust ZigBee RF4CE remote-control target for USB dongle or TV/STB implementations.



80300-02

**ABSOLUTE MAXIMUM RATINGS<sup>(1)</sup>**

|                            |  | MIN  | MAX                      | UNIT |
|----------------------------|--|------|--------------------------|------|
| Supply voltage             | All supply pins must have the same voltage                         | -0.3 | 3.9                      | V    |
| Voltage on any digital pin |  | -0.3 | $V_{DD} + 0.3, \leq 3.9$ | V    |
| Input RF level             |  |      | 10                       | dBm  |
| Storage temperature range  |  | -40  | 125                      | °C   |
| ESD <sup>(2)</sup>         | All pads, according to human-body model, JEDEC STD 22, method A114 |      | 2                        | kV   |
|                            | According to charged-device model, JEDEC STD 22, method C101       |      | 500                      | V    |

- (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) CAUTION: ESD-sensitive device. Precautions should be used when handling the device in order to prevent permanent damage.

## RECOMMENDED OPERATING CONDITIONS

|  | MIN | MAX | UNIT |
|--|-----|-----|------|
| Operating ambient temperature range, $T_A$ | -40 | 125 | °C   |
| Operating supply voltage                   | 2   | 3.6 | V    |

## ELECTRICAL CHARACTERISTICS

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$  and  $V_{DD} = 3\text{ V}$ , unless otherwise noted. **Boldface** limits apply over the entire operating range,  $T_A = -40^\circ\text{C}$  to  $125^\circ\text{C}$ ,  $V_{DD} = 2\text{ V}$  to  $3.6\text{ V}$ , and  $f_c = 2394\text{ MHz}$  to  $2507\text{ MHz}$ .

| PARAMETER         |   | TEST CONDITIONS   | MIN | TYP  | MAX         | UNIT          |
|-------------------|---|---|-----|------|-------------|---------------|
| $I_{\text{core}}$ | Core current consumption  | Digital regulator on. 16-MHz RCOSC running. No radio, crystals, or peripherals active.<br>Medium CPU activity: normal flash access <sup>(1)</sup> , no RAM access |     | 3.4  |             | mA            |
|                   |   | 32-MHz XOSC running. No radio or peripherals active.<br>Medium CPU activity: normal flash access <sup>(1)</sup> , no RAM access                                   |     | 6.5  | <b>8.9</b>  | mA            |
|                   |   | 32-MHz XOSC running, radio in RX mode, -50-dBm input power, no peripherals active, CPU idle   |     | 20.5 |             | mA            |
|                   |   | 32-MHz XOSC running, radio in RX mode at -100-dBm input power (waiting for signal), no peripherals active, CPU idle   |     | 24.3 | <b>29.6</b> | mA            |
|                   |   | 32-MHz XOSC running, radio in TX mode, 1-dBm output power, no peripherals active, CPU idle  |     | 28.7 |             | mA            |
|                   |   | 32-MHz XOSC running, radio in TX mode, 4.5-dBm output power, no peripherals active, CPU idle  |     | 33.5 | <b>39.6</b> | mA            |
|                   |   | Power mode 1. Digital regulator on; 16-MHz RCOSC and 32-MHz crystal oscillator off; 32.768-kHz XOSC, POR, BOD and sleep timer active; RAM and register retention  |     | 0.2  | 0.3         | mA            |
|                   |   | Power mode 2. Digital regulator off; 16-MHz RCOSC and 32-MHz crystal oscillator off; 32.768-kHz XOSC, POR, and sleep timer active; RAM and register retention     |     | 1    | 2           | $\mu\text{A}$ |
|                   |   | Power mode 3. Digital regulator off; no clocks; POR active; RAM and register retention  |     | 0.4  | 1           | $\mu\text{A}$ |
| $I_{\text{peri}}$ | <b>Peripheral Current Consumption</b> (Adds to core current $I_{\text{core}}$ for each peripheral unit activated) |   |     |      |             |               |
|                   | Timer 1   | Timer running, 32-MHz XOSC used   |     | 90   |             | $\mu\text{A}$ |
|                   | Timer 2   | Timer running, 32-MHz XOSC used   |     | 90   |             | $\mu\text{A}$ |
|                   | Timer 3   | Timer running, 32-MHz XOSC used   |     | 60   |             | $\mu\text{A}$ |
|                   | Timer 4   | Timer running, 32-MHz XOSC used   |     | 70   |             | $\mu\text{A}$ |
|                   | Sleep timer   | Including 32.753-kHz RCOSC  |     | 0.6  |             | $\mu\text{A}$ |
|                   | USB   | Measured on CC2531 dongle reference design, 48-MHz clock running, USB enabled   |     | 0.1  |             | mA            |
|                   | ADC   | When converting   |     | 1.2  |             | mA            |
|                   | Flash   | Erase   |     | 1    |             | mA            |
|                   |   | Burst write peak current  |     | 6    |             | mA            |

(1) Normal flash access means that the code used exceeds the cache storage, so cache misses happen frequently.

## GENERAL CHARACTERISTICS

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$  and  $V_{DD} = 3\text{ V}$ , unless otherwise noted.

| PARAMETER                  | TEST CONDITIONS   | MIN | TYP | MAX | UNIT          |
|----------------------------|---|-----|-----|-----|---------------|
| <b>WAKE-UP AND TIMING</b>  |   |     |     |     |               |
| Power mode 1 → active      | Digital regulator on, 16-MHz RCOSC and 32-MHz crystal oscillator off. Start-up of 16-MHz RCOSC                |     | 4   |     | $\mu\text{s}$ |
| Power mode 2 or 3 → active | Digital regulator off, 16-MHz RCOSC and 32-MHz crystal oscillator off. Start-up of regulator and 16-MHz RCOSC |     | 0.1 |     | ms            |
| Active → TX or RX          | Initially running on 16-MHz RCOSC, with 32-MHz XOSC off   |     | 0.5 |     | ms            |
|                            | With 32-MHz XOSC initially on   |     |     | 192 | $\mu\text{s}$ |

**GENERAL CHARACTERISTICS (continued)**

 Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$  and  $V_{DD} = 3\text{ V}$ , unless otherwise noted.

| PARAMETER                  | TEST CONDITIONS   | MIN  | TYP | MAX  | UNIT          |
|----------------------------|---|------|-----|------|---------------|
| RX/TX and TX/RX turnaround |   |      |     | 192  | $\mu\text{s}$ |
| USB PLL start-up time      | With 32-MHz XOSC initially on   |      | 32  |      | $\mu\text{s}$ |
| <b>RADIO PART</b>          |   |      |     |      |               |
| RF frequency range         | Programmable in 1-MHz steps, 5 MHz between channels for compliance with [1] | 2394 |     | 2507 | MHz           |
| Radio baud rate            | As defined by [1]   |      | 250 |      | kbps          |
| Radio chip rate            | As defined by [1]   |      | 2   |      | MChip/s       |
| Flash erase cycles         |   |      |     | 20   | k Cycles      |
| Flash page size            |   |      | 2   |      | KB            |

## RF RECEIVE SECTION

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$ ,  $V_{DD} = 3\text{ V}$ , and  $f_c = 2440\text{ MHz}$ , unless otherwise noted.

**Bold** limits apply over the entire operating range,  $T_A = -40^\circ\text{C}$  to  $125^\circ\text{C}$ ,  $V_{DD} = 2\text{ V}$  to  $3.6\text{ V}$ , and  $f_c = 2394\text{ MHz}$  to  $2507\text{ MHz}$ .

| PARAMETER  | TEST CONDITIONS   | MIN | TYP   | MAX | UNIT |
|--|---|-----|-------|-----|------|
|  |   |     |       |     |      |
| Receiver sensitivity   | PER = 1%, as specified by [1]<br>[1] requires -85 dBm   | -97 | -92   |     | dBm  |
|  |   |     |       | -88 |      |
| Saturation (maximum input level)   | PER = 1%, as specified by [1]<br>[1] requires -20 dBm   |     | 10    |     | dBm  |
| Adjacent-channel rejection, 5-MHz channel spacing  | Wanted signal -82 dBm, adjacent modulated channel at 5 MHz, PER = 1%, as specified by [1].<br>[1] requires 0 dB   |     | 49    |     | dB   |
| Adjacent-channel rejection, -5-MHz channel spacing   | Wanted signal -82 dBm, adjacent modulated channel at -5 MHz, PER = 1%, as specified by [1].<br>[1] requires 0 dB  |     | 49    |     | dB   |
| Alternate-channel rejection, 10-MHz channel spacing  | Wanted signal -82 dBm, adjacent modulated channel at 10 MHz, PER = 1%, as specified by [1]<br>[1] requires 30 dB  |     | 57    |     | dB   |
| Alternate-channel rejection, -10-MHz channel spacing   | Wanted signal -82 dBm, adjacent modulated channel at -10 MHz, PER = 1%, as specified by [1]<br>[1] requires 30 dB   |     | 57    |     | dB   |
| Channel rejection<br>≥ 20 MHz<br>≤ -20 MHz   | Wanted signal at -82 dBm. Undesired signal is an IEEE 802.15.4 modulated channel, stepped through all channels from 2405 to 2480 MHz. Signal level for PER = 1%.  |     | 57    |     | dB   |
|  |   |     | 57    |     |      |
| Co-channel rejection   | Wanted signal at -82 dBm. Undesired signal is 802.15.4 modulated at the same frequency as the desired signal. Signal level for PER = 1%.                          |     | -3    |     | dB   |
| Blocking/desensitization<br>5 MHz from band edge<br>10 MHz from band edge<br>20 MHz from band edge<br>50 MHz from band edge<br>-5 MHz from band edge<br>-10 MHz from band edge<br>-20 MHz from band edge<br>-50 MHz from band edge | Wanted signal 3 dB above the sensitivity level, CW jammer, PER = 1%. Measured according to EN 300 440 class 2.  |     | -33   |     | dBm  |
|  |   |     | -33   |     |      |
|  |   |     | -32   |     |      |
|  |   |     | -31   |     |      |
|  |   |     | -35   |     |      |
|  |   |     | -35   |     |      |
|  |   |     | -34   |     |      |
|  |   |     | -34   |     |      |
| Spurious emission. Only largest spurious emission stated within each band.<br>30 MHz–1000 MHz<br>1 GHz–12.75 GHz   | Conducted measurement with a 50-Ω single-ended load. Suitable for systems targeting compliance with EN 300 328, EN 300 440, FCC CFR47 Part 15, and ARIB STD-T-66. |     | ≤80   |     | dBm  |
|  |   |     | -57   |     |      |
| Frequency error tolerance <sup>(1)</sup>   | [1] requires minimum 80 ppm   |     | ±150  |     | ppm  |
| Symbol rate error tolerance <sup>(2)</sup>   | [1] requires minimum 80 ppm   |     | ±1000 |     | ppm  |
| Sensitivity impact of USB operation  | Measured on CC2531 dongle reference design with CDC bulk transfer to PC at maximum speed  |     | 0.5   |     | dB   |

(1) Difference between center frequency of the received RF signal and local oscillator frequency

(2) Difference between incoming symbol rate and the internally generated symbol rate

## RF TRANSMIT SECTION

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$ ,  $V_{DD} = 3\text{ V}$  and  $f_c = 2440\text{ MHz}$ , unless otherwise noted.

**Boldface** limits apply over the entire operating range,  $T_A = -40^\circ\text{C}$  to  $125^\circ\text{C}$ ,  $V_{DD} = 2\text{ V}$  to  $3.6\text{ V}$ , and  $f_c = 2394\text{ MHz}$  to  $2507\text{ MHz}$ .

| PARAMETER   | TEST CONDITIONS   | MIN       | TYP      | MAX       | UNIT |
|---|---|-----------|----------|-----------|------|
| Nominal output power                                    | Delivered to a single-ended 50-Ω load through a balun using maximum-recommended output-power setting<br>[1] requires minimum -3 dBm | 0         | 4.5      | 8         | dBm  |
|   |   | <b>-8</b> |          | <b>10</b> |      |
| Programmable output power range                         |   |           | 32       |           | dB   |
| Spurious emissions                                      | Max recommended output power setting <sup>(1)</sup><br>Measured according to stated regulations.                                    |           |          |           | dBm  |
| Only largest spurious emission stated within each band. | 25 MHz–1000 MHz (outside restricted bands)  |           | -60      |           |      |
|   | 25 MHz–2400 MHz (within FCC restricted bands)   |           | -60      |           |      |
|   | 25 MHz–1000 MHz (within ETSI restricted bands)  |           | -60      |           |      |
|   | 1800–1900 MHz (ETSI restricted band)  |           | -57      |           |      |
|   | 5150–5300 MHz (ETSI restricted band)  |           | -55      |           |      |
|   | At $2 \times f_c$ and $3 \times f_c$ (FCC restricted band)  |           | -42      |           |      |
|   | At $2 \times f_c$ and $3 \times f_c$ (ETSI EN 300-440 and EN 300-328) <sup>(2)</sup>  |           | -31      |           |      |
| 1 GHz–12.75 GHz (outside restricted bands)              |   | -53       |          |           |      |
|   | At 2483.5 MHz and above (FCC restricted band)<br>$f_c = 2480\text{ MHz}$ <sup>(3)</sup>   |           | -42      |           |      |
| Error vector magnitude (EVM)                            | Measured as defined by [1] using maximum-recommended output-power setting<br>[1] requires maximum 35%.                              |           | 2%       |           |      |
| Optimum load impedance                                  | Differential impedance as seen from the RF port (RF_P and RF_N) towards the antenna   |           | 69 + j29 |           | Ω    |

(1) Texas Instruments CC2530 EM reference design is suitable for systems targeting compliance with EN 300 328, EN 300 440, FCC CFR47 Part 15, and ARIB STD-T-66.

