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# *TI Designs*
# *Wireless Heart Rate Monitor Reference Design*

## TI Designs

TI Designs provide the foundation that you need including methodology, testing and design files to quickly evaluate and customize and system. TI Designs help ***you*** accelerate your time to market.

## Design Resources

| | |
|---|---|
| TIDA-00096 | Tool Folder Containing Design Files |
| ADS1293 | Product Folder |
| CC2541 | Product Folder |
| TPS61220 | Product Folder |
| CC Debugger | Small Programmer and Debugger for Low-Power RF System-on-Chips |

## Design Features

The Wireless Heart Rate Monitor with *Bluetooth*® low-energy (BLE) is a reference design for customers to develop end-products for battery-powered 3-channel health and fitness electrocardiogram (ECG) applications.

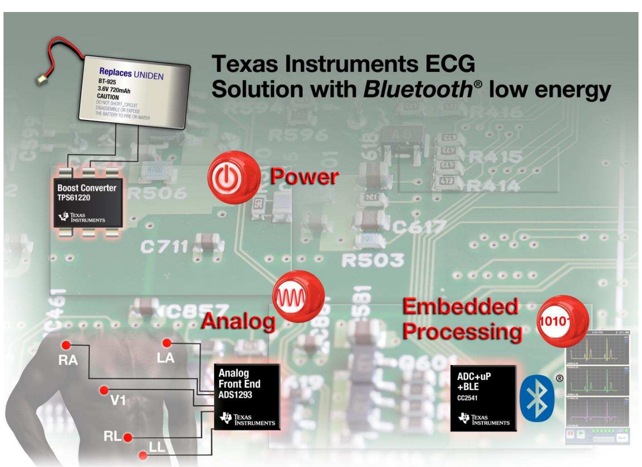
- Supports 5-Lead ECG applications
- Easily monitor heart rate data through an iOS Mobile Application
- Powered by a Lithium-ion battery
- EMI filters integrated in the ADS1293 device reject Interference from outside RF sources
- Open-source Firmware and iOS application enables quick time-to-market for customers

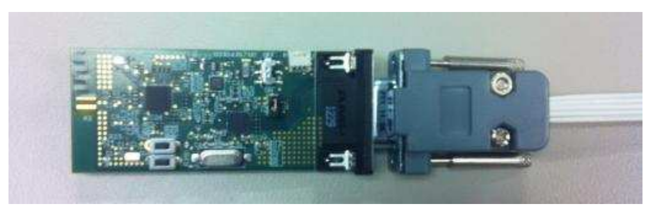
### Featured Applications

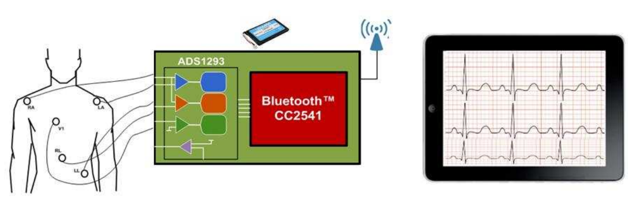
- Health and Fitness

TI E2E™ Community

ASK Our Analog Experts
WebBench™ Calculator Tools



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# 1 System Description

The heart of the Wireless Heart Rate Monitor is the ADS1293 device (analog front-end) and the CC2541 device (*Bluetooth*-low energy SOC) as shown in Figure 1. The ADS1293 device is a highly integrated low-power analog front-end (AFE) that features three high-resolution ECG channels. The CC2541 system-on-chip (SoC) adds a BLE wireless feature to the platform. BLE enables seamless connectivity to an iPhone® or an iPad® through a configurable iOS application that allows an end-user to remotely monitor the heart-rate data of a patient.

## *1.1 ADS1293*

The ADS1293 incorporates all features commonly required in portable, low-power medical, sports, and fitness electrocardiogram (ECG) applications. With high levels of integration and exceptional performance, the ADS1293 enables the creation of scalable medical instrumentation systems at significantly reduced size, power, and overall cost.

The ADS1293 features three high-resolution channels capable of operating up to 25.6ksps. Each channel can be independently programmed for a specific sample rate and bandwidth allowing users to optimize the configuration for performance and power. All input pins incorporate an EMI filter and can be routed to any channel via a flexible routing switch. Flexible routing also allows independent lead-off detection, right leg drive, and Wilson/Goldberger reference terminal generation without the need to reconnect leads externally. A fourth channel allows external analog pace detection for applications that do not utilize digital pace detection. For the ADS1293 block diagram, see Figure 2.

The ADS1293 incorporates a self-diagnostics alarm system to detect when the system is out of the operating conditions range. Such events are reported to error flags. The overall status of the error flags is available as a signal on a dedicated ALARMB pin. The device is packaged in a 5-mm × 5-mm × 0,8-mm, 28-pin LLP. Operating temperature ranges from –20°C to 85°C.

## *1.2 CC2541*

The CC2541 is a power-optimized true system-on-chip (SoC) solution for both *Bluetooth* low energy and proprietary 2.4-GHz applications. It enables robust network nodes to be built with low total bill-of-material costs. The CC2541 combines the excellent 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 supporting features and peripherals. The CC2541 is highly suited for systems where ultralow power consumption is required. This is specified by various operating modes. Short transition times between operating modes further enable low power consumption.

The CC2541 is pin-compatible with the CC2540 in the 6-mm × 6-mm QFN40 package, if the USB is not used on the CC2540 and the $I^2C$/extra I/O is not used on the CC2541. Compared to the CC2540, the CC2541 provides lower RF current consumption. The CC2541 does not have the USB interface of the CC2540, and provides lower maximum output power in TX mode. The CC2541 also adds a HW $I^2C$ interface.

The CC2541 is pin-compatible with the CC2533 RF4CE-optimized IEEE 802.15.4 SoC. The CC2541 comes in two different versions: CC2541F128/F256, with 128 KB and 256 KB of flash memory, respectively. For the CC2541 block diagram, see Figure 3.

## *1.3 TPS61220*

The TPS6122x family devices provide a power-supply solution for products powered by either a single-cell, two-cell, or three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-polymer battery. Possible output currents depend on the input-to-output voltage ratio. The boost converter is based on a hysteretic controller topology using synchronous rectification to obtain maximum efficiency at minimal quiescent currents. The output voltage of the adjustable version can be programmed by an external resistor divider, or is set internally to a fixed output voltage. The converter can be switched off by a featured enable pin. While being switched off, battery drain is minimized. The device is offered in a 6-pin SC-70 package (DCK) measuring 2 mm × 2 mm to enable small circuit layout size. For the TPS61220 block diagram, see Figure 4.

# 2 Block Diagram

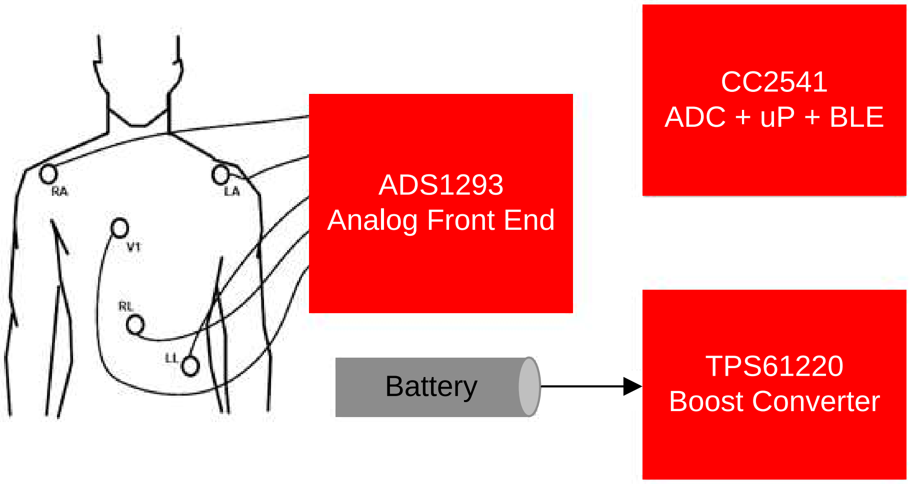


**Figure 1. Temperature Transmitter System Block Diagram**

## *2.1 Highlighted Products*

The Wireless Heart Rate Monitor Reference Design features the following devices:

- ADS1293
  - *ADS1293 Low Power, 3-Channel, 24-Bit Analog Front End for Biopotential Measurements*
- CC2541
  - *2.4-GHz Bluetooth™ low energy and Proprietary System-on-Chip*
- TPS61220
  - *TPS6122x Low Input Voltage, 0.7V Boost Converter With 5.5µA Quiescent Current*

For more information on each of these devices, see the respective product folders at www.TI.com.

### 2.1.1 ADS1293

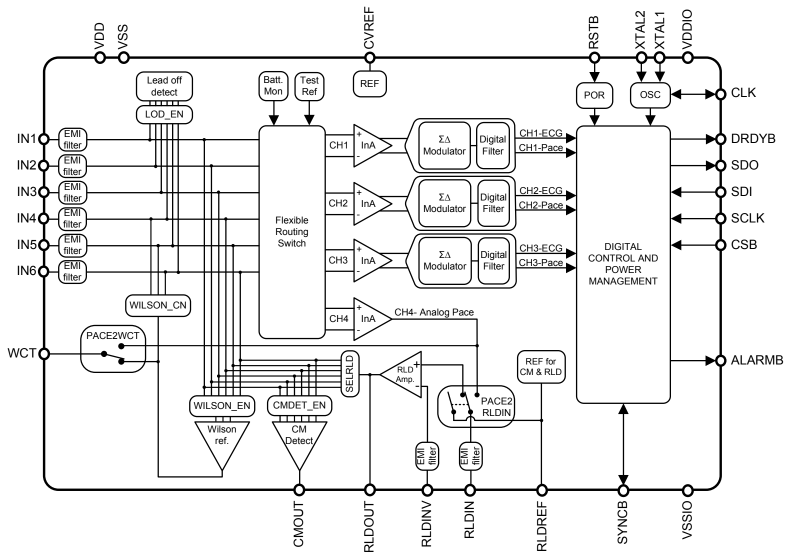


**Figure 2. ADS1293 Block Diagram**

- Low current consumption:
  - Duty-Cycle mode: 120 µA
  - Normal mode: 415 µA
- Wide supply range: 2.3 V to 5.5 V
- Programmable gain: 1 V/V to 128 V/V
- Programmable data rates: Up to 2 kSPS
- 50-Hz and 60-Hz rejection at 20 SPS
- Low-noise PGA: 90 $nV_{RMS}$ at 20 SPS
- Dual matched programmable current sources: 10 µA to 1500 µA
- Internal temperature sensor: 0.5°C Error (max)
- Low-drift internal reference
- Low-drift internal oscillator
- Two differential or four single-ended inputs
- SPI™-compatible interface
- 3,5 mm × 3,5 mm × 0,9 mm QFN package

