Design Guide: TIDA-010270

Biosensing Patch Reference Design for Continuous Vital Sign Monitoring With Bluetooth® Low Energy

Description

The wearable biosensing patch reference design provides a platform to evaluate TI's latest offerings for continuous monitoring of vital signs such as electrocardiogram (ECG), heart rate, respiration, pace pulse, temperature, and motion. The design utilizes the AFE4960 for accurate single-lead ECG signal acquisition and the TMP119 for the body temperature monitoring. The measured data is transferred by the CC2674R10 to the remote terminal such as a smartphone and medical monitoring system for the real-time display. The onboard light-emitting diode (LED) can be used to indicate status of the system like lead-off, low power, and Bluetooth® Low Energy connection. The whole design can be powered with 2 × CR2032 battery (3V input) or 1 AAA battery (1.5V input) with an operating life of 14 days.

Resources

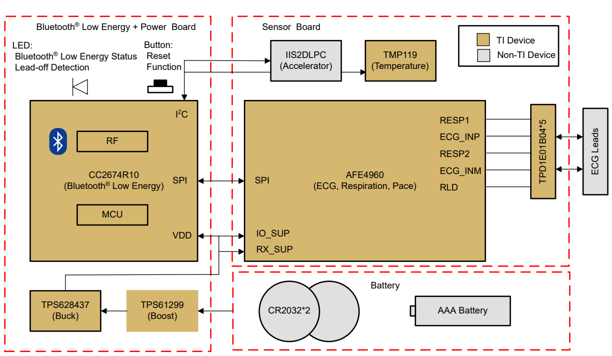
TIDA-010270	Design Folder
AFE4960, CC2674R10	Product Folder
TMP119, TPD1E01B04	Product Folder
TPS628437, TPS61299	Product Folder

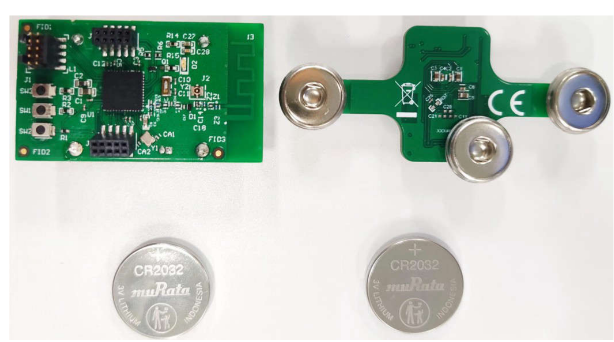
Features

- Small, multiparameter, single-chip patch design for synchronized ECG, respiration, and pace pulse detection
- High-accuracy digital temperature sensor for real-time body temperature monitoring
- High-performance, 2.4G Bluetooth® Low Energy 5.3, Arm® Cortex®-M33 processor supports wireless data transfer
- Highly efficient DC/DC converter to support both 2 × CR2032 (3V, 210mAh Coin-cell battery) and 1 × AAA battery (1.5V, 500mAh) with an operating life of 14 days
- Flexible Bluetooth® Low Energy platform to support the wearable patch and Holter designs
- SimpleLink™ Connect mobile app for the real-time ECG, respiration, pace pulse, and temperature display

Applications

- Medical sensor patches
- Electrocardiogram (ECG)
- Wearable fitness and activity monitor
- Smartwatch
- Smart trackers





1 System Description

1.1 Introduction to the Parameters Measured With TIDA-010270

TIDA-010207 is a wearable patch reference design that outputs vital sign data from the human body, including ECG, respiration, pacemaker pulse, heart rate, and body temperature.

ECG is the recording of the electrical activity of the heart using the electrodes attached around the heart. The patch design can be used to develop single-lead ECG detection. ECG waveforms can detect irregularities in the rhythm of the heart, or arrhythmias, which can indicate potential heart conditions. Monitoring the ECG can help in early detection of cardiovascular diseases and facilitate a timely intervention.

A pacemaker is used to control the heartbeat. The device stimulates the heart as needed to keep the heart beating regularly. Thus, pacemaker pulse monitoring is important for most ECG systems to continually deliver heart data of the patient to the clinician.

Figure 1-1 shows the typical ECG and pace pulse waveforms from an ECG simulator.

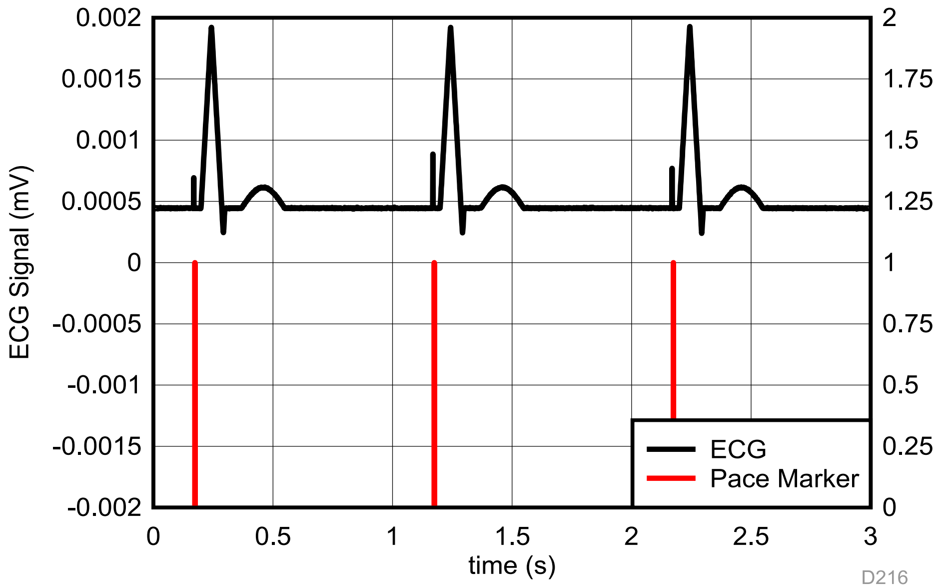


Figure 1-1. Waveform of ECG and Pacemaker From Simulator

In the ECG graph, a heartbeat is represented by a series of waves that show how the heart muscle contracts and relaxes over time. The largest deflection on an ECG is often the R wave; this represents the main muscle of the heart contracting which can be used to identify the heart rate. Pace signal consists of small, narrow pulses, which requires a specific algorithm to distinguish the valid signal from the background noise.

Respiration is defined as the breathing rate of a human, and contains a wealth of information about the health of a person. Figure 1-2 shows a typical respiration waveform from a simulator.

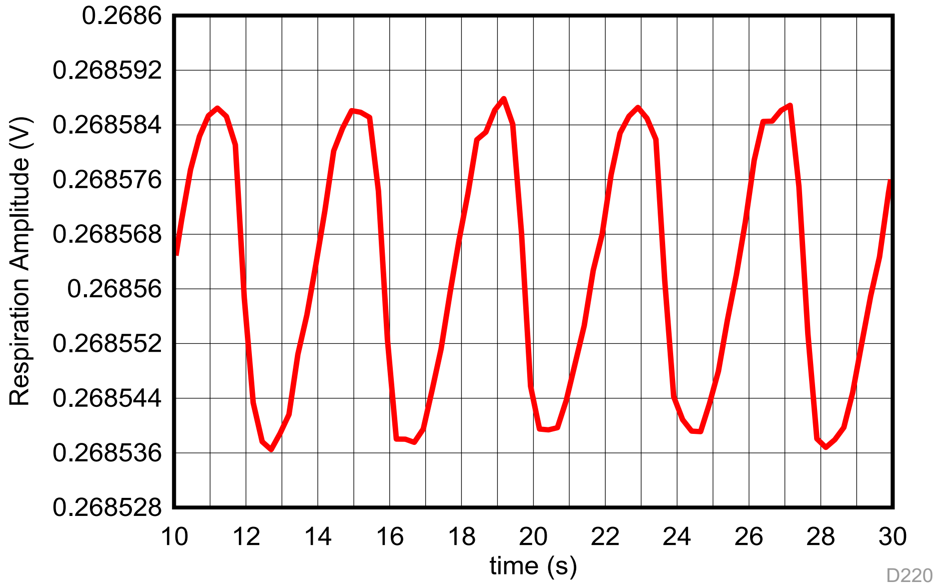


Figure 1-2. Waveform of Respiration From Simulator

Impedance pneumography is the commonly used method of monitoring the respiration rate. To get the respiration rate, bio-impedance (Bio-Z) data is first obtained by injecting a high-frequency sine wave or square wave into the body through two excitation electrodes. By capturing changes in thoracic impedance during breathing, Bio-Z data can be used to derive respiration rate and provide valuable insights of potential respiratory illnesses.

Body temperature is also a vital sign that can indicate the presence of an infection in the body. Real-time monitoring can assist individuals in recognizing early signs of illnesses and taking necessary medical treatment in time.

1.2 System Introduction and Application

The wearable patch is a type of medical device designed to provide continuous and real-time monitoring of various vital signs. These devices are usually small, lightweight, and can be attached to the skin for extended periods of time. The data collected can be transmitted wirelessly to a compatible device such as a smartphone or a tablet. This enables users to conveniently monitor vital signs, track trends over time, and share data with healthcare providers for remote monitoring or analysis. Figure 1-3 shows an overall block diagram of the system, including the biosensing analog front end, wireless module, power module, and remote terminal.

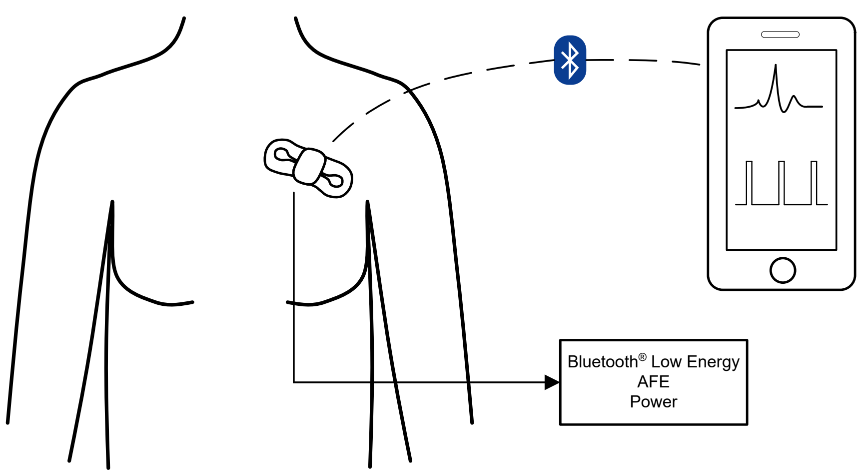


Figure 1-3. System-Level Block Diagram

The typical applications of this reference design are as follows:

- **Medical Sensor Patch:** Medical sensor patches are wearable devices that can track various physiological parameters, such as heart rate, body temperature, ECG, respiration, and more. These devices are designed for continuous monitoring, data collection and transmit using wireless methods (Bluetooth® Low Energy, Wi-Fi®, and so forth).
- **Handheld ECG Monitor:** These monitors are portable devices used to record and display ECG readings. An individual can monitor heart health at home or on-the-go with these monitors. Handheld ECG monitors can help detect irregular heart rhythms and other cardiac abnormalities.
- **Smartwatches:** Smartwatches currently offer features like fitness tracking, heart rate monitoring, sleep tracking, and notifications. The ability to record ECG can provide users with real-time body information, allowing for better tracking of overall health and fitness.
- **Wearable Fitness and Activity Monitor:** Fitness monitors are devices that track various aspects of physical activity and health. These monitors collect data in daily life and provide real-time feedback to users, helping them track progress towards fitness goals and make informed decisions about health. All parts of the system require ultra-low-power, embedded controllers, and low-power wireless for communication.

1.3 System Design Features

The TIDA-010270 reference design for evaluation and development of wearable medical patches has the following design features:

- Small PCB size, multiparameter, wearable patch design that provides for ECG, respiration, and pace-pulse detection (AFE4960)
  - Single-chip biosensing design for clinical wearables with 1-channel ECG + 1-channel respiration and pace pulse
- Wireless data transfer for real-time remote display (CC2674R10)
  - Powerful 48MHz Arm® Cortex®-M33 processor with Bluetooth® Low Energy 5.3 supported
  - 1024kB flash for data processing and 256kB of ultra-low leakage SRAM for high-reliability operation
  - Ultra-low power sensor controller with fast wake-up for low-power operation
  - Integrated DC/DC converter and LDO to increase the system efficiency
- Smartphone app for ECG, respiration, pace, temperature, and accelerator waveform display in real time
- ±0.08°C ultra-high accuracy, low-power, digital temperature sensor for temperature monitoring (TMP119)
- Highly efficient DC/DC converter to support both 2 × CR2032(3V, 210mAh coin-cell battery) and 1 × AAA battery (1.5V, 500mAh) with an operating life of 14 days (TPS61299, TPS628437)

1.4 Key System Specification

Table 1-1 lists the detailed design specifications of TIDA-010270.

Table 1-1. TIDA-010270 Design Specifications

CHARACTERISTIC	SPECIFICATIONS
Power Supply	2V–3V (CR2032 Cell Bat.), 1.0V–1.5V (AAA Bat.)
Wireless Bluetooth® Low Energy VDD	1.8V
AFE4960 RX_SUP	1.8V
TMP119 VDD	1.8V
Number of electrodes	3 electrodes
Respiration measurement	Yes
Pace pulse measurement	Yes
ECG lead-off detection	DC
AFE4960 data interrupt	FIFO_RDY
AFE4960 FIFO length	128
LED indications	Lead-Off
Communication	SPI for AFE4960, I2C for other sensors
ECG service UUID	F000BB00-0451-4000-B000-000000000000
ECG data characteristic UUID	F000BB01-0451-4000-B000-000000000000
Temperature service UUID	F000AA00-0451-4000-B000-000000000000
Temperature data characteristic UUID	F000AA01-0451-4000-B000-000000000000
Accelerator service UUID	F000FFA0 -0451-4000-B000-000000000000
Accelerator data characteristic UUID	F000FFA5 -0451-4000-B000-000000000000
Number of Bluetooth® Low Energy MTU	255
Type of broadcast	Notification
Operation time	14 days

2 System Overview

2.1 Block Diagram

Figure 2-1 is the overall TIDA-010270 block diagram, which is a small, simple parameter reference design for wearable patches. To match different designs (Holter and patch), the design consists of two separate boards; a Bluetooth® Low Energy board and a biosensing board, which are connected through 2 × 8-pin connectors.

The sensor board contains 3 different sensors for multiple bio-signal monitoring. AFE4960 is a single-chip biosensing analog front end for ECG, respiration, and pace pulse detection. The device can communicate with the CC2674 through SPI or I2C. TMP119 is an ultra-high accuracy, low-power digital temperature sensor for the body temperature measurement. An accelerator meter IIS2DLPC is also utilized for the motion measurement, which provides additional information for users. There are ESD diodes (TPD1E01B04) connected to every ECG lead for protecting the AFE4960 from damage.

The Bluetooth® Low Energy board includes the power management and the wireless microcontroller. Coin-cell and AAA batteries are common in wearable devices. To support both power rails of 1.5V and 3V in this reference design, the TPS61299 boost module is used to boost the voltage to 3.3V first for the analog front end (AFE) in Holter. After that, a TPS628437 buck module makes the 3.3V voltage down to 1.8V for the CC2674, AFE4960, and TMP119 power supply. For the actual design with fixed input voltage, the buck and boost module needs to convert the power rail (1.8V and 3.3V) separately from the battery directly to improve the efficiency. CC2674R10 is the Arm® Cortex®-M33 integrated 2.4GHz wireless MCU for the data capture and transition. A JTAG connector is reversed for the communication and debug. There is also an LED in the board as an indicator for the lead-off detection.

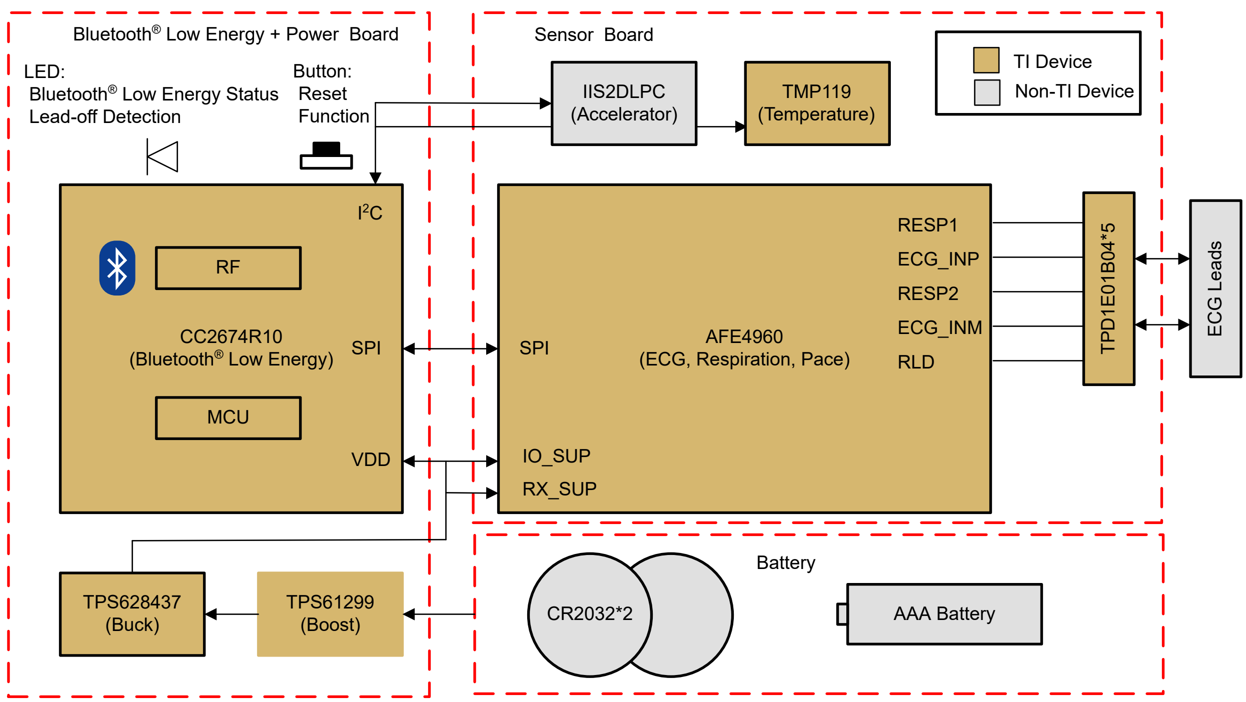


Figure 2-1. TIDA-010270 Block Diagram

2.2 Design Considerations

This section explains the design theory (and equations, if required) for each of the devices used in the design.