(2) Margins for passing conducted requirements at the third harmonic can be improved by using a simple band-pass filter connected between matching network and RF connector (1.8 pF in parallel with 1.6 nH); this filter must be connected to a good RF ground.

(3) Margins for passing FCC requirements at 2483.5 MHz and above when transmitting at 2480 MHz can be improved by using a lower output-power setting or having less than 100% duty cycle.

### 32-MHz CRYSTAL OSCILLATOR

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$  and  $V_{DD} = 3\text{ V}$ , unless otherwise noted.

| PARAMETER   | TEST CONDITIONS  | MIN | TYP | MAX | UNIT     |
|---|--|-----|-----|-----|----------|
| Crystal frequency                                     |  |     | 32  |     | MHz      |
| Crystal frequency accuracy requirement <sup>(1)</sup> |  | -40 |     | 40  | ppm      |
| ESR Equivalent series resistance                      |  | 6   |     | 60  | $\Omega$ |
| $C_0$ Crystal shunt capacitance                       |  | 1   |     | 7   | pF       |
| $C_L$ Crystal load capacitance                        |  | 10  |     | 16  | pF       |
| Start-up time   |  |     | 0.3 |     | ms       |
| Power-down guard time                                 | The crystal oscillator must be in power down for a guard time before it is used again. This requirement is valid for all modes of operation. The need for power-down guard time can vary with crystal type and load. | 3   |     |     | ms       |

(1) Including aging and temperature dependency, as specified by [1]

### 32.768-kHz CRYSTAL OSCILLATOR

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$  and  $V_{DD} = 3\text{ V}$ , unless otherwise noted.

| PARAMETER   | TEST CONDITIONS | MIN | TYP    | MAX | UNIT       |
|---|-----------------|-----|--------|-----|------------|
| Crystal frequency                                     |                 |     | 32.768 |     | kHz        |
| Crystal frequency accuracy requirement <sup>(1)</sup> |                 | -40 |        | 40  | ppm        |
| ESR Equivalent series resistance                      |                 |     | 40     | 130 | k $\Omega$ |
| $C_0$ Crystal shunt capacitance                       |                 |     | 0.9    | 2   | pF         |
| $C_L$ Crystal load capacitance                        |                 |     | 12     | 16  | pF         |
| Start-up time   |                 |     | 0.4    |     | s          |

(1) Including aging and temperature dependency, as specified by [1]

### 32-kHz RC OSCILLATOR

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$  and  $V_{DD} = 3\text{ V}$ , unless otherwise noted.

| PARAMETER                                 | TEST CONDITIONS | MIN | TYP         | MAX | UNIT                |
|---|-----------------|-----|-------------|-----|---------------------|
| Calibrated frequency <sup>(1)</sup>       |                 |     | 32.753      |     | kHz                 |
| Frequency accuracy after calibration      |                 |     | $\pm 0.2\%$ |     |                     |
| Temperature coefficient <sup>(2)</sup>    |                 |     | 0.4         |     | %/ $^\circ\text{C}$ |
| Supply-voltage coefficient <sup>(3)</sup> |                 |     | 3           |     | %/V                 |
| Calibration time <sup>(4)</sup>           |                 |     | 2           |     | ms                  |

(1) The calibrated 32-kHz RC oscillator frequency is the 32-MHz XTAL frequency divided by 977.

(2) Frequency drift when temperature changes after calibration

(3) Frequency drift when supply voltage changes after calibration

(4) When the 32-kHz RC oscillator is enabled, it is calibrated when a switch from the 16-MHz RC oscillator to the 32-MHz crystal oscillator is performed while SLEPCMD.OSC32K\_CALDIS is 0.



## 16-MHz RC OSCILLATOR

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$  and  $V_{DD} = 3\text{ V}$ , unless otherwise noted.

| PARAMETER                               | TEST CONDITIONS | MIN | TYP   | MAX | UNIT |
|---|-----------------|-----|-------|-----|------|
| Frequency <sup>(1)</sup>                |                 |     | 16    |     | MHz  |
| Uncalibrated frequency accuracy         |                 |     | ±18%  |     |      |
| Calibrated frequency accuracy           |                 |     | ±0.6% | ±1% |      |
| Start-up time                           |                 |     |       | 10  | μs   |
| Initial calibration time <sup>(2)</sup> |                 |     | 50    |     | μs   |

(1) The calibrated 16-MHz RC oscillator frequency is the 32-MHz XTAL frequency divided by 2.

(2) When the 16-MHz RC oscillator is enabled, it is calibrated when a switch from the 16-MHz RC oscillator to the 32-MHz crystal oscillator is performed while SLEEP\_CMD.OSC\_PD is set to 0.

## RSSI/CCA CHARACTERISTICS

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$  and  $V_{DD} = 3\text{ V}$ , unless otherwise noted.

| PARAMETER                               | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|-----------------|-----|-----|-----|------|
| RSSI range                              |                 |     | 100 |     | dB   |
| Absolute uncalibrated RSSI/CCA accuracy |                 |     | ±4  |     | dB   |
| RSSI/CCA offset <sup>(1)</sup>          |                 |     | 73  |     | dB   |
| Step size (LSB value)                   |                 |     | 1   |     | dB   |

(1) Real RSSI = Register value – offset

## FREQEST CHARACTERISTICS

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$  and  $V_{DD} = 3\text{ V}$ , unless otherwise noted.

| PARAMETER                     | TEST CONDITIONS | MIN | TYP  | MAX | UNIT |
|-------------------------------|-----------------|-----|------|-----|------|
| FREQEST range                 |                 |     | ±250 |     | kHz  |
| FREQEST accuracy              |                 |     | ±40  |     | kHz  |
| FREQEST offset <sup>(1)</sup> |                 |     | 20   |     | kHz  |
| Step size (LSB value)         |                 |     | 7.8  |     | kHz  |

(1) Real FREQEST = Register value – offset

## FREQUENCY SYNTHESIZER CHARACTERISTICS

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$ ,  $V_{DD} = 3\text{ V}$  and  $f_c = 2440\text{ MHz}$ , unless otherwise noted.

| PARAMETER                        | TEST CONDITIONS               | MIN | TYP  | MAX | UNIT   |
|----------------------------------|-------------------------------|-----|------|-----|--------|
| Phase noise, unmodulated carrier | At ±1-MHz offset from carrier |     | -110 |     | dBc/Hz |
|                                  | At ±2-MHz offset from carrier |     | -117 |     |        |
|                                  | At ±5-MHz offset from carrier |     | -122 |     |        |

## ANALOG TEMPERATURE SENSOR

Measured on Texas Instruments CC2530 EM reference design with  $T_A = 25^\circ\text{C}$  and  $V_{DD} = 3\text{ V}$ , unless otherwise noted.

| PARAMETER   | TEST CONDITIONS  | MIN | TYP  | MAX | UNIT       |
|---|--|-----|------|-----|------------|
| Output at 25°C  | Measured using integrated ADC, using internal bandgap voltage reference and maximum resolution |     | 1480 |     | 12-bit ADC |
| Temperature coefficient                                       |  |     | 4.5  |     | /1°C       |
| Voltage coefficient   |  |     | 1    |     | /0.1 V     |
| Initial accuracy without calibration                          |  |     | ±10  |     | °C         |
| Accuracy using 1-point calibration (entire temperature range) |  |     | ±5   |     | °C         |
| Current consumption when enabled (ADC current not included)   |  |     |      | 0.5 |            |

### ADC CHARACTERISTICS

T<sub>A</sub> = 25°C and V<sub>DD</sub> = 3 V, unless otherwise noted.

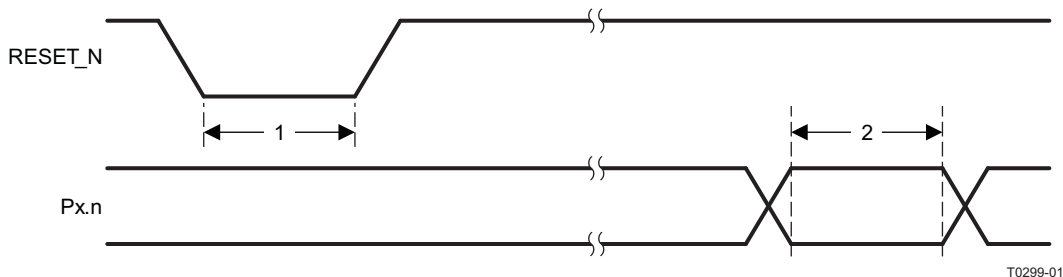
| PARAMETER                        |  | TEST CONDITIONS  | MIN | TYP             | MAX | UNIT    |
|----------------------------------|--|--|-----|-----------------|-----|---------|
|                                  | Input voltage                              | V <sub>DD</sub> is voltage on AVDD5 pin  | 0   | V <sub>DD</sub> |     | V       |
|                                  | External reference voltage                 | V <sub>DD</sub> is voltage on AVDD5 pin  | 0   | V <sub>DD</sub> |     | V       |
|                                  | External reference voltage differential    | V <sub>DD</sub> is voltage on AVDD5 pin  | 0   | V <sub>DD</sub> |     | V       |
|                                  | Input resistance, signal                   | Using 4-MHz clock speed  |     | 197             |     | kΩ      |
|                                  | Full-scale signal <sup>(1)</sup>           | Peak-to-peak, defines 0 dBFS   |     | 2.97            |     | V       |
| ENOB <sup>(1)</sup>              | Effective number of bits                   | Single-ended input, 7-bit setting  |     | 5.7             |     | bits    |
|                                  |  | Single-ended input, 9-bit setting  |     | 7.5             |     |         |
|                                  |  | Single-ended input, 10-bit setting   |     | 9.3             |     |         |
|                                  |  | Single-ended input, 12-bit setting   |     | 10.8            |     |         |
|                                  |  | Differential input, 7-bit setting  |     | 6.5             |     |         |
|                                  |  | Differential input, 9-bit setting  |     | 8.3             |     |         |
|                                  |  | Differential input, 10-bit setting   |     | 10.0            |     |         |
|                                  | Useful power bandwidth                     | 7-bit setting, both single and differential  |     | 0–20            |     | kHz     |
| THD <sup>(1)</sup>               | Total harmonic distortion                  | Single-ended input, 12-bit setting, –6 dBFS  |     | –75.2           |     | dB      |
|                                  |  | Differential input, 12-bit setting, –6 dBFS  |     | –86.6           |     |         |
|                                  | Signal to nonharmonic ratio <sup>(1)</sup> | Single-ended input, 12-bit setting   |     | 70.2            |     | dB      |
|                                  |  | Differential input, 12-bit setting   |     | 79.3            |     |         |
|                                  |  | Single-ended input, 12-bit setting, –6 dBFS  |     | 78.8            |     |         |
|                                  |  | Differential input, 12-bit setting, –6 dBFS  |     | 88.9            |     |         |
| CMRR                             | Common-mode rejection ratio                | Differential input, 12-bit setting, 1-kHz sine (0 dBFS), limited by ADC resolution |     | >84             |     | dB      |
|                                  | Crosstalk                                  | Single-ended input, 12-bit setting, 1-kHz sine (0 dBFS), limited by ADC resolution |     | >84             |     | dB      |
|                                  | Offset                                     | Midscale   |     | –3              |     | mV      |
|                                  | Gain error                                 |  |     | 0.68%           |     |         |
| DNL <sup>(1)</sup>               | Differential nonlinearity                  | 12-bit setting, mean   |     | 0.05            |     | LSB     |
|                                  |  | 12-bit setting, maximum  |     | 0.9             |     |         |
| INL <sup>(1)</sup>               | Integral nonlinearity                      | 12-bit setting, mean   |     | 4.6             |     | LSB     |
|                                  |  | 12-bit setting, maximum  |     | 13.3            |     |         |
| SINAD <sup>(1)</sup><br>(–THD+N) | Signal-to-noise-and-distortion             | Single-ended input, 7-bit setting  |     | 35.4            |     | dB      |
|                                  |  | Single-ended input, 9-bit setting  |     | 46.8            |     |         |
|                                  |  | Single-ended input, 10-bit setting   |     | 57.5            |     |         |
|                                  |  | Single-ended input, 12-bit setting   |     | 66.6            |     |         |
|                                  |  | Differential input, 7-bit setting  |     | 40.7            |     |         |
|                                  |  | Differential input, 9-bit setting  |     | 51.6            |     |         |
|                                  |  | Differential input, 10-bit setting   |     | 61.8            |     |         |
|                                  | Conversion time                            | 7-bit setting  |     | 20              |     | μs      |
|                                  |  | 9-bit setting  |     | 36              |     |         |
|                                  |  | 10-bit setting   |     | 68              |     |         |
|                                  |  | 12-bit setting   |     | 132             |     |         |
|                                  | Power consumption                          |  |     | 1.2             |     | mA      |
|                                  | Internal reference voltage                 |  |     | 1.15            |     | V       |
|                                  | Internal reference VDD coefficient         |  |     | 4               |     | mV/V    |
|                                  | Internal reference temperature coefficient |  |     | 0.4             |     | mV/10°C |

(1) Measured with 300-Hz sine-wave input and VDD as reference.