### 2.1.2 CC2541

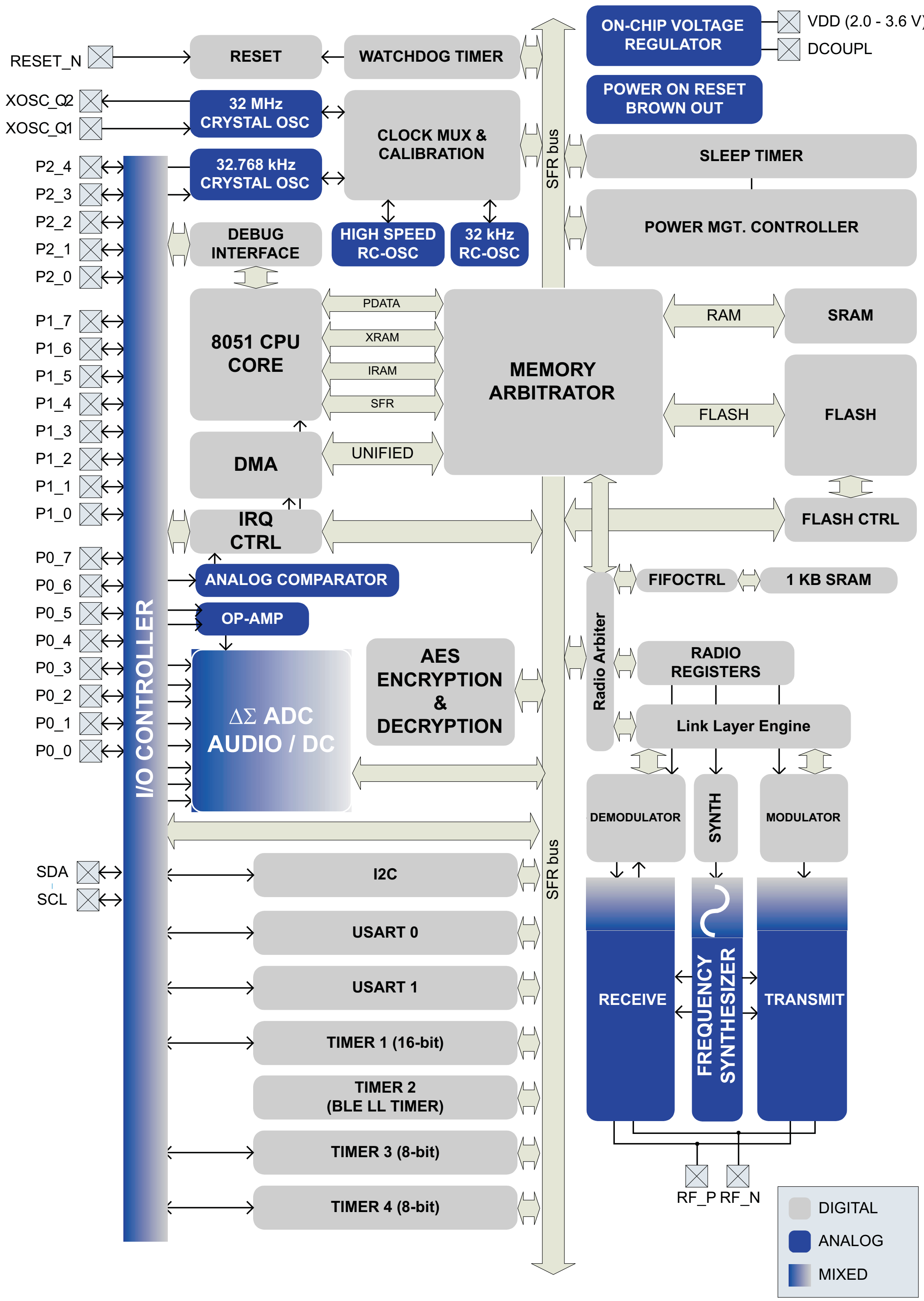


**Figure 3. CC2541 Block Diagram**

- **RF**
  - 2.4-GHz *Bluetooth* low energy Compliant and Proprietary RF System-on-Chip
  - Supports 250-kbps, 500-kbps, 1-Mbps, 2-Mbps Data Rates
  - Excellent link budget, enabling long-range applications without external front end
  - Programmable output power up to 0 dBm
  - Excellent receiver sensitivity (–94 dBm at 1 Mbps), selectivity, and blocking performance
  - Suitable for systems targeting compliance with worldwide radio frequency regulations: ETSI EN 300 328 and EN 300 440 Class 2 (Europe), FCC CFR47 Part 15 (US), and ARIB STD-T66 (Japan)
- **Layout**
  - Few external components
  - Reference design provided
  - 6-mm × 6-mm QFN-40 package
  - Pin-compatible with CC2540 (when not using USB or $I^2C$)
- **Low Power**
  - Active-mode RX down to: 17.9 mA
  - Active-mode TX (0 dBm): 18.2 mA
  - Power mode 1 (4-µs wake-up): 270 µA
  - Power mode 2 (sleep timer on): 1 µA
  - Power mode 3 (external interrupts): 0.5 µA
  - Wide Supply-voltage range (2 V–3.6 V)
- TPS62730 Compatible low power in active mode
  - RX down to: 14.7 mA (3-V supply)
  - TX (0 dBm): 14.3 mA (3-V supply)
- **Microcontroller**
  - High-performance and low-power 8051 microcontroller core with code Prefetch
  - In-system-programmable flash, 128- or 256-KB
  - 8-KB RAM with retention in all power modes
  - Hardware-debug support
  - Extensive baseband automation, including auto-acknowledgment and address decoding
  - Retention of all relevant registers in all power modes
- **Peripherals**
  - Powerful five-channel DMA
  - General-purpose timers (one 16-Bit, two 8-Bit)
  - IR generation circuitry
  - 32-kHz sleep timer with capture
  - Accurate digital RSSI 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
  - 23 general-purpose I/O Pins (21 × 4 mA, 2 × 20 mA)
  - $I^2C$ interface
  - Two I/O pins have LED Driving capabilities
  - Watchdog timer
  - Integrated high-performance comparator
- **Development Tools**

  - CC2541 evaluation module kit (CC2541EMK)
  - CC2541 mini development kit (CC2541DK-MINI)
  - SmartRF™ software
  - IAR embedded Workbench™ available
- **Software Features**
  - *Bluetooth* v4.0 compliant protocol stack for single-mode BLE solution
    - Complete power-optimized stack, including controller and host
      - GAP – central, peripheral, observer, or broadcaster (including combination roles)
      - ATT / GATT – client and server
      - SMP – AES-128 encryption and decryption
      - L2CAP
    - Sample applications and profiles
      - Generic applications for GAP central and peripheral roles
      - Proximity, accelerometer, simple keys, and battery GATT services
      - More applications supported in BLE Software Stack
    - Multiple configuration options
      - Single-chip configuration, allowing applications to run on CC2541
      - Network processor interface for applications running on an external microcontroller
    - BTool – Windows PC application for evaluation, development, and test

### 2.1.3 TPS61220

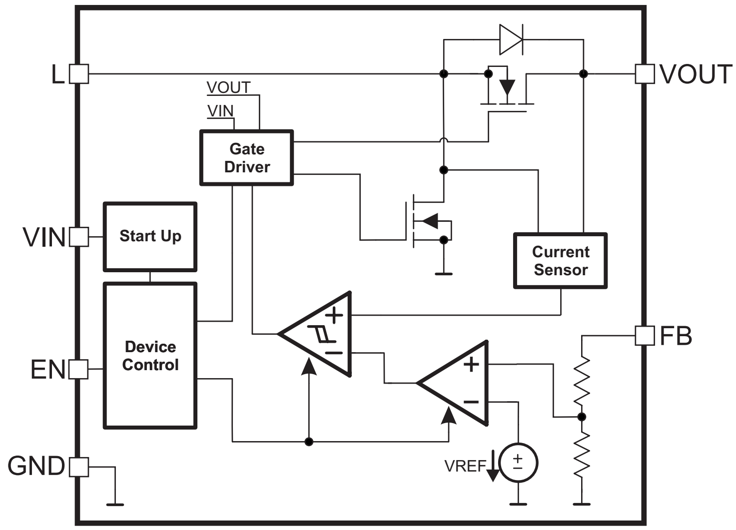


**Figure 4. TPS61220 Block Diagram**

- Up to 95% efficiency at typical operating conditions
- 5.5 µA quiescent current
- Startup into load at 0.7-V input voltage
- Operating input voltage from 0.7 V to 5.5 V
- Pass-through function during shutdown
- Minimum switching current 200 mA
- **Protections:**
  – Output overvoltage
  – Overtemperature
  – Input undervoltage lockout
- Adjustable output voltage from 1.8 V to 6 V
- Fixed output voltage versions
- Small 6-pin SC-70 package

# 3 Theory of Operation

## *3.1 5-Lead ECG Application*

Figure 5 shows the ADS1293 device in a 5-Lead ECG system setup. The ADS1293 device uses the Common-Mode Detector to measure the common-mode of the patient's body by averaging the voltage of input pins IN1, IN2 and IN3, and uses this signal in the right leg drive feedback circuit.

**NOTE:** The ideal values of $R_1$, $R_2$ and $C_1$ will vary per system/application; typical values for these components are: $R_1$ = 100kΩ, $R_2$ = 1MΩ and $C_1$ = 1.5nF.

The output of the RLD amplifier is connected to the right leg electrode, which is IN4, to drive the common-mode of the patient's body. The Wilson Central Terminal is generated by the ADS1293 and is used as a reference to measure the chest electrode, V1. The chip uses an external 4.096MHz crystal oscillator connected between the XTAL1 and XTAL2 pins to create the clock sources for the device.

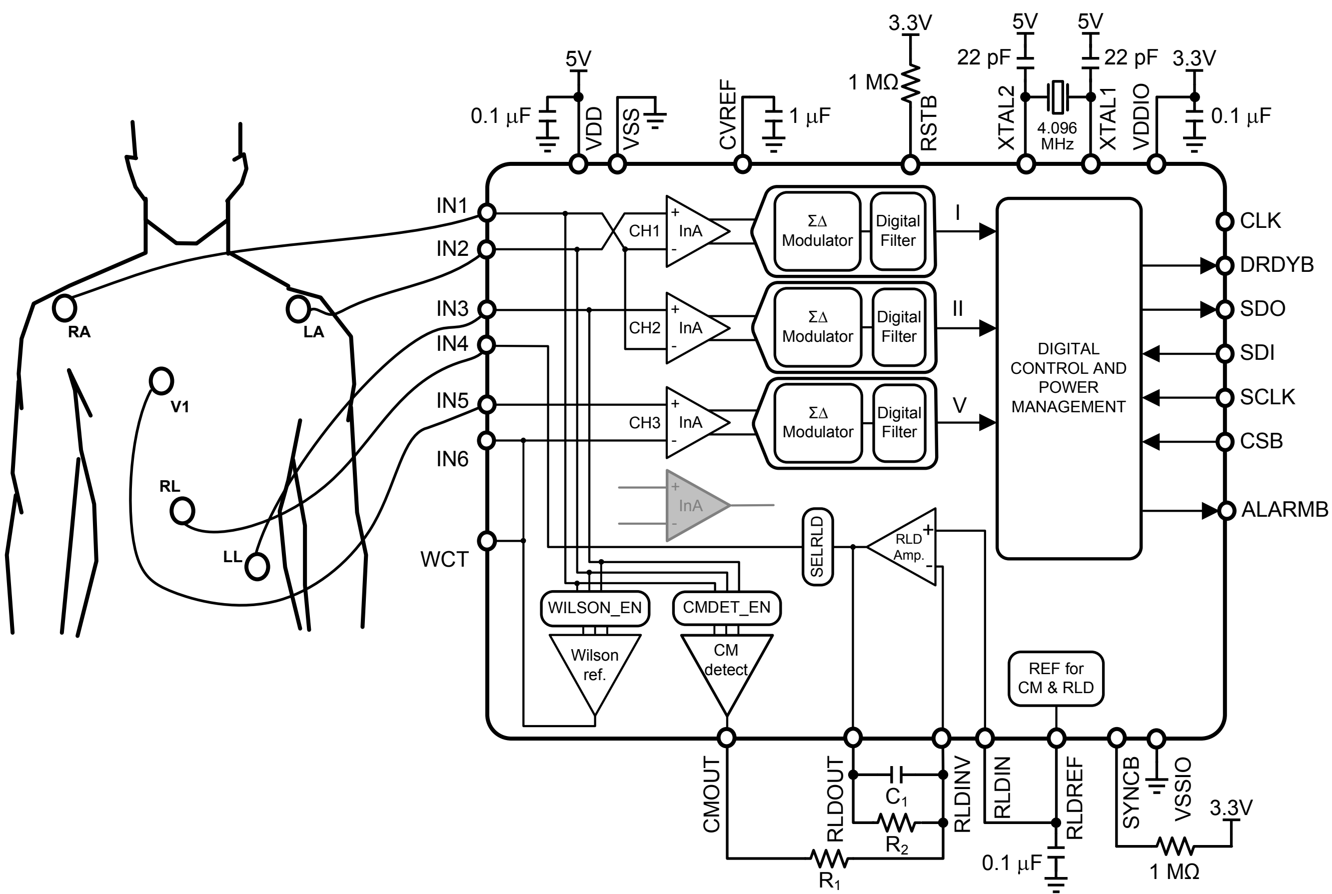


**Figure 5. 5-Lead ECG Application**

### CC2541 Communication

The CC2541 device communicates to the ADS1293 device through SPI interface. The CC2541 device implements the application software to run this application through the 8051 microcontroller core in addition to running the BLE stack. For additional information, see Section 4.4.

### 3.2 Battery Life Calculation

For battery life calculations, TI highly recommends that the user reviews *CC2541 Battery Life Calculation*, SWRA347.

Comparing the power consumption of a BLE device to another device using a single metric is impossible. For example, a device gets rated by its peak current. While the peak current plays a part in the total power consumption, a device running the BLE stack only consumes current at the peak level during transmission. Even in very high throughput systems, a BLE device is transmitting for only a small percentage of the total time that the device is connected (see Figure 6).