2.2.1 AFE4960 and Power Supply

Figure 2-2 shows the power filter and pin mappings for the AFE4960.

There are two power supplies: RX_SUP and IO_SUP in AFE4960, which support the power range from 1.7V to 1.9V. The TPS628437 buck converter is used in the patch design to generate the 1.8V power supply for the AFE4960. To provide a clean supply for the chip, TI recommends adding the decoupled capacitors (C1, C2, C3, and C4) for each SUP pin (RX_SUP and IO_SUP) and make sure to place the capacitors close to the AFE4960 device.

For the ECG measurement, the ECG1, ECG2 are the pins connection to external electrodes for single-lead ECG application. The ECG_RLD pin is used for the right-leg drive signal.

For the respiration measurement, the RESP1 and RESP2 pins are used for the sine wave or square wave excitation to measure the Bio-Z.

AFE4960 supports both SPI and I2C interface for data communication. In this design, SPI is the default selection, so the I2C_SPI_SEL pin connects to the GND. ADC_RDY and GPIO2 can be configured for different interrupt of AFE events (see also the *Interrupts* section in the *AFE4960 Two-Channel ECG, Respiration and Pace Pulse Detection Analog Front End (AFE) for Clinical Wearables* data sheet. In this design, ADC_RDY and GPIO2 are selected for the interrupts of FIFO ready and lead off, respectively.

The BG pin is the band-gap voltage output of the chip, TI recommends using a 1µF decoupling capacitor (C5) on the board.

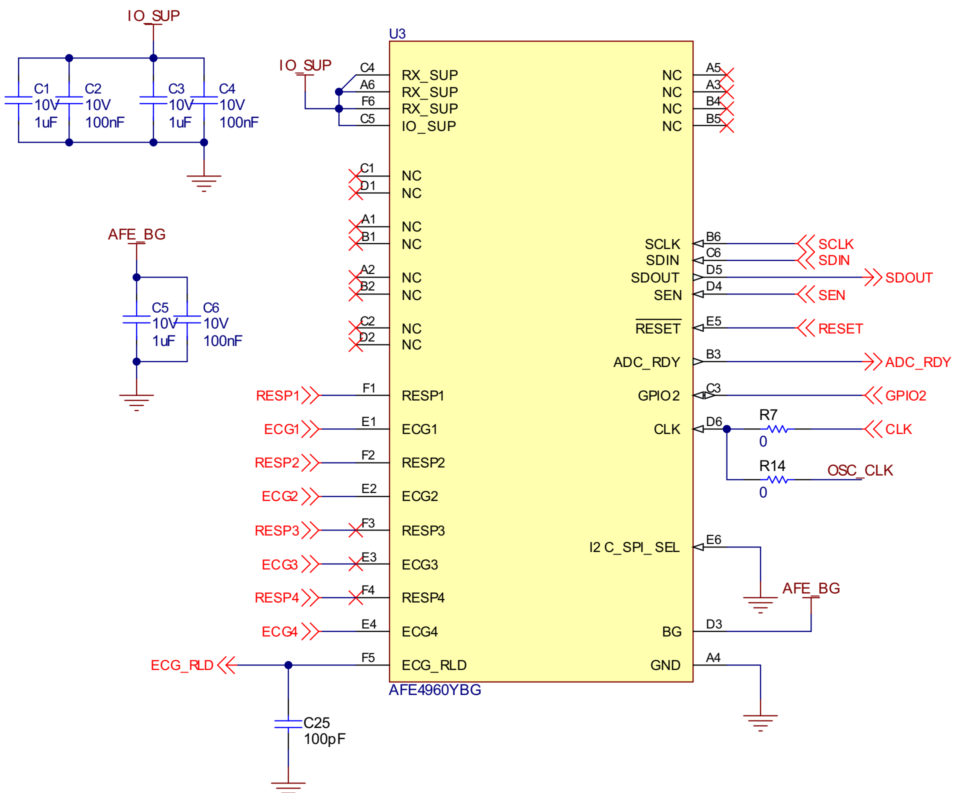


Figure 2-2. AFE4960 Connections

Table 2-1 shows the connections between AFE4960 and CC2397R10.

Table 2-1. Connections Between AFE4960 and CC2674R10

AFE4960 PIN NUMBER	NAME	CC2674R10 PIN NUMBER	NAME	COMMENTS
B6	SCLK	16	DIO_10	SPI_SCLK
C6	SDIN	15	DIO_9	SPI_PICO
D5	SDOUT	14	DIO_8	SPI_ POCI
D4	SEN	29	DIO_19	Chip-select pin for the SPI
E5	RESETZ	41	DIO_28	AFE device reset pin
B3	ADC_RDY	37	DIO_24	Output of FIFO_RDY
C3	GPIO2	43	DIO_30	Output of lead off interrupt
D6	CLK	38	DIO_25	CLK pin for external clock

2.2.2 CC2674R10 Bluetooth® Low Energy Microcontroller

The CC2674R10 is a multiprotocol 2.4GHz wireless 48MHz MCU with 1MB flash and 256K SRAM device, which meets the ECG data processing and storage requirements for patch and Holter devices. The integrated ultra-low power sensor controller can be programed to interface with different sensors for decreasing the overall power consumption.

Figure 2-3 shows the pin connections of the Bluetooth® Low Energy device. U1 is the CC2674R106T0RGZ microcontroller with 31 GPIOs to interface with difference peripherals. Y1 is the 48MHz crystal oscillator and Y2 is the 32.768kHz crystal oscillator.

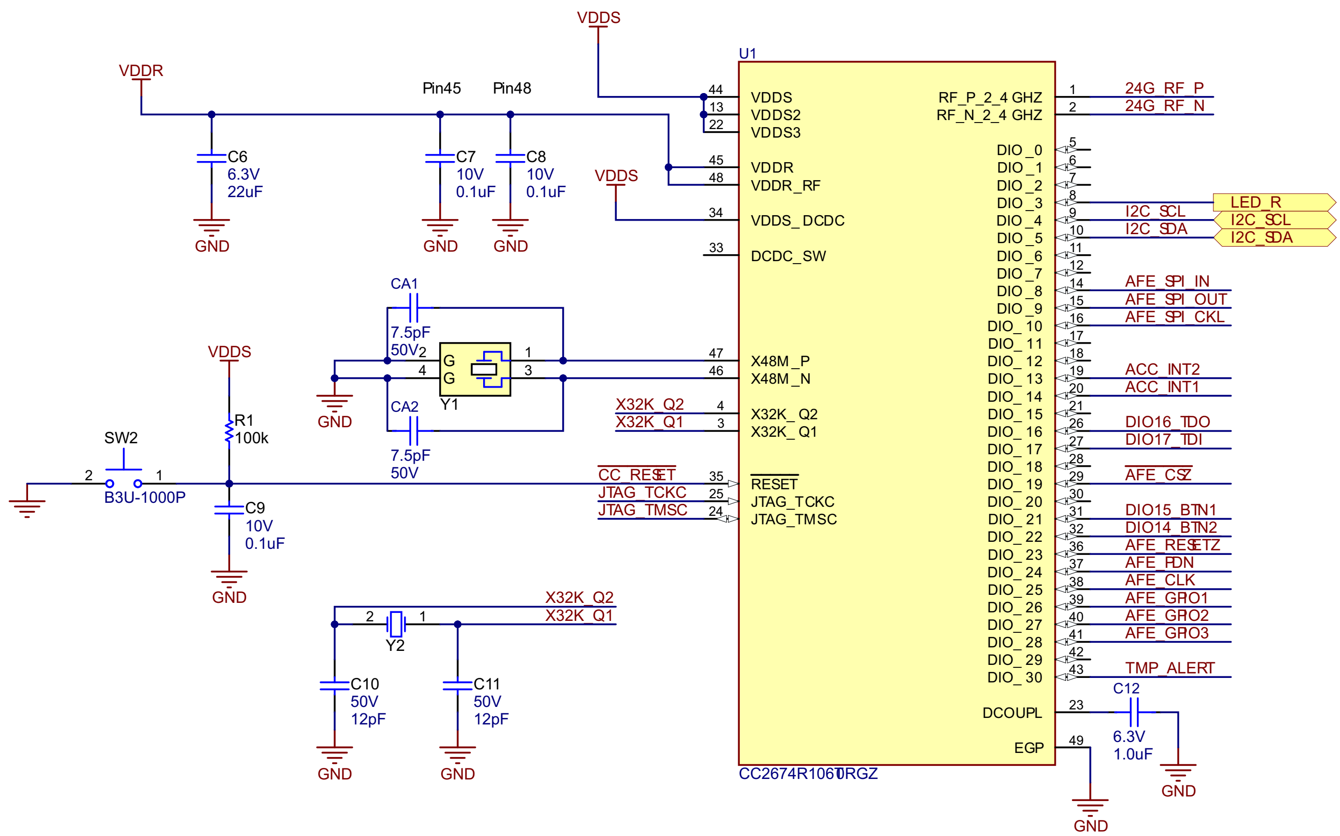


Figure 2-3. CC2674R10 Schematic

VDDS, VDDS2, and VDDS3 are the main power supplies for the chip, IO and internal DC/DC converter, and all of these components must be at the same potential. These points are powered by the 1.8V supply from TPS628437. VDDR and VDDR_RF and internal supplies must be powered from the internal DC/DC converter or the internal LDO. Because the power supply is 1.8V, internal DC/DC is less efficient than the global LDO. For that configuration, the DCDC_SW pin is disconnected and VDDS_DCDC is directly connected to the VDDS. The global LDO is connected internally to the VDDR pin, which must be connected externally to the VDDR_RF pin. A µF-sized capacitor (C6) is necessary for decoupling. Also, TI recommends adding capacitors (C7, C7) close to the VDDR and VDDR_RF pins. The decoupling capacitor (C12) is required to connect with DCOUPL pin for internal regulated digital-supply.

Figure 2-4 is the schematic of the decoupling for VDDS. The 1.8V power supply is derived from the TPS628437 buck converter. A ferrite bead (L1) is designed for filtering the high-frequency noise in the power line. The CC2674 decoupling capacitors for the power supplies are C1, C2, C3, C4, and C5. Place these capacitors close to the corresponding pins.

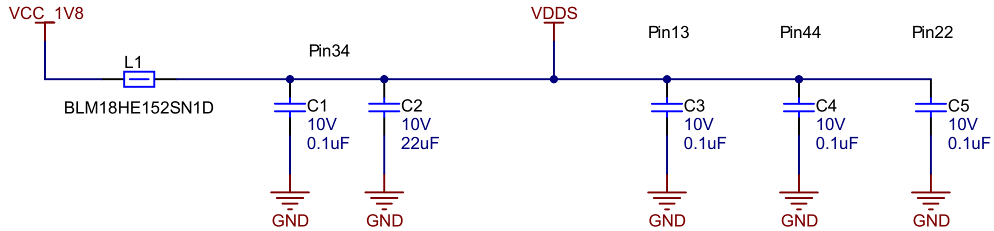


Figure 2-4. Decoupling for VDDS Schematic

Figure 2-5 shows the schematic of the 2.4G antenna path for CC2674. RF_P and RF_N are used as a differential RF interface. The onboard balun network is designed for the RF frond end. The LC filter L3, C14, L4, and C18 are placed between the balun and the antenna for harmonics attenuation and impedance transformation. A meandered Inverted-F Antenna (MIFA) is implemented in this design, since the MIFA is the smallest available onboard 2.4G design. See more design guidance in the *CC13xx/CC26xx Hardware Configuration and PCB Design Considerations* application note. Developers can select chip antenna to further minimize the PCB size.

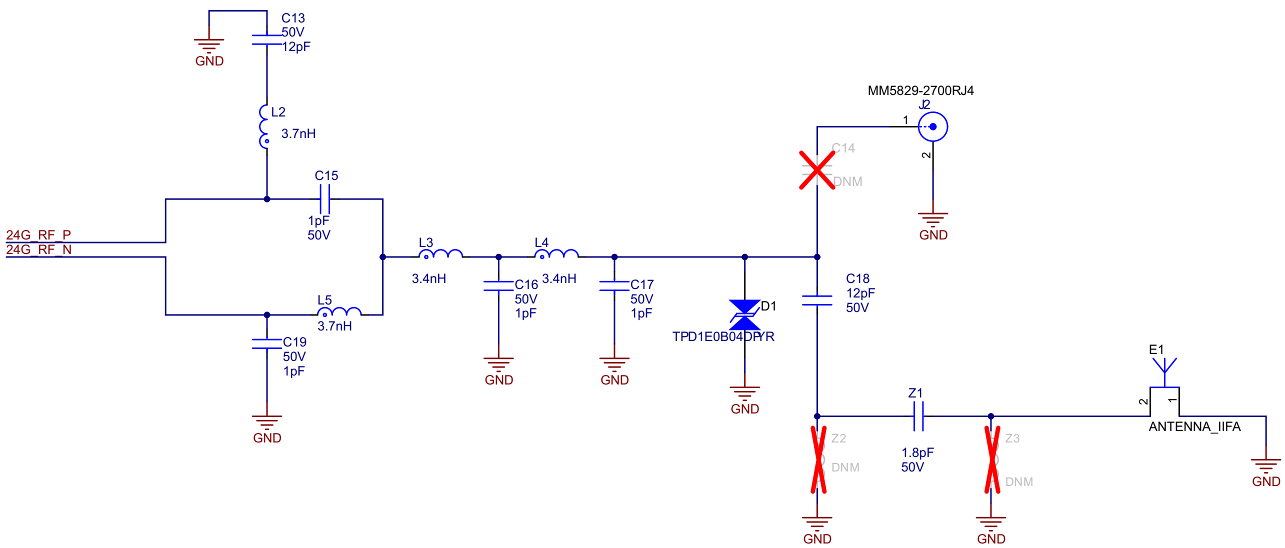


Figure 2-5. 2.4G Antenna Design Schematic

To program the CC2674, the JTAG interface is used for flash programming and debug access. Figure 2-6 shows the connections between the JTAG header and CC2674.

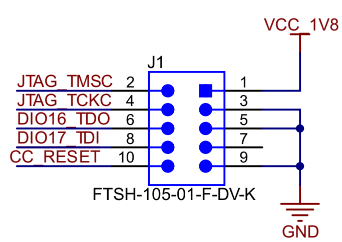


Figure 2-6. JTAG Connection for Programming

2.2.3 ECG and Respiration Lead Configuration

The AFE4960 is a low power, fully-integrated sensor interface design for ECG measurement and respiration detection. The device can be configured as either a 2-channel ECG receiver or as a 1-channel ECG receiver and a respiration impedance channel. In this patch design, 3-electrode configuration is taken for the single-lead ECG measurement and respiration detection. Figure 2-7 shows the electrode configuration on the sensor board.