**CONTROL INPUT AC CHARACTERISTICS**

T<sub>A</sub> = -40°C to 125°C, V<sub>DD</sub> = 2 V to 3.6 V, unless otherwise noted.

| PARAMETER  | TEST CONDITIONS  | MIN | TYP | MAX | UNIT |
|--|--|-----|-----|-----|------|
| System clock, f <sub>SYSCLK</sub><br>t <sub>SYSCLK</sub> = 1/f <sub>SYSCLK</sub> | The undivided system clock is 32 MHz when crystal oscillator is used. The undivided system clock is 16 MHz when calibrated 16-MHz RC oscillator is used.   | 16  |     | 32  | MHz  |
| RESET_N low duration   | See item 1, Figure 1. This is the shortest pulse that is recognized as a complete reset pin request. Note that shorter pulses may be recognized but might not lead to complete reset of all modules within the chip. | 1   |     |     | μs   |
| Interrupt pulse duration   | See item 2, Figure 1. This is the shortest pulse that is recognized as an interrupt request.   | 20  |     |     | ns   |

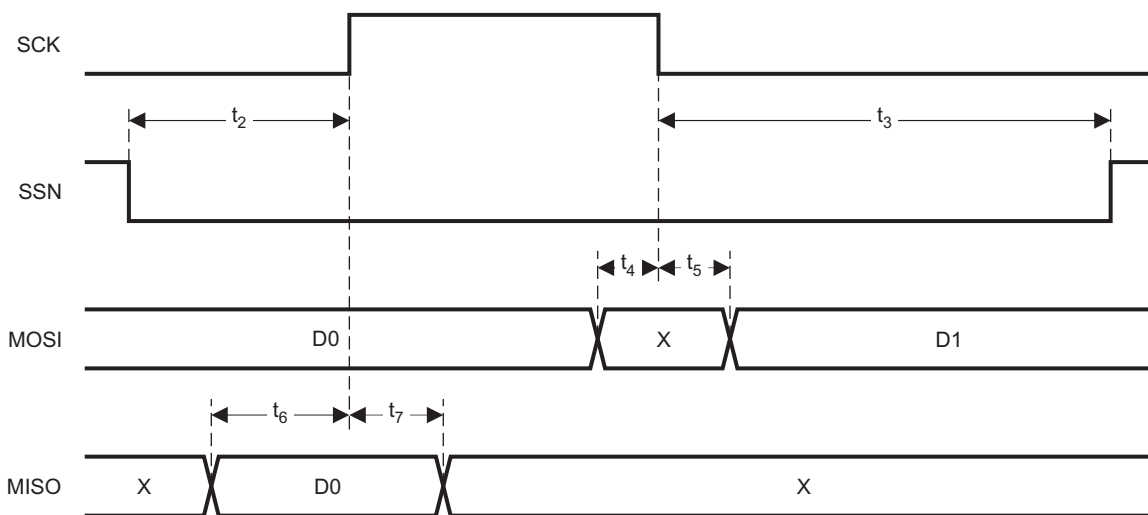


**Figure 1. Control Input AC Characteristics**

### SPI AC CHARACTERISTICS

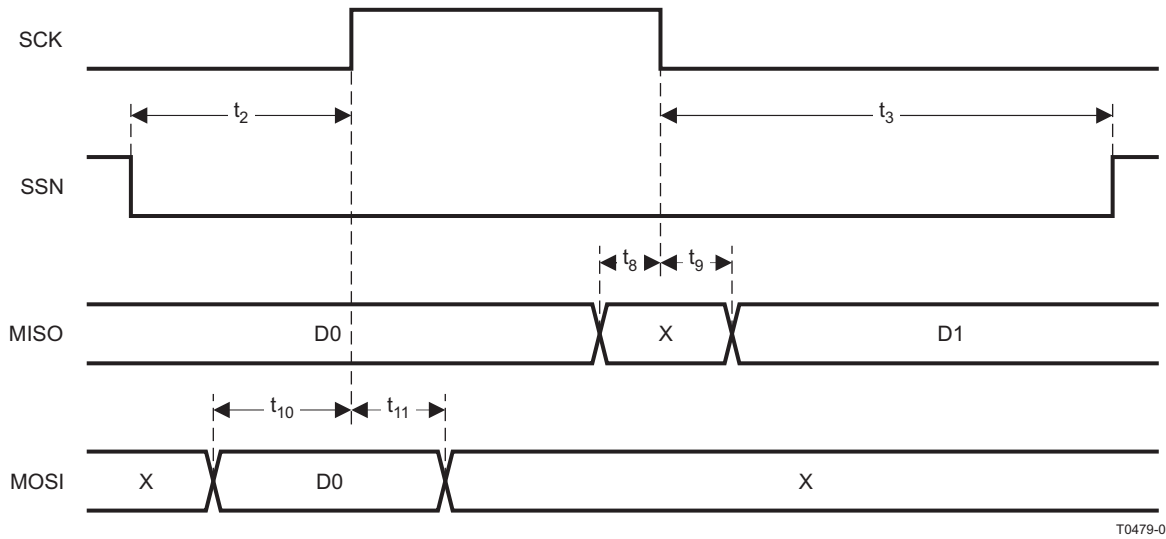
T<sub>A</sub> = -40°C to 125°C, VDD = 2 V to 3.6 V, unless otherwise noted.

| PARAMETER                      | TEST CONDITIONS      | MIN | TYP | MAX | UNIT |
|--------------------------------|----------------------|-----|-----|-----|------|
| SCK period                     | Master, RX and TX    | 250 |     |     | ns   |
| SCK duty cycle                 | Master               |     | 50% |     |      |
| t <sub>2</sub> SSN low to SCK  | Master               | 63  |     |     | ns   |
| t <sub>3</sub> SCK to SSN high | Master               | 63  |     |     | ns   |
| t <sub>4</sub> MOSI early out  | Master, load = 10 pF |     |     | 7   | ns   |
| t <sub>5</sub> MOSI late out   | Master, load = 10 pF |     |     | 10  | ns   |
| t <sub>6</sub> MISO setup      | Master               | 90  |     |     | ns   |
| t <sub>7</sub> MISO hold       | Master               | 10  |     |     | ns   |
| t <sub>1</sub> SCK period      | Slave, RX and TX     | 250 |     |     | ns   |
| SCK duty cycle                 | Slave                |     | 50% |     |      |
| t <sub>2</sub> SSN low to SCK  | Slave                | 63  |     |     | ns   |
| t <sub>3</sub> SCK to SSN high | Slave                | 63  |     |     | ns   |
| t <sub>8</sub> MISO early out  | Slave, load = 10 pF  |     |     | 0   | ns   |
| t <sub>9</sub> MISO late out   | Slave, load = 10 pF  |     |     | 95  | ns   |
| t <sub>10</sub> MOSI setup     | Slave                | 35  |     |     | ns   |
| t <sub>11</sub> MOSI hold      | Slave                | 10  |     |     | ns   |
| Operating frequency            | Master, TX only      |     |     | 8   | MHz  |
|                                | Master, RX and TX    |     |     | 4   |      |
|                                | Slave, RX only       |     |     | 8   |      |
|                                | Slave, RX and TX     |     |     | 4   |      |



T0478-01

Figure 2. SPI Master AC Characteristics



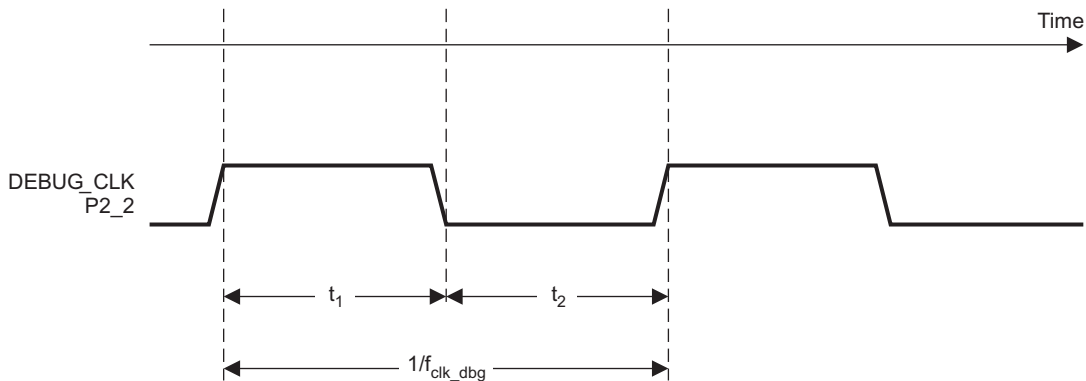
T0479-01

Figure 3. SPI Slave AC Characteristics

### DEBUG INTERFACE AC CHARACTERISTICS

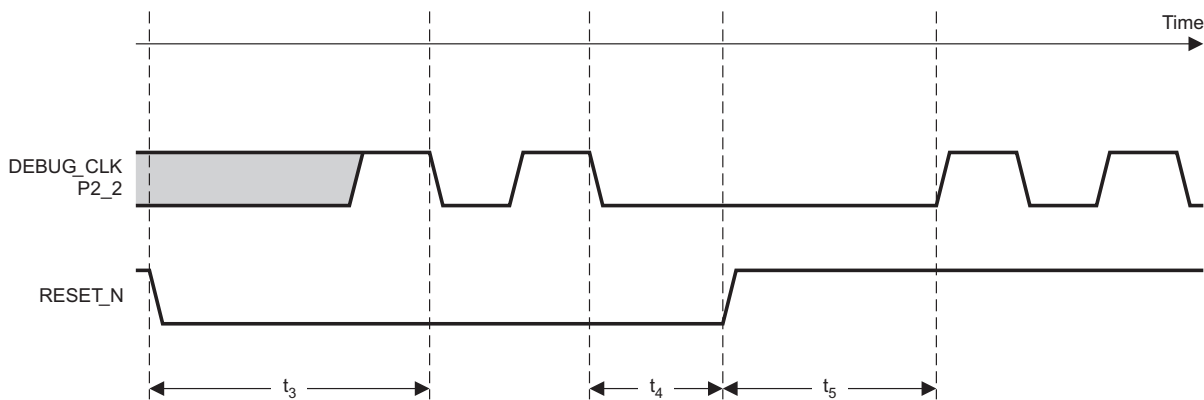
T<sub>A</sub> = -40°C to 125°C, V<sub>DD</sub> = 2 V to 3.6 V, unless otherwise noted.

