ADS1x9xECG-FE Demonstration Kit

User's Guide

TEXAS INSTRUMENTS

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ADS1x9xECG-FE Demonstration Kit

This user's guide describes the characteristics, operation, and use of the ADS1x9xECG-FE. This demonstration kit models the ADS1192, ADS1292 and ADS1292R. The family of devices are two-channel, 16/24-bit, low-power, integrated analog front-end (AFE) designed for portable electrocardiogram (ECG) and respiration applications. The ADS1x9xECG-FE is intended for prototyping and evaluation. This user's guide includes a complete circuit description, schematic diagram, and Bill of Materials.

1   ADS1x9xECG-FE

1.1   Important Disclaimer Notice

NOTICE: The ADS1x9x demonstration kits are intended for feasibility and evaluation testing only in laboratory and development environments. This product is not for diagnostic use. This product is not for use with a defibrillator:

- The **ADS1x9xECG-FE** to be used only under these conditions:
  - The **ADS1x9xECG-FE demonstration kit** must not be used for diagnostic purposes.
  -
  - The **ADS1x9xECG-FE demonstration kit** is intended solely for evaluation and development purposes. It is not intended for use and may not be used as all or part of an end equipment product.
  - The **ADS1x9xECG-FE demonstration kit** should be used solely by qualified engineers and technicians who are familiar with the risks associated with handling electrical and mechanical components, systems and subsystems.
  - You are responsible for the safety of you and your employees and contractors when using or handling the **ADS1x9x** demonstration kit. Furthermore, you are fully responsible for the contact interface between the human body and electronics; consequently, you are responsible for preventing electrical hazards such as shock, electrostatic discharge, and electrical overstress of electric circuit components.

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2 Overview

2.1 Introduction

> **NOTE:** From this point on, unless otherwise noted, ADS1x9x refers to ADS1192, ADS1292 and ADS1292R based demonstration kits.

This user's guide describes ADS1x9x software and hardware. The appendix contains the Bill of Materials and schematic design. The demonstration board shown in Figure 1 is provided to accomodate evaluation and system development activities related to ADS1x9x devices.
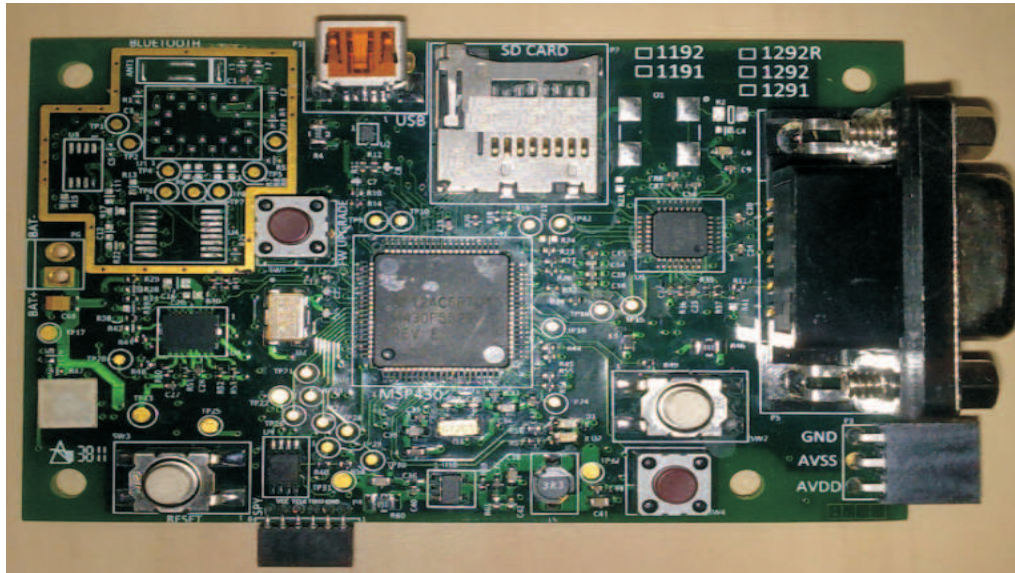
Figure 1. ADS1x9xECG-FE Demonstration Kit

The hardware is designed so all of the following ECG front end devices can be evaluated:

1. ADS1292 – 2 channels at 24 bits
2. ADS1292R – 2 channel at 24 bit with respiration
3. ADS1291 – 1 channel at 24 bit
4. ADS1191 – 1 channel at 16 bit
5. ADS1192 – 2 channel at 16 bit

The board can be assembled with any of these chips. ADS1292, ADS1292R and ADS1192 demonstration kits are available. The MSP430 firmware and PC application are designed to automatically detect the installed part and configure to accommodate the part.

Throughout this document, the term demonstration kit is synonymous with the **ADS1x9xECG-FE**.

2.2 Features Supported in this Version

1. Four electrode ECG cable support
2. View six ECG Leads: Lead I, Lead II, Lead III, Lead aVR, Lead aVL, Lead aVF and respiration channel (ADS1292R only) .
3. Two modes of operation: Evaluation and Live ECG / Respiration
4. Acquire data at up to 8 kHz in Evaluation mode
5. Current based Lead off detection
6. USB based power and PC application connectivity
7. Access to all ADS1x9x registers via an easy to use GUI.

8. Built-in time domain, histogram, FFT and ECG / Resp related analysis on the PC application

9. Live ECG with heart rate calculation.

10. Live Respiration wave with respiration rate calculation

11. USB based firmware upgrade option

12. MSP430 Firmware debugging using ez430 USB emulator

3 Software Installation

3.1 Minimum Requirements

Before installing the software, verify that your PC meets the minimum requirements outlined in this section

3.1.1 Required Setup for ADS1x9xECG-FE Demo Software

- IBM PC-compatible computer
- Pentium™ III/ Celeron™ 866 MHz or equivalent processor
- Minimum 256 MB of RAM (512 MB or greater recommended)
- Hard disk drive with at least 200 MB free space
- Microsoft Windows® XP SP2 operating system or Windows 7 operating system
- 1280 × 1024 or greater display screen resolution

3.1.2 Additional Requirements for use with Hardware

- ADS1x9xECG-FE Demonstration Kit
- USB to mini USB cable
- DB9 ECG Cable

3.2 Installing the Software (PC application)

Before installing the software, make sure the ADS1x9xECG-FE is NOT connected to the PC. If using a machine with Windows 7, we recommend having administrator rights to avoid problems during installation. Unzip the installer file, and then find and double click **setup.exe** to install the software. Unless otherwise specified during the install process, the software installs at *C:\Program Files\Texas Instruments\ADS1x9xEVM*. It creates a program menu item ADS1x9xEVM under *Programs → Texas Instruments → ADS1x9xevm* to execute the software. The following steps ensure proper installation of the PC application.

Click on **setup.exe** and the following screen appears. Click "Next"

Figure 2. PC Application Installation Screen 1

Accept the License Agreement and click "Next".
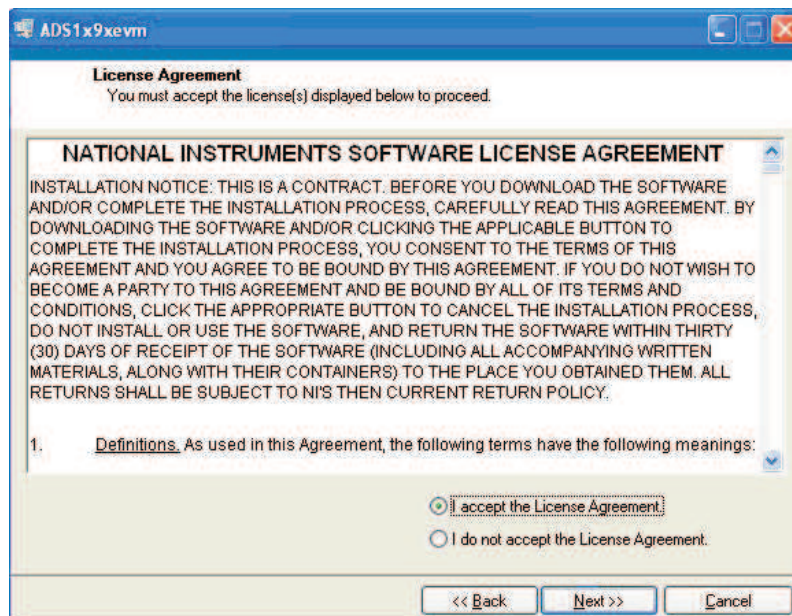
Figure 3. PC Application Installation Screen 2