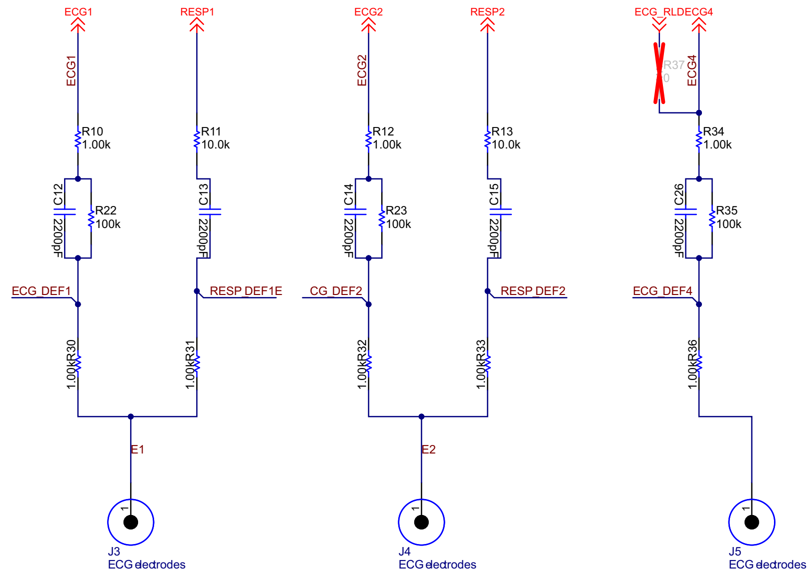


Figure 2-7. ECG and Respiration Measurement Interface

Figure 2-7 shows the configuration of 2-point respiration with ECG. ECG1, ECG2, and ECG_RLD pins are used to configure the single-lead ECG measurement with 3 electrodes. The ECG signal is acquired by measuring the electrical potential difference between Right Arm (RA) and Left Arm (LA), which can be assigned on ECG1 and ECG2. For the right leg drive, either the ECG_RLD pin or any of the ECGx pins can be set for DC bias voltage. In this design, ECG4 is routed for the RLD drive according to the data sheet recommendation. The respiration pins, RESP1 and RESP2, share the same pins with ECG to support 1-channel ECG + Respiration impedance in this design. The resistors (R30, R31, R32, R33, R36 in Figure 2-7) and the TVS diodes (D5, D6, D7, D8, D9 in Figure 2-8) comprise the protection network against high energy events. The protection resistors are shared between the excitation and sense paths of the respiration. The components R11, C13, R13, and C15 determine the excitation current for the respiration impedance drive. R10, R22, R12, C12, R23, R34, C14, R35, and C16 are designed for the DC fault protection. The value of each component takes the reference from the AFE4960 data sheet.

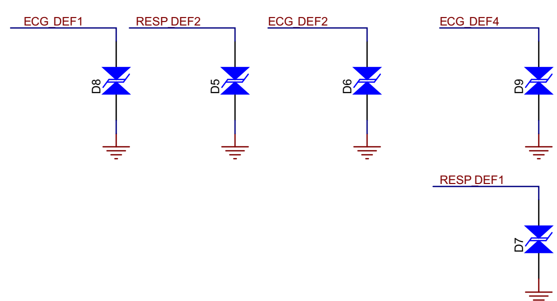


Figure 2-8. ESD Protection for the Electrodes

Table 2-2 shows the TIDA-010270 design parameters.

Table 2-2. Design Parameter

PARAMETER	VALUE
Number of ECG sense electrodes	2 (RA, LA)
Number of Right leg drive electrodes	1 (RLD)
Number of ECG channels	1
Number of Respiration channels	1
Number of Pace detect channels	1

The AFE4960 integrates a switch matrix at the ECG inputs and Respiration input/outputs. The device makes the chip fully flexible to connect any of the ECGx and RESPx pins to Channel 1 or Channel 2. Table 2-3 shows the pin mappings to the channel inputs and RLD drive.

Table 2-3. Pins Mappings of the ECG Input Channels

ECG AND RESPIRATION PIN	CONNECTION TO CHANNEL	ELECTRODE ASSIGMENT
ECG1	Channel 1 Positive input	LA
ECG2	Channel 1 Negative input	RA
ECG3	Not used	Not assigned
ECG4	ECG RL drive	RLD
ECG_RLD	Not used	Not assigned
RESP1	BIOZ_OUTP	LA
RESP2	BIOZ_OUTM	RA
RESP3	Not used	Not assigned
RESP4	Not used	Not assigned

2.2.4 Temperature Sensor

The TMP119 is a high-precision digital temperature sensor. The TMP119 provides a 16-bit temperature result with a resolution of 0.0078°C and an accuracy of up to ±0.08°C across the temperature range of 0°C to 45°C with no calibration. In this design, the device is configured to interface with the Bluetooth® Low Energy controller by I2C for the body temperature measurement. Figure 2-9 shows the TMP119 schematic. ADD0 is connected to the ground directly, which sets the address to 0x48.

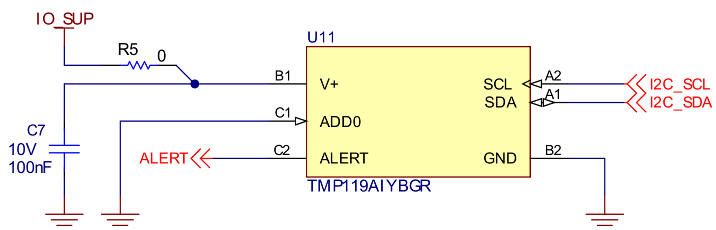


Figure 2-9. TMP119 Schematic

2.2.5 Selecting Power Supplies

Table 2-4 summarizes the power rails needed in this design.

Note

For the patch reference design, 1.8V is selected to support all the power rails. While in the Holter reference design, both 1.8V and 3.3V are necessary to power the AFE1594.

Table 2-4. Recommended Operation Voltage

DEVICE	POWER SUPPLY	MIN	MAX	UINT
AFE4960	RX_SUP Receiver supply	1.7	1.9	V
	IO_SUP I/O supply	1.7	1.9	V
CC2674R10	Operating supply voltage (VDDS)	1.8	3.8	V
TMP119	V+, T_A = –55°C to 70°C	1.7	5.5	V
IIS2DLPCTR	Voltage supply	1.62	3.6	V

The Coin-cell battery (3V) and AAA battery (1.5V) are the most commonly-used batteries for patches and Holter monitors in the market. Since all the power supplies in the patch are 1.8V, a boost converter or a buck converter can be implemented according to the battery type, which can improve the efficiency of the system. To support both batteries and the AFE1594 3.3V supply, the TPS61299 boost converter and TPS628437 buck converter are designed in series to boost the voltage to 3.3V first, and then step the voltage down to 1.8V.

2.2.6 Power Supplies

Table 2-5 shows the 3.3V power rail design requirement which is used for the AFE1594 AVDD supply.

Table 2-5. 3.3V Power Supply Specification

PARAMETER	VALUE
Input voltage	0.9V–1.5V or 2.0V–3V
Output voltage	3.3V
Output current	50mA
Output voltage ripple	50mV

The TPS61299x is a synchronous boost converter with 100nA ultra-low quiescent current. The device has a wide input voltage range from 0.5V to 5.5V and output voltage range from 1.8V to 5.5V. Due to the high efficiency under light load, the TPS61299x achieves a long operation time using coin-cell batteries for portable devices. Figure 2-10 shows the TPS61299 schematic design.

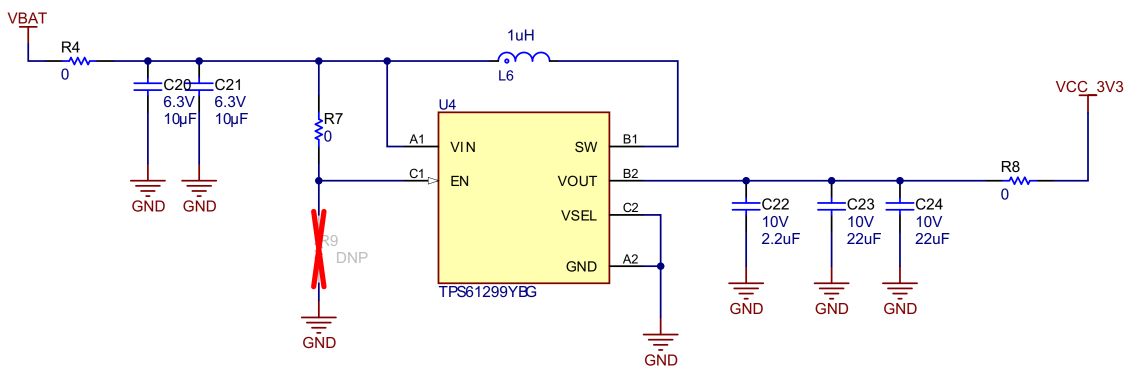


Figure 2-10. TPS61299 Schematic

The TPS61299 supports 21 internal output voltage setting options by connecting a resistor between the VSEL pin and ground. The device checks the configuration conditions of the VSEL pin when the output voltage approaches 1.8V. For the proper operation, the setting resistance accuracy must be 1%. For the 3.3V output, VSEL is connected to the ground.

The TPS61299 does not have fixed frequency and the device keeps the inductor ripple current constant in the range of 350mA, so the frequency is determined by the operation condition.

The maximum output capability of the TPS61299 is determined by the input-to-output ratio and the current limit of the boost converter. The maximum output current can be estimated using Equation 1.

$$I_{OUT(max)} = \frac{V_{IN} I_{LIM}}{V_{OUT}} \eta \quad (1)$$

where

- I_{LIM} is the average switch current limit
- η is the conversion efficiency, 89%–94.8% as ramping from 2V to 3V, use 89% for estimation

In this design, $I_{OUT(max)}$ = 0.97A ($I_{OUT(IN)}$ = 3V, I_{LIM} = 1.2A, V_{OUT} = 3.3V, and η = 89%).

For the inductor selection, TPS61299 is designed to work with an inductor value of 1µH (L6). Table 2-6 shows the recommended TPS61299 inductors from the *TPS61299x/xA 95nA Quiescent Current, 5.5V Boost Converter with Input Current Limit and Fast Transient Performance* data sheet.

Table 2-6. TPS61299 Recommended Inductors

PART NUMBER	L (µH)	DCR MAX (mΩ)	SATURATION CURRENT (A)	SIZE (L × W × H)
HTTH16080H-1R0MSR-99	1	110	2.3	1.6 × 0.8 × 0.8
WIP252010P-1R0ML	1	54	3.5	2.5 x 2.0 x 1.0
WPN252010H1R0MT	1	76	3.5	2.5 x 2.0 x 1.0

For the output capacitor selection, TI recommends using the X5R or X7R ceramic output capacitor in the range of 4µF to 1000µF effective capacitance to meet the requirements for output ripple and loop stability. If the output capacitor is below the range, the boost regulator can potentially become unstable. Increasing the output capacitor makes the output ripple voltage smaller in PWM mode. Consider the margin on the voltage rating to make sure there is adequate capacitance at the required output voltage, avoiding the derating of a ceramic capacitor under DC bias voltage, aging, and AC signal. Three 10µF capacitors: C22, C23, and C24 are in parallel as the output voltage to filter the output voltage. These capacitors must be placed as close as possible to the V_{OUT} and GND pins of the IC.

For the input decoupling capacitors, multilayer X5R or X7R ceramic capacitors are excellent choices as these capacitors have extremely low ESR and are available in small footprints. Input capacitors must be located as close as possible to the device. While a 10µF input capacitor is sufficient for most applications, larger values can be used to reduce input current ripple without limitations. C20 and C21 are the 10µF capacitors to minimize the input voltage ripple, suppresses input voltage spikes, and provide a stable system rail for the device.

Table 2-7 shows the 1.8V power rail design requirement for the patch and Holter monitor. For different batteries (AAA: 1.5V, Coin cell: 3V), a buck-boost regulator is an excellent choice. The discharge of the AAA battery can bring risk to the system, since the minimum input voltage of a buck-boost regulator needs to be higher than 1.3V. To simplify the design, a buck converter is selected for the 1.8V power rail. But this topology decreases the power efficiency. For the fixed battery design, selecting a boost converter or a buck converter circuit increases the overall efficiency.

Table 2-7. Specification of the 1.8V Power Supply

PARAMETER	VALUE
Input voltage	3.3V
Output voltage	1.8V
Output current	50mA
Output voltage ripple	50mV

The TPS62843 is a high-efficiency step-down converter family with ultra-low operating quiescent current of typically 275nA. The device supports the input voltage range from 1.8V to 5.5V and the output voltage range from 0.4V to 3.6V. There are 18 pre-defined output voltages that can be selected by connecting a resistor to the VSET pin. Given that the output voltage is 1.8V, TPS628437 is selected in this design which provides the output voltage from 0.8V–1.8V. Figure 2-11 shows the TPS628437 schematic in TIDA-010270.

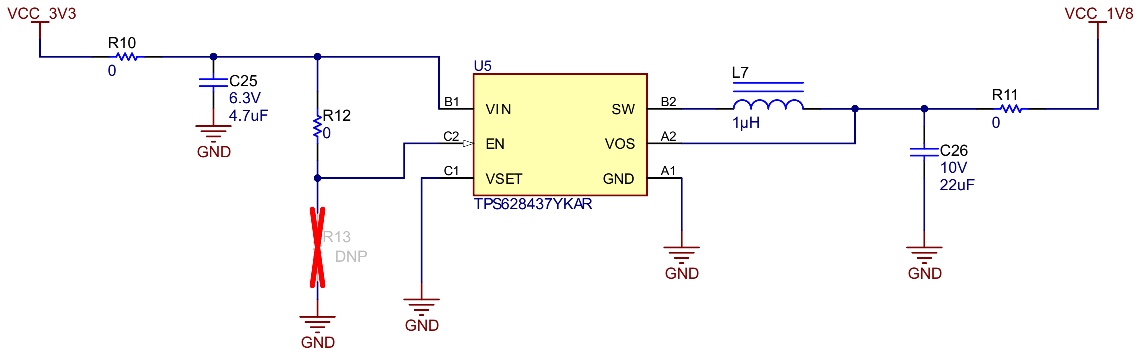


Figure 2-11. TPS628437 Schematic

The TPS628437 output voltage is set with a single external resistor connected between the VSET pin and GND. The internal resistor-to-digital conversion detects the external resistor, Rset, within the start-up delay time to set the correct output voltage. TI recommends using the resistor with 1% accuracy. According to the *TPS62843 1.8V to 5.5V, 600mA, 275nA I_Q, Small-Size Step-Down Converters* data sheet, connecting the VSET pin to ground sets the output voltage to 1.8V.

The TPS628437 is optimized for a tiny 1µH inductor over the entire recommended operation range to provide one of the smallest chips and smallest design-sizes in the industry. The device operates with a typical switching frequency of 1.5MHz and extends a high efficiency at light-load down to 100µA load current and below.

For the input capacitors, a 4.7µF capacitor is recommended in the data sheet to reduce the input voltage ripple. The output capacitor is suggested to be in the range from 4µF to 25µF. The total output capacitance must remain within the recommended range in the data sheet for proper operation. A larger capacitor can reduce the output voltage ripple and improve the load transient response. In this reference design, C25 (4.7µF), C26 (22µF), and L7 (1µH) are selected for the system.

TI provides the customer with the online WEBENCH® simulation to simplify the power design. See also the TPS62843 product page.

2.2.7 LED Indicator

To indicate the different status of the ECG leads, a LED indicator is designed as an indicator. The LED (D2) is powered by 3.3V with a current limit resistor R15. The indicator is controlled by the MCU with external MOSFET (Q1). Figure 2-12 shows the LED indicator schematic.

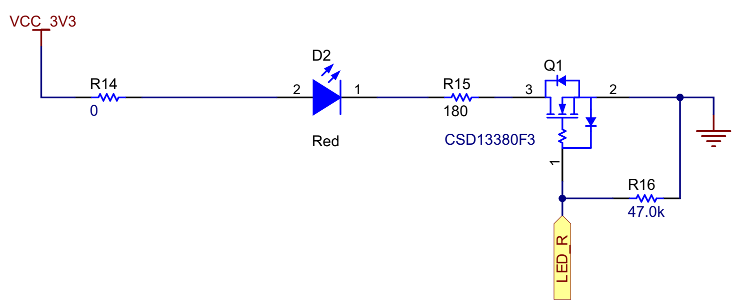


Figure 2-12. LED Indicator Schematic

2.3 Highlighted Products

2.3.1 AFE4960

The AFE4960 can be configured as either a 2-channel ECG receiver or as a 1-channel ECG receiver and a respiration impedance channel. The AFE signal chains can interface in a flexible manner to up to 4 electrodes. A Right Leg Drive (RLD) amplifier output, can be used to set the body bias. The AFE has DC lead biasing for lead on or lead off detection, and AC lead biasing for measuring the lead impedance. Pacemaker pulse detection is supported on one channel.

All the signal chain outputs are converted by a single ADC in well-defined time slots and stored as 24-bit words in a 128-sample FIFO which can be read out using a SPI or an I^2C interface.

The AFE4960 is a fully-integrated design to realize a 3-lead ECG system. Synchronized operation of two AFEs in parallel can be used to realize a 5-lead ECG.

2.3.2 CC2674R10

The SimpleLink™ CC2674R10 device is a multiprotocol and multiband Sub-1GHz and 2.4GHz wireless microcontroller (MCU) supporting Thread, ZigBee, Bluetooth® Low Energy 5.3, IEEE 802.15.4g, IPv6-enabled smart objects (6LoWPAN), mioty, Wi-SUN, Amazon Sidewalk, proprietary systems, including the TI 15.4-Stack (Sub-1GHz and 2.4GHz), and concurrent multiprotocol through a Dynamic Multiprotocol Manager (DMM) driver. The device is optimized for low-power wireless communications, with advanced security features and on-chip over-the-air (OAD) update capability. The device enables long range and reliable communication in building security systems, HVAC, smart meters, medical, wired networking, portable electronics, home theater & entertainment, and connected peripherals markets.

The CC2674R10 device is part of the SimpleLink™ MCU platform, which consists of Wi-Fi®, Bluetooth® Low Energy, Thread, ZigBee®, Sub-1GHz MCUs, and host MCUs that all share a common, easy-to-use development environment with a single core software development kit (SDK) and rich tool set. A one-time integration of the SimpleLink™ platform enables addition of any combination of the devices in a portfolio into a design, allowing 100 percent code reuse when the design requirements change. See also the *SimpleLink MCU platform*.