| PARAMETER  | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|--|-----------------|-----|-----|-----|------|
| f <sub>clk_dbg</sub> Debug clock frequency (see Figure 4)                          |                 |     |     | 12  | MHz  |
| t <sub>1</sub> Allowed high pulse on clock (see Figure 4)                          |                 | 35  |     |     | ns   |
| t <sub>2</sub> Allowed low pulse on clock (see Figure 4)                           |                 | 35  |     |     | ns   |
| t <sub>3</sub> EXT_RESET_N low to first falling edge on debug clock (see Figure 5) |                 | 167 |     |     | ns   |
| t <sub>4</sub> Falling edge on clock to EXT_RESET_N high (see Figure 5)            |                 | 83  |     |     | ns   |
| t <sub>5</sub> EXT_RESET_N high to first debug command (see Figure 5)              |                 | 83  |     |     | ns   |
| t <sub>6</sub> Debug data setup (see Figure 6)                                     |                 | 2   |     |     | ns   |
| t <sub>7</sub> Debug data hold (see Figure 6)                                      |                 | 4   |     |     | ns   |
| t <sub>8</sub> Clock-to-data delay (see Figure 6)                                  | Load = 10 pF    |     |     | 30  | ns   |



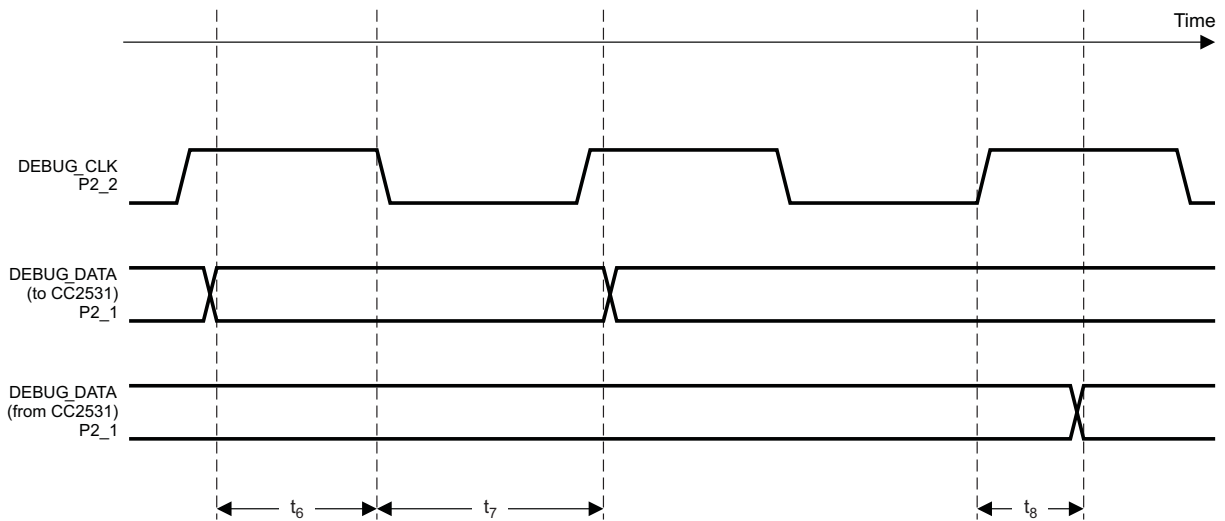
T0436-01

Figure 4. Debug Clock – Basic Timing



T0437-01

Figure 5. Data Setup and Hold Timing



T0438-01

Figure 6. Debug Enable Timing

### TIMER INPUTS AC CHARACTERISTICS

T<sub>A</sub> = -40°C to 125°C, V<sub>DD</sub> = 2 V to 3.6 V, unless otherwise noted.

| PARAMETER                    | TEST CONDITIONS   | MIN | TYP | MAX | UNIT               |
|------------------------------|---|-----|-----|-----|--------------------|
| Input capture pulse duration | Synchronizers determine the shortest input pulse that can be recognized. The synchronizers operate at the current system clock rate (16 or 32 MHz). | 1.5 |     |     | t <sub>SYCLK</sub> |

### DC CHARACTERISTICS

T<sub>A</sub> = 25°C, V<sub>DD</sub> = 3 V, unless otherwise noted.

| PARAMETER                             | TEST CONDITIONS              | MIN | TYP | MAX | UNIT |
|---------------------------------------|------------------------------|-----|-----|-----|------|
| Logic-0 input voltage                 |                              |     |     | 0.5 | V    |
| Logic-1 input voltage                 |                              | 2.5 |     |     | V    |
| Logic-0 input current                 | Input equals 0 V             | -50 |     | 50  | nA   |
| Logic-1 input current                 | Input equals V <sub>DD</sub> | -50 |     | 50  | nA   |
| I/O-pin pullup and pulldown resistors |                              |     | 20  |     | kΩ   |
| Logic-0 output voltage, 4-mA pins     | Output load 4 mA             |     |     | 0.5 | V    |
| Logic-1 output voltage, 4-mA pins     | Output load 4 mA             | 2.4 |     |     | V    |
| Logic-0 output voltage, 20-mA pins    | Output load 20 mA            |     |     | 0.5 | V    |
| Logic-1 output voltage, 20-mA pins    | Output load 20 mA            | 2.4 |     |     | V    |

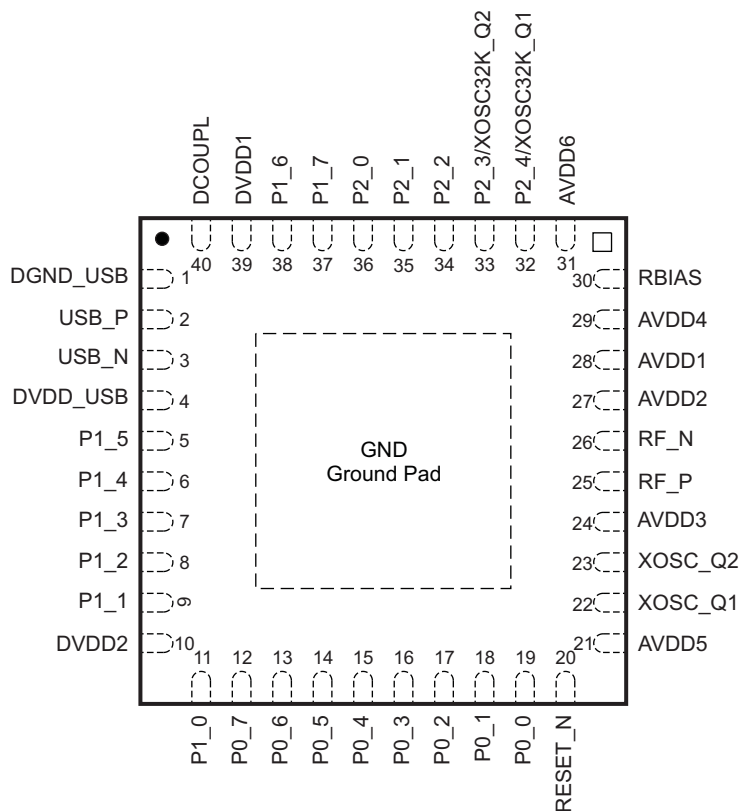
### USB INTERFACE DC CHARACTERISTICS

T<sub>A</sub> = 25°C, V<sub>DD</sub> = 3 V to 3.6 V, unless otherwise noted.

| PARAMETER                    | TEST CONDITIONS                  | MIN | TYP | MAX | UNIT |
|------------------------------|----------------------------------|-----|-----|-----|------|
| USB pad voltage output, high | V <sub>DD</sub> 3.6 V, 4-mA load |     | 3.4 |     | V    |
| USB pad voltage output, low  | V <sub>DD</sub> 3.6 V, 4-mA load |     | 0.2 |     | V    |

### DEVICE INFORMATION

#### RHA PACKAGE (TOP VIEW)



NOTE: The exposed ground pad must be connected to a solid ground plane, as this is the ground connection for the chip.

#### Pin Descriptions

| PIN NAME | PIN | PIN TYPE          | DESCRIPTION  |
|----------|-----|-------------------|--|
| AVDD1    | 28  | Power (analog)    | 2-V–3.6-V analog power-supply connection   |
| AVDD2    | 27  | Power (analog)    | 2-V–3.6-V analog power-supply connection   |
| AVDD3    | 24  | Power (analog)    | 2-V–3.6-V analog power-supply connection   |
| AVDD4    | 29  | Power (analog)    | 2-V–3.6-V analog power-supply connection   |
| AVDD5    | 21  | Power (analog)    | 2-V–3.6-V analog power-supply connection   |
| AVDD6    | 31  | Power (analog)    | 2-V–3.6-V analog power-supply connection   |
| DCOUPL   | 40  | Power (digital)   | 1.8-V digital power-supply decoupling. Do not use for supplying external circuits. |
| DGND_USB | 1   | Ground (USB pads) | USB Ground   |
| DVDD1    | 39  | Power (digital)   | 2-V–3.6-V digital power-supply connection  |
| DVDD2    | 10  | Power (digital)   | 2-V–3.6-V digital power-supply connection  |
| DVDD_USB | 4   | Power (USB Pads)  | 3.3V USB power supply connection   |
| GND      | —   | Ground            | The ground pad must be connected to a solid ground plane.                          |
| P0_0     | 19  | Digital I/O       | Port 0.0   |
| P0_1     | 18  | Digital I/O       | Port 0.1   |
| P0_2     | 17  | Digital I/O       | Port 0.2   |
| P0_3     | 16  | Digital I/O       | Port 0.3   |
| P0_4     | 15  | Digital I/O       | Port 0.4   |
| P0_5     | 14  | Digital I/O       | Port 0.5   |



**Pin Descriptions (continued)**

| PIN NAME            | PIN | PIN TYPE                   | DESCRIPTION  |
|---------------------|-----|----------------------------|--|
| P0_6                | 13  | Digital I/O                | Port 0.6   |
| P0_7                | 12  | Digital I/O                | Port 0.7   |
| P1_0                | 11  | Digital I/O                | Port 1.0 – 20-mA drive capability  |
| P1_1                | 9   | Digital I/O                | Port 1.1 – 20-mA drive capability  |
| P1_2                | 8   | Digital I/O                | Port 1.2   |
| P1_3                | 7   | Digital I/O                | Port 1.3   |
| P1_4                | 6   | Digital I/O                | Port 1.4   |
| P1_5                | 5   | Digital I/O                | Port 1.5   |
| P1_6                | 38  | Digital I/O                | Port 1.6   |
| P1_7                | 37  | Digital I/O                | Port 1.7   |
| P2_0                | 36  | Digital I/O                | Port 2.0   |
| P2_1                | 35  | Digital I/O                | Port 2.1   |
| P2_2                | 34  | Digital I/O                | Port 2.2   |
| P2_3/<br>XOSC32K_Q2 | 33  | Digital I/O,<br>analog I/O | Port 2.3/32.768 kHz XOSC   |
| P2_4/<br>XOSC32K_Q1 | 32  | Digital I/O,<br>analog I/O | Port 2.4/32.768 kHz XOSC   |
| RBIAS               | 30  | Analog I/O                 | External precision bias resistor for reference current                                   |
| RESET_N             | 20  | Digital input              | Reset, active-low  |
| RF_N                | 26  | RF I/O                     | Negative RF input signal to LNA during RX<br>Negative RF output signal from PA during TX |
| RF_P                | 25  | RF I/O                     | Positive RF input signal to LNA during RX<br>Positive RF output signal from PA during TX |
| USB_N               | 3   | USB I/O                    | USB differential data minus (D-)   |
| USB_P               | 2   | USB I/O                    | USB differential data plus (D+)  |
| XOSC_Q1             | 22  | Analog I/O                 | 32-MHz crystal oscillator pin 1 or external-clock input                                  |
| XOSC_Q2             | 23  | Analog I/O                 | 32-MHz crystal oscillator pin 2  |