Accept the License Agreement and click "Next".
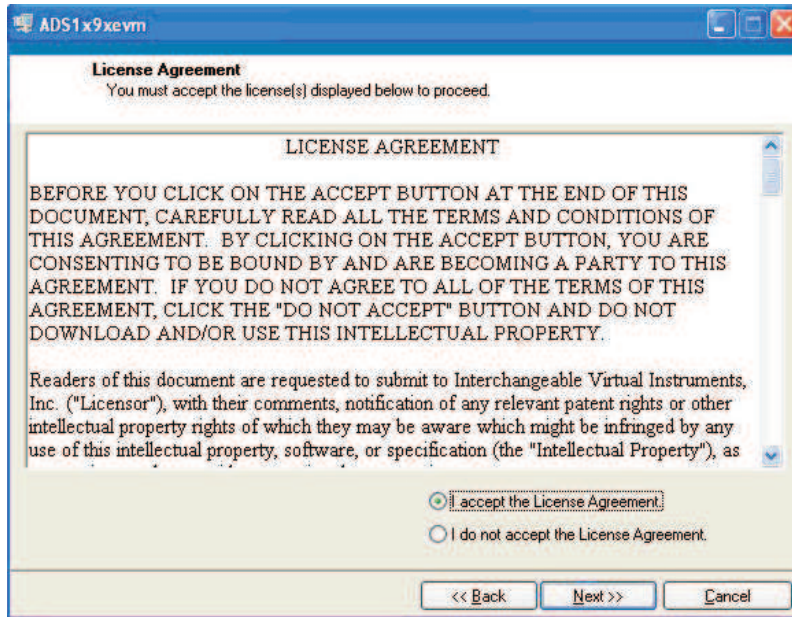
Figure 4. PC Application Installation Screen 3

The LabVIEW application software is installed now. Click "Next" to install the Microsoft C++ 2008 Redistributable Package (x86).
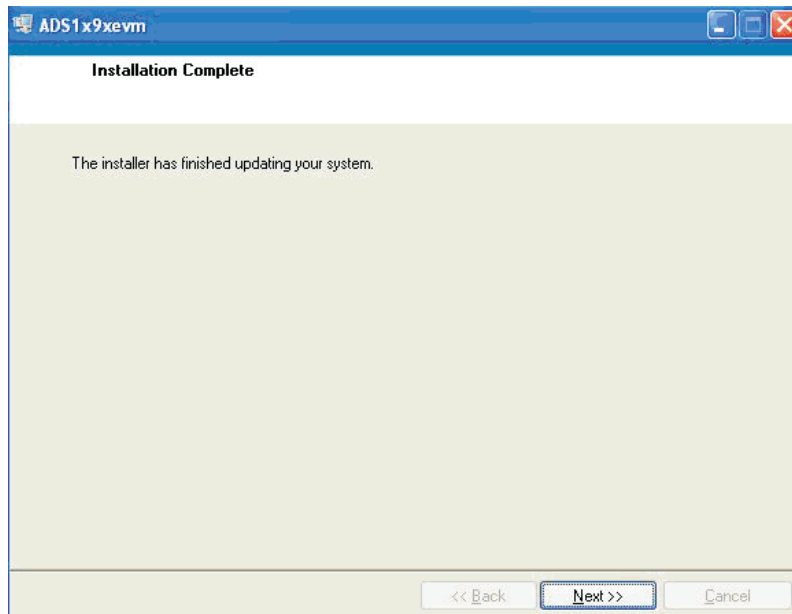
Figure 5. PC Application Installation Screen 4

If your system already has the Microsoft C++ 2008 Redistributable Package (x86) installed, then the following screen appears. Click "Cancel" to proceed.
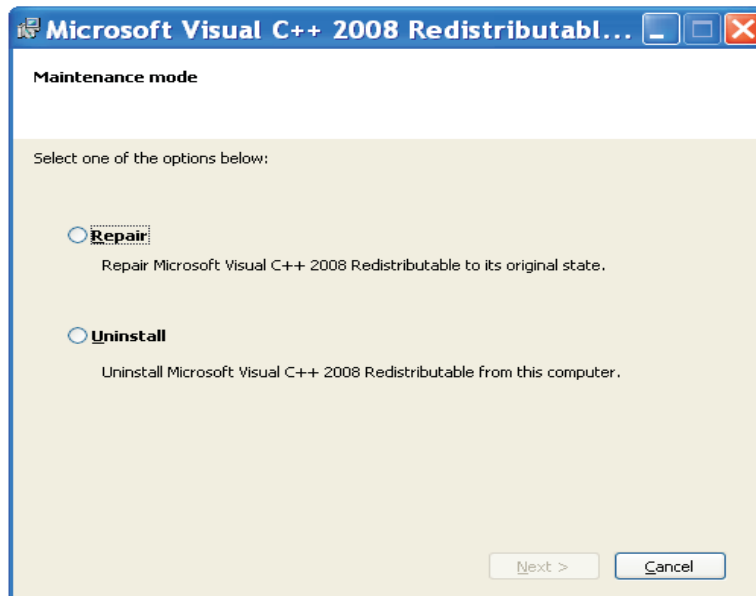
Figure 6. PC Application Installation Screen 5

Click "Finish" to complete the installation procedure.
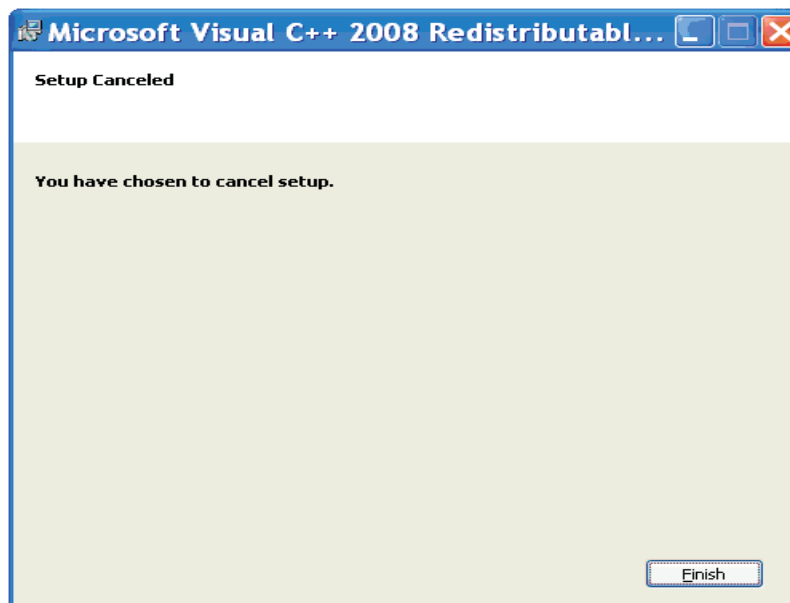
Figure 7. PC Application Installation Screen 6

If your system does not have the Microsoft C++ 2008 Redistributable Package (x86) installed, then the following screen appears. Click "Next".
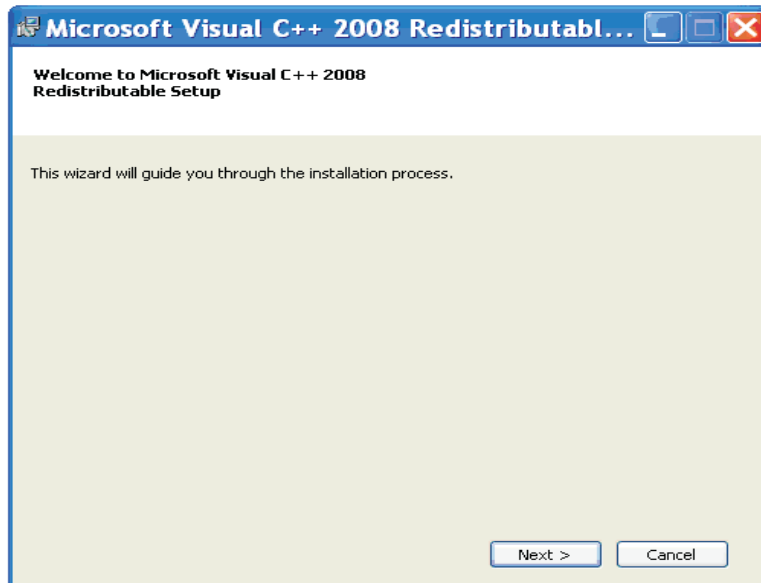
Figure 8. PC Application Installation Screen 7