In addition to the software compatibility within the multiband wireless MCUs, there is pin-to-pin compatibility from 352kB of flash up to 1MB of flash in the 7mm × 7mm QFN package for maximum design scalability. See also *Sub-1GHz products*.

2.3.3 TMP119

The TMP119 is a high-precision digital temperature sensor. The device is designed to help meet ASTM E1112 and ISO 80601 accuracy requirements for electronic patient thermometers. The TMP119 provides a 16-bit temperature result with a resolution of 0.0078°C and an accuracy of up to ±0.08°C across the temperature range of 0°C to 45°C with no calibration. The TMP119 has an interface that is I2C- and SMBus™-compatible, programmable alert functionality, and the device can support up to four devices on a single bus. Integrated EEPROM is included for device programming with an additional 48-bits memory available for general use. The TMP119 operates from 1.7V to 5.5V and typically consumes 3.5µA for a 1Hz conversion cycle.

For non-medical applications, the TMP119 can serve as a single chip digital alternative to a Platinum RTD. The TMP119 has an accuracy comparable to a Class AA RTD, while only using a fraction of the power of the power typically needed for a PT100 RTD. The TMP119 simplifies the design effort by removing many of the complexities of RTDs such as precision references, matched traces, complicated algorithms, and calibration. The device is designed to be strain tolerant, allowing robustness over typical strains often seen in PCB manufacturing, including device soldering, molding, underfill, and board flexing.

The TMP119 units are 100% tested on a production setup that is NIST traceable and verified with equipment that is calibrated to ISO-IEC 17025 accredited standards.

2.3.4 TPD1E01B04

The TPD1E01B04 is a bidirectional TVS ESD protection diode array for USB Type-C® and Thunderbolt 3 circuit protection. The TPD1E01B04 is rated to dissipate ESD strikes at the maximum level specified in the IEC 61000-4-2 international standard (Level 4).

This device features a 0.18- to 0.20pF (typical) IO capacitance making the TPD1E01B04 an excellent choice for protecting high-speed interfaces up to 20Gbps such as USB 3.1 Gen2 and Thunderbolt 3. The low dynamic resistance and low clamping voltage provide system-level protection against transient events.

The TPD1E01B04 is offered in the industry standard 0201 (DPL) package and 0402 (DPY) packages.

2.3.5 TPS628437

The TPS62843 is a high-efficiency, step-down converter family with ultra-low operating quiescent current of typically 275nA. The device features a 4nA shutdown (typical) current when disabled.

The device uses DCS-Control with a low and RF friendly output voltage ripple to power radios.

The device operates with a typical switching frequency of 1.5MHz and extends a high efficiency at light-load down to 100µA load current and below.

3 × 18 pre-defined output voltages can be selected by connecting a resistor to the VSET pin, making the family usable across various applications with a minimum set of passive components.

2.3.6 TPS61299

The TPS61299 is a synchronous boost converter with 95nA ultra-low quiescent current and average input current limit. The device provides a power design for portable equipment with alkaline battery and coin cell battery. This device has high efficiency under light-load condition to achieve long operation time and average input current limit can avoid battery discharging with high current.

The TPS61299 has wide input voltage range from 0.5V to 5.5V and output voltage range from 1.8V to 5.5V. The device has different versions for average input current limit from 5mA to 1.9A. The TPS61299 with 1.2A current limit can support up to 500mA output current from 3V to 5V conversion and achieve approximately 94% efficiency at 200mA load.

The TPS61299 has optional fast-load transient performance at output voltage is 4.5V, 5V or 5.5V. In fast-load transient, the typical setting time is 8µs when output current transient from 0A to 200mA.

The TPS61299 supports true shutdown function when disabled.

The TPS61299 offers a very small design size with a 6-ball 1.2mm × 0.8mm WCSP package and a 6-pin 1.6mm × 1.6mm SOT563 package.

2.4 Battery Life Calculations

This section introduces the calculations for battery life of the 2 × CR2032 coin-cell battery. The main power consumption is from AFE4960 and CC2674R10 while the temperature sensor and accelerator contribute less in this design. Therefore, the main paths are as follows:

- Battery to AFE4960, biosensing analog front end
- Battery to CC2674R10, Bluetooth® Low Energy microcontroller

All the current paths above are powered by a 1.8V power rail, which is generated from the TPS61299 and TPS628437 devices.

2.4.1 AFE4960 Current Consumption

The AFE4960 has separate signal chains to support the acquisition of ECG, bio-impedance and pace pulse. The power consumption of AFE4960 is mainly depending on the frequency of the repeating acquisition cycle (RAC) and the signal acquisition mode. There are three modes (ECG Only, ECG + Pace, and ECG + Respiration + Pace) that users can choose depending on the application. Figure 2-13 shows the RX_SUP current vs RAC frequency across different signal acquisition modes and RAC frequency. Typical specifications are at T_A = 25°C, RX_SUP = IO_SUP = 1.8V, and 32.768kHz input clock.

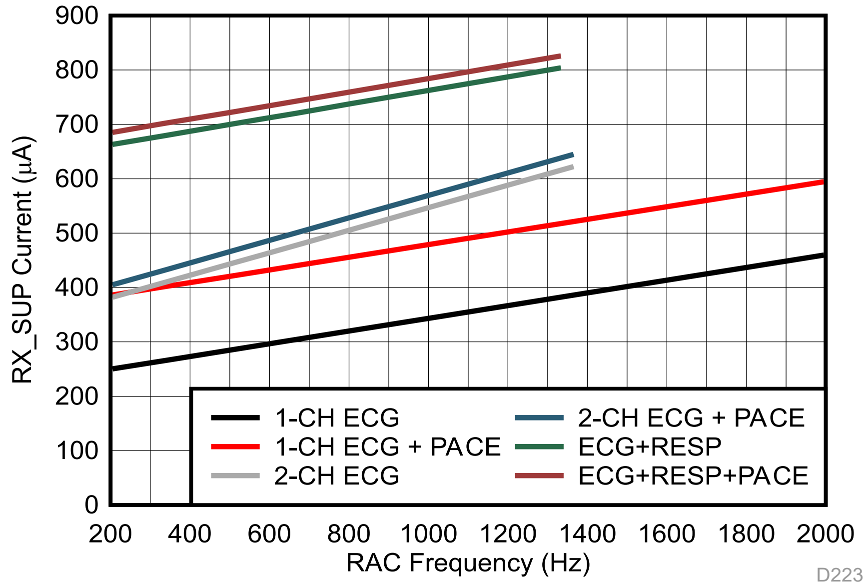


Figure 2-13. RX_SUP Current vs RAC Frequency Across Different Signal Acquisition Modes

Generally, a 256Hz, 512Hz sample rate is sufficient for most applications. From the plot, the chip consumes less with ECG modes under low RAC frequency, which is about 290µA (1-CH ECG) and 420µA (2-CH ECG) with 500Hz. ECG + Respiration + Pace mode is about 720µA under 500Hz. Therefore, the power and sample rate can be traded depending on the application requirement.

In this design, the frequency of RAC is set to be 1.33kHz for high performance. According to the Figure 2-13, the estimated current consumption is to be 820µA. Giving the IO_SUP current consumption (not mentioned in the data sheet) and the buffer, the total consumption of the AFE4960 is taken to be 900µA.

2.4.2 CC2674R10 Current Consumption

The power consumption of CC2674R10 consists of the core current consumption, the peripheral current consumption and the radio current. Find the specifications in the *power consumption - power modes* topic of the *CC2674R10 SimpleLink™ High-Performance Multiprotocol 2.4GHz Wireless MCU* data sheet. Additionally, the power supply, connection interval and the data length per transition influences the total power consumption of the Bluetooth® Low Energy device during operation.

TI provides a Bluetooth power calculator tool for customers to calculate the power easily according to the design parameters in the system. Figure 2-14 shows the global settings of the calculator where the customer can set custom specifications in the system. For the TIDA-010270, the supply voltage is 1.8V. The connection interval is 30ms and the connection data length is 216 bytes, which are designed to notify all the ECG data with CC2674R10.

Supply Voltage	1.8	
Battery capacity [mAh]	220	
RF Configuration	Diff.	*
Output Power [dBm]	0	
Advertising Interval [ms]	100	
Advertising data length (legacy) [#bytes]	7	
Advertising data length (extended advertising) [#bytes]	7	
Connection Interval [ms]	45	
Connection data length [#bytes]	216	**
Scan Response data length [#bytes]	27	
Crystal used	external 32kHz	

Figure 2-14. Global Settings for Bluetooth® Low-Energy Consumption

When fixing the design parameter in the global settings, the estimated current consumption is calculated automatically according to the device role. The patch design is *Connected as Peripheral* in the Bluetooth® Low Energy network and the average current consumption is to be 830.0µA. Figure 2-15 shows the detailed calculation.

Connected as Peripheral

	State	Time [µs]	Current [mA]	Time * Current
1	Wake Up & Pre-processing	1283.89	5.17	6636.14
2	Preparation for Recieve	394.22	5.96	2349.25
3	Recieve (RX)	219.67	11.15	2448.95
4	RX to TX transition	109.22	8.68	948.29
5	Transmit (TX)	1731.56	12.23	21183.36
6	Post-Processing	853.44	4.37	3732.71
7		0.00	0.00	0.00
8		0.00	0.00	0.00
9		0.00	0.00	0.00
10		0.00	0.00	0.00
11		0.00	0.00	0.00
12		0.00	0.00	0.00
13		0.00	0.00	0.00
14		0.00	0.00	0.00
15		0.00	0.00	0.00
16		0.00	0.00	0.00
	Total time of connection event [us]	4592.01		
	Total time * current [us*mA]			37298.7
	Average Current draw during connection event [uA]			8122.5

Average current draw during connection:	**830.0**	uA
Expected battery life:	**265**	Hours
Expected battery life:	**11**	Days

Figure 2-15. Current Consumption of CC2674R10 as Peripheral

2.4.3 On-State Current Calculations

Considering the worst-case performance of the TMP119 (135µA) and the IIS2DLPC (120uA), the total average current consumption is calculated to be 1.98mA ($I_{AFE4960} + I_{CC2674} + I_{TMP119} + I_{Accelerator}$). The reflected current on the input side of the TPS628437 device is given in Equation 2. The efficiency is taken to be 95% according to the simulation from WEBENCH®.

$$I_{TPS628437} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times \eta} = \frac{1.8 \times 1.98}{3.3 \times 0.95} = 1.14mA \tag{2}$$

The reflected current on the input side of the TPS61299 device is calculated in Equation 3 with the efficiency of 94.8%.

$$I_{TPS61299} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times \eta} = \frac{3.3 \times 1.14}{3 \times 0.948} = 1.32mA \tag{3}$$

For 2 × CR2032 coin-cell battery, the calculated battery life is given in Equation 4.

$$Life(hrs) = \frac{2 \times 220mAh}{1.36mA} = 333hrs = 13Days21hrs \tag{4}$$

3 Hardware, Software, Testing Requirements, and Test Results

3.1 Hardware Requirements

3.1.1 Introduction for Bluetooth® Low Energy Board

Figure 3-1 shows the top view of the Bluetooth® Low Energy board from Altium Designer®. The important sections are highlighted in the red box. A JTAG connecter is reversed for CCS programming. There are two buttons designed for external interrupt which can be assigned for user instructions. Two receptacles are used for matching different sensor boards (Patch and Holter).

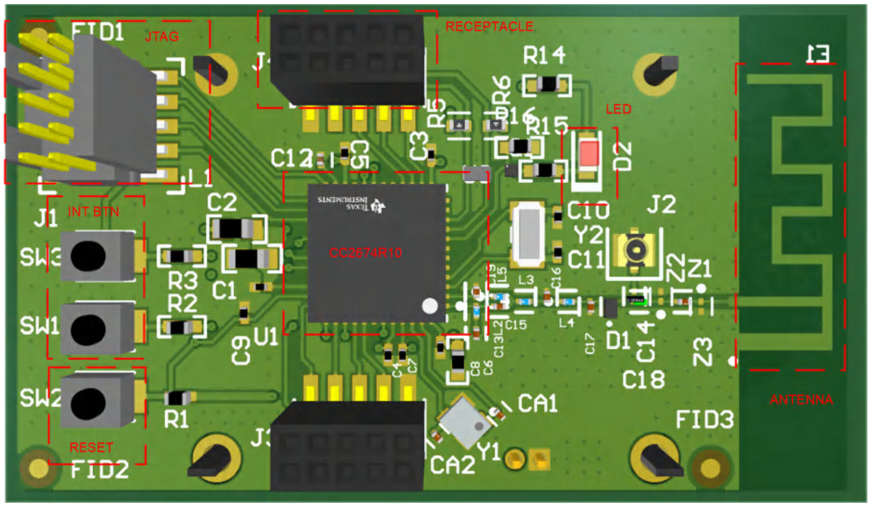


Figure 3-1. Top View of the Bluetooth® Low Energy Board

Figure 3-2 shows the bottom view of Bluetooth® Low Energy board. The coin-cell battery holders are removed to demonstrate the TPS61299 boost and TPS628437 buck converter. The AAA battery connecter is reversed for the connection.

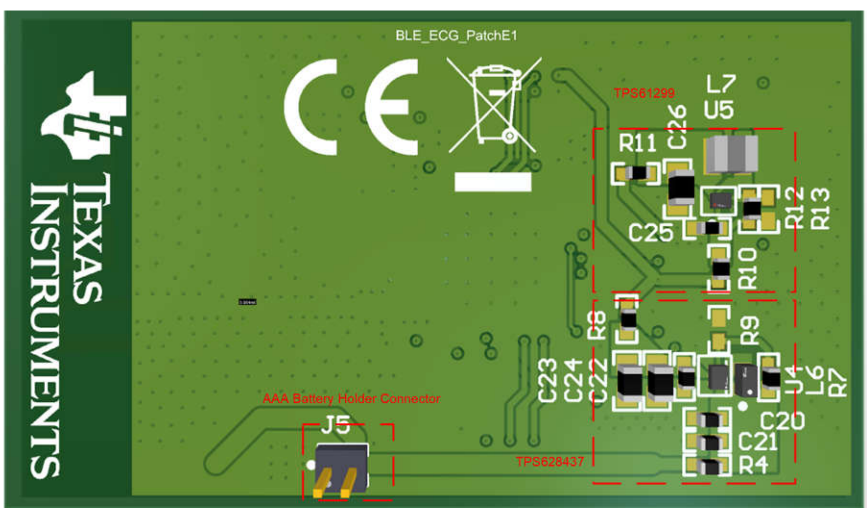


Figure 3-2. Bottom View of the Bluetooth® Low Energy Board Without Coin-Cell Battery Holders

Figure 3-3 is the bottom view of the Bluetooth® Low Energy with the CR2032 battery holders.

Figure 3-3. Bottom View of the Bluetooth® Low Energy Board With Coin-Cell Battery Holders

3.1.2 Sensor Board Introduction

Figure 3-4 shows the PCB assemble of the sensor board which contains the AFE4960, TMP119, and IIS2DLPCTR devices. There are three electrodes connecters on this board for LA, RA, and RLD. The headers can match the Bluetooth® Low Energy board flawlessly for the ECG measurement.

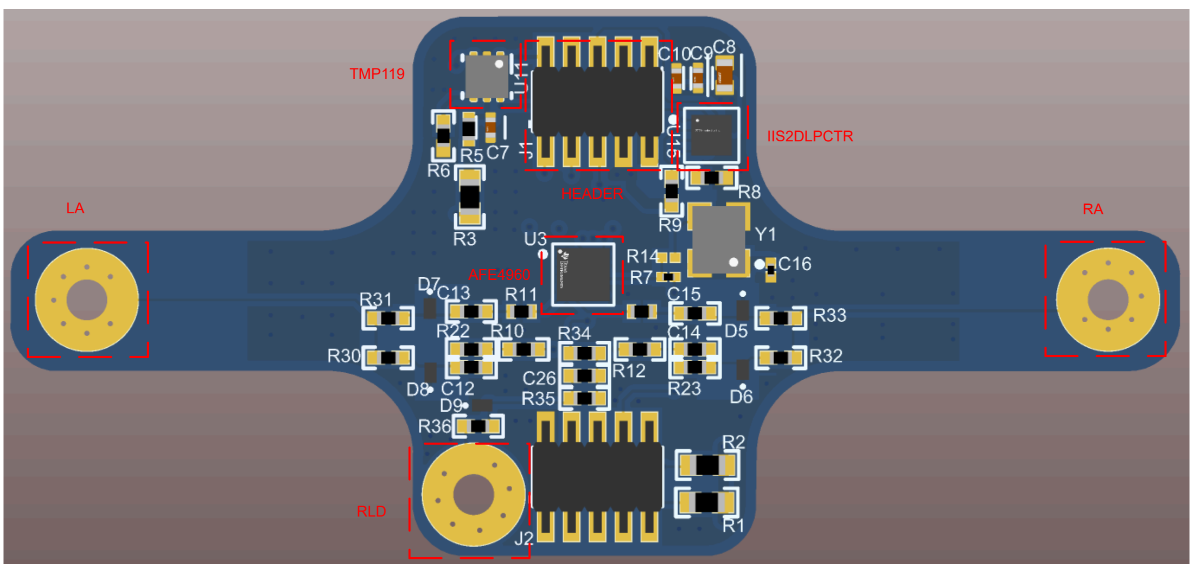


Figure 3-4. Sensor Board

Figure 3-5 shows the assembly of these two boards. Three electrodes pads are available for the connections of ECG leads.