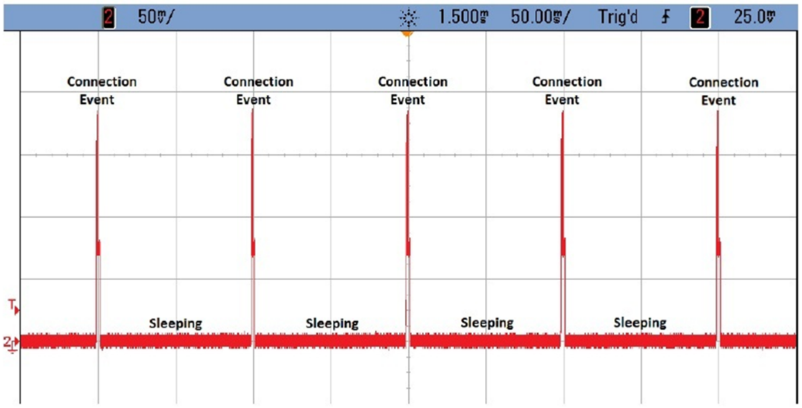


**Figure 6. Current Consumption**

In addition to transmitting, there are other factors to consider when calculating battery life. A BLE device can go through several other modes, such as receiving, sleeping, and waking up from sleep. Even if the current consumption of a device in each different mode is known, there is not enough information to determine the total power consumed by the device. Each layer of the BLE stack requires a certain amount of processing to remain connected and to comply with the specifications of the protocol. The MCU takes time to perform this processing, and during this time, current is consumed by the device. In addition, some power might be consumed while the device switches between modes (see Figure 7). All of this must be considered to get an accurate measurement of the total current consumed.

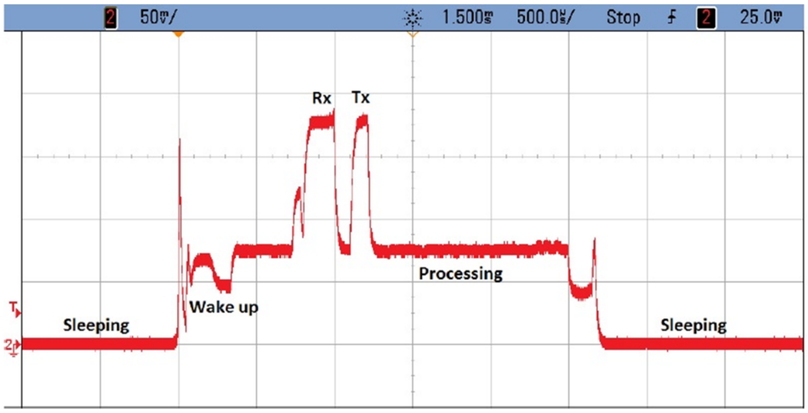


**Figure 7. Current Consumption-Active versus Sleep Modes**

# 4 Getting Started

## 4.1 Software

Requirements:

- An iOS device: iPhone 4S and newer generations; iPad 3 and newer generations; fifth generation iPod (www.Apple.com)
- 3.6-V Lithium-ion battery, recommended model BT-0001


**Figure 8. 3.6-V Lithium-Ion Battery**

- CC Debugger (http://www.ti.com/tool/cc-debugger)

### 4.1.1 Installing the Application

The application is not on iTunes (Apple Approved) for download. Download the application from the following link: TIDA-00096 iOS Application Software .

Since the application is not on iTunes, use the steps below to install it manually. When the application is distributed manually, there is a limit on how many devices can the application can be loaded on. The UDID of each device needs to be provided before the application can be installed.

Use the following steps to install the Wireless Heart Rate Monitor application on a device.

1. Connect the iPhone or iPad to the PC.
2. Open the iTunes application on the PC.
3. Wait for iTunes to identify that the device is connected to the PC.
4. The serial number of the device is listed as shown in Figure 9.


**Figure 9. Opening iTunes**

5. In order to view the Identifier number (UDID), double click on *Serial Number* as shown in Figure 10


**Figure 10. Finding the UDID Number**

6. Report the identifier number (UDID) number to the iPad developer.
7. After the UDID is added to the application (by the iPad developer), a .zip file is sent to the iTunes user that contains the application to download onto the smart device such as an iPhone4S®, iPhone 5®, or iPad4®.
8. Unzip the folder to view the application, ecgmonitor.ipa.
9. Open iTunes

Once iTunes is open, use the following steps to install the application on the device.

1. Click the top-left button in the iTunes interface shown in Figure 11.

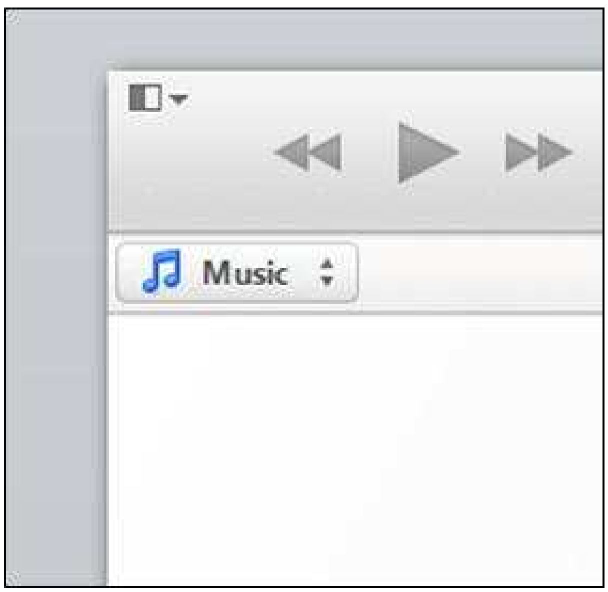


**Figure 11. iTunes library**

2. Once the top-left button is clicked, a menu appears, click on *Add File to Library* (see Figure 12) to navigate to and select the ecgmonitor.ipa file from the file directory.


**Figure 12. Add File to Library**

3. Go to the iPad page and click on the Apps menu as shown in Figure 13.


**Figure 13. Installing the Application on the iOS Device**

4. Click on *Install* and then click *Apply*. Next, click on *Sync*. Then finally click *Done*.

## *4.2 Hardware*

Use to following steps to connect the Demo board.

1. Connect the battery (3.6 V nominal) to the P1 connector on the ADS1293BLE board.
2. Set the U2 switch to the ON position.
3. Uninstall J3.
4. Connect the ECG cable to the J1 connector on the ADS1293BLE board (see Figure 14).

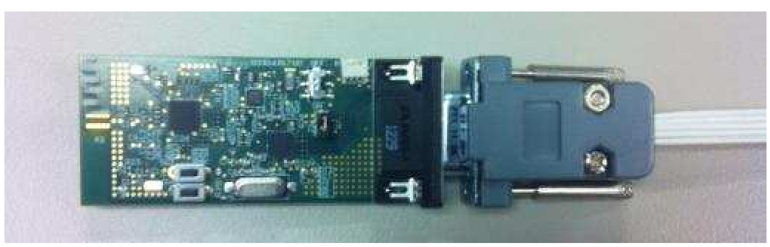

**Figure 14. Hardware Setup**

5. Connect the five leads to either an ECG simulator or to five electrode pads attached to the body. On the back of each lead is a label (RL, LL, LA, RA, and V1).

**NOTE:** For the SKX2000 simulators connect V1 to the C1 terminal. If using the SKX2000 simulator, turn the simulator on and off by pressing the red button on the left side (see Figure 15).

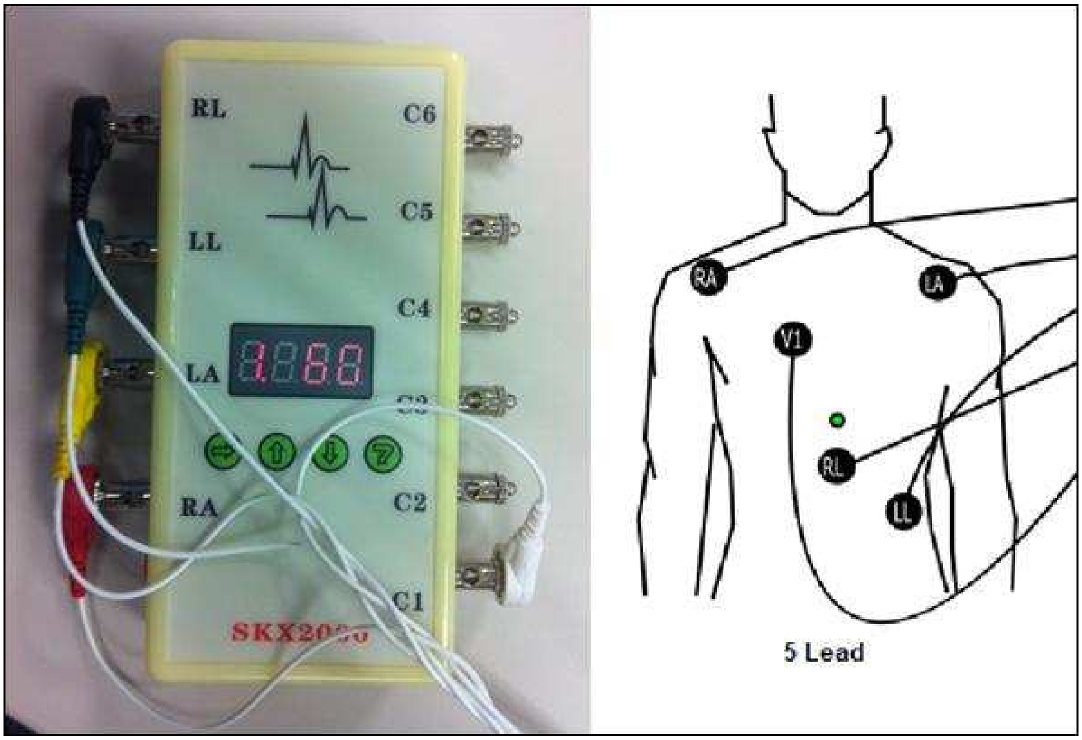


**Figure 15. ECG Emulator**

### 4.3 Running the Demo

- Open up the ADS1293 ECG monitor application on either an iPad or iPhone.


**Figure 16. ECG Monitor Application**

- Press the *Start Scanning* button as shown in Figure 17.


**Figure 17. Launch Application**

- After several moments, the ADS1293 ECG Demo START button and the *Bluetooth* symbol appear as shown in Figure 18.

**NOTE:** If the *Bluetooth* symbol does not appear, close the application and repeat the steps listed in Section 4.3. If the problem continues, see Section 5 below.

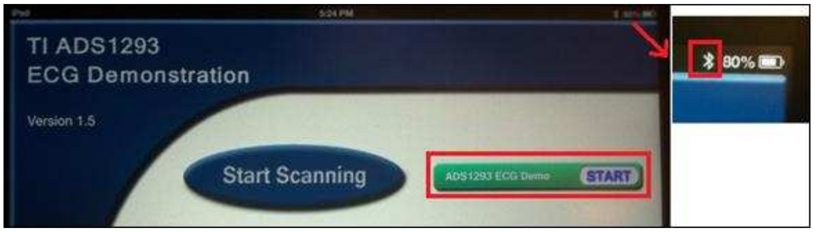


**Figure 18. Enable *Bluetooth* on iOS Device**

- The three channel readings are now available on the screen. If the board and ECG simulator are properly connected, the screen will appear similar to Figure 19 or Figure 20.
  - Figure 19 appears when connected to SKX2000 ECG Simulator.

**Figure 19. ECG Data Connected to the Simulator**

  - Figure 20 appears when connected to the body.

**Figure 20. ECG Data Connected to the Body**

### *4.4 Firmware*

This section describes the over-the-air protocol to be used in the Wireless Heart Rate Monitor Reference Design. This section also provides an overview of the firmware development platform.

To download the software and firmware, go to TIDA-00096.

- iOS source code
- CC2541 BLE source code

#### 4.4.1 Communication Overview

ECG data is sent as a burst of six BLE-notification packets every 14 ms. Each notification packet consists of 20 bytes containing the following:

- ECG Sample1 (Raw ADC data)
  – Channel1 (3 bytes)
  – Channel2 (3 bytes)
  – Channel3 (3 bytes)
- ECG Sample2 (Raw ADC data)
  – Channel1 (3 bytes)
  – Channel2 (3 bytes)
  – Channel3 (3 bytes)

An ECG error or status packet is sent once every 17 ECG samples. ECG status packets contain the following:

- 2-byte running counter
- Status packet begin indication: 0xFF, 0xFF, 0xFF
- 7-byte error status (ERROR_LOD, ERROR_STATUS, ERROR_RANGE1, ERROR_RANGE2, ERROR_RANGE3, ERROR_SYNC, ERROR_MISC)
- Status packet end: 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF, 0xFF

#### 4.4.2 ADS1293 ECG Demo: Complete Attribute Table

Figure 21 shows the complete attribute table for the ADS1293 ECG-Demo. Services are shown in yellow, characteristics are shown in blue, and characteristic values and descriptors are shown in grey. The ADS1293 ECG demo implements a BLE peripheral device. The Demo supports an ECG peripheral profile based on the heart rate example of the CC254x Simple BLE Peripheral frame work.