Accept the license terms and click "Install".
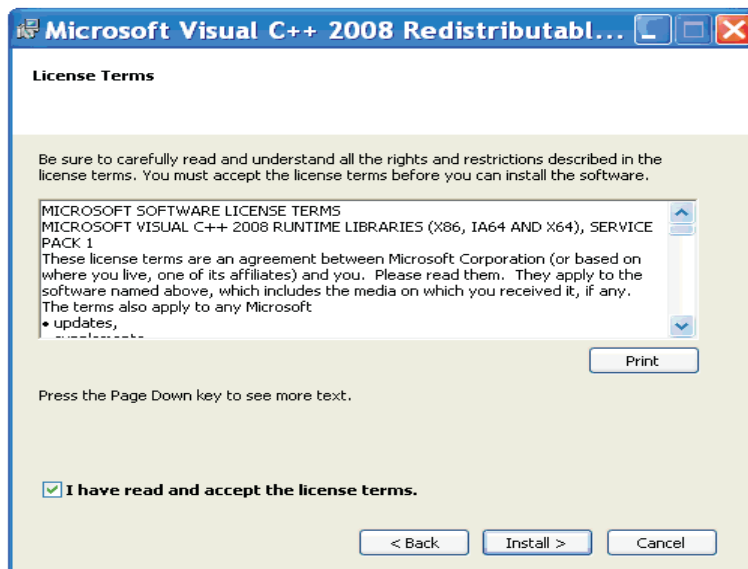
Figure 9. PC Application Installation Screen 8

Click "Finish" to complete the installation.
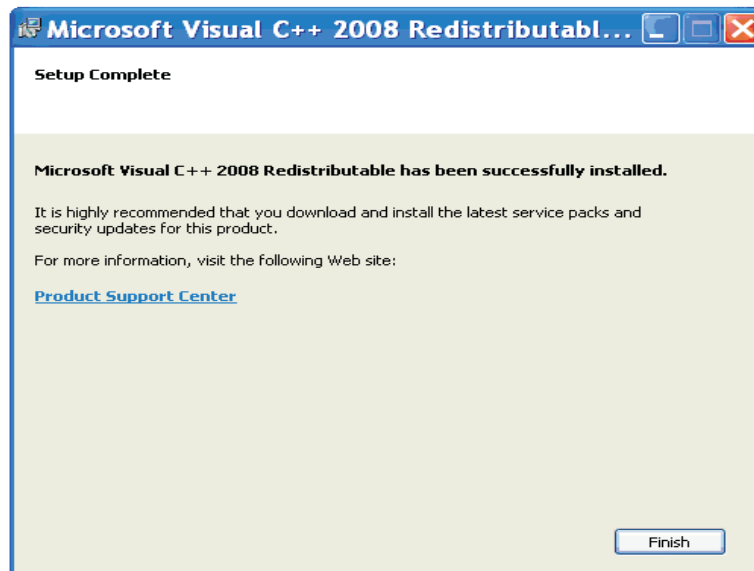
Figure 10. PC Application Installation Screen 9

The following screen might appear for the first time installation. Restart the machine.
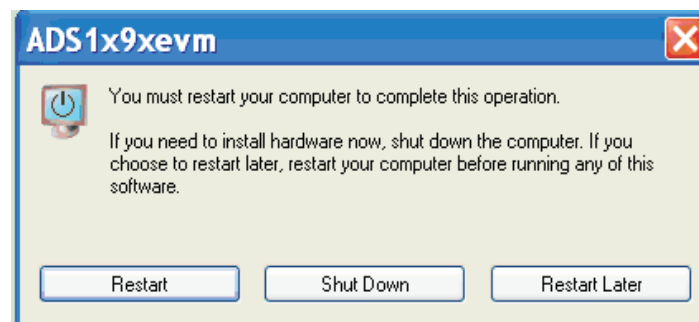
Figure 11. PC Application Installation Screen 10

The PC application is now ready to use.

3.3 Installing the USB Drivers

The communication interface between the ADS1x9xECG-FE board and PC is through USB using CDC profile. A onetime installation of the USB driver is required for the communication between ADS1x9xECG-FE and PC application.

The following steps will ensure proper installation of the USB drivers.

1. Plug-in USB to mini USB cable to P1 of ADS1x9xECG-FE and the other end to the USB port on the PC.
2. The operating system will prompt for USB driver for the *"ADS1x9x - ECG Recorder"* device. When the wizard comes up, select the options *"No, not this time"* as shown in Figure 12. Click "Next"

Figure 12. Hardware Wizard Screen 1

Select the option "Install from a list or specific locations (Advanced)" and click "Next".
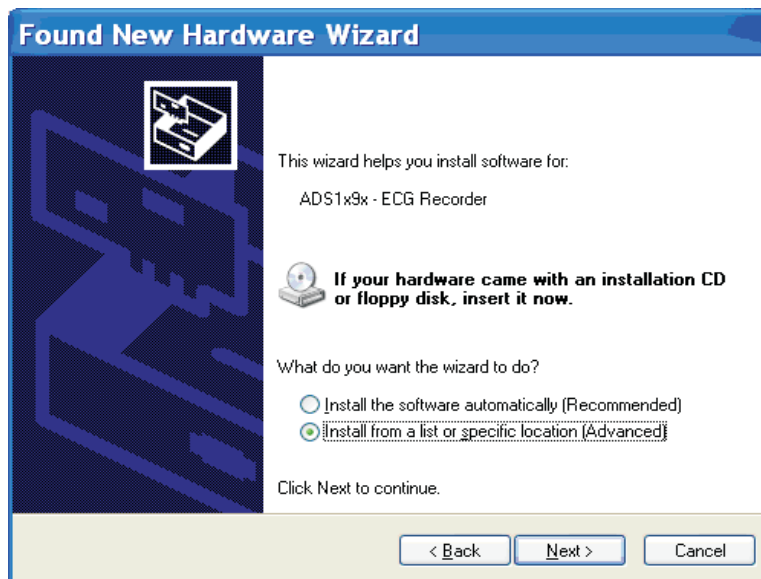
Figure 13. Hardware Wizard Screen 2

As shown in Figure 14 navigate to the directory in which "MSP430-CDC.inf" file is located (C:\Program Files\Texas Instruments\ADS1x9xevm\USB Drivers). This file will be copied to the directory while installing the PC application.

Click "Next"
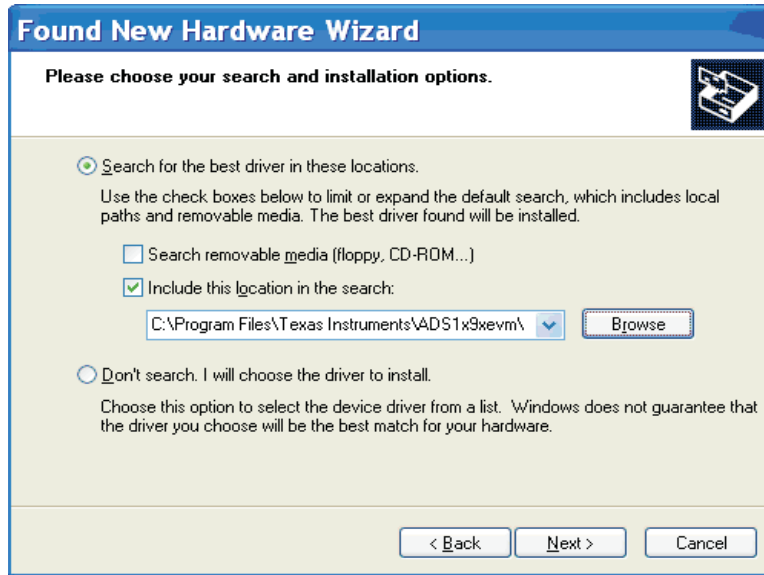
Figure 14. Hardware Wizard Screen 3
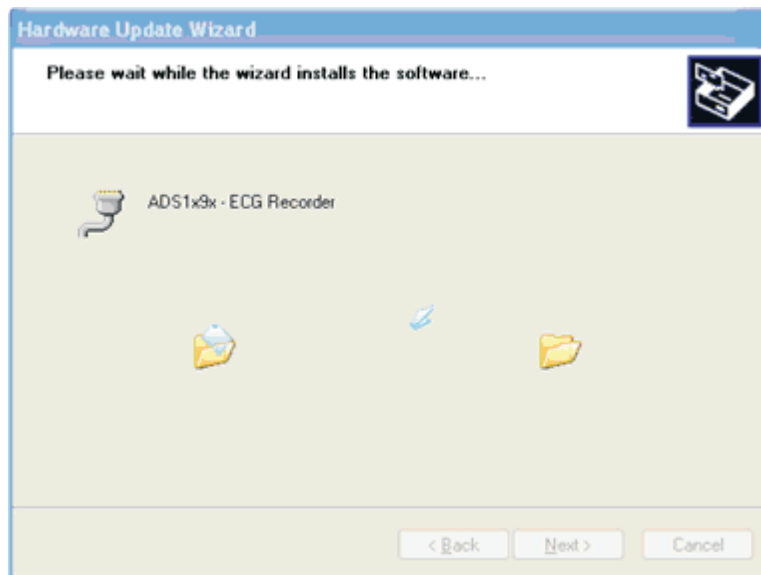
Figure 15. Hardware Wizard Screen 4