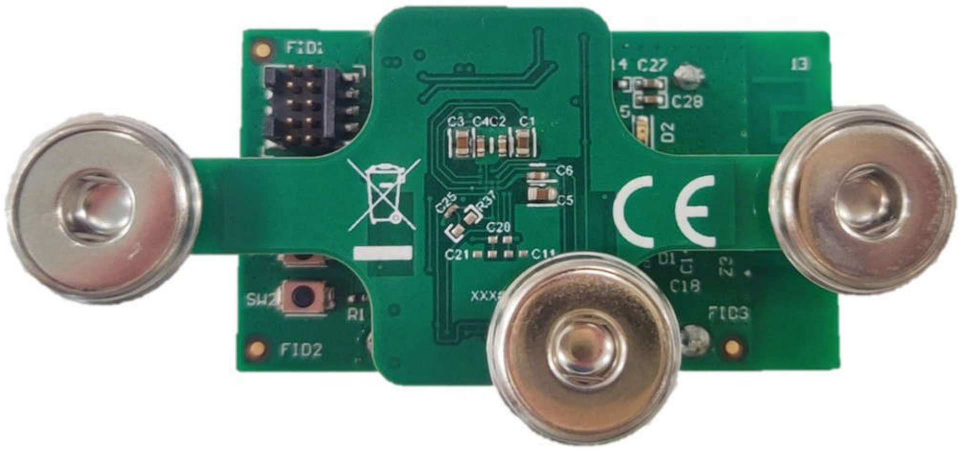


Figure 3-5. ECG Patch Assembly

3.1.3 Board Connection and XDS110 Interface

The LP-XDS110ET LaunchPad™ development kit debugger is a tool to program and debug Texas Instruments (TI) microcontrollers, microprocessors, and DSP XDS-compatible devices. The LP-XDS110ET was designed to connect directly to split LaunchPad development kits through the 20-pin edge connector or 10-pin XDS110 out connector. Figure 3-6 shows the LP-XDS110ET board.

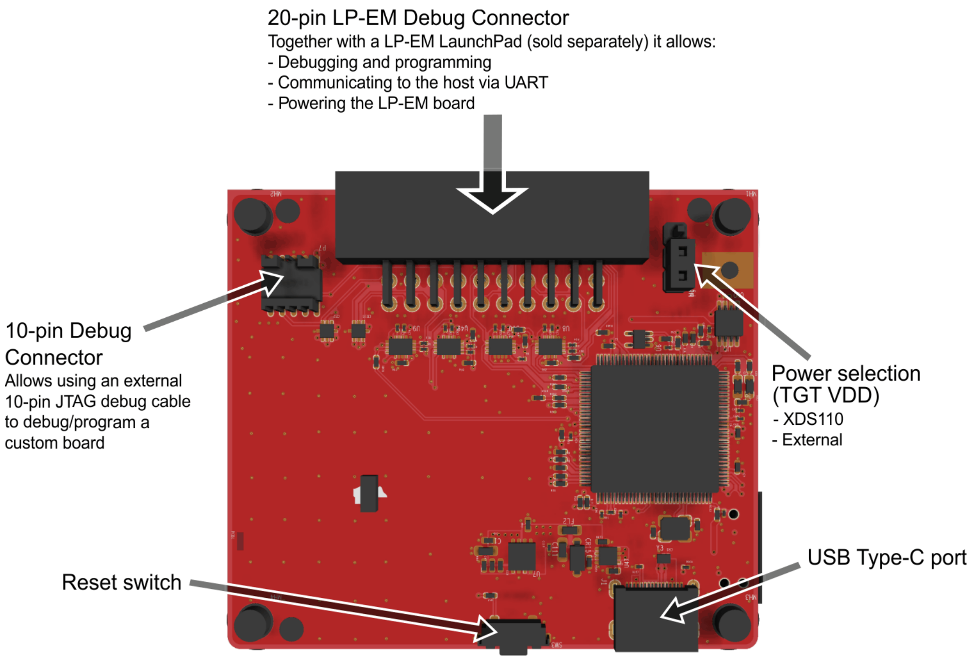


Figure 3-6. XDS110 Board

The patch reversed a JTAG connector which can be interfaced with the 10-pin debug connector of the LP-XDS110 board. Figure 3-7 shows the debug connection between the patch and the LP-XDS110.

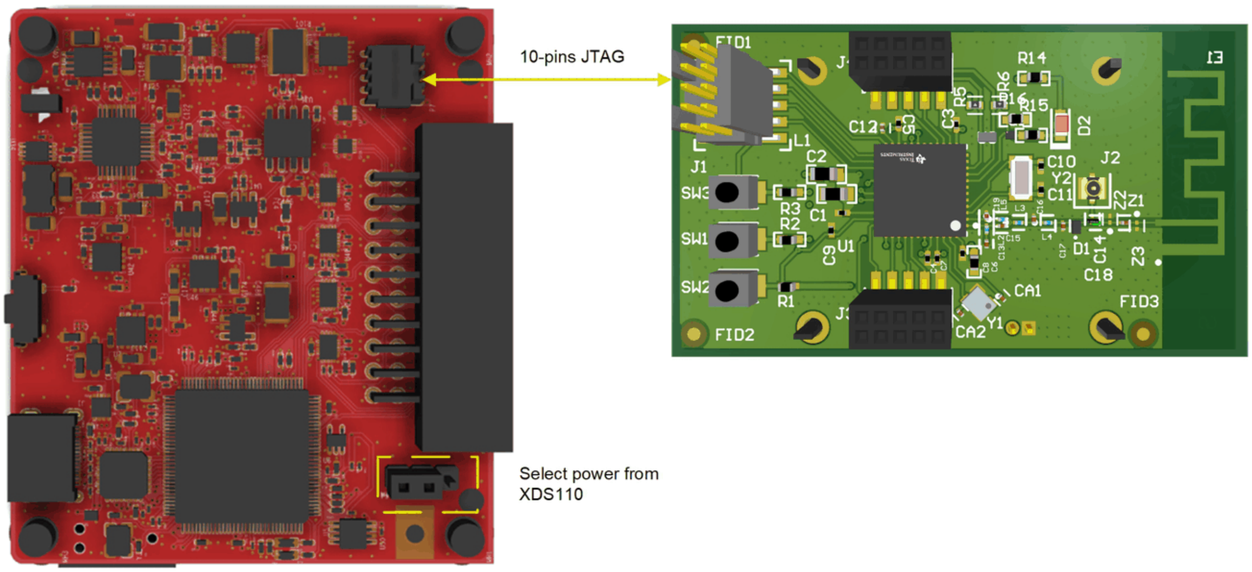


Figure 3-7. Connection Between the Patch and the LP-XDS110

There is a power selection jumper on the LP-XDS110 where the user can define the power source during the programming. If selecting *Power from XDS110*, that means there is already a power path provided by the JTAG connector. So, the battery is not allowed to connect with the patch during the programming in case of a conflict of the power. If selecting *Power from External*, the battery is needed for the Bluetooth® Low Energy board to power the whole system.

3.2 Software Requirements

TI provides both the program for Bluetooth® Low Energy operation using the CC2674R10 device and the simple demonstration software run under the Android™ platform (typically, the smartphone). This software gives the developers a basic overview for the ECG, respiration, pace pulse, temperature, and motion measurement.

3.2.1 Biosensing Demonstration Loading With Code Composer Studio™ (CCS) IDE

Download the design files from the TIDA-010270 reference design page. Extract all the files from `ECG_Patch_Design_File` and compile the Biosensing Patch demonstration in CCS (do not use a version earlier than version 12.4.0). Connect the Bluetooth® Low Energy board and the LP-XDS110 through the 10-pin JTAG and flash the software. Figure 3-8 shows the connection.

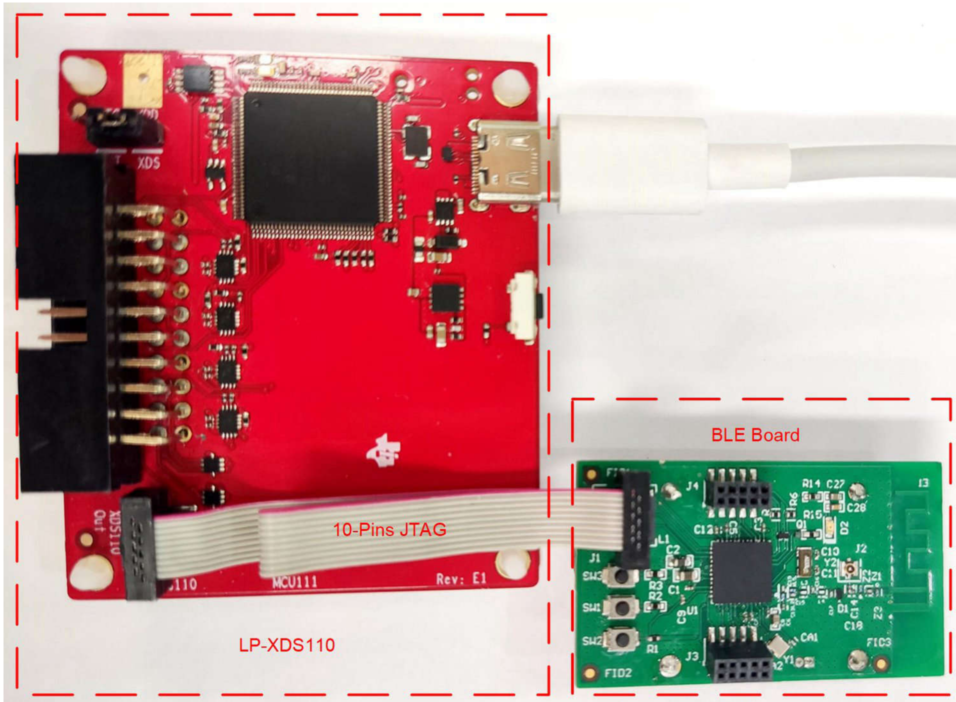


Figure 3-8. Flashing the Biosensing Example

3.2.2 SimpleLink™ MCU Connect

To demonstrate the multi-sensors measurement result of the patch, smartphone software is provided for developers. The `Android APK` file is found in the design file. Figure 3-9 shows the Biosensing Application after the installation.

Figure 3-9. SimpleLink ™ MCU Connect for Biosensing Patch

Figure 3-10 shows the pages of the Biosensing Demonstration that run under the smartphone (Android Version 13.0). The application asks for the Bluetooth® Low Energy permission when running the software the first time. The software scans the nearby Bluetooth® Low Energy devices and displays all the available connections. Connect to the patch by clicking the *Biosensing_test* in the list and a sub-page scrolls up from the bottom to display the results of the temperature sensor and acceleration meter. The waveform of the ECG, respiration and pace pulse are shown in another window after clicking the corresponding service.

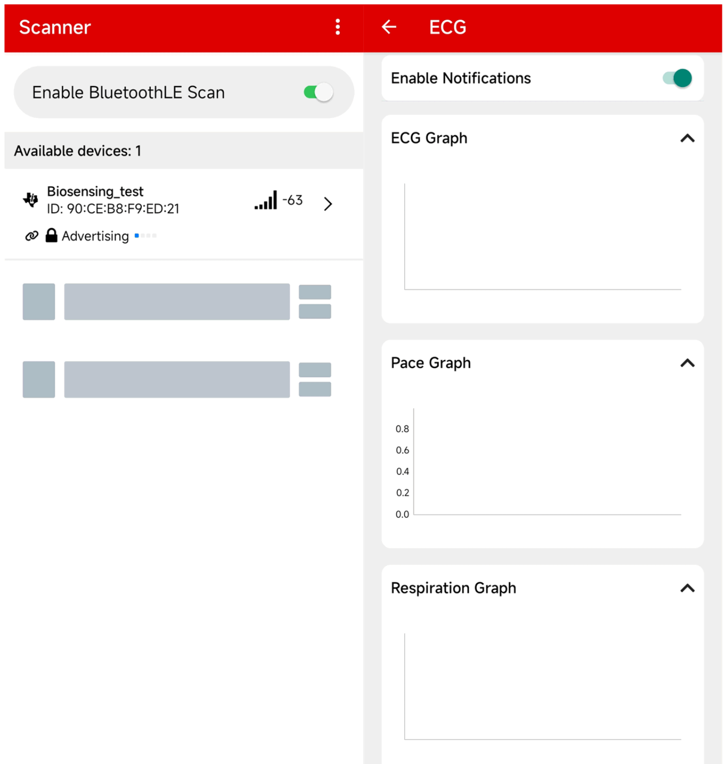


Figure 3-10. Biosensing Demonstration Connection Pages

3.2.3 AFE4960 Configuration

The AFE4960 device is configured to measure the one-channel ECG and one-channel respiration in this design. Follow the register settings in the *design example – 3-lead ECG* section of the AFE4960 data sheet (Contact TI).

Table 3-1 shows the custom configurations apart from the recommendations in the *design example – 3-lead ECG* section of the in AFE4960 data sheet.

Table 3-1. Custom Configuration for TIDA-010270 Testing

PARAMETER	REGISTER	VALUE (DEC)	SETTING | COMMENTS
Interrupt configuration	INT_MUX_ADC_RDY_1	2	FIFO_RDY interrupt on ADC_RDY pin
	EN_GPIO2_OUT	1	Single-pin interrupt on GPIO2 pin
	INT_MUX_GPIO2_2	1	
Watermark Level	REG_WM_FIFO	107	Set FIFO length to be 108
Interrupt on GPIO2	MASK_DC_LEAD_DET	0	Enable interrupt of DC lead-off detection on GPIO2
	MASK_ADC_FIFO_RDY	1	No ADC, FIFI ready interrupt
	MASK_PACE_VALID_INT	1	No pace valid interrupt
	MASK_AC_LEAD_ON	1	No AC lead off detection interrupt on GPIO2
	MASK_AC_LEAD_OFF	1	

3.2.4 Biosensing Demonstration Flow Chart for CC2674R10

Figure 3-11 shows the flow chart of the biosensing demonstration for CC2674R10. The program is based on TI Real Time Operation System (TIRTOS7). Thus, the microcontroller maintains several tasks and performs the task according to the priority level.

There are three tasks established in the biosensing demonstration program. `BLE_stack_task` is the basic function for Bluetooth® Low Energy setup, connection, transmitting and receiving data.

`Project_zero_task` is the custom task for the, Generic Access Profile (GAP), Generic Attribute Profile (GATT), and GATT Specification Supplement (GSS) configuration. Also, temperature sensor and accelerator are initialized in this task. A timer is set to read these two sensors every 1s and send the notification out.

`AFE4960_read_task` is programed to initialize the device and wait for the interrupt from the ADC_RDY pin and the GPIO2 pin. Once the FIFO_RDY interrupt occurs, CC2674R10 reads all the data out from the FIFO by SPI. To avoid the ECG data mismatching, the length of the data equals to the FIFO length set by the REG_WM_FIFO register. After the SPI read, the Bluetooth® Low Energy transmitting task is awakened to send the ECG data out by notification.

In this design, the FIFO length is set to be 108, which are 432 Bytes read out during 2 FIFO_RDY interrupts. Since the maximum transmission unit for Bluetooth® Low Energy 5.3 is 255bytes, the notification API is called twice to send all the data out. After sending the data, the AFE4960_read_task is blocked to wait for the next interrupt from FIFO_RDY.

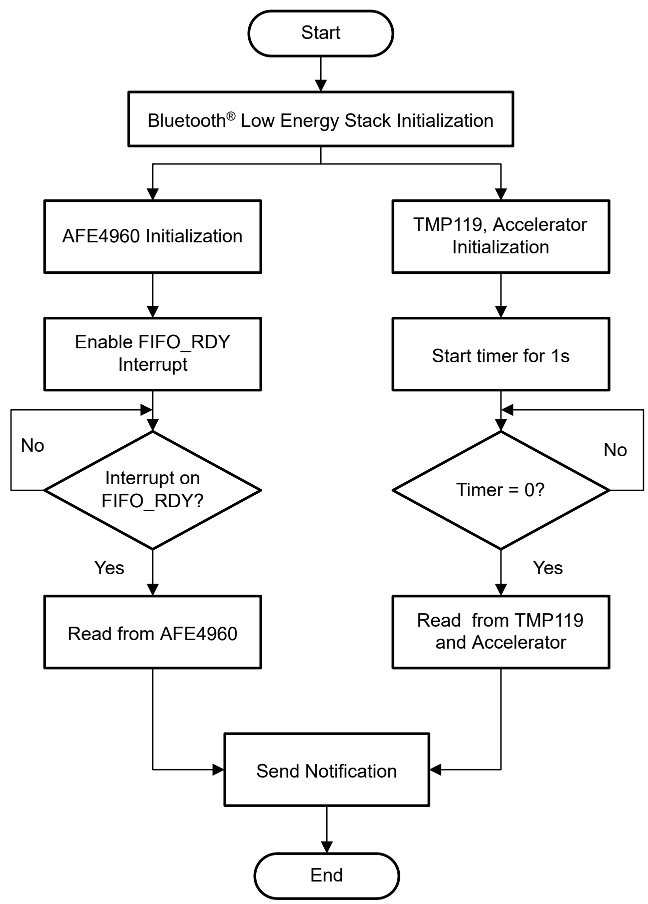


Figure 3-11. Biosensing Demonstration Flow Chart

3.3 Test Setup

This section describes the test setup for the TIDA-010270 board. Figure 3-12 shows the board connection between the Biosensing patch and ECG simulator.