When configured by a peer device, the ECG peripheral application sends notification of the ECG measurement. On power up, advertising is enabled and the peer device must discover and initiate a connection procedure to the ECG peripheral. When the peer device configures the ECG measurement for notification, a timer starts and ECG measurements are sent periodically. In addition to ECG measurement, the peer device can read the number of ECG channels supported (characteristic 2) and the number of ECG-sample data sets per packet (characteristic 3).

The peer device may also discover and configure the battery service for battery level-state notifications. This functionality is the same as supported in Simple BLE Peripheral framework.

| ECG Peripheral Application: Complete Attribute Table | | | | | |
|---|---|---|---|---|---|
| handle (hex) | Type (hex) | Type | Hex / Text Value (default) | GATT Server Permissions | Notes |
| 0x10 | 0x2800 | GATT_PRIMARY_SERVICE_UUID | 0x2D0D (ECG_SERV_UUID) | GATT_PERMIT_READ | Start of ECG Profile Service |
| 0x11 | 0x2803 | ECG_PROFILE_CHARACTER1_UUID | 10 (properties: notify only)<br>12 00 (handle: 0x0012)<br>37 2D (UUID: 0x2D37) | GATT_PERMIT_READ | Characteristic1 declaration |
| 0x12 | 0x2D37 | ECG_MEAS_UUID | 00:00:00:00:00:00:00:00:00:00:00:00 (12 bytes) | (none) | ECG data value |
| 0x13 | 0x2902 | GATT_CLIENT_CHAR_CFG_UUID | 00:00 (2 bytes) | GATT_PERMIT_READ \| GATT_PERMIT_WRITE | Write "01:00" to enable notifications. "00:00" to disable |
| 0x14 | 0x2901 | GATT_CHAR_USER_DESC_UUID | "ECG Measurement Data\0" (21 bytes) | GATT_PERMIT_READ | Characteristic1 user description |
| 0x15 | 0x2803 | ECG_PROFILE_CHARACTER2_UUID | 02 (properties: read only)<br>16 00 (handle: 0x0016)<br>38 2D (UUID: 0x2D38) | GATT_PERMIT_READ | Characteristic2 declaration |
| 0x16 | 0x2D38 | ECG_NUM_CHANS | 03 (1 byte) | GATT_PERMIT_READ | Number of ECG Channels |
| 0x17 | 0x2901 | GATT_CHAR_USER_DESC_UUID | "Number of ECG Channels\0" (23 bytes) | GATT_PERMIT_READ | Characteristic3 user description |
| 0x18 | 0x2803 | ECG_PROFILE_CHARACTER3_UUID | 02 (properties: read only)<br>19 00 (handle: 0x0019)<br>39 2D (UUID: 0x2D39) | GATT_PERMIT_READ | Characteristic3 declaration |
| 0x19 | 0x2D39 | ECG_SAMPLE_SETS | 01 (1 byte) | GATT_PERMIT_READ | Number of ECG Sample Sets per packet |
| 0x1A | 0x2901 | GATT_CHAR_USER_DESC_UUID | "ECG Sample Sets Per Packet\0" (27 bytes) | GATT_PERMIT_READ | Characteristic3 user description |
| 0x1B | 0x2803 | ECG_PROFILE_CHARACTER4_UUID | 08 (properties: write only)<br>1C 00 (handle: 0x001C)<br>3A 2D (UUID: 0x2D3A) | GATT_PERMIT_WRITE | Characteristic4 declaration |
| 0x1C | 0x2D3A | ECG_COMMAND | 00 (1 byte) | GATT_PERMIT_READ | ECG command set |

**Figure 21. ECG Peripheral Application: Complete Attribute Table**

### 4.4.3 ECG Notification Packet

Figure 22 shows an example of captured ECG notification packets.

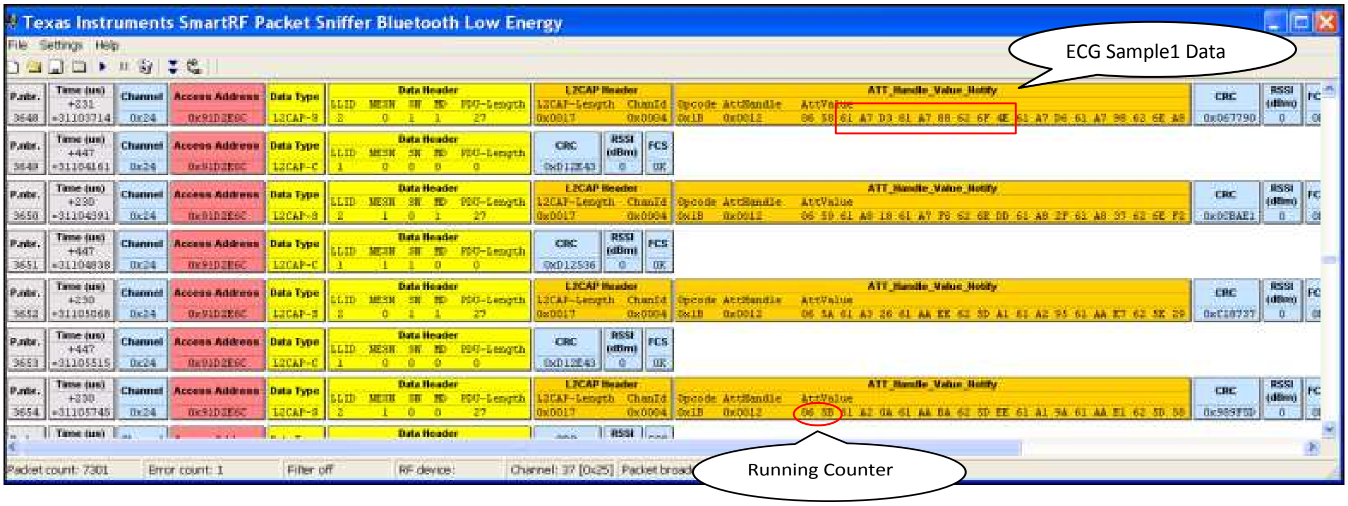


**Figure 22. ECG Notification Packet**

Table 1 lists the ECG notification data consisting of 20 bytes and the format.

**Table 1. ECG Notification Data Format(1)**

| Byte Number | Default Value | Description |
|---|---|---|
| 0 | xxxx | Running Counter – High byte |
| 1 | xxxx | Running Counter – Low byte |
| 2 | 0xD1 | ECG Sample1: Channel 1 ADC High byte |
| 3 | 0xD2 | ECG Sample1: Channel 1 ADC Middle byte |
| 4 | 0xD3 | ECG Sample1: Channel 1 ADC Low byte |
| 5 | 0xD4 | ECG Sample1: Channel 2 ADC High byte |
| 6 | 0xD5 | ECG Sample1: Channel 2 ADC Middle byte |
| 7 | 0xD6 | ECG Sample1: Channel 2 ADC Low byte |
| 8 | 0xD7 | ECG Sample1: Channel 3 ADC High byte |
| 9 | 0xD8 | ECG Sample1: Channel 3 ADC Middle byte |
| 10 | 0xD9 | ECG Sample1: Channel 3 ADC Low byte |
| 11 | 0xD1 | ECG Sample2: Channel 1 ADC High byte |
| 12 | 0xD2 | ECG Sample2: Channel 1 ADC Middle byte |
| 13 | 0xD3 | ECG Sample2: Channel 1 ADC Low byte |
| 14 | 0xD4 | ECG Sample2: Channel 2 ADC High byte |
| 15 | 0xD5 | ECG Sample2: Channel 2 ADC Middle byte |
| 16 | 0xD6 | ECG Sample2: Channel 2 ADC Low byte |
| 17 | 0xD7 | ECG Sample2: Channel 3 ADC High byte |
| 18 | 0xD8 | ECG Sample2: Channel 3 ADC Middle byte |
| 19 | 0xD9 | ECG Sample2: Channel 3 ADC Low byte |

(1) The Allowed maximum size of notification packet is 20 bytes.

### 4.4.4 Connection Setup

*Bluetooth* low-energy uses a 20-ms connection interval. Twenty user-data bytes (which is equal to 2-samples for each channel and 2-bytes running counter) are sent in GATT notifications. Data from ADS1293 device is ping-pong buffered and up to six notifications are sent every 14 ms based on an OSAL timer. The ADS1293 sample rate is set as 160 samples/sec (SPS) (see the ADS1293 data sheet, SNAS602, for more information on R1 = 4, R2 = 5, and R3 = 32). Each sample is 3 bytes and is sending 3 channels.

#### Firmware Development Platform

One of the development platforms for the CC2541 8051 microcontroller is the IAR development platform. For information on this platform, goto http://www.iar.com. To communicate to the development platform through IAR, the CC Debugger is required as shown in Figure 23

The CC Debugger (shown in Figure 23) must be connected to the 10-pin header on the SAT0015 board. Ensure the notch on the cable that connects to the 10-pin header is towards the outside. If connected properly, the LED on the CC Debugger lights green.


**Figure 23. CC Debugger**

Launch the IAR project workspace as shown in Figure 24.

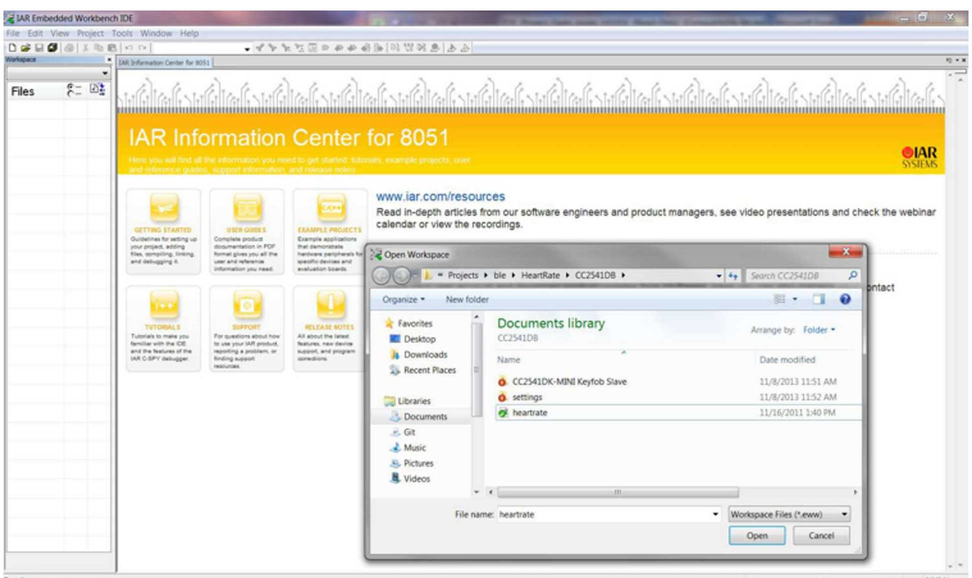


**Figure 24. Project Details.**

Ensure that the software is on version 8.20.1 or newer as shown in Figure 25.

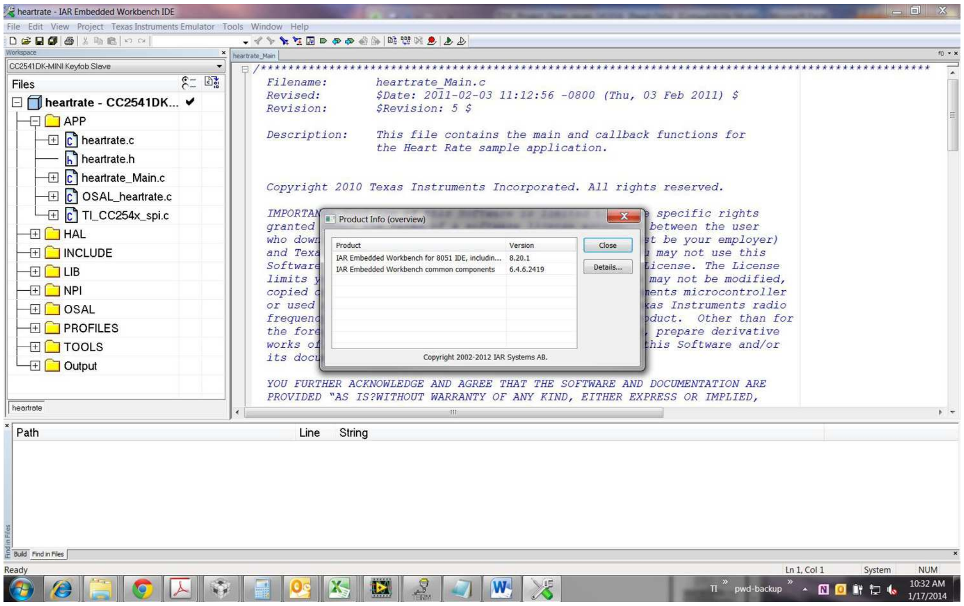

Figure 25. Version Control

Figure 26 shows the main entry function.