For the following warning message click on "Continue Anyway"
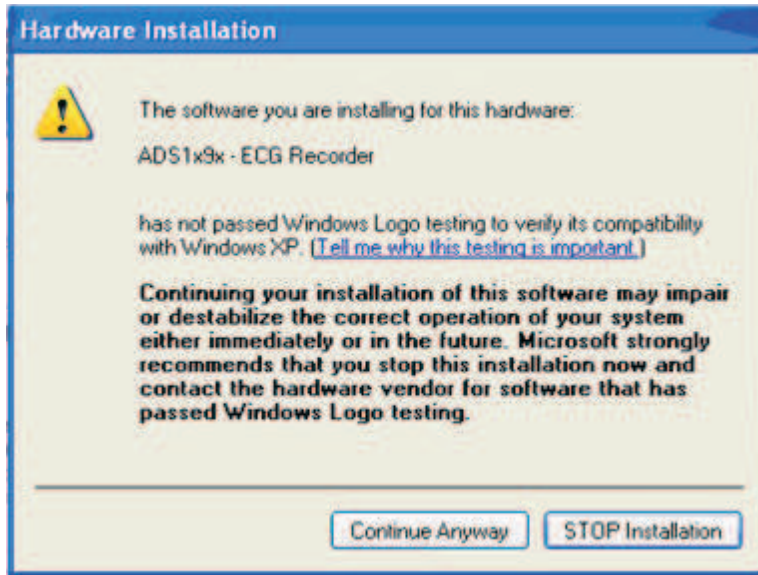
Figure 16. Hardware Wizard Screen 5

Click on Finish
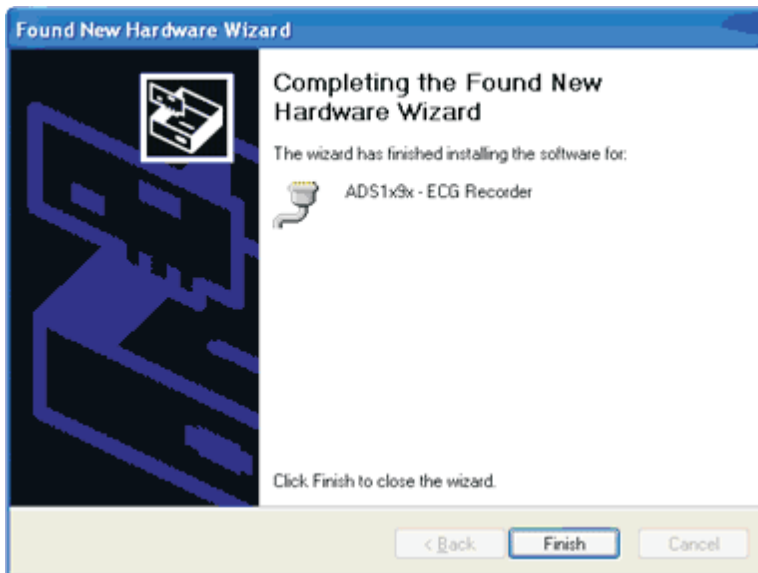
Figure 17. Hardware Wizard Screen 6

The ADS1x9xECG-FE now will get recognized as Virtual COM port under Device Manager as shown in Figure 18.
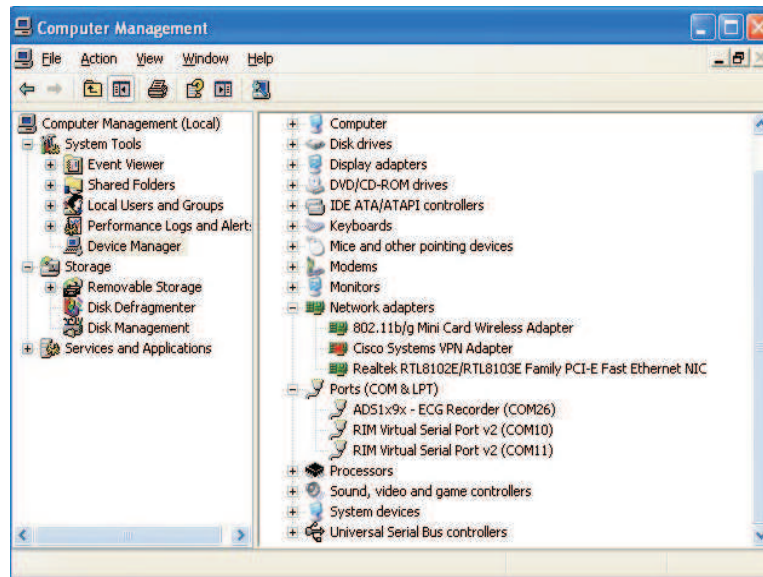
Figure 18. Device Manager Screen

The USB driver installation is now complete and ADS1x9xEVM is now ready to use.

4 Running the Software

From the Start menu, select *Programs>Texas Instruments>ADS1x9xevm* to run the ADS1x9xEVM software. Unless the hardware has been disconnected, the user will observe messages that confirm that the connection has been established and the program will wait in idle mode for user input.

If the connection to the ADS1x9xECG-FE board is not established, then the program will prompt the user to check the connection between the PC and ADS1x9xECG-FE and retry.
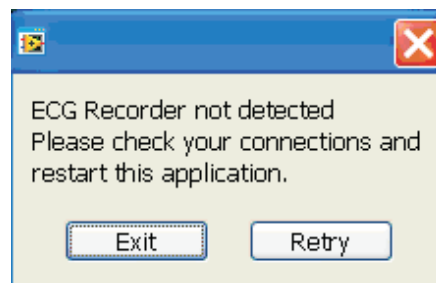
Figure 19. EVM not connected Error Message

4.1 Overview of the Features

This section provides a quick overview of the various features and functions of the ADS1x9xECG-FE software package.

The main tabs consist of:

- About
- ADC Register - Allows the user to configure all the ADS1x9x user registers
- Analysis - Allows the user to view and analyze the raw data
- Save - Allows the user to write data samples and analysis results to a file
- Live ECG\RESP Display - Provides streaming ECG signals along with heart rate, lead off information and respiration

4.1.1 ADC Registers Tab

The *ADC register* tab allows the user to configure the various registers of the ADS1x9x. Please see the ADS1x9x datasheet for register details of the chip.