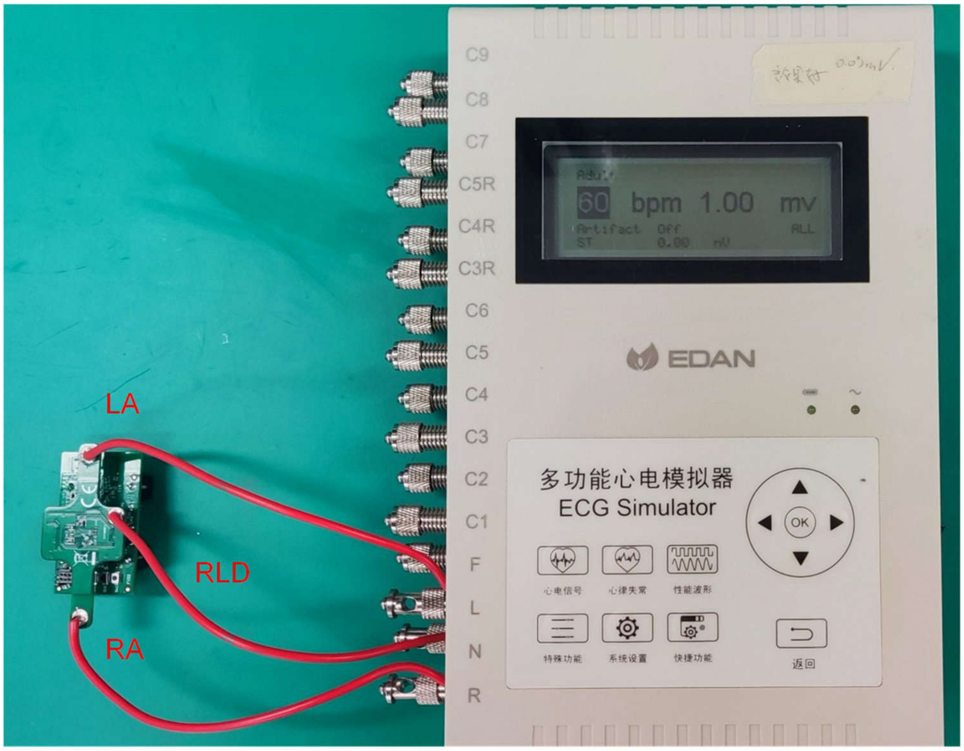


Figure 3-12. Hardware Setup for the Biosensing Board

Follow these steps when setting up the tests:

1. Compile the Biosensing Patch demonstration in CCS and flash the example to the Bluetooth® Low Energy board using 10-pin JTAG connector
2. Install the Biosensing Demonstration Application on the smartphone (Android platform)
3. Disconnect the JTAG from the LP_XDS110 and plug the AFE4960 sensor board on to the Bluetooth® Low Energy board
4. Insert the CR2032 coin-cell batteries and connect the RA, LA, and RLD electrodes to the corresponding pins of the ECG simulation
5. Run the Biosensing Demonstration and connect to the Biosensing Patch using Bluetooth® Low Energy

3.4 Test Results

This section describes the test results for the TIDA-010270 board. Figure 3-13 captures the ECG waveforms from the *Biosensing Demonstration App*. The simulator is configured to output ECG with 50 beats per minute (BPM). From the following demonstrations, the cardiac cycle is about 1.2s (time duration is 1.5s for the full screen). Thus, the calculated heart rate is to be 60 / 1.25 = 50 BPM, which is the configured output of the simulator.

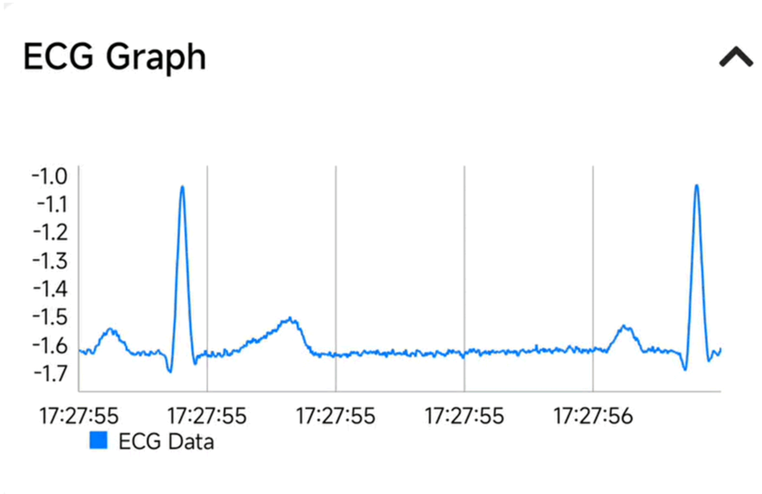


Figure 3-13. ECG Waveform (50BPM)

Figure 3-14 shows the ECG waveform with the setup of 100 BPM. The number of heart beats is doubled compared with 50 BPM.

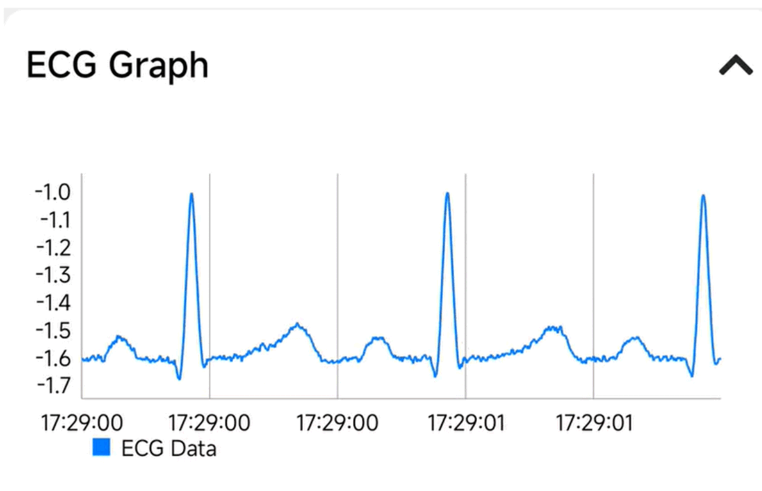


Figure 3-14. ECG Waveform (100 BPM)

Figure 3-15 and Figure 3-16 show the measurement of respiration from the simulator. The setup for Figure 3-15 is 10 respirations per minute (RPM). According to the waveform, there are 5 respiration cycles in 30 seconds which is 10 respirations in 1 minute.

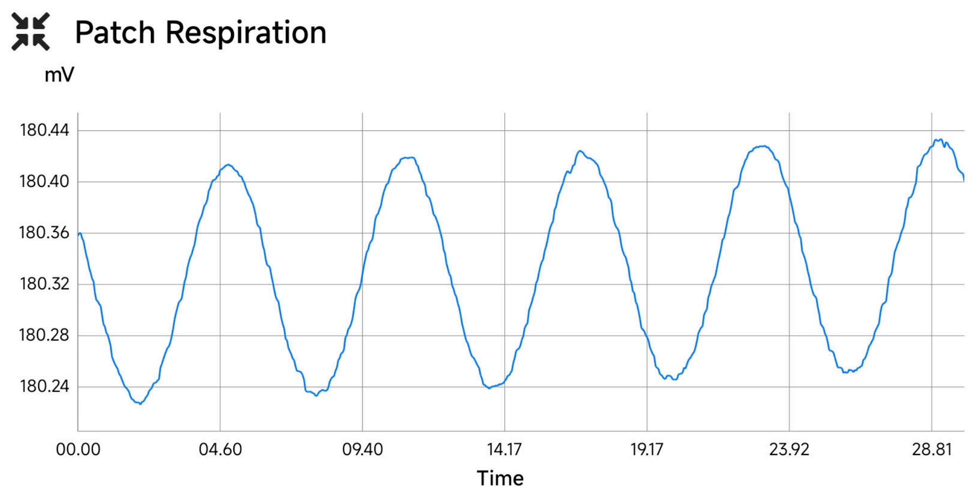


Figure 3-15. Respiration Waveform (10 RPM)

Figure 3-16 shows the respiration waveforms with the setup of 20 RPM.

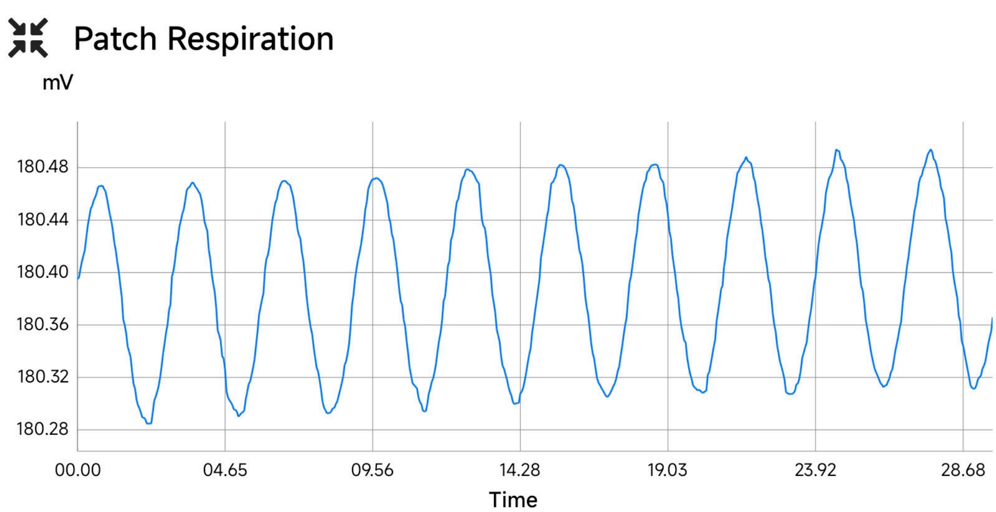


Figure 3-16. Respiration Waveform (20TPM)

AFE4960 integrates the pace pulse detection function and output as the Pace flag with the ECG data. Figure 3-17 shows the pace pulse waveforms acquired by the patch.

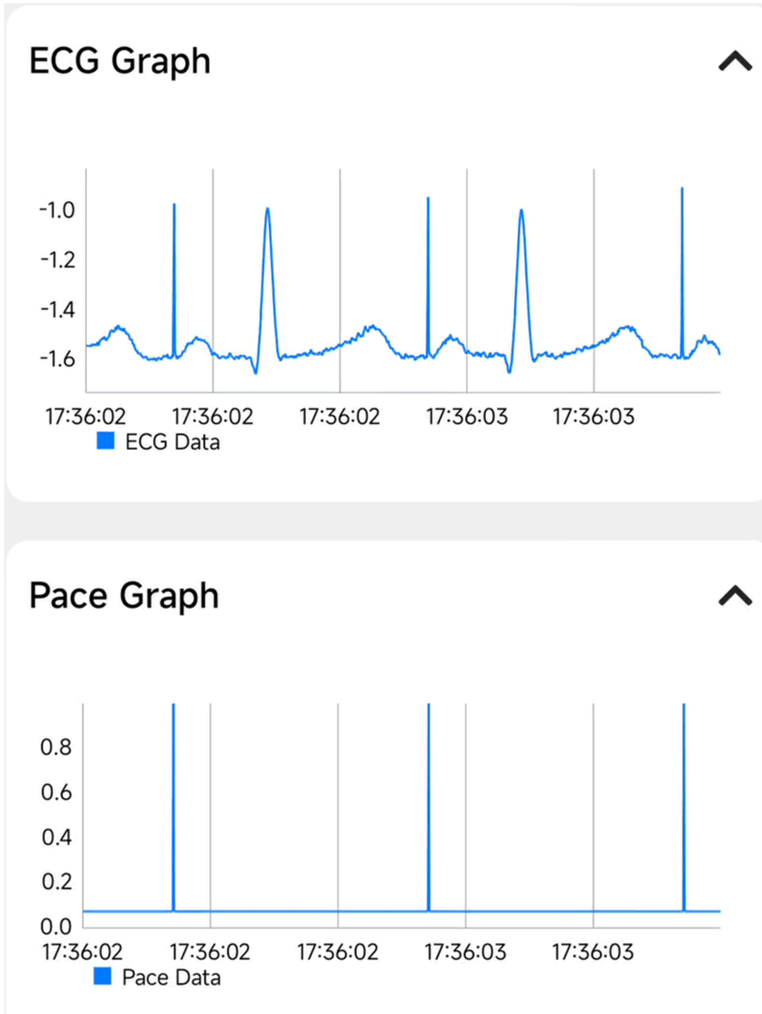


Figure 3-17. Pace Pulse Detection With 70 BPM

3.4.1 Real-Time ECG and Respiration Measurement

TIDA-010270 is designed to fit the ECG electrode with stud (2.6mm) for real-time ECG and respiration measurement. Figure 3-18 shows the ECG electrodes and the assembly of the wearable patch design which can be attached on the chest.

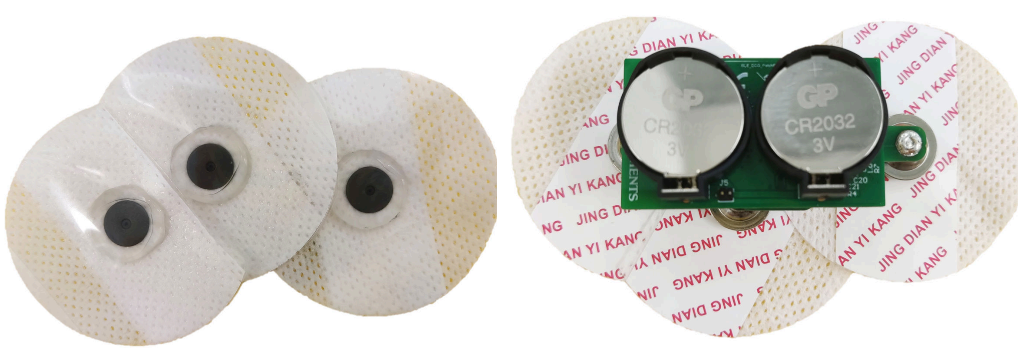


Figure 3-18. ECG Electrodes and Patch Assembly

Figure 3-19 and Figure 3-20 show the ECG waveforms and respiration acquired by the biosensing patch. Since there is no filter or algorithm integrated in the android app, some drift and noise is seen in the displayed chart. The high-pass filter (HPF) is recommended to remove the drift in the signal. Also, the best practice is to add a low-pass filter (LPF) to get cleaner ECG (40Hz or 150Hz) and respiration (4Hz) data. The designer can integrate a self-created algorithm for the data processing after receiving the data from Bluetooth® Low Energy.

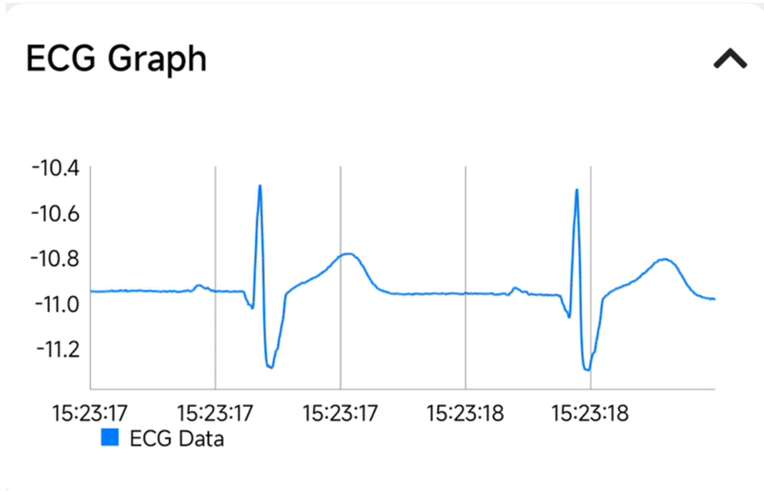


Figure 3-19. Real-Time ECG Waveform

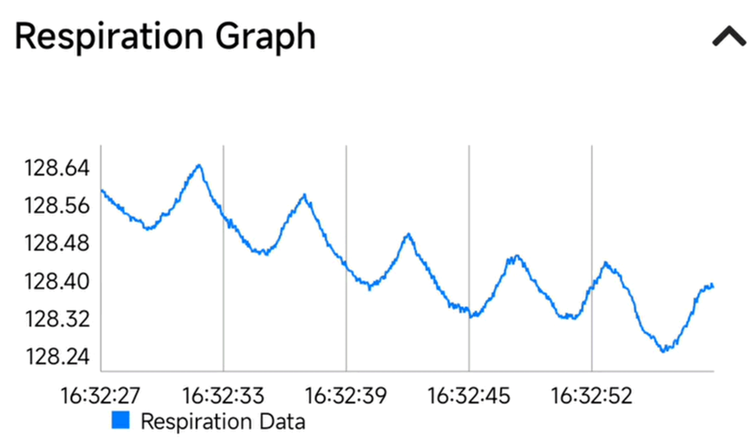


Figure 3-20. Real-Time Respiration Waveform

3.4.2 DC Lead-Off Detection

AFE4960 integrates both DC lead-off detection and AC lead-off detection and comes out as a single interrupt on the GIPO2 pin. The device simplifies the lead-off detection in the ECG device system design. While the RBIAS DC lead detect is meant to be used for continuous monitoring of the lead-on and lead-off status, the IBIAS AC lead detect is best used as an on-demand feature for checking the strength of the leads.