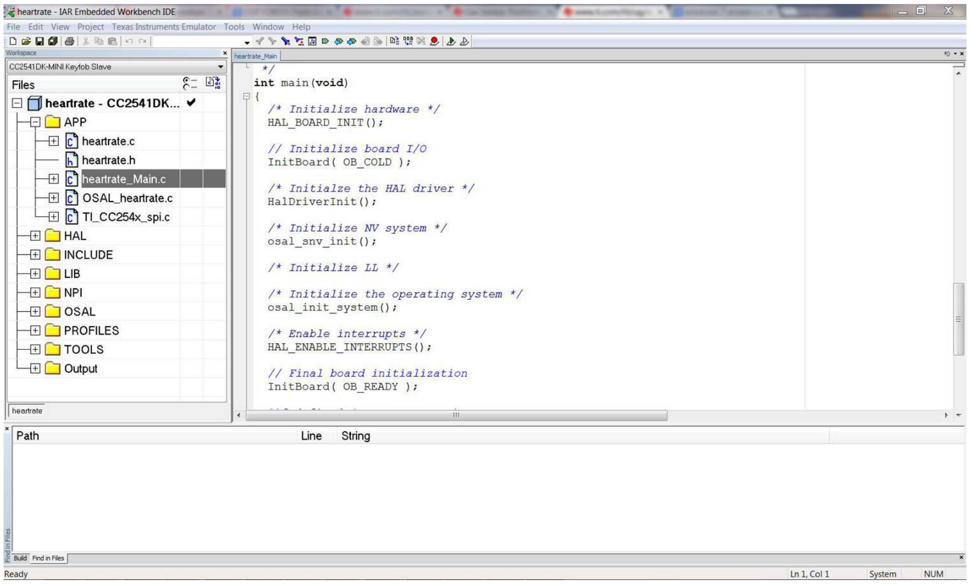

Figure 26. Main Function

Figure 27 shows the various communication settings for the application.

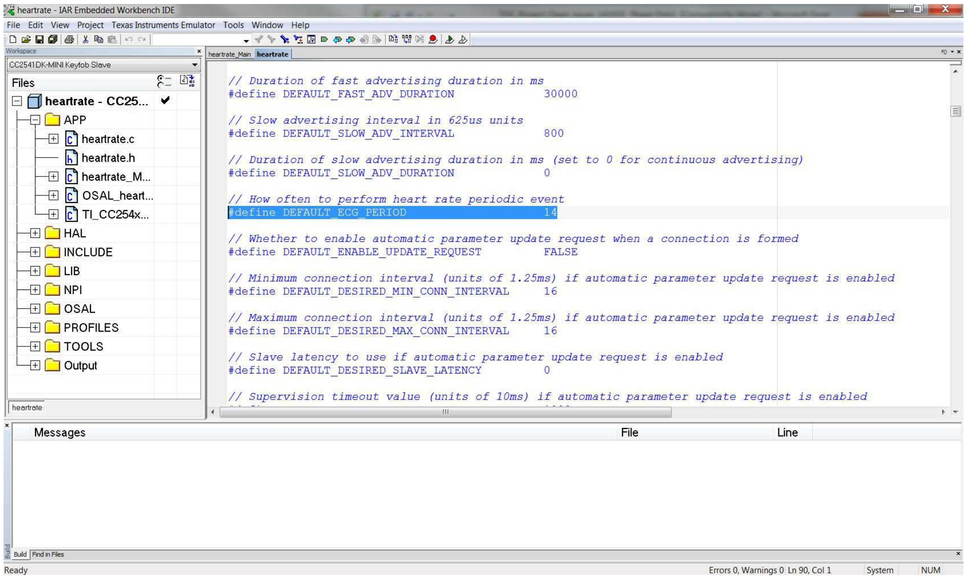

**Figure 27. Key Parameters**

Figure 28 shows that all of the key-configuration settings for the ADS1293 device are easily updated through the single function.

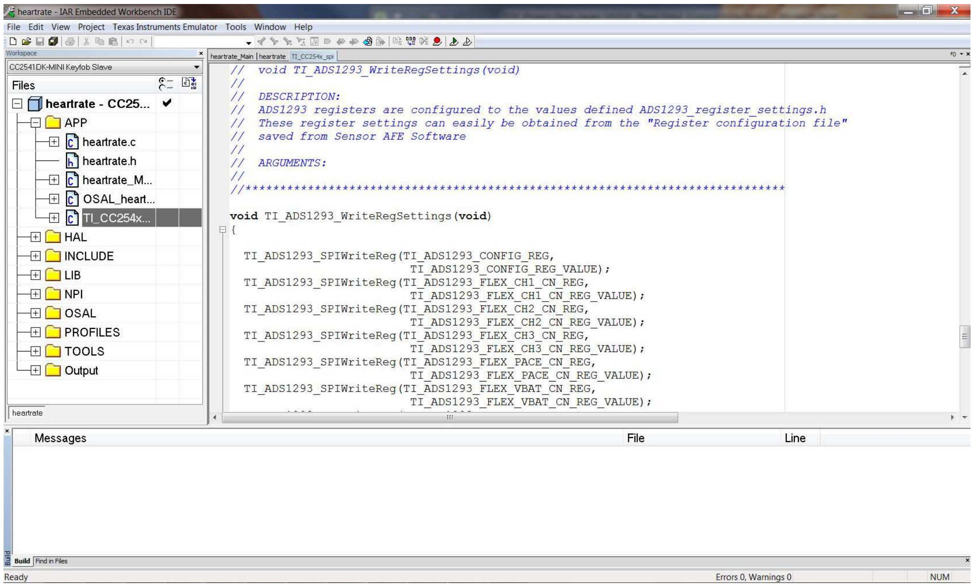

**Figure 28. Key Configuration Settings**

## 5 Common Issues and Solutions

**Issue —**The iPad or iPhone will not connect to the demo through *Bluetooth*.

**Solution:** Ensure that the application is shut down completely before trying to reconnect. To shut down the application, hold the home button on the iPad or iPhone until the *task manager* window appears. This window shows all of the applications running in the background. Press and hold on the ADS1293 application until the *X* or - symbol appears. Click the *X* or - to completely shut down the application. Start again to reconnect the demo board. If the issue continues, see the following solution on adjusting the input voltage from the battery.

# 6 Test Data and Simulation Results

## 6.1 Antenna Simulations

The following data was simulated using the High-Frequency Structural Simulator (HFSS) from ANSYS (www.ansys.com).

The goal of the antenna simulations was to validate that the 2.45-GHz antenna performed as expected.

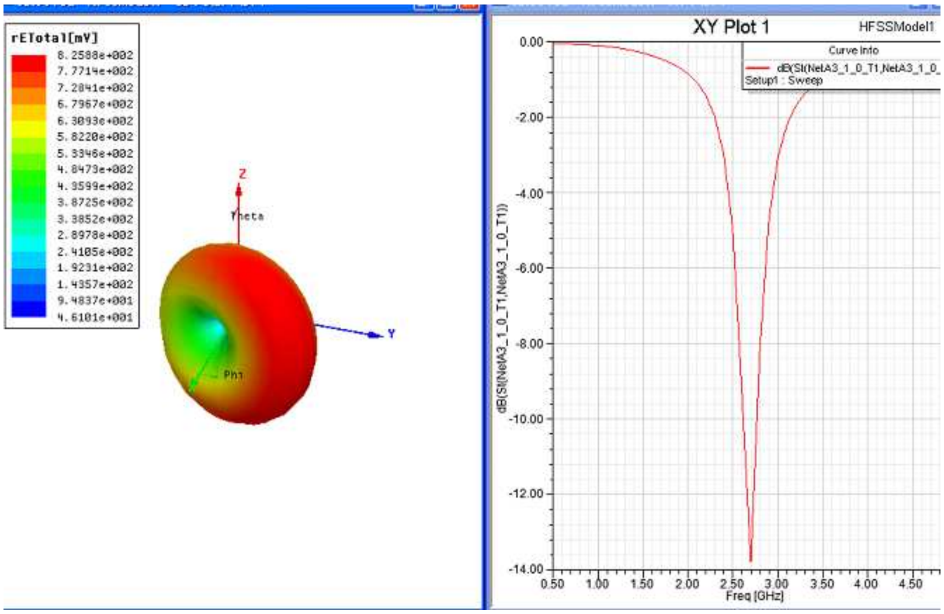


**Figure 29. Antenna Simulation**

## 6.2 Noise Test Results

Figure 30 and Figure 31 show the input referred noise of the AFE.

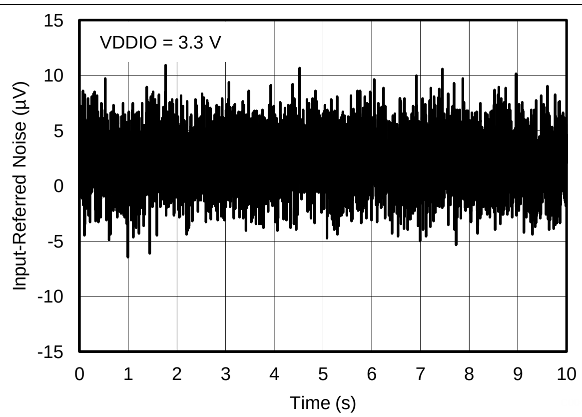


**Figure 30. Input-Referred Noise**

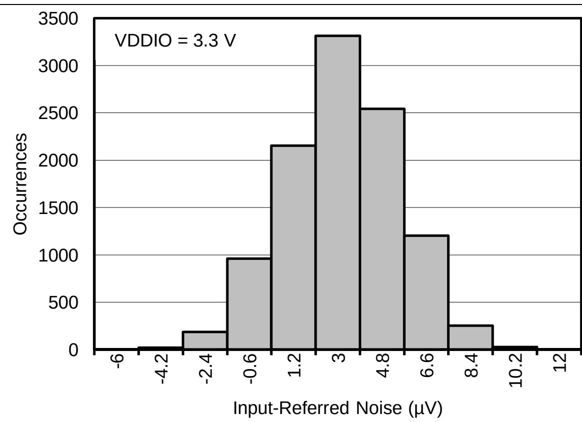


**Figure 31. Noise Histogram**

## 6.3 FFT Results

Figure 32 and Figure 33 show the FFT results of the ADS1293 device corresponding to different peak rates.

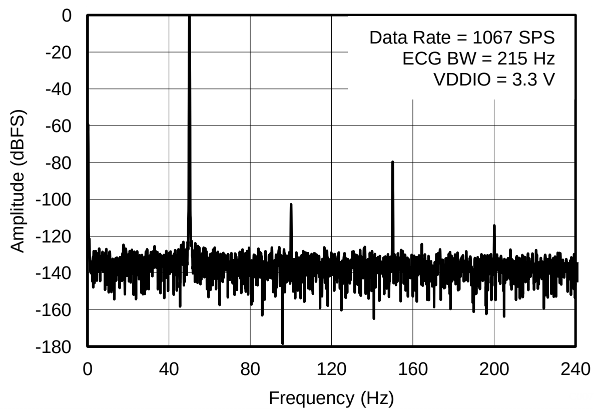


**Figure 32. FFT Plot ECG Channel (50-Hz Signal)**

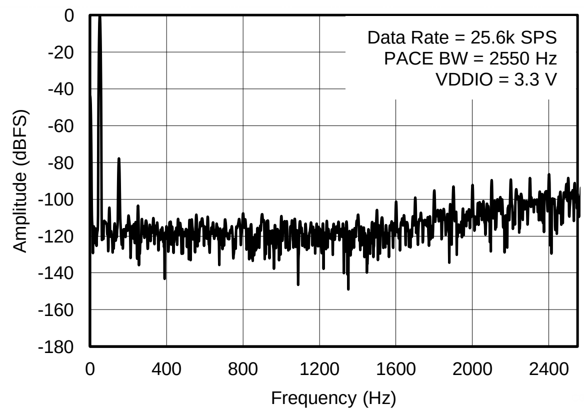


**Figure 33. FFT Plot Pace Channel (50-Hz Signal)**

## 6.4 EMI Test Results of the ADS1293

**Table 2. Test Results**

| DUT | Frequency MHz | Vos_Off (uV) | Vos_On (uV) | Vrf_pp (mV) | EMIRR |
|---|---|---|---|---|---|
| 4L2 | 400 | -4.94 | -4.93 | 130.8 | 132.6231099 |
| 4L2 | 900 | -4.82 | -5 | 103.4 | 103.4341716 |
| 4L2 | 1800 | -5.05 | -4.98 | 90 | 109.2265398 |
| 4L2 | 2400 | -4.95 | -4.9 | 45.2 | 100.1849375 |
| 6L1 | 400 | 19.03 | 18.99 | 218.1 | 129.463827 |
| 6L1 | 900 | 19 | 18.97 | 225.6 | 132.5499389 |
| 6L1 | 1800 | 19 | 18.98 | 185.7 | 132.6906764 |
| 6L1 | 2400 | 19.01 | 18.99 | 41.9 | 106.8267612 |
| 11L1 | 400 | -4.55 | -4.36 | 204.1 | 114.7774483 |
| 11L1 | 900 | -4.38 | -4.26 | 204.8 | 118.8283733 |
| 11L1 | 1800 | -4.39 | -4.48 | 147.2 | 115.5902624 |
| 11L1 | 2400 | -4.42 | -4.37 | 47.73 | 101.1310575 |