CIRCUIT DESCRIPTION

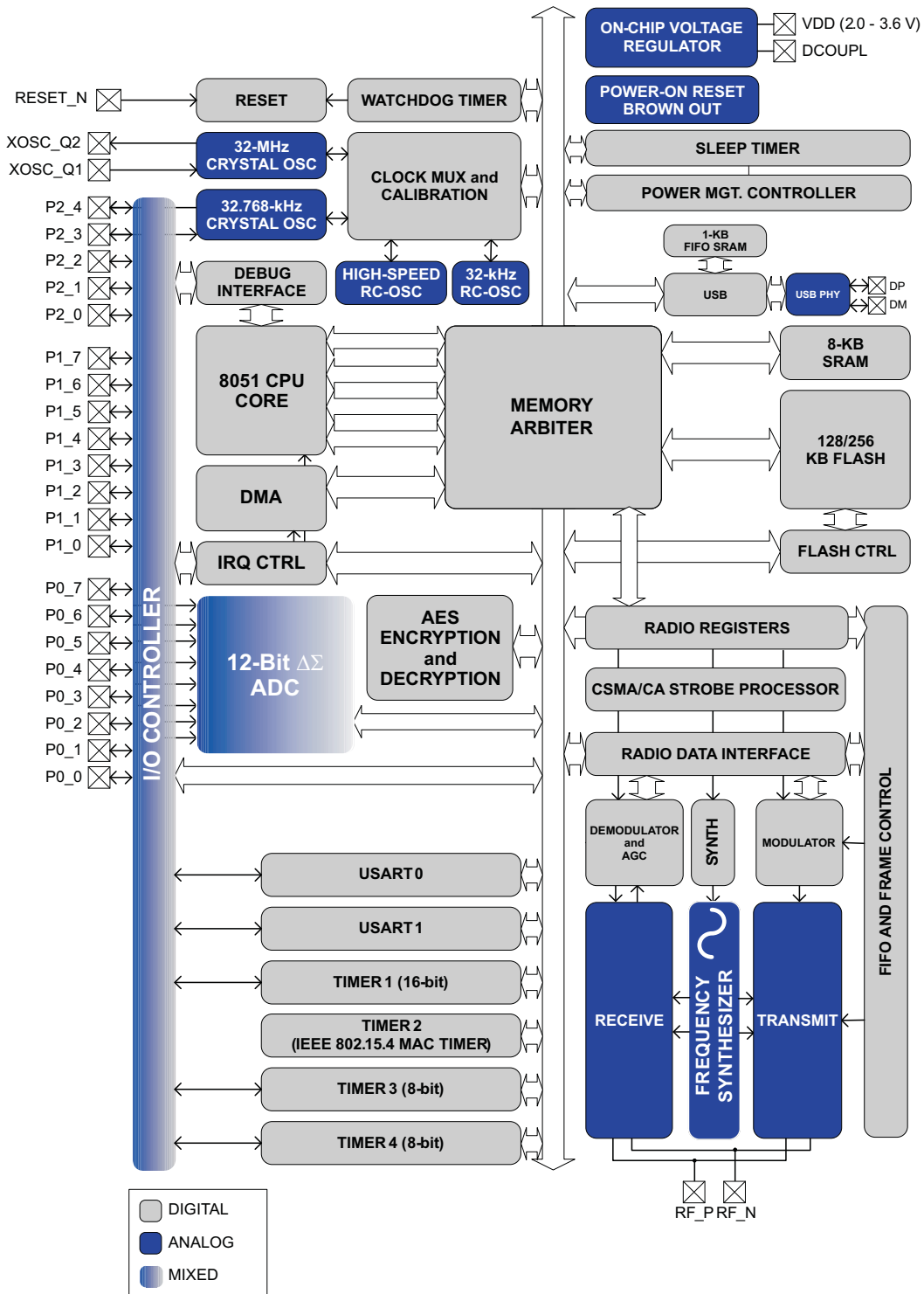


Figure 7. CC2531 Block Diagram

A block diagram of the CC2531 is shown in Figure 7. The modules can be roughly divided into one of three categories: CPU- and memory-related modules; modules related to peripherals, clocks, and power management; and radio-related modules. In the following subsections, a short description of each module that appears in Figure 7 is given.

For more details about the modules and their usage, see the corresponding chapters in the CC253x User's Guide ([SWRU191](#)).

## CPU and Memory

The **8051 CPU** core used in the CC253x device family is a single-cycle 8051-compatible core. It has three different memory-access buses (SFR, DATA, and CODE/XDATA) with single-cycle access to SFR, DATA, and the main SRAM. It also includes a debug interface and an 18-input extended interrupt unit.

The **interrupt controller** services a total of 18 interrupt sources, divided into six interrupt groups, each of which is associated with one of four interrupt priorities. Any interrupt service request is serviced also when the device is in idle mode by going back to active mode. Some interrupts can also wake up the device from sleep mode (power modes 1–3).

The **memory arbiter** is at the heart of the system, as it connects the CPU and DMA controller with the physical memories and all peripherals through the SFR bus. The memory arbiter has four memory access points, access of which can map to one of three physical memories: an 8-KB SRAM, flash memory, and XREG/SFR registers. It is responsible for performing arbitration and sequencing between simultaneous memory accesses to the same physical memory.

The **8-KB SRAM** maps to the DATA memory space and to parts of the XDATA memory spaces. The 8-KB SRAM is an ultralow-power SRAM that retains its contents even when the digital part is powered off (power modes 2 and 3). This is an important feature for low-power applications.

The **256 KB flash block** provides in-circuit programmable non-volatile program memory for the device, and maps into the CODE and XDATA memory spaces. In addition to holding program code and constants, the non-volatile memory allows the application to save data that must be preserved such that it is available after restarting the device. Using this feature one can, e.g., use saved network-specific data to avoid the need for a full start-up and network find-and-join process.

## Clocks and Power Management

The digital core and peripherals are powered by a 1.8-V low-dropout **voltage regulator**. It provides **power management** functionality that enables low-power operation for long battery life using different power modes. Five different **reset** sources exist to reset the device.

## Peripherals

The CC2531 includes many different peripherals that allow the application designer to develop advanced applications.

The **debug interface** implements a proprietary two-wire serial interface that is used for in-circuit debugging. Through this debug interface, it is possible to perform an erasure of the entire flash memory, control which oscillators are enabled, stop and start execution of the user program, execute supplied instructions on the 8051 core, set code breakpoints, and single-step through instructions in the code. Using these techniques, it is possible to perform in-circuit debugging and external flash programming elegantly.

The device contains flash memory for storage of program code. The flash memory is programmable from the user software and through the debug interface. The **flash controller** handles writing and erasing the embedded flash memory. The flash controller allows page-wise erasure and 4-bitwise programming.

The **I/O controller** is responsible for all general-purpose I/O pins. The CPU can configure whether peripheral modules control certain pins or whether they are under software control, and if so, whether each pin is configured as an input or output and if a pullup or pulldown resistor in the pad is connected. CPU interrupts can be enabled on each pin individually. Each peripheral that connects to the I/O pins can choose between two different I/O pin locations to ensure flexibility in various applications.

A versatile five-channel **DMA controller** is available in the system, accesses memory using the XDATA memory space, and thus has access to all physical memories. Each channel (trigger, priority, transfer mode, addressing mode, source and destination pointers, and transfer count) is configured with DMA descriptors anywhere in memory. Many of the hardware peripherals (AES core, flash controller, USARTs, timers, ADC interface) achieve highly efficient operation by using the DMA controller for data transfers between SFR or XREG addresses and flash/SRAM.

**Timer 1** is a 16-bit timer with timer/counter/PWM functionality. It has a programmable prescaler, a 16-bit period value, and five individually programmable counter/capture channels, each with a 16-bit compare value. Each of the counter/capture channels can be used as a PWM output or to capture the timing of edges on input signals. It can also be configured in **IR Generation Mode**, where it counts Timer 3 periods and the output is ANDed with the output of Timer 3 to generate modulated consumer IR signals with minimal CPU interaction.

**Timer 2 (the MAC Timer)** is specially designed for supporting an IEEE 802.15.4 MAC or other time-slotted protocol in software. The timer has a configurable timer period and a 24-bit overflow counter that can be used to keep track of the number of periods that have transpired. A 40-bit capture register is also used to record the exact time at which a start-of-frame delimiter is received/transmitted or the exact time at which transmission ends, as well as two 16-bit output compare registers and two 24-bit overflow compare registers that can send various command strobes (start RX, start TX, etc.) at specific times to the radio modules.

**Timer 3 and Timer 4** are 8-bit timers with timer/counter/PWM functionality. They have a programmable prescaler, an 8-bit period value, and one programmable counter channel with an 8-bit compare value. Each of the counter channels can be used as a PWM output.

The **sleep timer** is an ultralow-power timer that counts 32-kHz crystal oscillator or 32-kHz RC oscillator periods. The sleep timer runs continuously in all operating modes except power mode 3 (PM3). Typical applications of this timer are as a real-time counter or as a wake-up timer to come out of power mode 1 (PM1) or 2 (PM2).

The **ADC** supports 7 to 12 bits of resolution in a 30-kHz to 4-kHz bandwidth, respectively. DC and audio conversions with up to eight input channels (Port 0) are possible. The inputs can be selected as single-ended or differential. The reference voltage can be internal, AVDD, or a single-ended or differential external signal. The ADC also has a temperature-sensor input channel. The ADC can automate the process of periodic sampling or conversion over a sequence of channels.

The **random-number generator** uses a 16-bit LFSR to generate pseudorandom numbers, which can be read by the CPU or used directly by the command strobe processor. It can be seeded with random data from noise in the radio ADC.

The **AES encryption/decryption core** allows the user to encrypt and decrypt data using the AES algorithm with 128-bit keys. The core is able to support the AES operations required by IEEE 802.15.4 MAC security, the ZigBee network layer, and the application layer.

A built-in **watchdog timer** allows the CC2531 to reset itself in case the firmware hangs. When enabled by software, the watchdog timer must be cleared periodically; otherwise, it resets the device when it times out. It can alternatively be configured for use as a general 32-kHz timer.

**USART 0 and USART 1** are each configurable as either a SPI master/slave or a UART. They provide double buffering on both RX and TX and hardware flow control, and are thus well suited to high-throughput full-duplex applications. Each has its own high-precision baud-rate generator, thus leaving the ordinary timers free for other uses.

The **USB** device operates at full-speed, 12-Mbps transfer rate. The controller has 5 bidirectional endpoints in addition to control endpoint 0. The endpoints support bulk, interrupt, and isochronous operation for implementation of a wide range of applications. The 1024 bytes of dedicated, flexible FIFO memory combined with DMA access ensures that a minimum of CPU involvement is needed for USB communication.

## Radio

The CC2531 features an IEEE 802.15.4-compliant radio transceiver. The RF core controls the analog radio modules. In addition, it provides an interface between the MCU and the radio which makes it possible to issue commands, read status, and automate and sequence radio events. The radio also includes a packet-filtering and address-recognition module.

TYPICAL CHARACTERISTICS

RX CURRENT (–100-dBm INPUT)  
vs  
TEMPERATURE

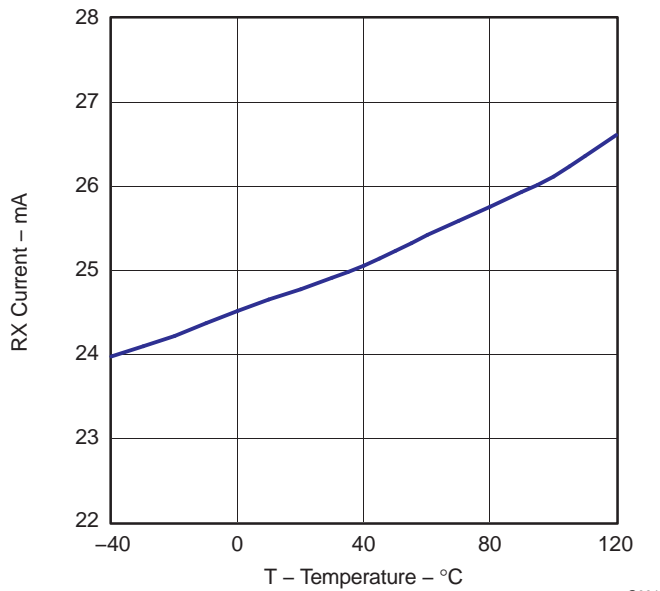


Figure 8.

G001

TX CURRENT (TXPOWER = 0xF5)  
vs  
TEMPERATURE

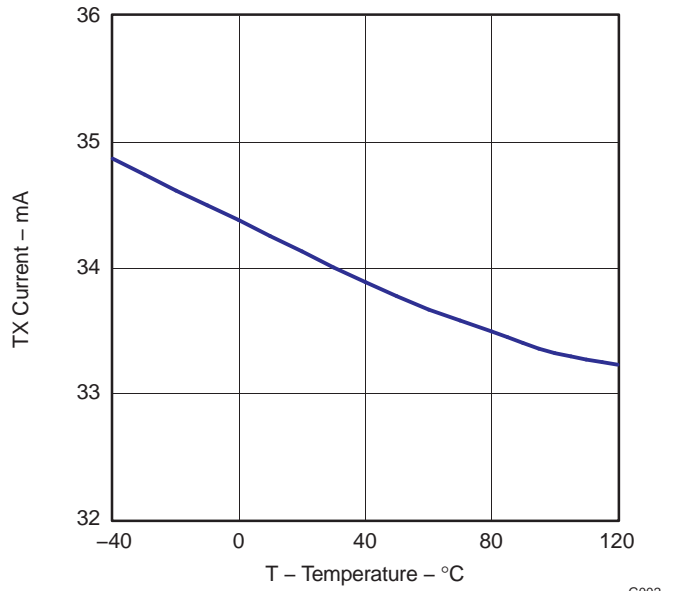


Figure 9.