This design is configured to use DC lead-off detection. In RBIAS DC lead detect, the inputs of the two channels are biased using internal resistors. Lead detection is achieved using the analog comparators block. When the leads are not contacted, the resistor biasing of the leads pulls the INA inputs close to the rails. When leads are contacted, the INA inputs come within normal range because the body is biased by the RLD. So, the state of the leads can be detected using comparators at the INA input pins.

Figure 3-21 shows the lead-off detection for the patch. An interrupt pulse can be observed on the GPIO2 when lead-off occurs. The red LED can be set to indicate the status of the leads.

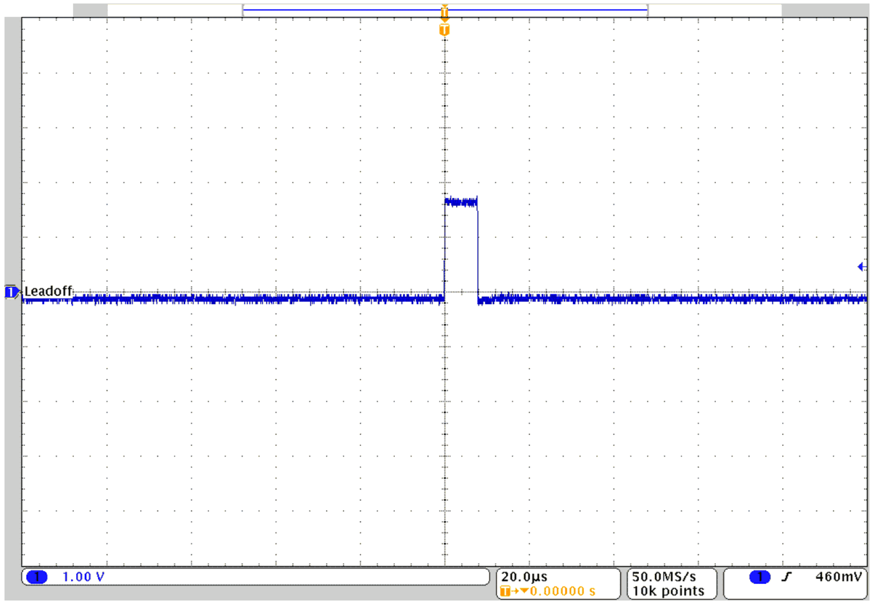


Figure 3-21. Interrupt for DC Lead-Off Detection on GPIO2

3.4.3 DC/DC Converters Waveforms

Figure 3-22 and Figure 3-23 show the input and output voltage waveforms of the TPS61299 and TPS628417 devices, respectively.

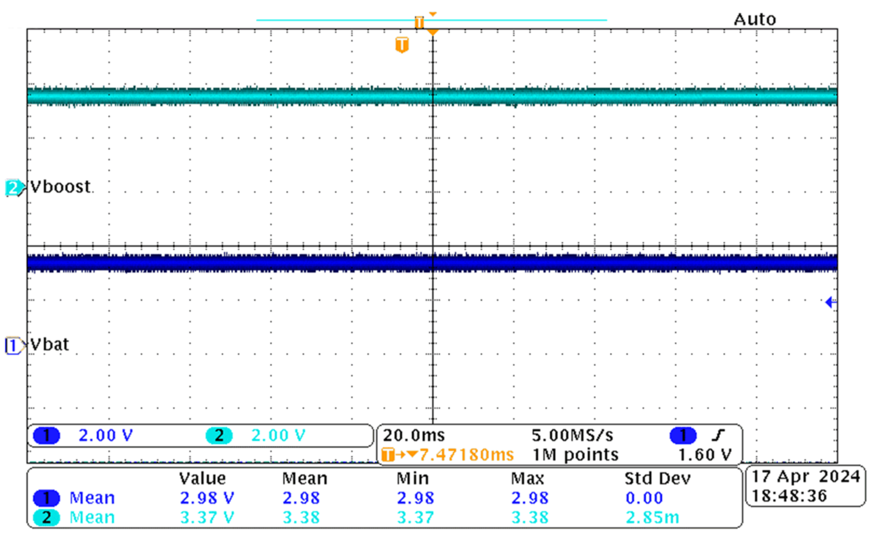


Figure 3-22. TPS61299 Waveform

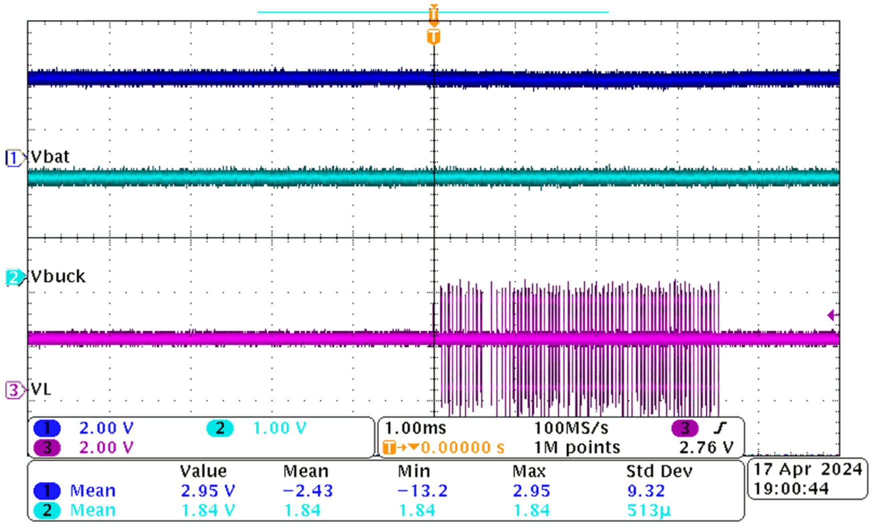


Figure 3-23. TPS628437 Waveform

3.4.4 Power Consumption Test

The total power consumption of the patch board is measured by the power analyzer which provides 3V supply to the patch board. As Figure 3-24 shows, with all functions (ECG, respiration, pace, temperature, accelerator, and Bluetooth® Low Energy advertising) on, the average current is measured to be 1.21mA, which can run for 15 days and 5 hours using 2 coin-cell batteries (CR2032, 220mAh). The test result is a little smaller than the calculation in Section 2.4.3, because the calculations are for worst-case performance. The LP-XDS110ET also integrates circuitry for power measurements to support EnergyTrace™ software in Code Composer Studio (CCS). Performing the power testing during debugging is convenient.

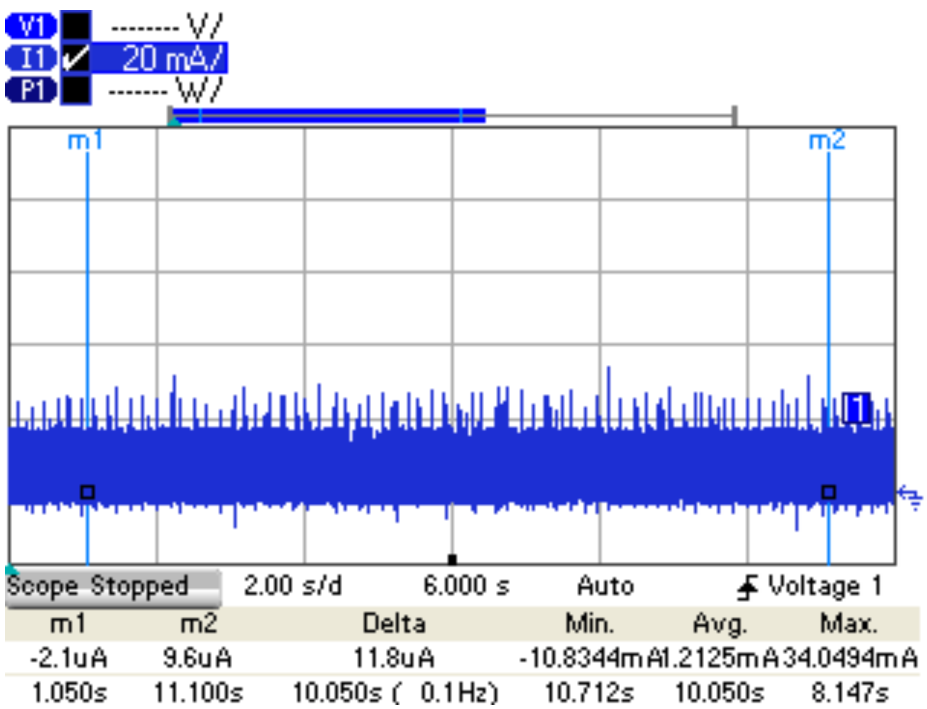


Figure 3-24. Current Consumption Waveforms for Bluetooth® Low Energy Transmission

4 Design and Documentation Support

4.1 Design Files

4.1.1 Schematics

To download the schematics, see the design files at TIDA-010270.

4.1.2 BOM

To download the bill of materials (BOM), see the design files at TIDA-010270.

4.2 PCB Layout Recommendations

4.2.1 Layout for the Main Board

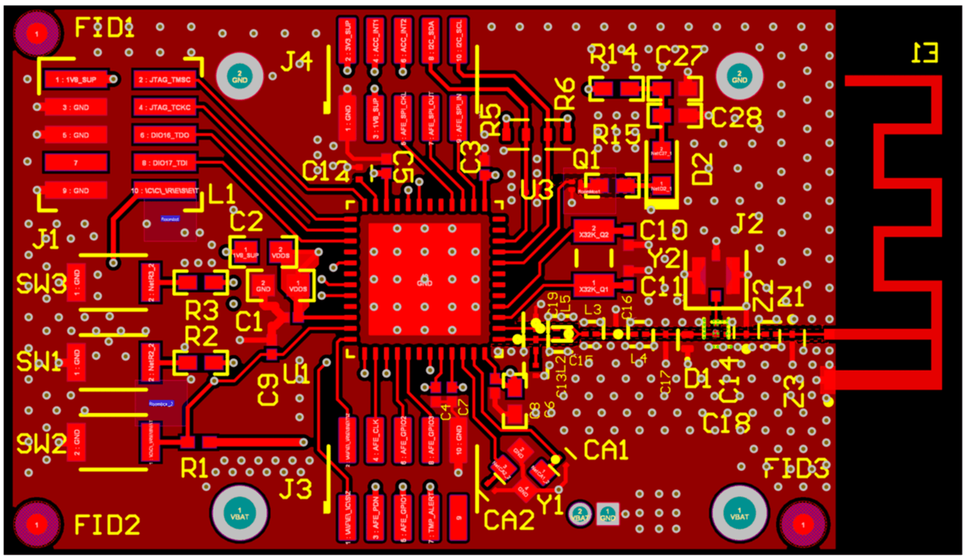


Figure 4-1. Top Layer for TIDA-010270 Board

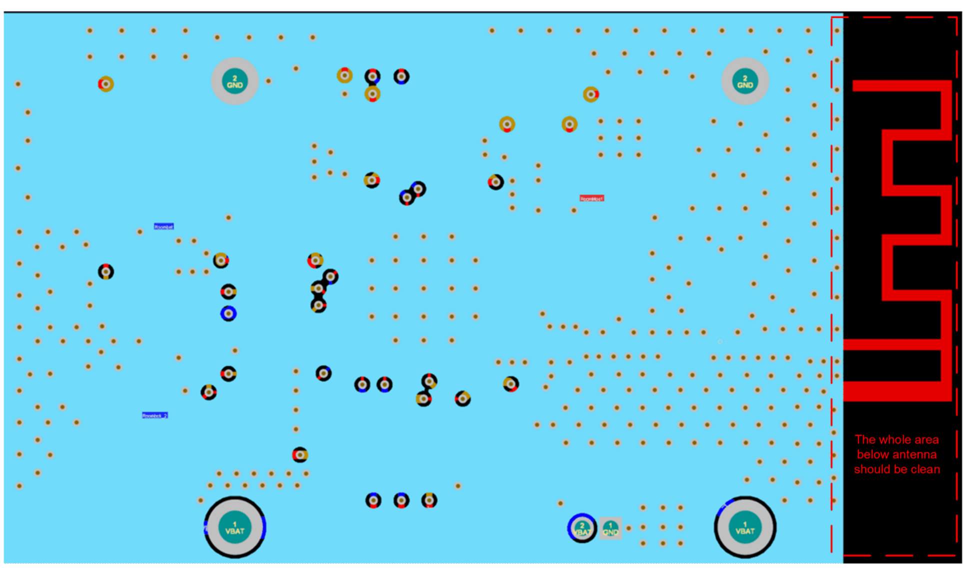


Figure 4-2. Ground Layer for TIDA-010270 Board

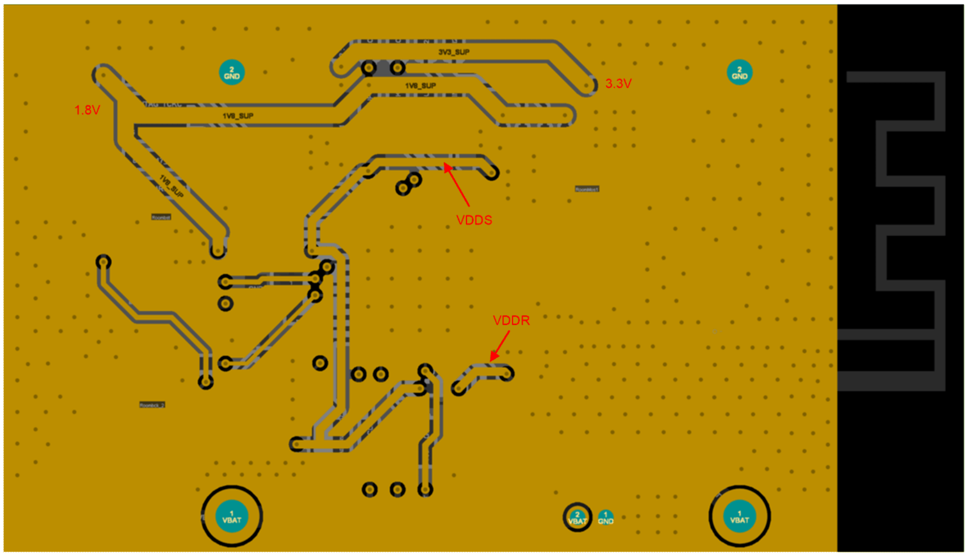


Figure 4-3. Power Layer for TIDA-010270 Board

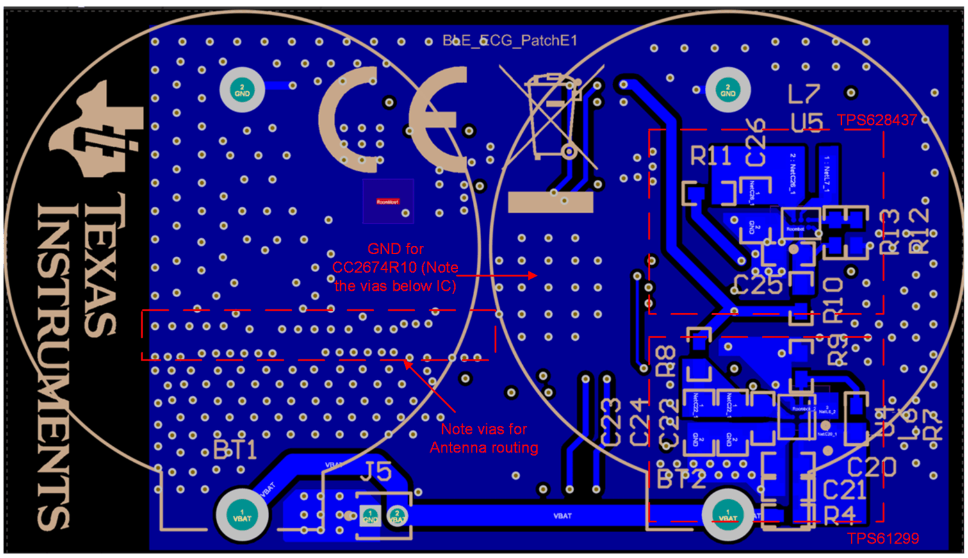


Figure 4-4. Bottom Layer for TIDA-01580 Board

Figure 4-5 shows the PCB layout of the onboard inverted F antenna. The copper under the antenna must be removed to ensure the signal transmission. The RF path is required to be 50Ω for matching the characteristic impedance. See also, the *Small Size 2.4GHz PCB antenna* application note.