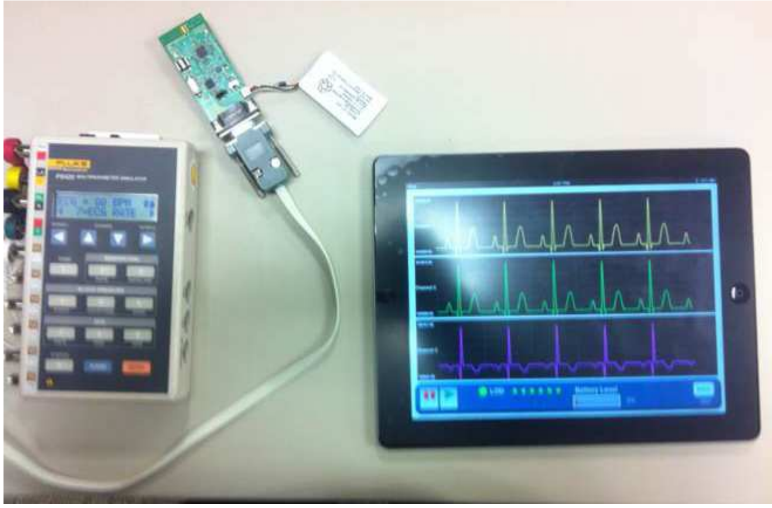

**Figure 34. Setup for ECG Data**

**Figure 35. ECG Data as Shown on an iOS Device**

## FCC Compliance

The Wireless Heart Rate Monitor Reference Design platform uses a similar RF design (antenna design) that complied with the following standards:

- EN 300 328
- FCC 15.247
- IC RSS-210
- EN 301 489-17

  FCC and IC Regulatory Compliance standards:
  - FCC – Federal Communications Commission Part 15, Class A
  - IC – Industry Canada ICES-003 Class A

See the Gas Sensor Platform Reference Design (SNOA922) for reference.

## 7 Schematics

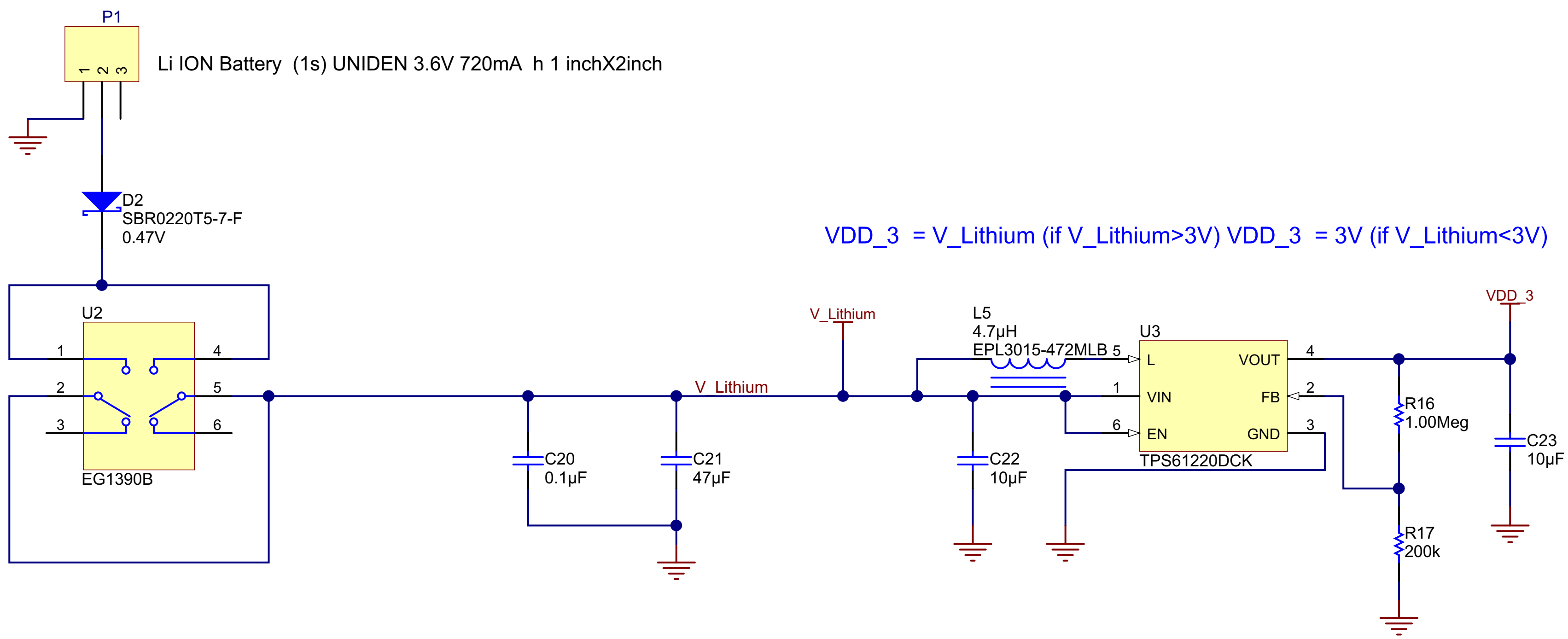


**Figure 36. Power Section**

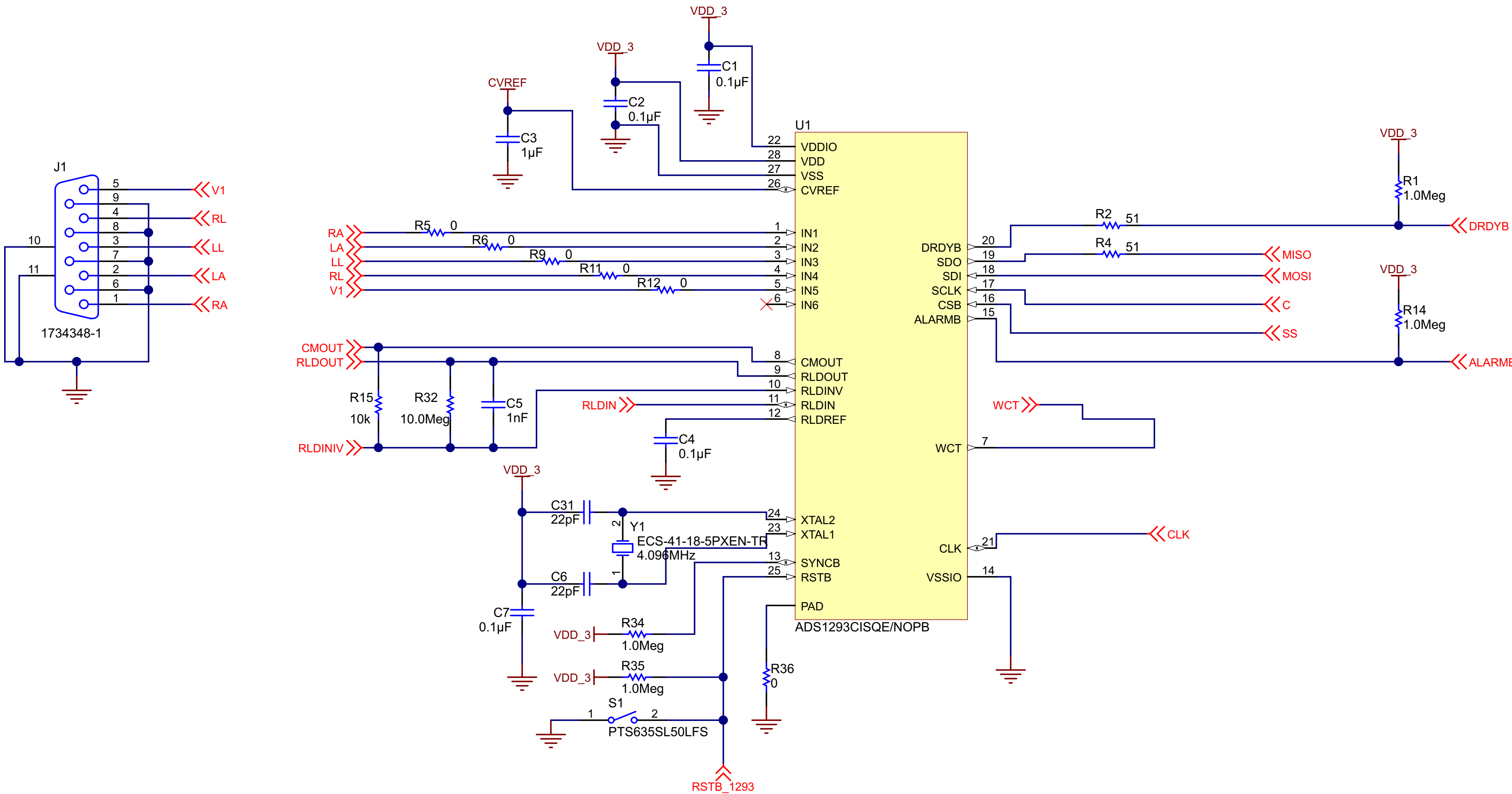


**Figure 37. Analog Front End**

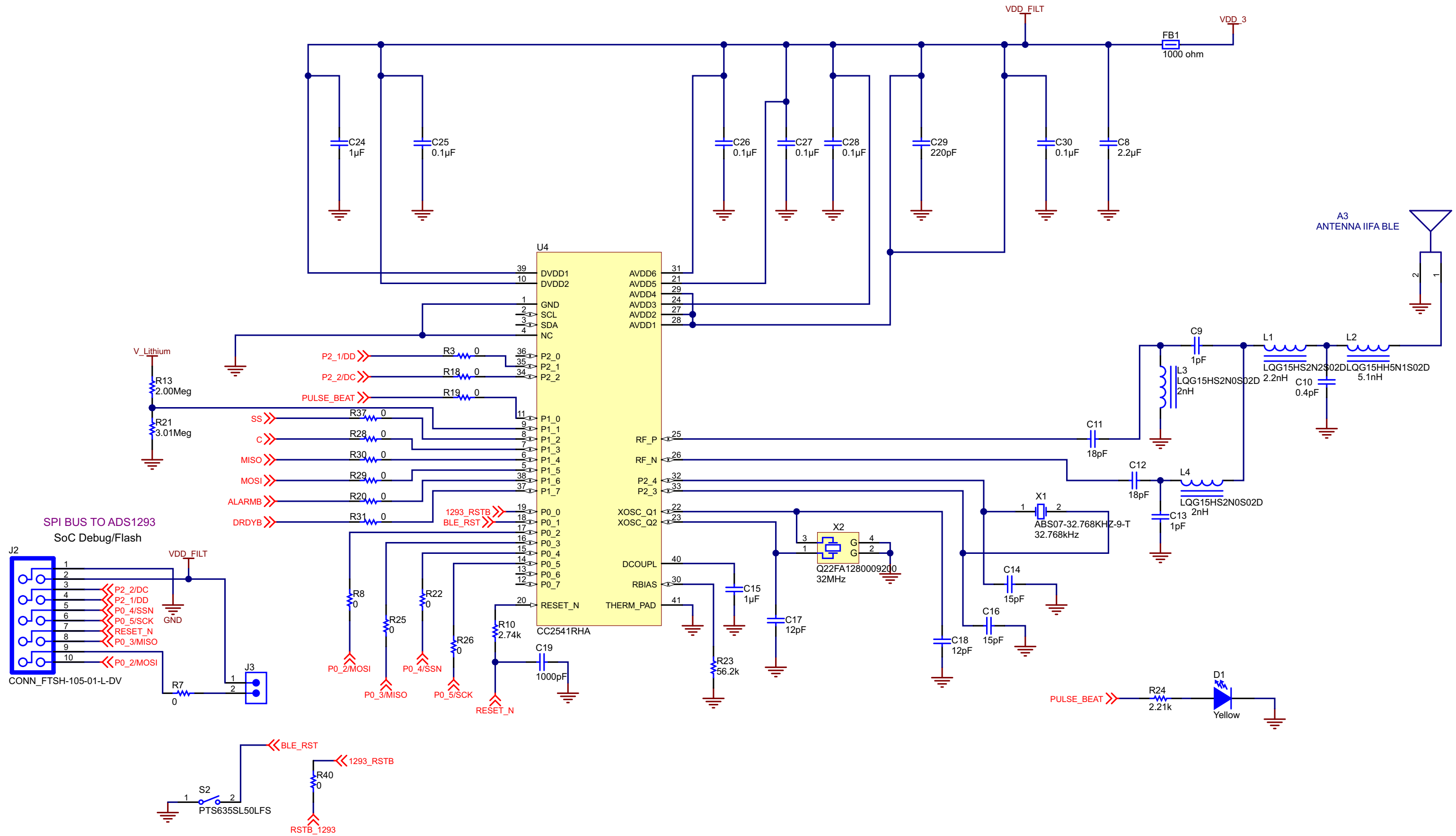


**Figure 38. ADS1293 Section**

## 8 Bill of Materials

To download the bill of materials (BOM) for each board, see the design files at TIDA-00096. Table 3 lists the BOM.