G002

RX CURRENT (–100-dBm INPUT)  
vs  
SUPPLY VOLTAGE

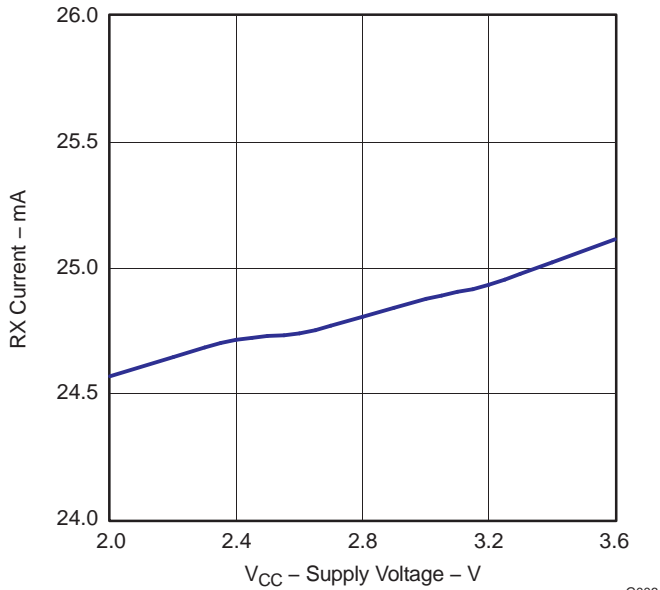


Figure 10.

G003

TX CURRENT (TXPOWER = 0xF5)  
vs  
SUPPLY VOLTAGE

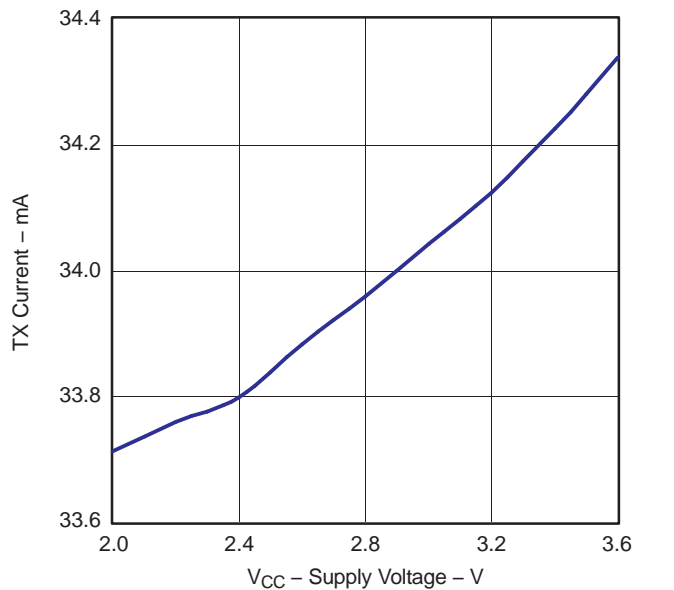
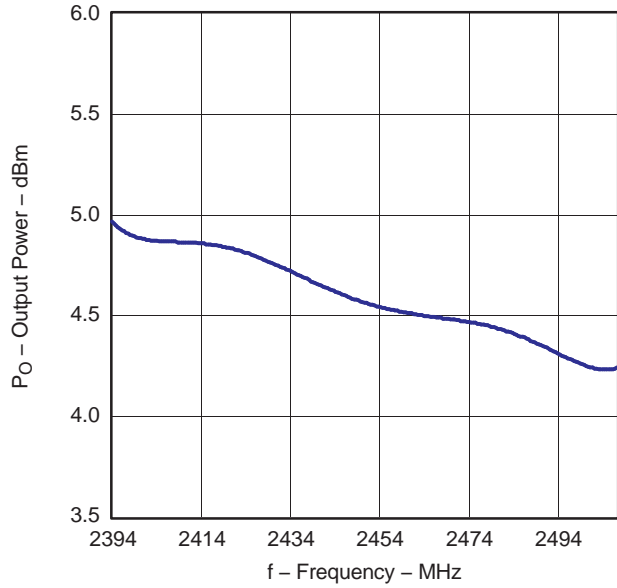


Figure 11.

G004

**TYPICAL CHARACTERISTICS (continued)**

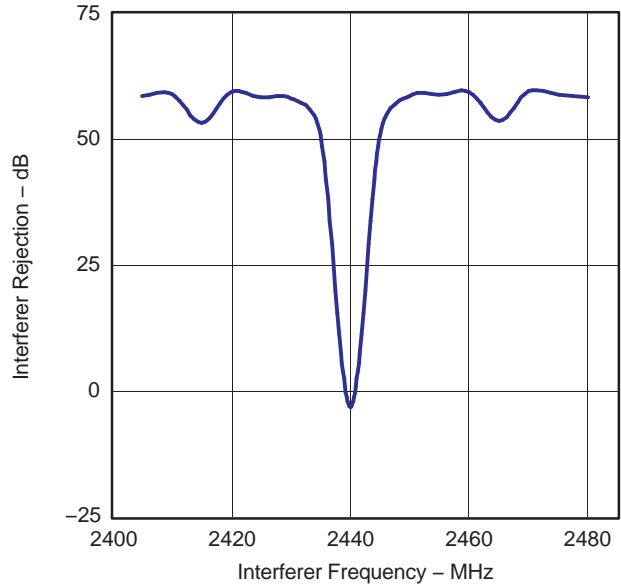
**OUTPUT POWER (TXPOWER = 0xF5)  
vs  
FREQUENCY**



G005

**Figure 12.**

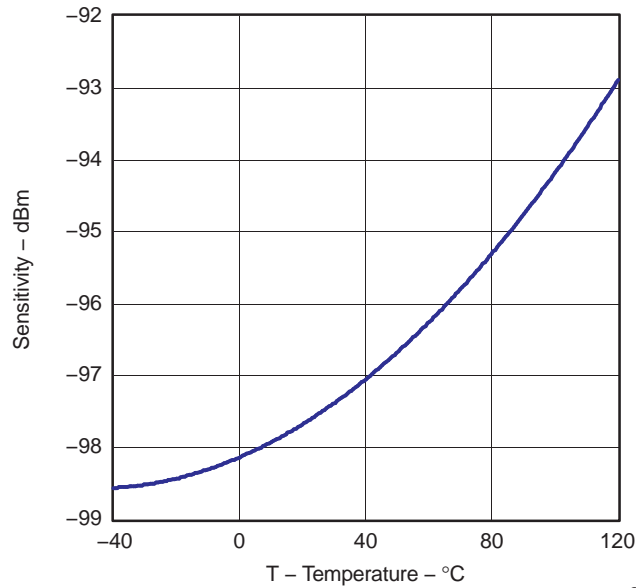
**INTERFERER REJECTION (802.15.4 INTERFERER)  
vs  
INTERFERER FREQUENCY (CARRIER AT -82 dBm, 2440 MHz)**



G006

**Figure 13.**

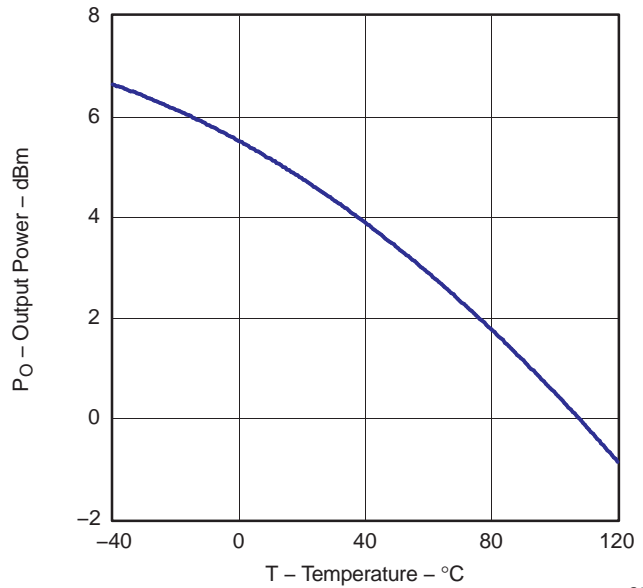
**SENSITIVITY  
vs  
TEMPERATURE**



G007

**Figure 14.**

**OUTPUT POWER (TXPOWER = 0xF5)  
vs  
TEMPERATURE**



G008

**Figure 15.**

TYPICAL CHARACTERISTICS (continued)

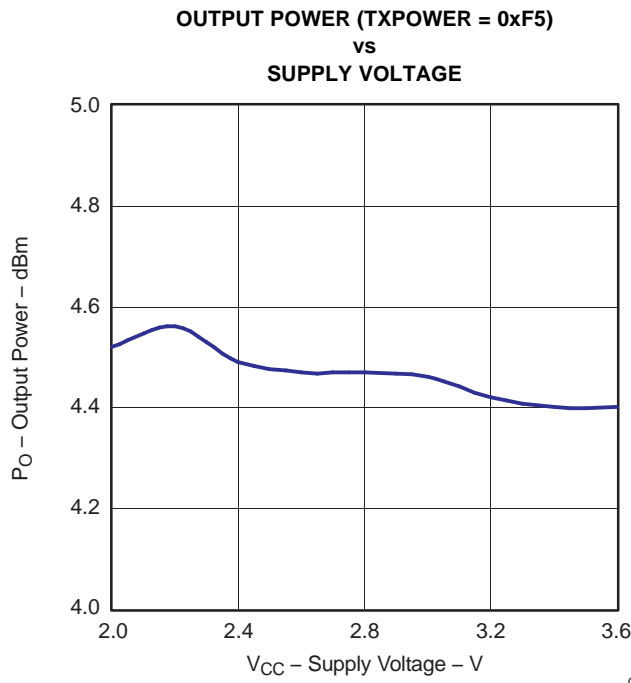


Figure 16.

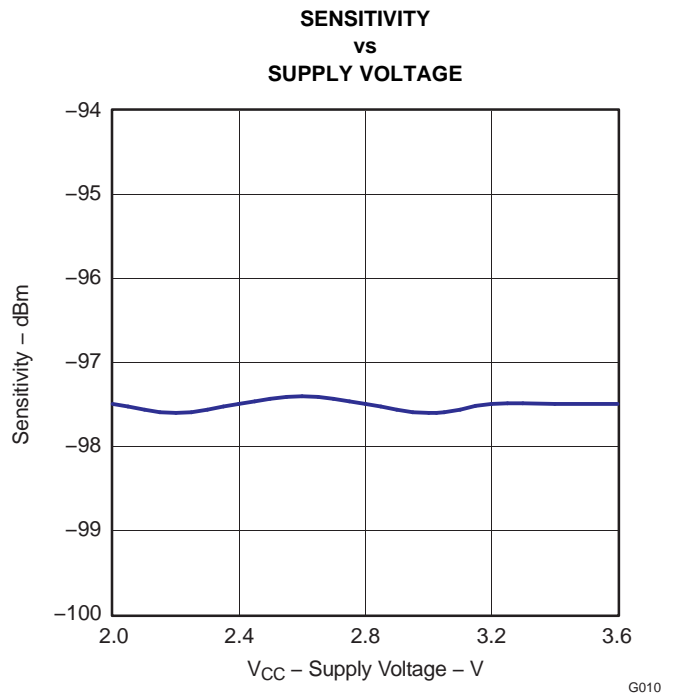


Figure 17.