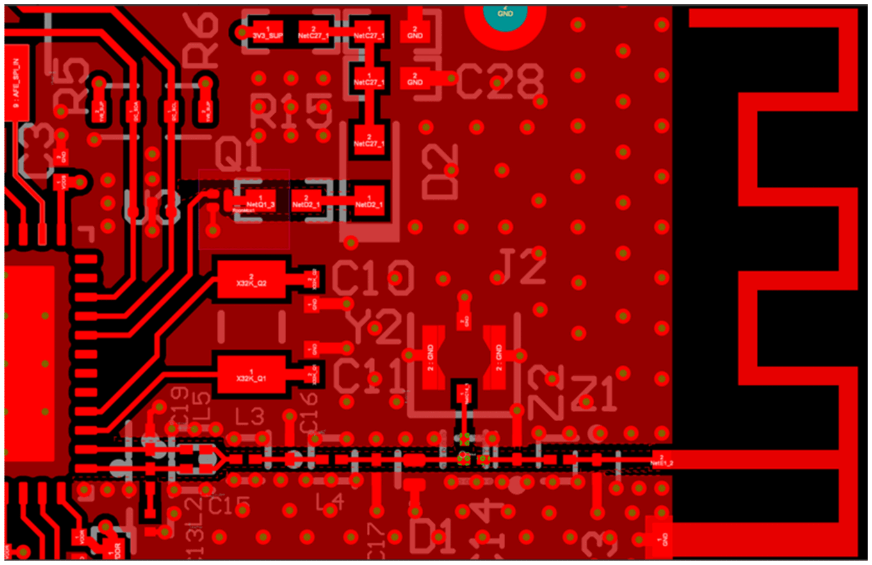


Figure 4-5. Layout for the Antenna

4.2.2 Layout for the Sensor Board

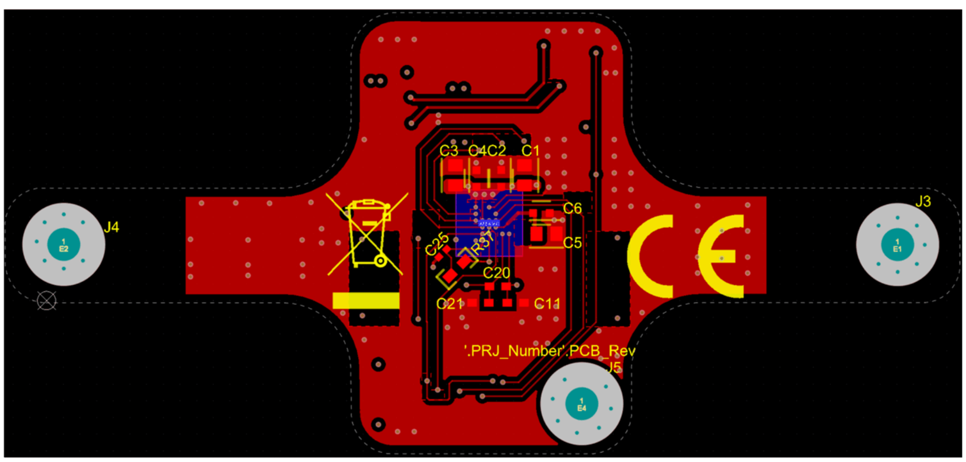


Figure 4-6. Layout for the Top Layer of Sensor Board

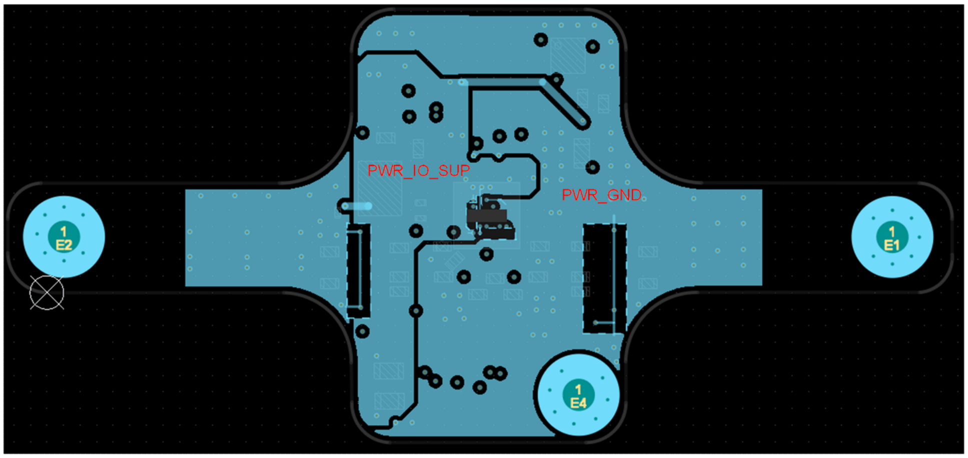


Figure 4-7. Layout for the Power Layer of Sensor Board

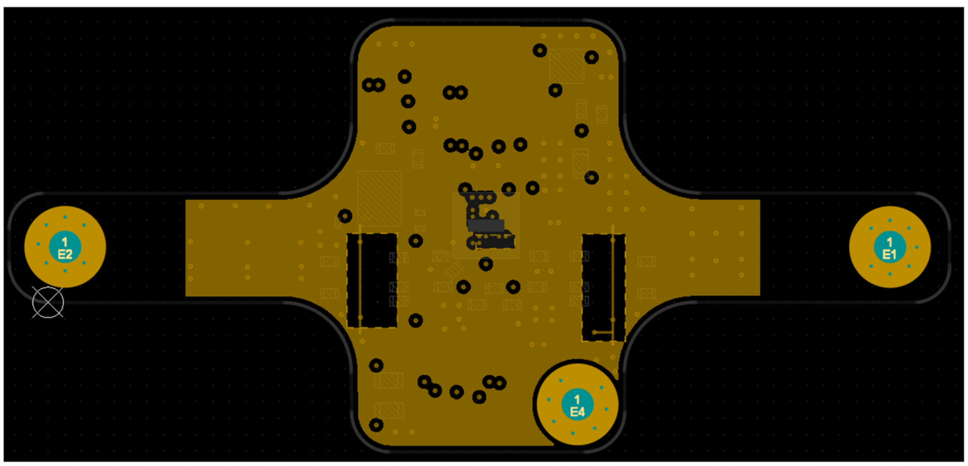


Figure 4-8. Layout for the GND Layer of Sensor Board

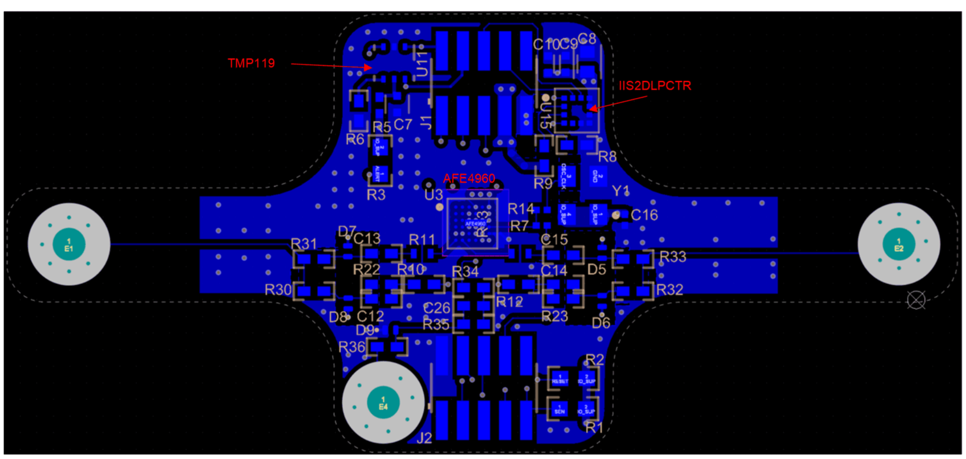


Figure 4-9. Layout for the Bottom Layer of Sensor Board

Figure 4-10 shows the route of BG(D3) and ECG_RLD(F5) pins. These pins are sensitive lines and need to be shielded from high-speed digital tracks like I2C and SPI.

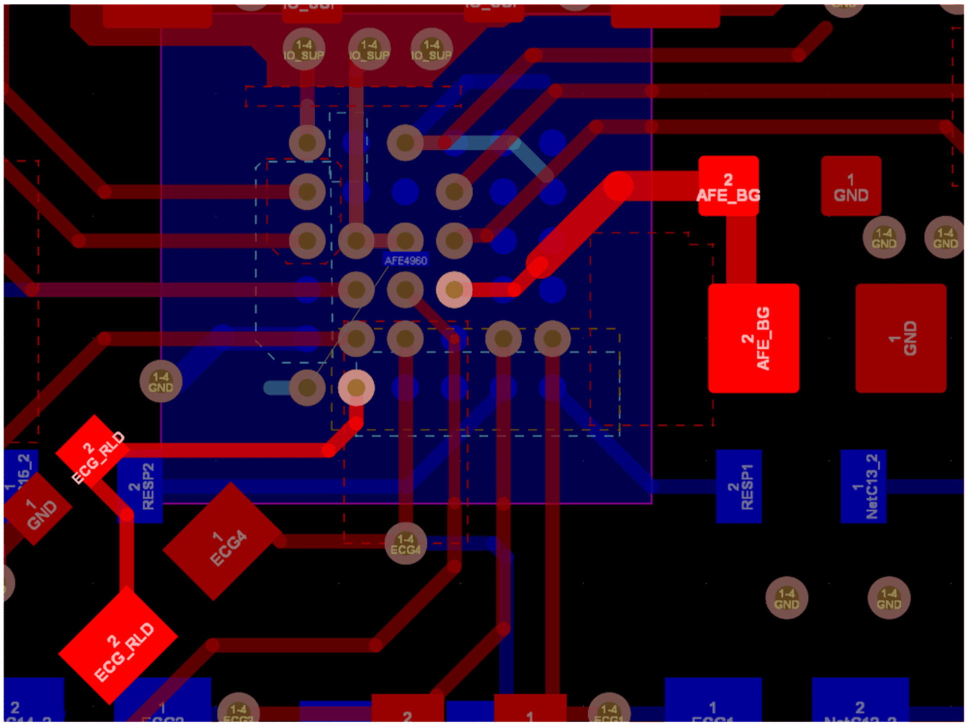


Figure 4-10. Route of BG(D3) and ECG_RLD(F5)

Figure 4-11 is the layout connection of the ECG and respiration line. Route the electrodes pins with care to make sure that the pins have low parasitic to switching lines. High-speed digital tracks (ADC_RDY, GPIO2) need to be away from the ECG and respiration input.

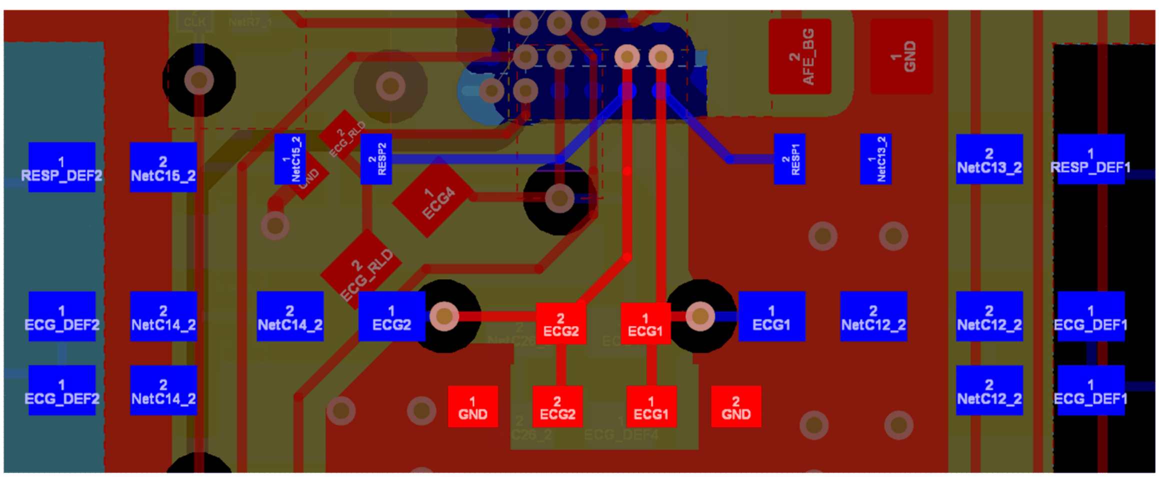


Figure 4-11. Layout of the ECG and Respiration Line

The ECG4 pin is close to the SPI pins, be sure to minimize the parasitic capacitance between the routings of ECG4 pin and the SPI lines (specifically SDOUT). For this reason, TI recommends that the ECG4 pin be used for the RLD drive since the RLD drive is a strongly driven node, and less susceptible to coupling. Figure 4-12 shows the route connection for the ECG4 and ECG_RLD pin.

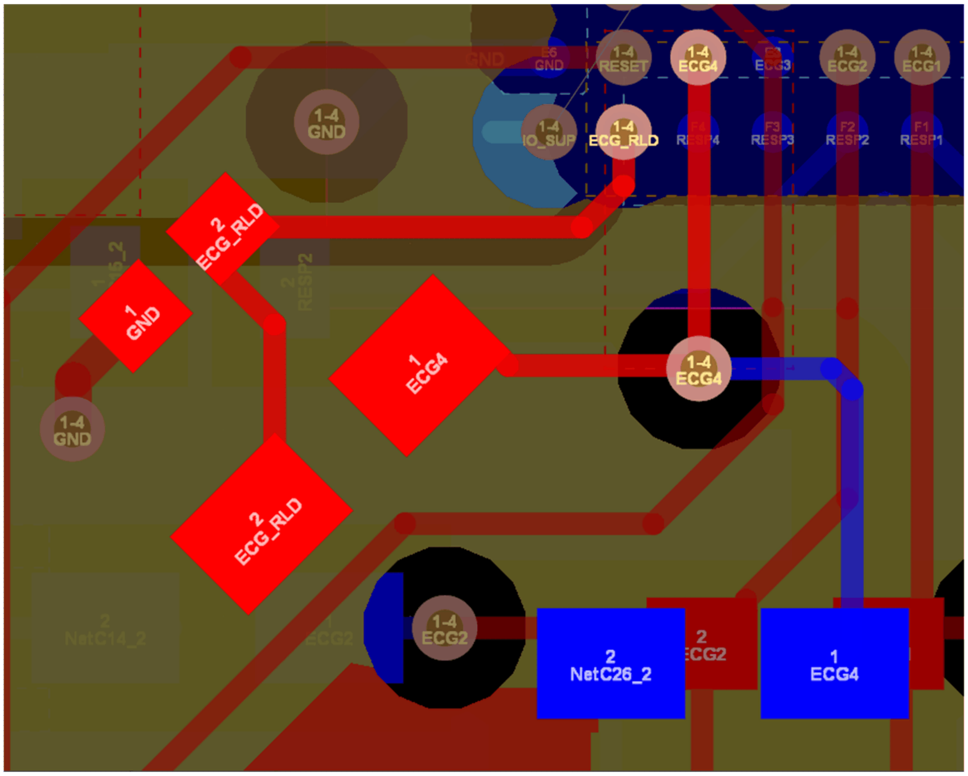


Figure 4-12. Route Connection for ECG4 and ECG_RLD Pin

4.3 Tools and Software

Tools

WEBENCH® Circuit Designer	Create customized power supply and active filter circuits
BT-POWER-CALC	Bluetooth Power Calculator Tool
LP-XDS110ET	XDS110ET LaunchPad™ development kit debugger with EnergyTrace™ software

Software

CCSTUDIO	Code Composer Studio™ integrated development environment (IDE)
SIMPLELINK-LOWPOWER-SDK	SimpleLink™ low power software development kits (SDKs)
SIMPLELINK-CONNECT-SW-MOBILE-APP	SimpleLink Connect mobile app

4.4 Documentation Support

1. Texas Instruments, *AFE4960 Two-Channel ECG, Respiration and Pace Pulse Detection Analog Front End (AFE) for Clinical Wearables Data Sheet*
   SBASAE1
   SBASAD4
2. Texas Instruments, *CC2674R10 SimpleLink™ High-Performance Multiprotocol 2.4GHz Wireless MCU Data Sheet*
3. Texas Instruments, *TMP119 Ultra-High Accuracy, Low-Power, Digital Temperature Sensor With SMBus™- and I2C-Compatible Interface Data Sheet*
4. Texas Instruments, *TPD1E01B04 1-Channel ESD Protection Diode for USB Type-C and Thunderbolt 3 Data Sheet*
5. Texas Instruments, *TPS62843 1.8V to 5.5V, 600mA, 275nA I_Q, Small-Size Step-Down Converters Data Sheet*
6. Texas Instruments, *TPS61299x/xA 95nA Quiescent Current, 5.5V Boost Converter with Input Current Limit and Fast Transient Performance Data Sheet*

4.5 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

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5 About the Author

MATTHEW CHEN is a Systems Engineer at Texas Instruments, where he is responsible for developing subsystem designs for the Medical and Healthcare sector. Matthew earned his masters degree in Tianjin University of Instrumentation Engineering in 2021, and joined in TI after his graduation.

JASON DING is a System Engineer at Texas Instruments, responsible for power-sensitive bio-sensor system design.

ROGELIO ARMINO is a Systems Engineer at Texas Instruments, where he is responsible for developing system-level designs for the medical sector. Rogelio earned his bachelor's in biomedical engineering from the University of Texas at Dallas and continues to support the UTD engineering program through senior project opportunities.

TONY LIU is a Field Application Engineer at Texas Instruments, providing technical support to large-size medical enterprise. Tony earned his masters degree in University of New South Wales of Electrical Engineering in 2022 , and worked as Hardware Engineer at DaJiang Innovation (DJI) before joining TI in 2023.

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