> **NOTE:** The ADS1x9xECG-FE GUI only supports Continuous Conversion Mode. Single Shot Mode is not supported.
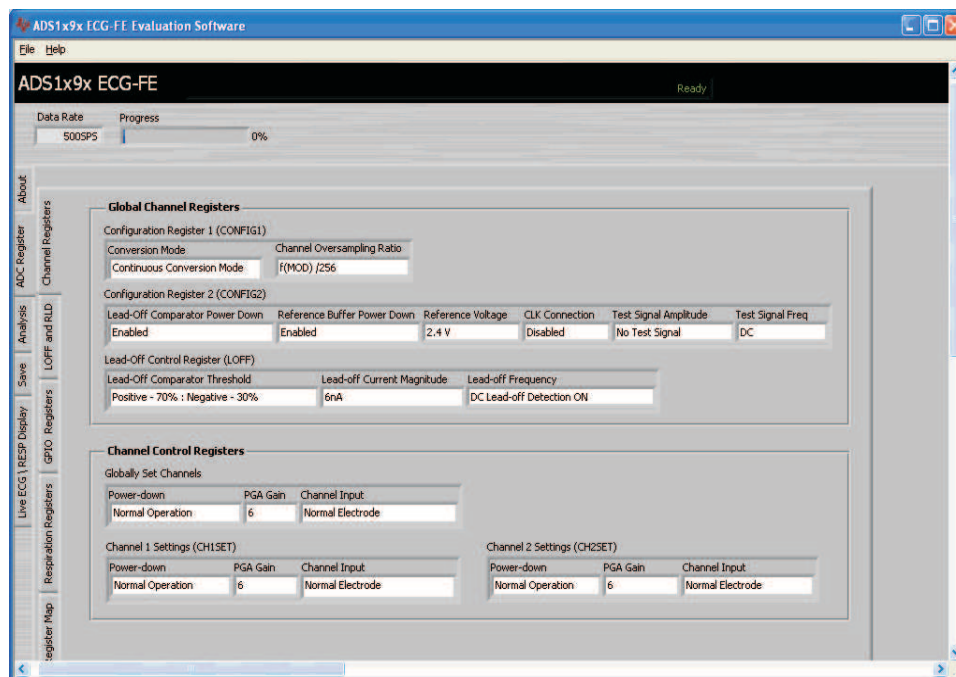
Figure 20. Register Configuration - Channel Registers

The *LOFF and RLD* tab consists of the settings to enable lead-off, selecting the channels for lead-off detection and deriving the Right Leg Drive signal. General options including clocking are also available on this tab.
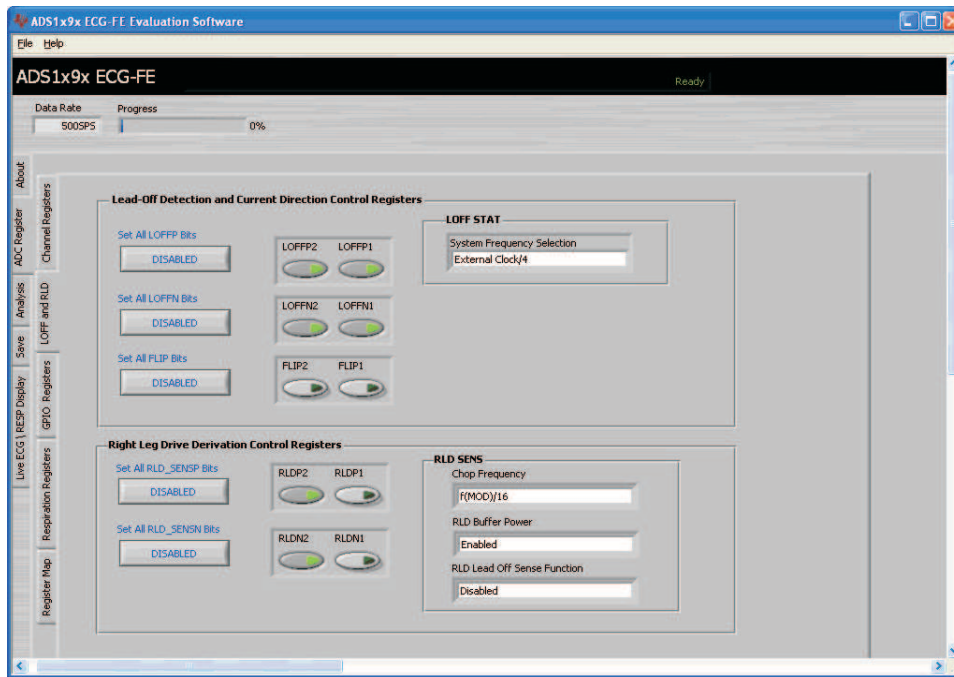
Figure 21. Register Configuration – LOFF and RLD

The *GPIO Registers* tab consists of the GPIO settings.
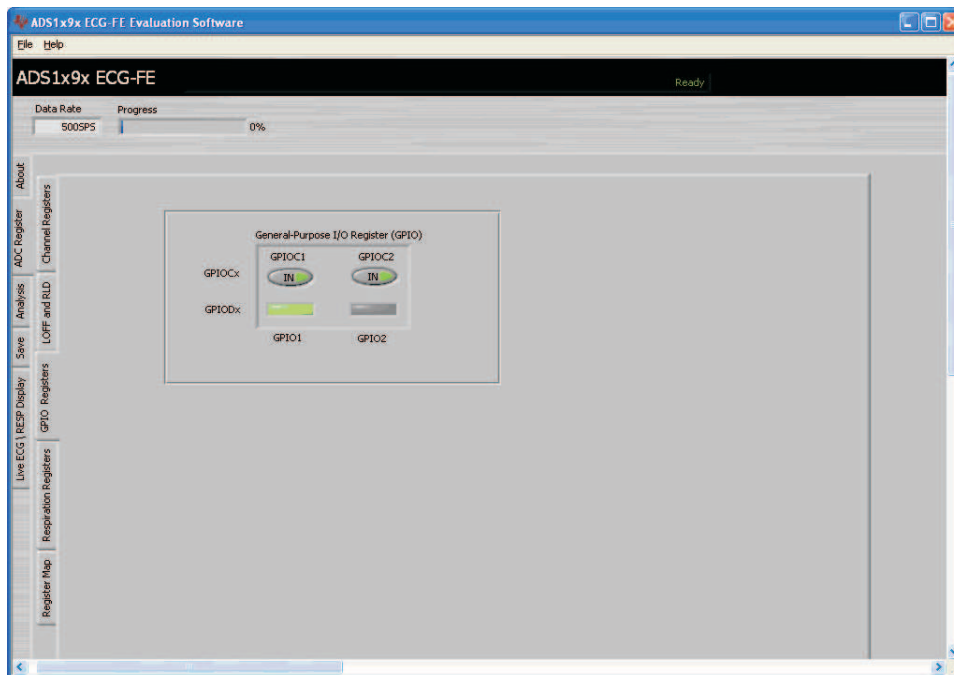
Figure 22. Register Configuration – GPIO

The *Respiration Registers* tab consists of the settings needed for respiration and RLD reference signals. The respiration controls are specific to the ADS1292R, they are not applicable for the ADS1192 and ADS1292.
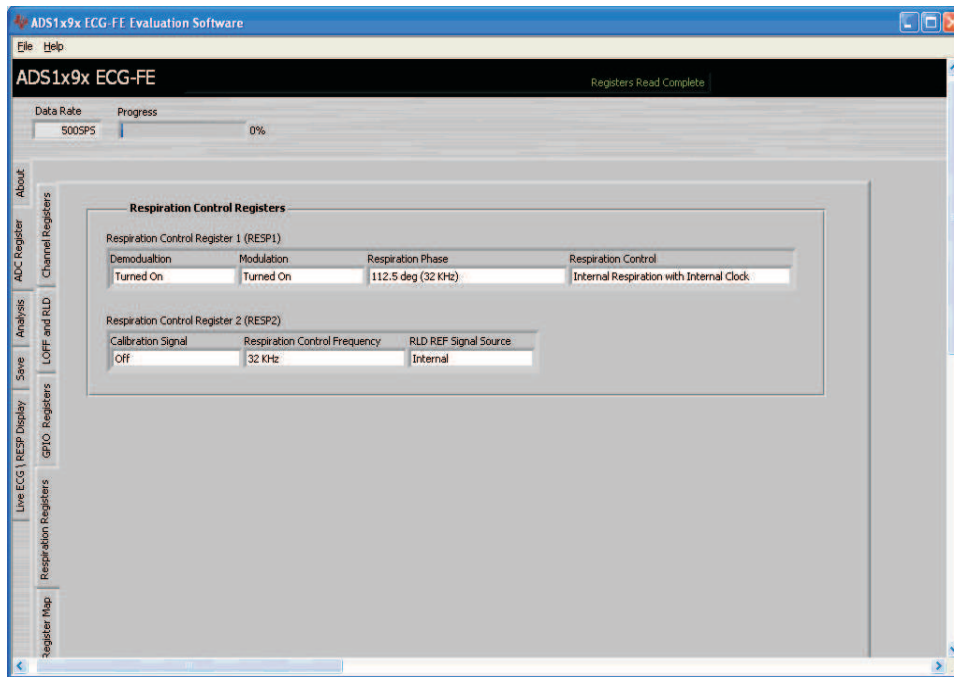
Figure 23. Register Configuration – Respiration Registers