**Table 3. BOM**

| Designator | Quantity | Value | Description | PackageReference | PartNumber | Manufacturer |
|---|---|---|---|---|---|---|
| !PCB | 1 | | Printed Circuit Board | | SAT0015 | Any |
| C1, C2, C4, C7 | 4 | 0.1 µF | CAP, CERM, 0.1 µF, 25 V, ±5%, X7R, 0603 | 0603 | 06033C104JAT2A | AVX |
| C3 | 1 | 1 µF | CAP, CERM, 1 µF, 16 V, ±10%, X5R, 0805 | 0805 | 0805YD105KAT2A | AVX |
| C5 | 1 | 1000 pF | CAP, CERM, 1000 pF, 100 V, ±5%, C0G/NP0, 0603 | 0603 | C1608C0G2A102J | TDK |
| C6, C31 | 2 | 22 pF | CAP, CERM, 22 pF, 50 V, ±5%, C0G/NP0, 0603 | 0603 | 06035A220JAT2A | AVX |
| C8 | 1 | 2.2 µF | CAP, CERM, 2.2 µF, 6.3 V, ±20%, X5R, 0402 | 0402 | JMK105BJ225MV-F | Taiyo Yuden |
| C9, C13 | 2 | 1 pF | CAP, CERM, 1 pF, 50 V, ±5%, C0G/NP0, 0402 | 0402 | GRM1555C1H1R0CA01D | MuRata |
| C10 | 1 | 0.4 pF | CAP, CERM, 0.4 pF, 50 V, ±25%, C0G/NP0, 0402 | 0402 | GRM1555C1HR40BA01D | MuRata |
| C11, C12 | 2 | 18 pF | CAP, CERM, 18 pF, 50 V, ±5%, C0G/NP0, 0402 | 0402 | GRM1555C1H180JA01D | MuRata |
| C14, C16 | 2 | 15 pF | CAP, CERM, 15 pF, 50 V, ±5%, C0G/NP0, 0402 | 0402 | GRM1555C1H150JA01D | MuRata |
| C15, C24 | 2 | 1 µF | CAP, CERM, 1 µF, 6.3 V, ±20%, X5R, 0402 | 0402 | C1005X5R0J105M | TDK |
| C17, C18 | 2 | 12 pF | CAP, CERM, 12 pF, 50 V, ±5%, C0G/NP0, 0402 | 0402 | GRM1555C1H120JA01D | MuRata |
| C19 | 1 | 1000 pF | CAP, CERM, 1000 pF, 50 V, ±5%, C0G/NP0, 0402 | 0402 | GRM1555C1H102JA01D | MuRata |
| C20, C25, C26, C27, C28, C30 | 6 | 0.1 µF | CAP, CERM, 0.1 µF, 10 V, ±10%, X7R, 0402 | 0402 | GRM155R71A104KA01D | MuRata |
| C21 | 1 | 47 µF | CAP, CERM, 47 µF, 6.3 V, ±10%, X5R, 1206 | 1206 | GRM31CR60J476KE19L | MuRata |
| C22, C23 | 2 | 10 µF | CAP, CERM, 10 µF, 6.3 V, ±20%, X5R, 0603 | 0603 | GRM188R60J106ME47D | MuRata |
| C29 | 1 | 220 pF | CAP, CERM, 220 pF, 50 V, ±5%, C0G/NP0, 0402 | 0402 | GRM1555C1H221JA01D | MuRata |
| D1 | 1 | Yellow | LED, Yellow, SMD | Yellow LED | SML-P12YTT86 | RΩ |
| D2 | 1 | 0.47V | Diode, Schottky, 20 V, 0.2 A, SOD-523 | SOD-523 | SBR0220T5-7-F | Diodes Inc. |
| FB1 | 1 | 1000 Ω | 0.25A Ferrite Bead, 1000 Ω at 100 MHz, SMD | 0402 | BLM15HG102SN1D | MuRata |
| J1 | 1 | | Conn D-SUB RCPT R/A 9POS GOLD/FL, TH | D-SUB 9 PIN | 1734348-1 | TE Connectivity |
| J2 | 1 | FTSH-105-01-L-DV | Header, 2 × 5 pin 50 mil spacing | 0.222 × 0.330 inch | FTSH-105-01-L-DV | Samtec |
| J3 | 1 | | Header, TH, 100mil, 2 × 1, Gold plated, 230 mil above insulator | TSW-102-07-G-S | TSW-102-07-G-S | Samtec, Inc. |
| L1 | 1 | 2.2nH | Inductor, Multilayer, Air Core, 2.2 nH, 0.3 A, 0.12 Ω, SMD | 0402 polarized | LQG15HS2N2S02D | MuRata |
| L2 | 1 | 5.1nH | Inductor, Multilayer, Ferrite, 5.1 nH, 0.3 A, 0.2 Ω, SMD | 0402 | LQG15HH5N1S02D | MuRata |

**Table 3. BOM (continued)**

| Designator | Quantity | Value | Description | PackageReference | PartNumber | Manufacturer |
|---|---|---|---|---|---|---|
| L3, L4 | 2 | 2nH | Inductor, Multilayer, Ferrite, 2 nH, 0.3 A, 0.1 Ω, SMD | 0402 | LQG15HS2N0S02D | MuRata |
| L5 | 1 | 4.7uH | Inductor, Shielded, Ferrite, 4.7 µH, 1.2 A, 0.14 Ω, SMD | Inductor, 3 × 1,55 × 3 mm | EPL3015-472MLB | Coilcraft |
| P1 | 1 | | Header, 3-Pin, Right Angle | | 0530480310 | Molex |
| R1, R14, R34, R35 | 4 | 1.0Meg | RES, 1 MΩ, 5%, 0.063 W, 0402 | 0402 | CRCW04021M00JNED | Vishay-Dale |
| R2, R4 | 2 | 51 | RES, 51 Ω, 5%, 0.063 W, 0402 | 0402 | CRCW040251R0JNED | Vishay-Dale |
| R3, R5, R6, R7, R8, R9, R11, R12, R18, R19, R20, R22, R25, R26, R28, R29, R30, R31, R36, R37, R40 | 21 | 0 | RES, 0 Ω, 5%, 0.063 W, 0402 | 0402 | CRCW04020000Z0ED | Vishay-Dale |
| R10 | 1 | 2.74k | RES, 2.74 kΩ, 1%, 0.063 W, 0402 | 0402 | CRCW04022K74FKED | Vishay-Dale |
| R13 | 1 | 2 Meg | RES, 2 MΩ, 1%, 0.063 W, 0402 | 0402 | CRCW04022M00FKED | Vishay-Dale |
| R15 | 1 | 10k | RES, 10 kΩ, 5%, 0.063 W, 0402 | 0402 | CRCW040210K0JNED | Vishay-Dale |
| R16 | 1 | 1 Meg | RES, 1 MΩ, 1%, 0.063 W, 0402 | 0402 | CRCW04021M00FKED | Vishay-Dale |
| R17 | 1 | 200k | RES, 200 kΩ, 1%, 0.063 W, 0402 | 0402 | CRCW0402200KFKED | Vishay-Dale |
| R21 | 1 | 3.01 Meg | RES, 3.01 MΩ, 1%, 0.063 W, 0402 | 0402 | CRCW04023M01FKED | Vishay-Dale |
| R23 | 1 | 56.2k | RES, 56.2k Ω, 1%, 0.063 W, 0402 | 0402 | CRCW040256K2FKED | Vishay-Dale |
| R24 | 1 | 2.21k | RES, 2.21k Ω, 1%, 0.063 W, 0402 | 0402 | CRCW04022K21FKED | Vishay-Dale |
| R32 | 1 | 10 Meg | RES, 10 MΩ, 1%, 0.063 W, 0402 | 0402 | CRCW040210M0FKED | Vishay-Dale |
| S1, S2 | 2 | | Switch, tactile, SPST-NO, 0.05 A, 12V, TH | SW, SPST 3,5 × 5 mm | PTS635SL50LFS | C&K Components |
| U1 | 1 | | ADS1293 low power, 3-channel, 24-bit analog front-end for Biopotential measurements, RSG0028A | RSG0028A | ADS1293CISQE/NOPB | Texas Instruments |
| U2 | 1 | | Slide switch DPDT 0.3 A, SMT | 7,2 × 3,5 × 3,5 mm | EG1390B | E-Switch |
| U3 | 1 | | Low input voltage step-up converter in 6-pin SC-70 package, DCK0006A | DCK0006A | TPS61220DCK | Texas Instruments |
| U4 | 1 | | 2.4-GHz *Bluetooth* low energy and proprietary System-on-Chip, RHA0040H | RHA0040H | CC2541RHA | Texas Instruments |
| X1 | 1 | | CRYSTAL, 32.768 KHZ, 9 pF, SMD | 3,2 × 0.9 × 1,5 mm | ABS07-32.768KHZ-9-T | Abracon Corportation |
| X2 | 1 | | Crystal, 32 MHz, 10 pF, SMD | Crystal, 2,6 × 0,5 × 1,6 mm | Q22FA1280009200 | Epson |
| Y1 | 1 | | Crystal, 4.096 MHz, 18 pF, SMD | Crystal, 11,4 × 4,3 × 3,8 mm | ECS-41-18-5PXEN-TR | ECS, Inc. |

# 9 Layer Plots

To download the layer plots for each board, see the design files at TIDA-00096. Figure 39 shows the layer plots.

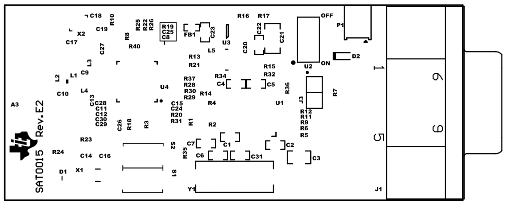

**Figure 0. UNDEFINED**

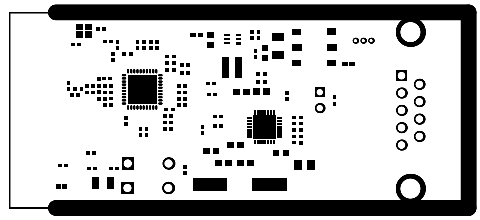

**Figure 0. UNDEFINED**

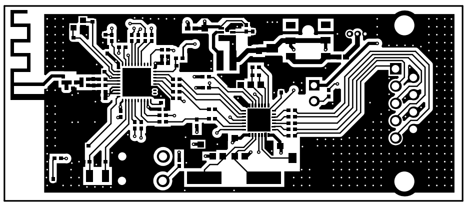

**Figure 0. UNDEFINED**

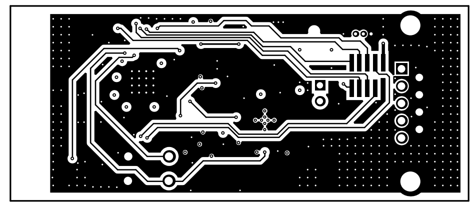

**Figure 0. UNDEFINED**

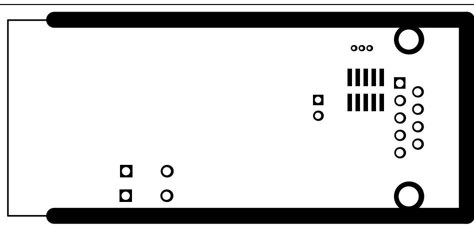

**Figure 0. UNDEFINED**

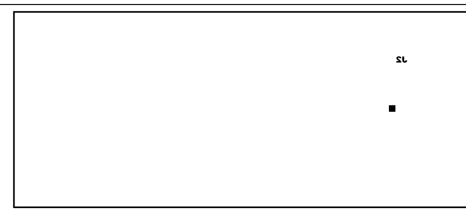

**Figure 0. UNDEFINED**

**Figure 39. Layer Plot**

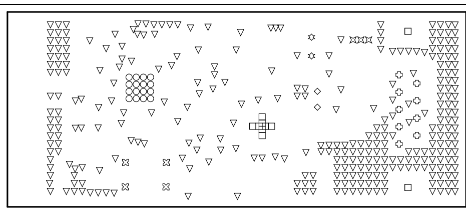

**Figure 0. UNDEFINED**

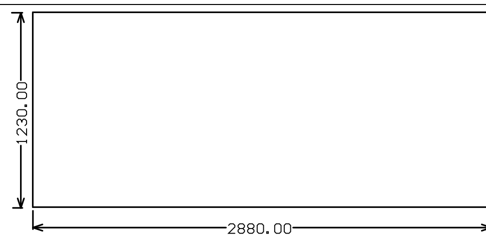


**Figure 0. UNDEFINED**

## 10 Altium Project

To download the Altium project files for each board, see the design files at TIDA-00096. Figure 40, Figure 41, Figure 42, and Figure 43 show the layout.