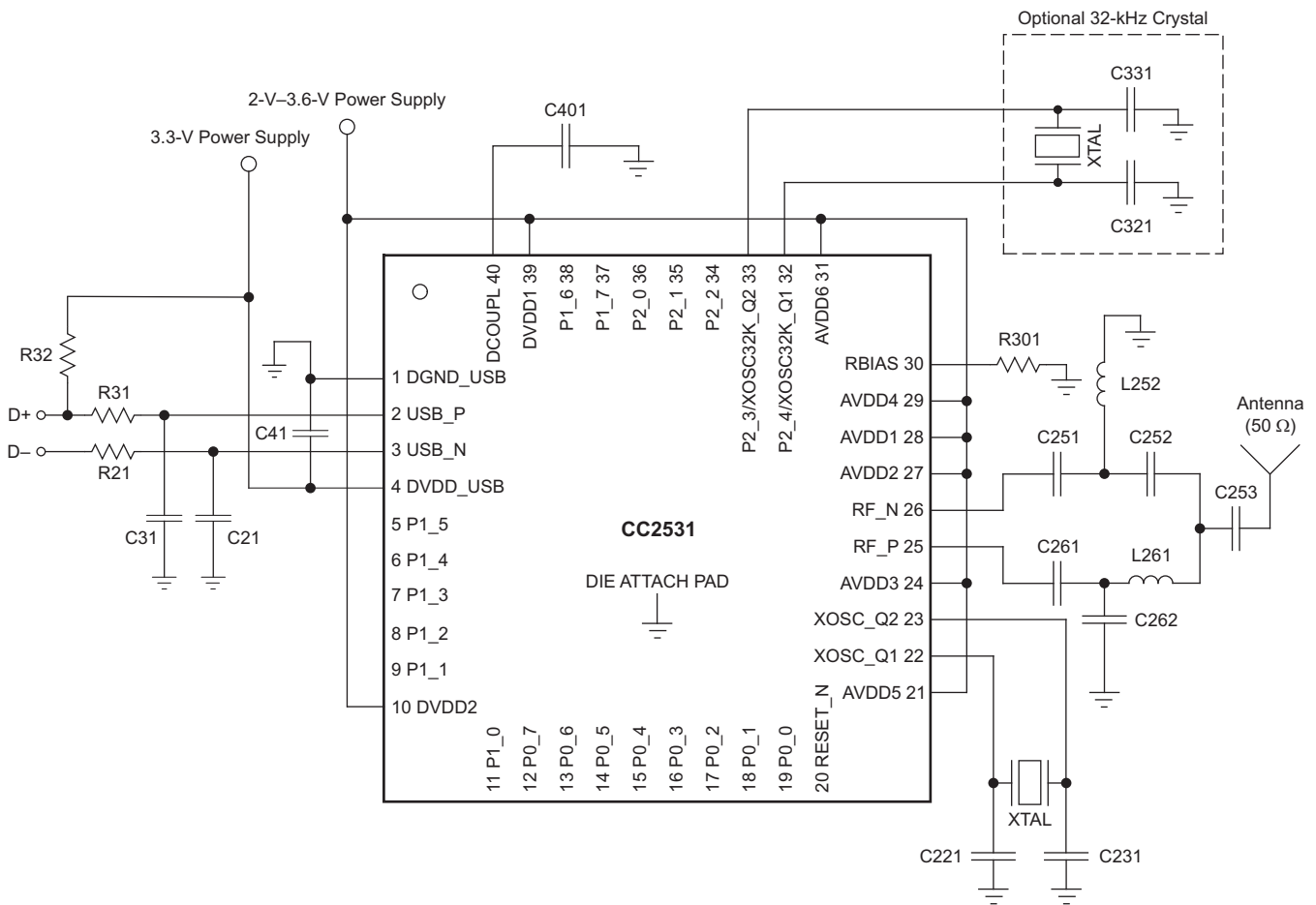
Table 1. Recommended Output Power Settings<sup>(1)</sup>

| TXPOWER Register Setting | Typical Output Power (dBm) | Typical Current Consumption (mA) |
|--------------------------|----------------------------|----------------------------------|
| 0xF5                     | 4.5                        | 34                               |
| 0xE5                     | 2.5                        | 31                               |
| 0xD5                     | 1                          | 29                               |
| 0xC5                     | -0.5                       | 28                               |
| 0xB5                     | -1.5                       | 27                               |
| 0xA5                     | -3                         | 27                               |
| 0x95                     | -4                         | 26                               |
| 0x85                     | -6                         | 26                               |
| 0x75                     | -8                         | 25                               |
| 0x65                     | -10                        | 25                               |
| 0x55                     | -12                        | 25                               |
| 0x45                     | -14                        | 25                               |
| 0x35                     | -16                        | 25                               |
| 0x25                     | -18                        | 24                               |
| 0x15                     | -20                        | 24                               |
| 0x05                     | -22                        | 23                               |
| 0x05 and TXCTRL = 0x09   | -28                        | 23                               |

(1) Measured on Texas Instruments CC2530 EM reference design with T<sub>A</sub> = 25°C, V<sub>DD</sub> = 3 V, and f<sub>c</sub> = 2440 MHz, unless otherwise noted.

### APPLICATION INFORMATION

Few external components are required for the operation of the CC2531. A typical application circuit is shown in Figure 18. For a complete USB-certified reference design, see the CC2531 product page on [www.ti.com](http://www.ti.com). Typical values and description of external components are shown in Table 2. The USB\_P and USB\_N pins need series resistors R21 and R31 for impedance matching, and the D+ line must have a pullup resistor, R32. The series resistors should match the  $90 \Omega \pm 15\%$  characteristic impedance of the USB bus. Notice that the pullup resistor and DVDD\_USB must be connected to a voltage source between 3 V and 3.6 V (typically 3.3 V). The voltage source should be derived from or controlled by the VBUS power supply provided by the USB cable. In this way, the pullup resistor does not provide current to the D+ line when VBUS is removed. The pullup resistor may be connected directly between VBUS and the D+ line. As an alternative, if the CC2531 firmware needs the ability to disconnect from the USB bus, a GPIO on the CC2531 can be used to control the pullup resistor.



S0383-04

Power supply decoupling capacitors are not shown. Digital I / O not connected.

**Figure 18. CC2531 Application Circuit**



**Table 2. Overview of External Components (Excluding Supply Decoupling Capacitors)**

| Component | Description   | Value  |
|-----------|---|--------|
| C21       | USB D– decoupling                                       | 47 pF  |
| C31       | USB D+ decoupling                                       | 47 pF  |
| C41       | Decoupling capacitor for USB pad power supply           | 10 pF  |
| C221      | 32-MHz xtal-loading capacitor                           | 27 pF  |
| C231      | 32-MHz xtal-loading capacitor                           | 27 pF  |
| C251      | Part of the RF matching network                         | 18 pF  |
| C252      | Part of the RF matching network                         | 1 pF   |
| C253      | Part of the RF matching network                         | 2.2 pF |
| C261      | Part of the RF matching network                         | 18 pF  |
| C262      | Part of the RF matching network                         | 1 pF   |
| C321      | 32-kHz xtal-loading capacitor                           | 15 pF  |
| C331      | 32-kHz xtal-loading capacitor                           | 15 pF  |
| C401      | Decoupling capacitor for the internal digital regulator | 1 μF   |
| L252      | Part of the RF matching network                         | 2 nH   |
| L261      | Part of the RF matching network                         | 2 nH   |
| R21       | USB D– series resistor                                  | 33 Ω   |
| R31       | USB D+ series resistor                                  | 33 Ω   |
| R32       | USB D+ pullup resistor to signal full-speed device      | 1.5 kΩ |
| R301      | Resistor used for internal biasing                      | 56 kΩ  |

## Input/Output Matching

When using an unbalanced antenna such as a monopole, a balun should be used to optimize performance. The balun can be implemented using low-cost discrete inductors and capacitors. The recommended balun shown consists of C262, L261, C252, and L252.

If a balanced antenna such as a folded dipole is used, the balun can be omitted.

## Crystal

An external 32-MHz crystal, XTAL1, with two loading capacitors (C221 and C231) is used for the 32-MHz crystal oscillator. See the [32-MHz Crystal Oscillator](#) section for details. The load capacitance seen by the 32-MHz crystal is given by:

$$C_L = \frac{1}{\frac{1}{C_{221}} + \frac{1}{C_{231}}} + C_{\text{parasitic}} \quad (1)$$

XTAL2 is an optional 32.768-kHz crystal, with two loading capacitors (C321 and C331) used for the 32.768-kHz crystal oscillator. The 32.768-kHz crystal oscillator is used in applications where both low sleep-current consumption and accurate wake-up times are needed. The load capacitance seen by the 32.768-kHz crystal is given by:

$$C_L = \frac{1}{\frac{1}{C_{321}} + \frac{1}{C_{331}}} + C_{\text{parasitic}} \quad (2)$$

A series resistor may be used to comply with the ESR requirement.

## On-Chip 1.8-V Voltage-Regulator Decoupling

The 1.8-V on-chip voltage regulator supplies the 1.8-V digital logic. This regulator requires a decoupling capacitor (C401) for stable operation.

## Power-Supply Decoupling and Filtering

Proper power-supply decoupling must be used for optimum performance. The placement and size of the decoupling capacitors and the power supply filtering are important to achieve the best performance in an application. TI provides a recommended compact reference design for the user to follow.

### References

1. IEEE Std. 802.15.4-2006: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANS)  
<http://standards.ieee.org/getieee802/download/802.15.4-2006.pdf>
2. CC253x User's Guide – CC253x System-on-Chip Solution for 2.4 GHz IEEE 802.15.4 and ZigBee Applications (SWRU191)
3. Universal Serial Bus Revision 2.0 Specification [http://www.usb.org/developers/docs/usb\\_20\\_052709.zip](http://www.usb.org/developers/docs/usb_20_052709.zip)

### Additional Information

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- RF design help
- E2E interaction

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- Low-power RF and ZigBee module solutions and development tools
- RF certification services and RF circuit manufacturing

For help with modules, engineering services or development tools:

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Sign up at: [www.ti.com/lprfnewsletter](http://www.ti.com/lprfnewsletter)

## REVISION HISTORY

| Changes from Revision Original (September 2009) to Revision A  | Page |
|--|------|
| • Changed recommendation for single-crystal implementations to asynchronous networks. ....   | 1    |
| • Added F128 version of CC2531 to data sheet. ....   | 1    |
| • Added number of erase cycles and page size for flash. ....   | 4    |
| • Added number of erase cycles and page size for flash. ....   | 5    |
| • Updated ESR for 32 kHz crystal. ....   | 8    |
| • Updated voltage coefficient for temperature sensor. ....   | 9    |
| • Changed SPI AC characteristics SSN low from SCK negative edge to SCK positive edge and split it into separate master and slave figures. .... | 12   |
| • Corrected description of Timer 2 (MAC Timer). ....   | 20   |
| • Improved readability of sleep timer description. ....  | 20   |
| • Removed sentence that pseudorandom data can be used for security. ....   | 20   |

**PACKAGING INFORMATION**

| Orderable Device | Status<br>(1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan<br>(2) | Lead finish/<br>Ball material<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples   |
|------------------|---------------|--------------|-----------------|------|-------------|-----------------|--------------------------------------|----------------------|--------------|-------------------------|---|
| CC2531F128RHAR   | ACTIVE        | VQFN         | RHA             | 40   | 2500        | RoHS & Green    | NIPDAU   NIPDAUAG                    | Level-3-260C-168 HR  | -40 to 125   | CC2531<br>F128          |  |
| CC2531F128RHAT   | ACTIVE        | VQFN         | RHA             | 40   | 250         | RoHS & Green    | NIPDAU   NIPDAUAG                    | Level-3-260C-168 HR  | -40 to 125   | CC2531<br>F128          |  |
| CC2531F256RHAR   | ACTIVE        | VQFN         | RHA             | 40   | 2500        | RoHS & Green    | NIPDAU   NIPDAUAG                    | Level-3-260C-168 HR  | -40 to 125   | CC2531<br>F256          |  |
| CC2531F256RHAT   | ACTIVE        | VQFN         | RHA             | 40   | 250         | RoHS & Green    | NIPDAU   NIPDAUAG                    | Level-3-260C-168 HR  | -40 to 125   | CC2531<br>F256          |  |

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

**ACTIVE:** Product device recommended for new designs.

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

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

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

**OBSELETE:** TI has discontinued the production of the device.

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

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

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

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

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

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

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

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**TAPE AND REEL INFORMATION**

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**


\*All dimensions are nominal

| Device         | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|----------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| CC2531F128RHAR | VQFN         | RHA             | 40   | 2500 | 330.0              | 16.4               | 6.3     | 6.3     | 1.5     | 12.0    | 16.0   | Q2            |

**TAPE AND REEL BOX DIMENSIONS**


\*All dimensions are nominal

| Device         | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|----------------|--------------|-----------------|------|------|-------------|------------|-------------|
| CC2531F128RHAR | VQFN         | RHA             | 40   | 2500 | 350.0       | 350.0      | 43.0        |