The *Registers Map* tab reads back the register bit values from the ADS1x9xECG-FE. The **Refresh Registers** button provided in this tab read back the register values from the ADS1x9xECG-FE at any time.
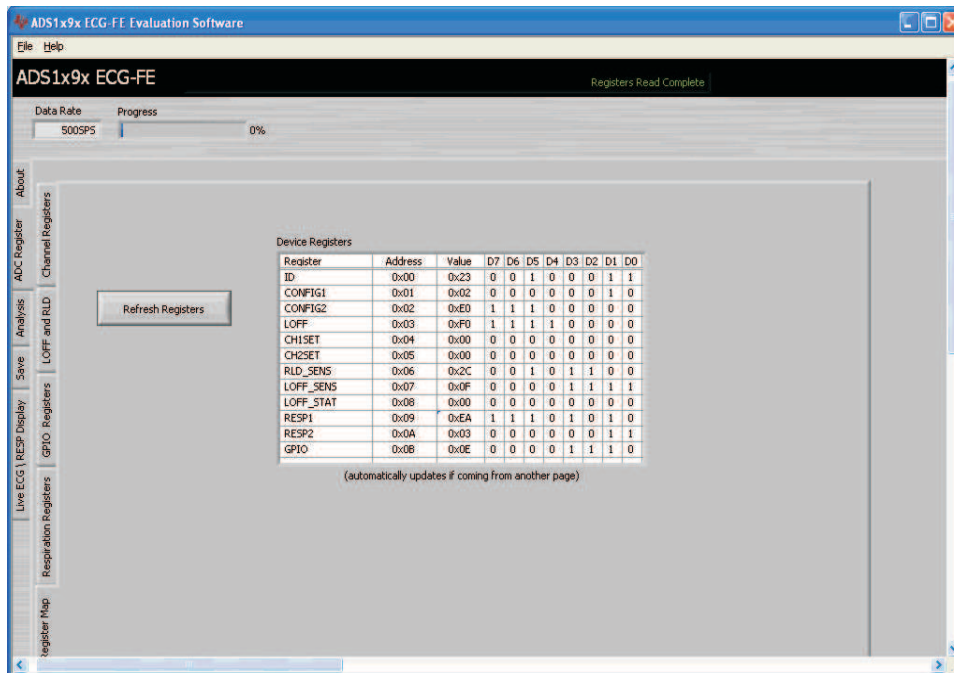
Figure 24. Register Configuration – Register Map

4.1.2 Analysis Tab

The **Analysis** tab consists of various analysis routines and displays. The following sub-tabs are available for the **Analysis** tab

*   Scope
*   Histogram
*   FFT
*   ECG\Resp Display

The data is acquired from the EVM by clicking *ACQUIRE* button. The number of samples (block size) to be acquired must be given in the space provided. The *CONTINUOUS* button acquires the data from the EVM continuously in the designated block size.

Scope Sub-Tab
The **Scope** sub-tab displays the data in the time-domain. The units are converted from codes to volts using the voltage reference value set in the *ADC Registers* tab and are plotted as either input referred (output divided by PGA gain setting) or non-input referred using the checkbox located in the top right corner of the GUI. The **Scope Analysis** button activates a pop-up that displays the mean voltage, root mean square (RMS) voltage and peak to peak voltage for noise analysis.
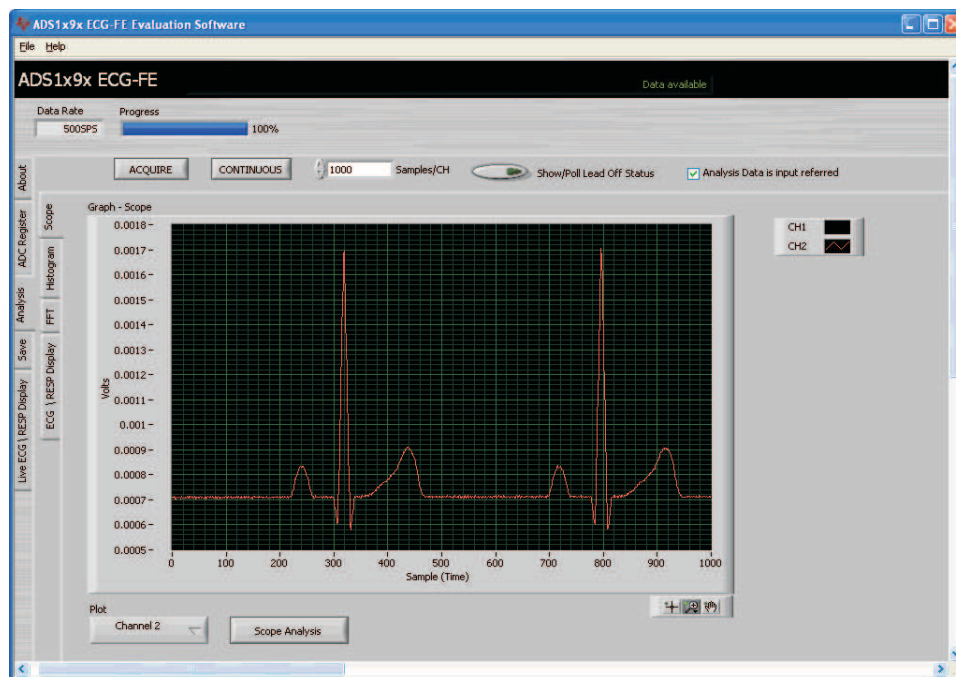
Figure 25. PC Application Analysis – SCOPE

The following main buttons/controls are available in this sub-tab

Button/Control	Description
Scope Analysis	Displays the mean, root mean square (RMS), and peak-to-peak for noise analysis of the acquired data
Plot	Channel selection button allow selecting All channels, Channel 1, or Channel 2 for display

Histogram Sub-Tab

The *Histogram* sub-tab displays the data in a histogram format for the two channels. The data is arranged in the total number of histogram bins set within the tab following acquisition. The **Histogram Analysis** button can be used to view the mean voltage, root mean square (RMS) voltage and peak to peak voltage for analysis.
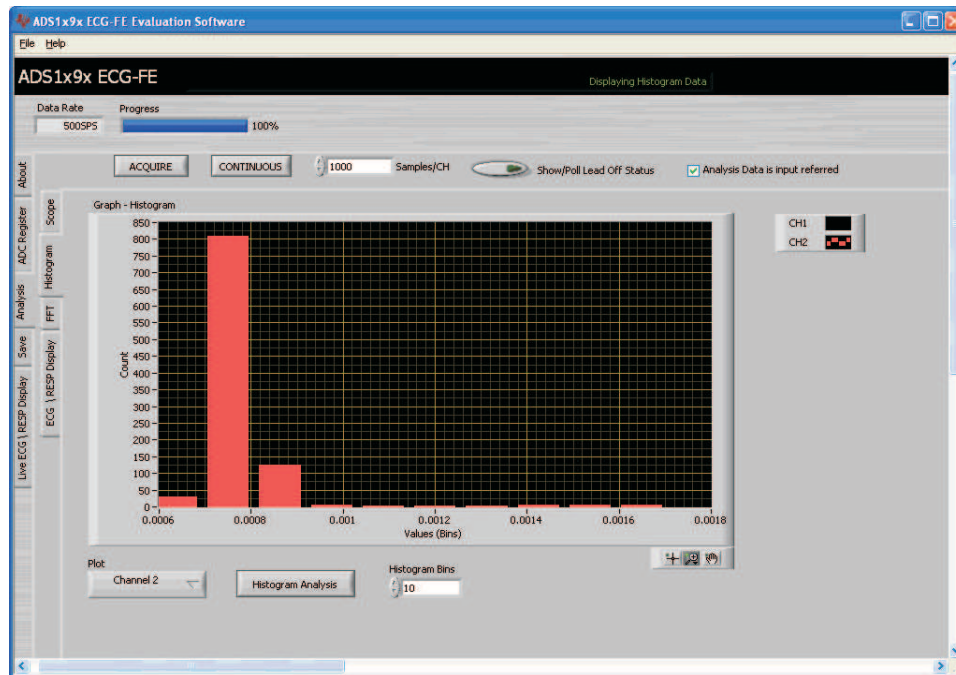
Figure 26. PC Application Analysis - Histogram