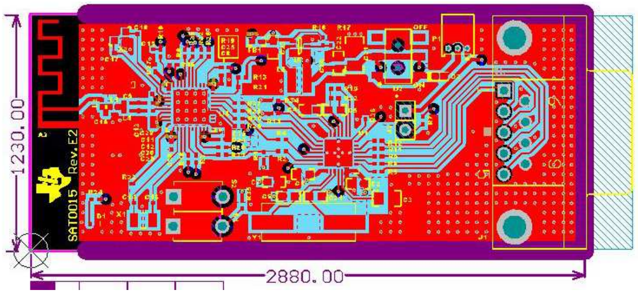

Figure 40. All Layers

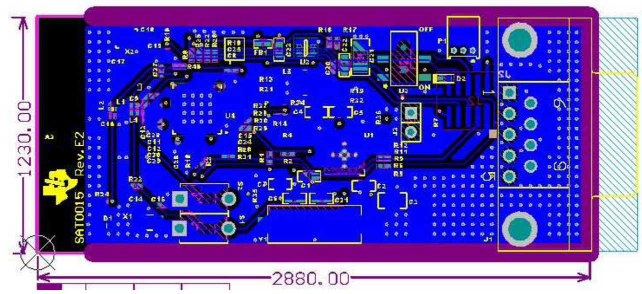

Figure 41. Bottom Layer

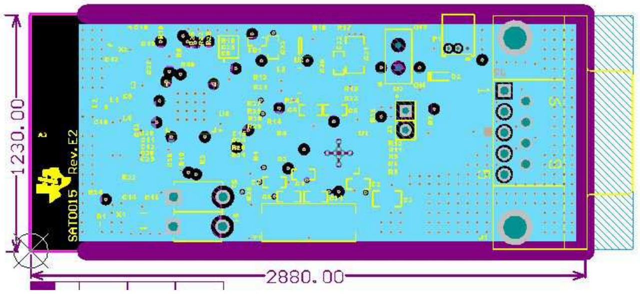

Figure 42. Ground Layer

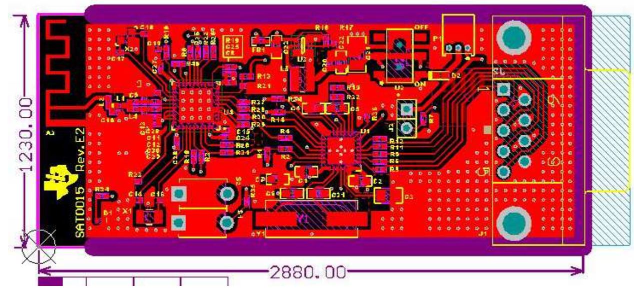

Figure 43. Top Layer

## 11 Gerber Files

To download the Gerber files for each board, see the design files at TIDA-00096.

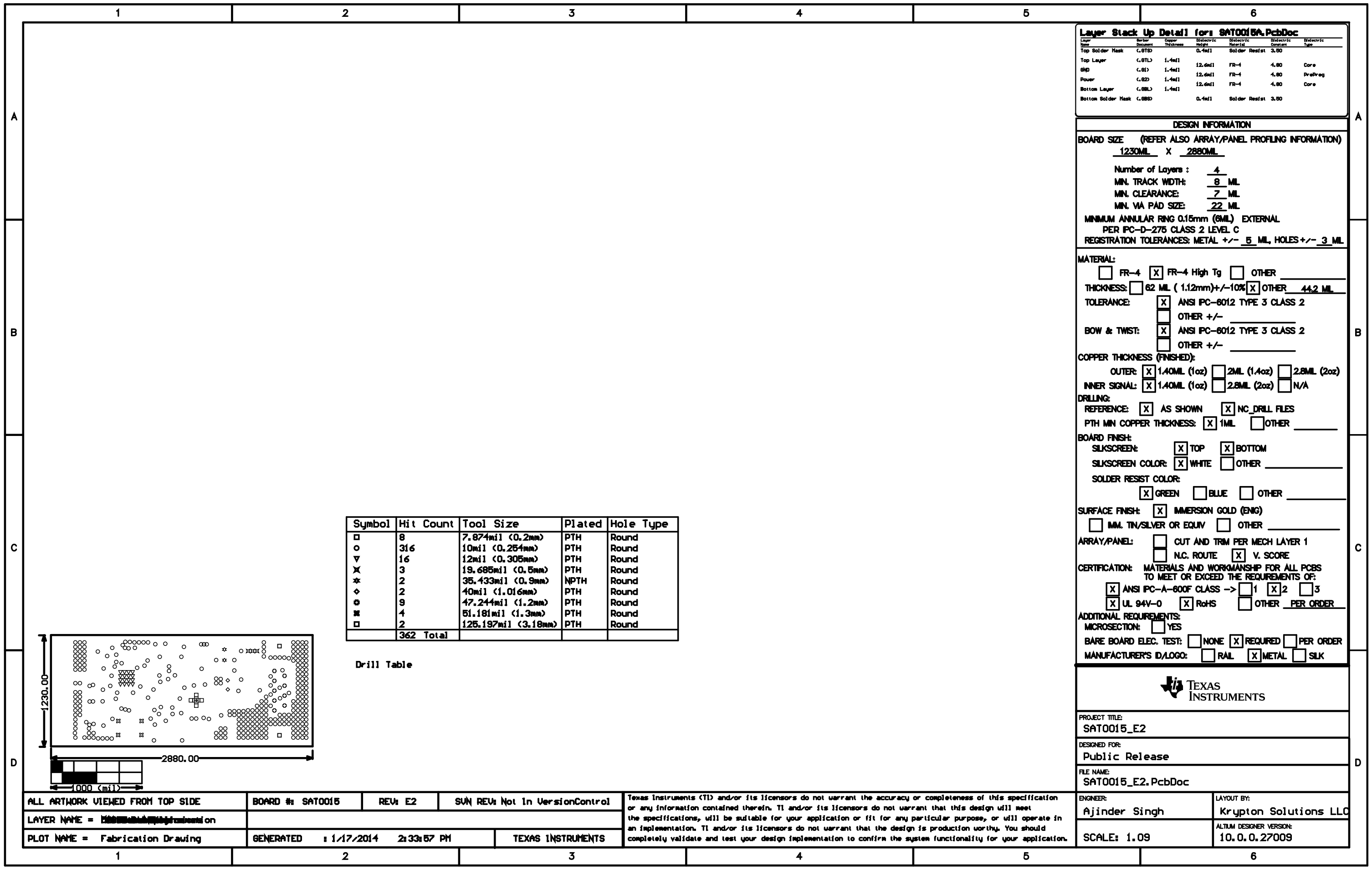


**Figure 44. Fab Drawing**

## 12 Software Files

To download the software files for the reference design, see the design files at TIDA-00096.

## References

For additional references, please see the following:

1. *Bluetooth Low Energy CC2540 Mini Development Kit User's Guide*, SWRU270

## 13 About the Author

**AJINDER PAL SINGH** is a Systems Architect at Texas Instruments where he is responsible for developing reference design solutions for the industrial segment. Ajinder brings to this role his extensive experience in high-speed digital, low-noise analog and RF system-level design expertise. Ajinder earned his Master of Science in Electrical Engineering (MSEE) from Texas Tech University in Lubbock, TX. Ajinder is a member of the Institute of Electrical and Electronics Engineers (IEEE).

**NATARAJAN VISWANATHAN**, also known as Vishy, is an Applications Engineer at Texas Instruments Silicon Valley Analog where he is involved in developing embedded firmware, evaluation tools, and customer demo systems. Vishy has broad experience with system on chips, microcontrollers, and application processors. Vishy earned his Masters and PhD from the Indian Institute of Science, Bangalore.

# Revision History

| Changes from Original (January 2014) to A Revision | Page |
|---|---|
| • Changed to the correct name for the design. | 3 |
| • Added paragraph explaining that installation of application is manual, but the designer must still connect to iTunes to install the application. | 11 |

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

## STANDARD TERMS AND CONDITIONS FOR EVALUATION MODULES

1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, or documentation (collectively, an "EVM" or "EVMs") to the User ("User") in accordance with the terms and conditions set forth herein. Acceptance of the EVM is expressly subject to the following terms and conditions.

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   1.2 EVMs are not intended for consumer or household use. EVMs may not be sold, sublicensed, leased, rented, loaned, assigned, or otherwise distributed for commercial purposes by Users, in whole or in part, or used in any finished product or production system.

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   2.1 These terms and conditions do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.

   2.2 TI warrants that the TI EVM will conform to TI's published specifications for ninety (90) days after the date TI delivers such EVM to User. Notwithstanding the foregoing, TI shall not be liable for any defects that are caused by neglect, misuse or mistreatment by an entity other than TI, including improper installation or testing, or for any EVMs that have been altered or modified in any way by an entity other than TI. Moreover, TI shall not be liable for any defects that result from User's design, specifications or instructions for such EVMs. Testing and other quality control techniques are used to the extent TI deems necessary or as mandated by government requirements. TI does not test all parameters of each EVM.

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3 *Regulatory Notices:*

   3.1 *United States*

   3.1.1 *Notice applicable to EVMs not FCC-Approved:*

   This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

   3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

   **CAUTION**

   This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

   Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

   **FCC Interference Statement for Class A EVM devices**

   *NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.*

**FCC Interference Statement for Class B EVM devices**

*NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:*

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210*

**Concerning EVMs Including Radio Transmitters:**

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

**Concernant les EVMs avec appareils radio:**

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: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

**Concerning EVMs Including Detachable Antennas:**

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

**Concernant les EVMs avec antennes détachables**

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d’usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page

3.3.2 *Notice for Users of EVMs Considered “Radio Frequency Products” in Japan:* EVMs entering Japan are NOT certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, User is required by Radio Law of Japan to follow the instructions below with respect to EVMs:

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry’s Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】

本開発キットは技術基準適合証明を受けておりません。

本製品のご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。

日本テキサス· インスツルメンツ株式会社

東京都新宿区西新宿６丁目２４番１号

西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

   6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY WRITTEN DESIGN MATERIALS PROVIDED WITH THE EVM (AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

   6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS AND CONDITIONS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT MADE, CONCEIVED OR ACQUIRED PRIOR TO OR AFTER DELIVERY OF THE EVM.

7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS AND CONDITIONS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS ANDCONDITIONS OR THE USE OF THE EVMS PROVIDED HEREUNDER, REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN ONE YEAR AFTER THE RELATED CAUSE OF ACTION HAS OCCURRED.

   8.2 *Specific Limitations.* IN NO EVENT SHALL TI'S AGGREGATE LIABILITY FROM ANY WARRANTY OR OTHER OBLIGATION ARISING OUT OF OR IN CONNECTION WITH THESE TERMS AND CONDITIONS, OR ANY USE OF ANY TI EVM PROVIDED HEREUNDER, EXCEED THE TOTAL AMOUNT PAID TO TI FOR THE PARTICULAR UNITS SOLD UNDER THESE TERMS AND CONDITIONS WITH RESPECT TO WHICH LOSSES OR DAMAGES ARE CLAIMED. THE EXISTENCE OF MORE THAN ONE CLAIM AGAINST THE PARTICULAR UNITS SOLD TO USER UNDER THESE TERMS AND CONDITIONS SHALL NOT ENLARGE OR EXTEND THIS LIMIT.

9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265

# IMPORTANT NOTICE FOR TI REFERENCE DESIGNS



Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265