## GENERIC PACKAGE VIEW

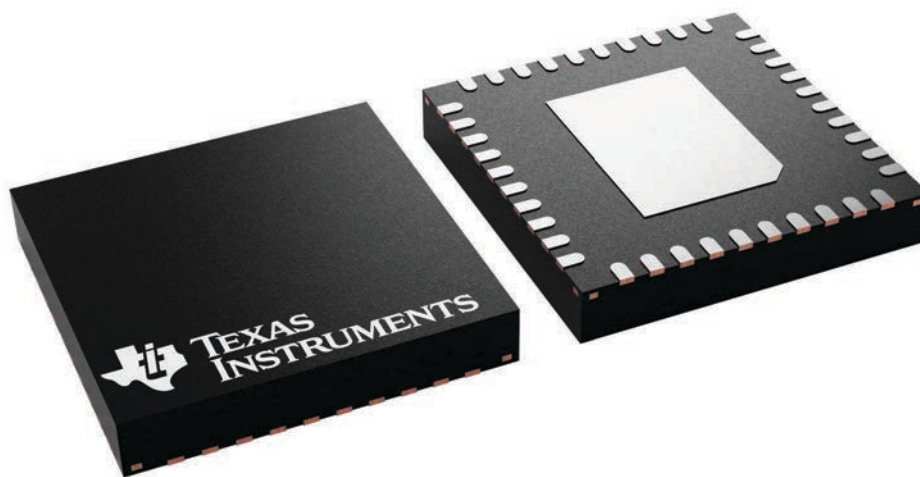
**RHA 40**

**VQFN - 1 mm max height**

6 x 6, 0.5 mm pitch

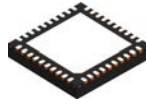
PLASTIC QUAD FLATPACK - NO LEAD

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



4225870/A

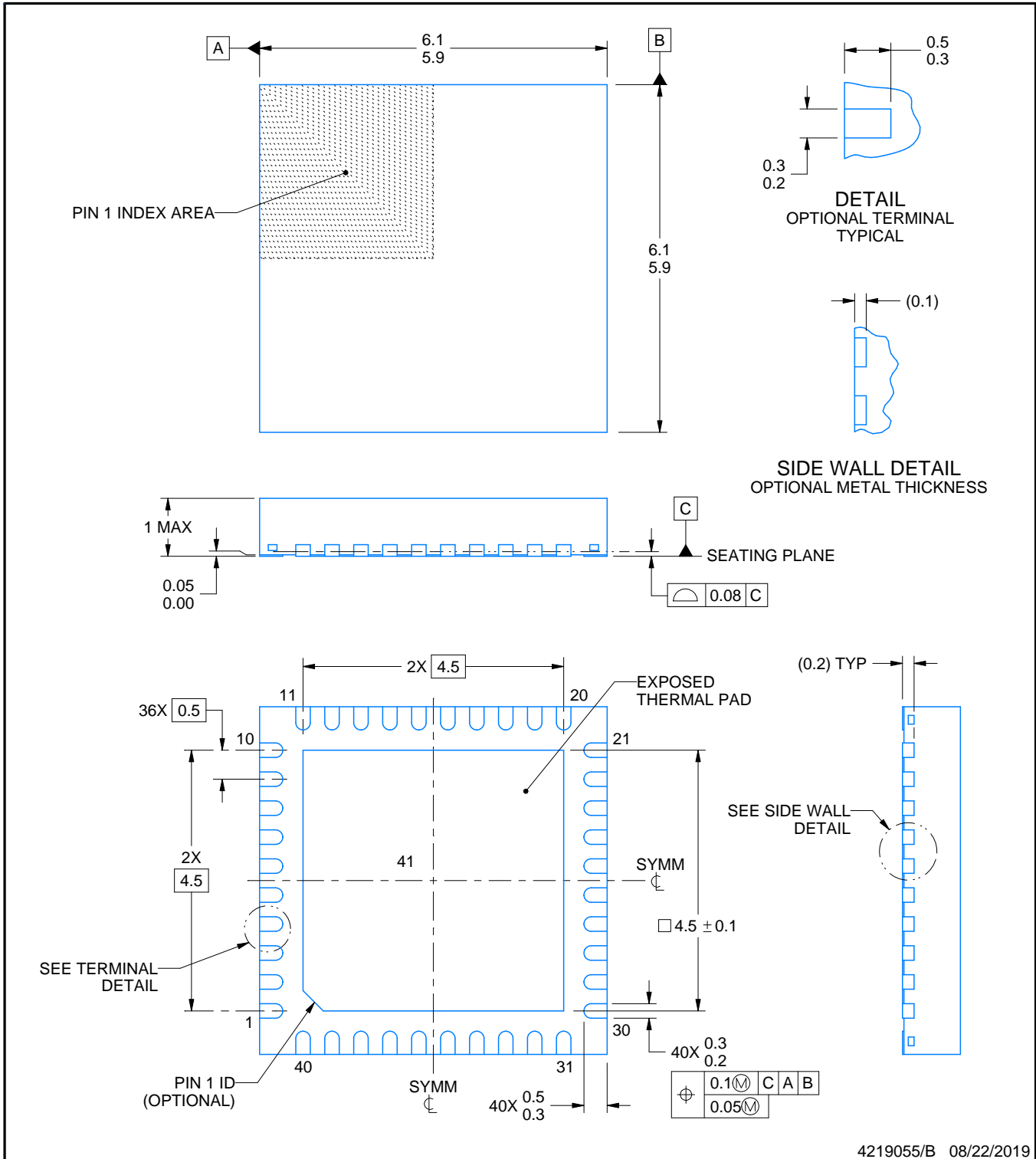
# RHA0040H



# PACKAGE OUTLINE

## VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



4219055/B 08/22/2019

### NOTES:

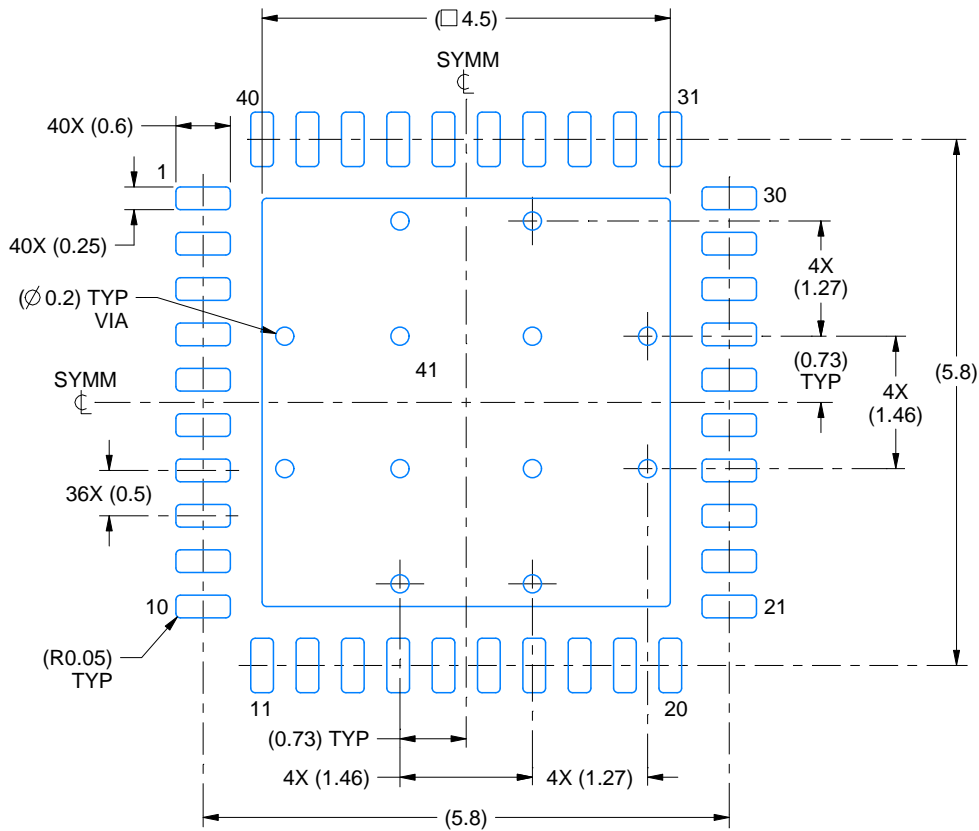
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.

# EXAMPLE BOARD LAYOUT

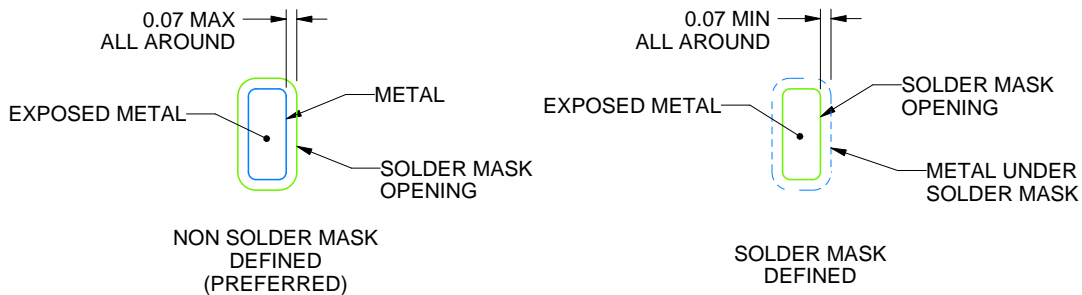
RHA0040H

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:12X



SOLDER MASK DETAILS

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NOTES: (continued)

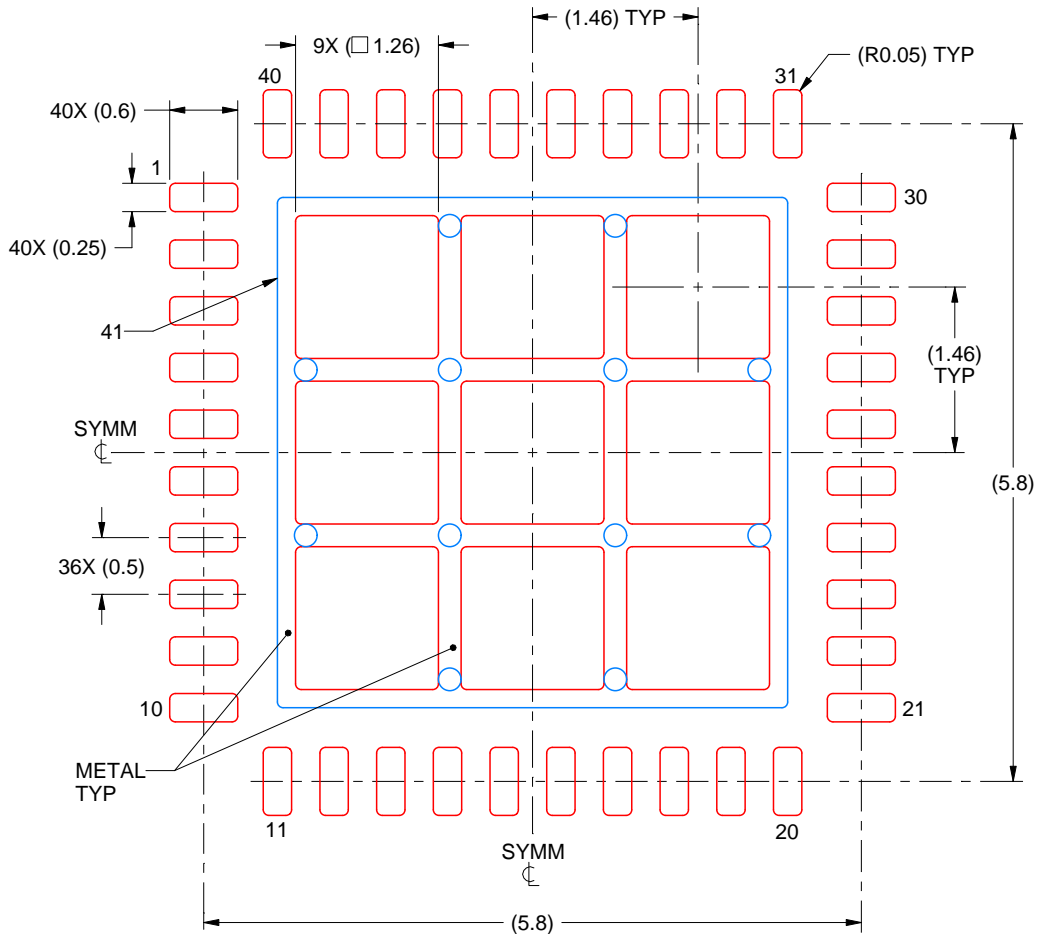
4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/slua271](http://www.ti.com/lit/slua271)).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

# EXAMPLE STENCIL DESIGN

RHA0040H

VQFN - 1 mm max height

PLASTIC QUAD FLATPACK - NO LEAD



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

EXPOSED PAD 41:  
70% PRINTED SOLDER COVERAGE BY AREA  
SCALE:15X

4219055/B 08/22/2019

NOTES: (continued)

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

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