The following buttons/controls are available in this sub-tab

Button/Control	Description
Histogram Analysis	Runs histogram of the selected channel(s) for the selected number of samples
Plot	Channel selection button allow selecting all channels or Channel 1 or Channel 2 for the display
Histogram Bins	Set the total number of bins to arrange the individual channels
Display Plane(Right click on the display area and then select "Optional Plane" menu item)	Various display planes can be selected for the histogram display. The options available are: • Nyquist • Nichols • S Plane • Z Plane

FFT Sub-Tab

The *FFT* sub-tab displays the data in the frequency domain by performing a FFT on the two channels. Details of the FFT, including SNR, THD, etc. can be viewed using the **FFT Analysis** button located in the bottom left corner of the display.
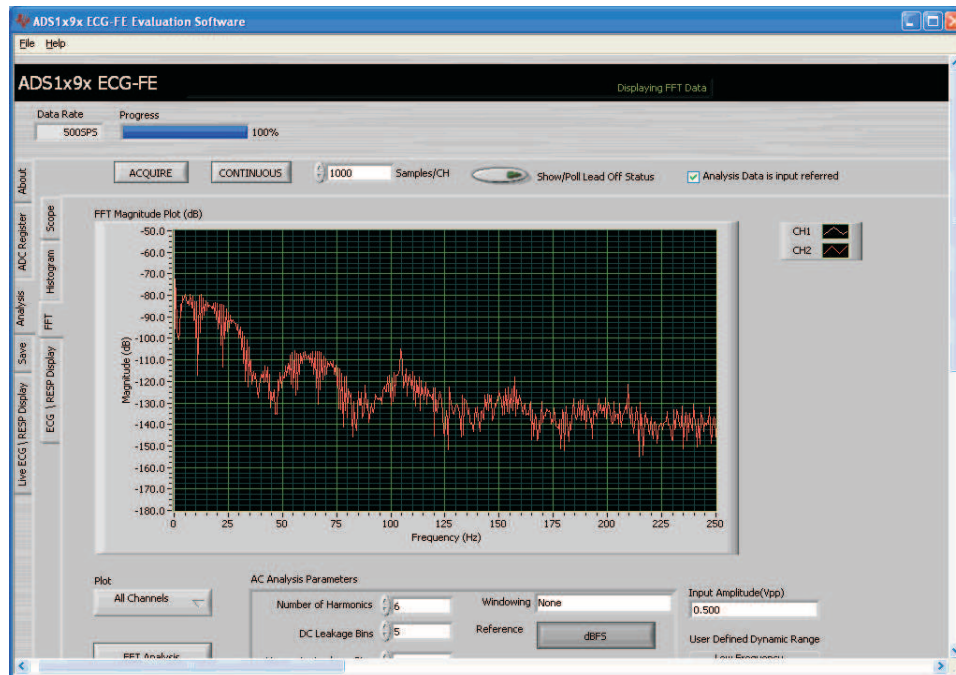
Figure 27. PC Application Analysis - FFT

Button / Control	Description
FFT Analysis	Runs FFT analysis of the selected channel(s) and result will be shown on the pop-up window
Plot	Channel selection button allow selecting All channels, Channel 1, or Channel 2 for display
AC Analysis Parameters Section	Various AC analysis parameter configuration
Coherent Frequency Calculator Section	Provision for entering desired Ain Frequency
User Defined Dynamic Range Section	Provision for selecting Low and High frequency

ECG\RESP Sub-Tab

The *ECG\RESP Display* sub-tab displays the ECG data for Lead I, Lead II, Lead III, Lead aVR, Lead aVL, or Lead aVF for the ADS1192 and ADS1292. The ADS1292R only displays Lead I or Respiration data.
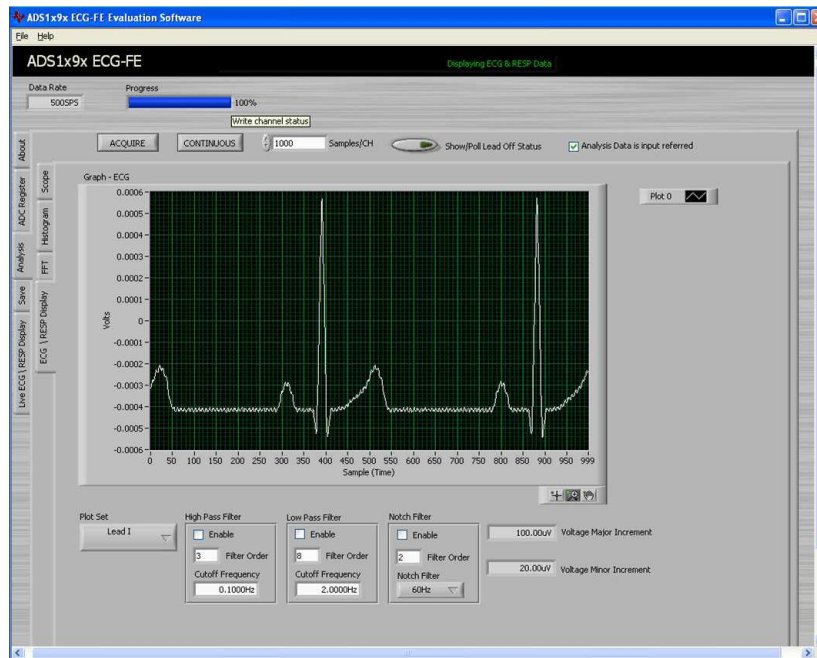
Figure 28. PC Application Analysis – ECG
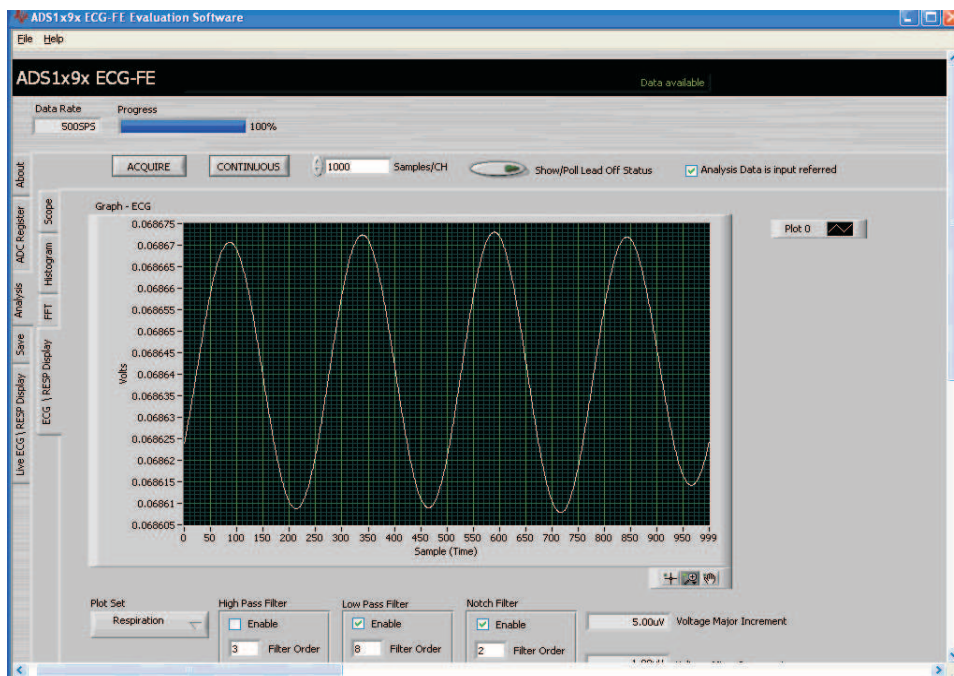
Figure 29. PC Application Analysis – ADS1292R Respiration (Low Pass Filter Enabled)

The following buttons/controls are available in this sub-tab:

Button/Control	Description
Plot Set	Option to select ECG Lead I, Lead II, Lead III, Lead aVR, Lead aVL, Lead aVF or Respiration Channel (ADS1292R only)
High Pass Filter	Provision for enabling a high pass filter with support for selecting the order of the filter and cut off frequency[1]
Low Pass Filter	Provision for enabling a low pass filter with support for selecting the order of the filter and cut off frequency[1]
Notch Filter	Provision for enabling a notch filter for 50Hz or 60Hz with support for selecting the order of the filter. This filter will be applied on the acquired data for the sampling rate of 500SPS[1]

[1] Post- processing for filter done in GUI.

Apart from the above specific buttons / control on each sub-tabs, the following options are available by right-clicking in the display area:

Display Options	Description
Auto scaling	Both x-scale and y-scale auto scaling is possible. User can enable or disable this feature
Export Data	The displayed data can be exported to excel or Clipboard
Annotation Provision	Provision provided for creating and deleting annotation
Visible Items selector	Option to display x-scale, y-scale, Plot legends, x-scrollbar
Plot legend options	Plot legend gives various option to change the color of the plotting, various plotting styles etc

4.1.3 Save Tab

The *Save* tab provides provisions to save the analysis or data to a file. By default, the data is saved to *C:\Program Files\Texas Instruments\ADS1x9xevm\saved*. Use the **Directory to Save Files** option to select the folder where data is to be saved. In the pop up window, navigate to the folder where the file is to be saved and select **Use Current Folder**. Then select **Save to File** to save the file.
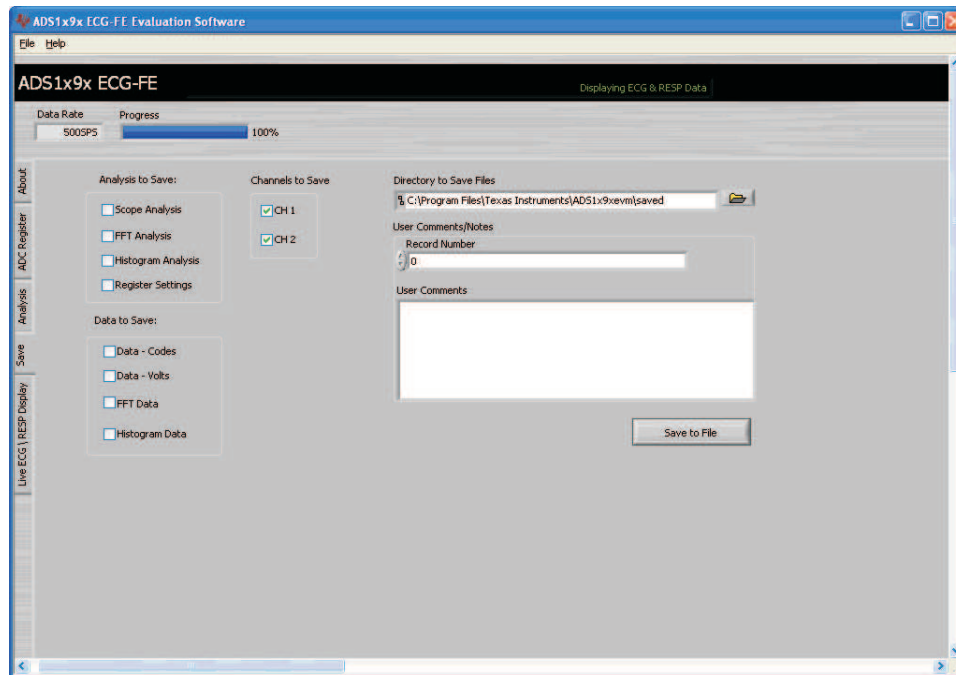
Figure 30. PC Application Save

The following options are provided in the *Save* tab.

Button/Control	Description
Scope Analysis	For saving scope analysis result. The result will be saved in the file "Device_<record number>_Analysis.xls".
FFT Analysis	For saving FFT analysis result. The result will be saved in the file "Device_<record number>_Analysis.xls".
Histogram Analysis	For saving histogram analysis result. The result will be saved in the file "Device_<record number>_Analysis.xls".
Register Setting	All the current register values will be read from the EVM and stored. The result will be saved in the file "Device_<record number>_Analysis.xls".
Data - Codes	Acquired data sample values will be stored to the file "Device_ <record number>_Codes.xls"
Data - Volts	Acquired data sample's voltage values will be stored to the file "Device_ <record number>_Volts.xls"
FFT Data	Acquired data sample's FFT values will be stored to the file "Device_ <record number>_FFT.xls"
Histogram Data	Acquired data sample's histogram values will be stored to the file "Device_ <record number>_Histogram.xls"

The **Record Number** saves files with the provided number in the file name. There are options to select Channel 1 and Channel 2 while saving the corresponding data to the file.

User notes also can be added to the file by typing the notes in the **User Comments** control.

4.1.4   Live ECG / RESP Display Tab

Live ECG and respiration data are shown on the **Live ECG/RESP Display** tab. This tab also shows the heart rate, respiration rate and lead-off information.

Figure 31. PC Application Live ECG for ADS1292R
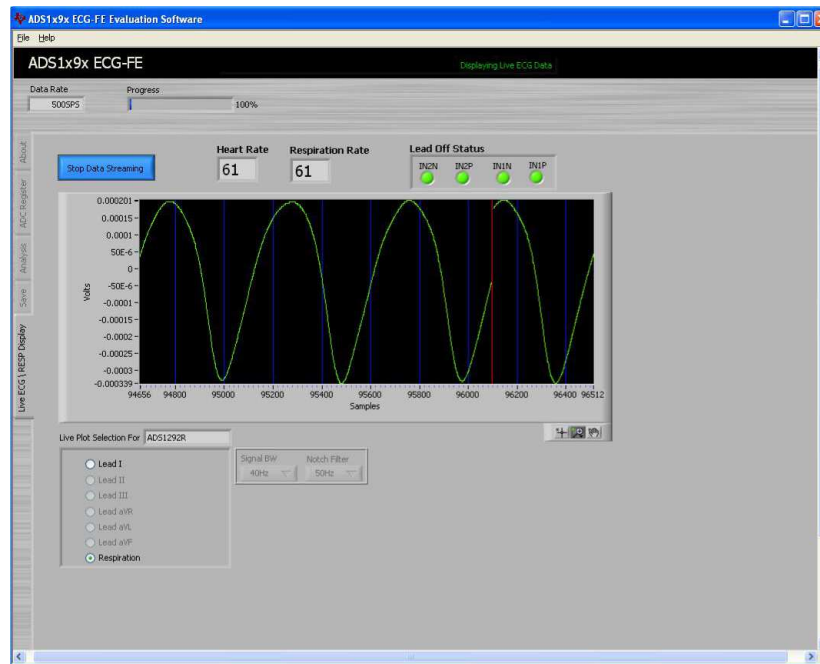
Figure 32. PC Application Live Respiration Channel

Live ECG display or respiration display is started by clicking on **Start Data Streaming** and can be stopped by clicking on **Stop Data Streaming**.

The following buttons/controls are available in this sub-tab:

Buttons/Control	Description
Lead selection	The following can be selected for the live display
	● ECG Lead I
	● ECG Lead II
	● ECG Lead III
	● ECG Lead aVR
	● ECG Lead aVL
	● ECG Lead aVF
	● Respiration Channel (ADS1292R only)
Signal BW	Signal bandwidth can be selected to either 40 Hz or 150 Hz. The filter on the EVM board is automatically enabled based on the selection made.
Notch filter	Provision for selecting either 50-Hz or 60-Hz notch filter. The filter on the EVM board is automatically enabled based on the selection made.
Auto scaling (Right-click on the display area)	Both x-scale and y-scale auto scaling is possible. User can enable or disable this feature.
Export data (Right-click on the display area)	The displayed data can be exported to EXCEL™ or the clipboard.
Visible items selector (Right-click on the display area)	Option to display x-scale, y-scale, plot legends, x-scrollbar.
Plot legend options (Right-click on the plot legend)	Plot legend gives various option to change the color of the plot, various plotting styles, etc.

The Lead-off Status is interpreted as shown in the table below.

Leads	Lead Off Status
LL off	IN2P is red
RA off	IN2N and IN1N are red
LA off	IN1P is red

Monitoring lead-off information is achieved by polling the Status byte in the data-word after each conversion. Within the ADS1x9xECG-FE software, there are two ways to view the Lead-Off Status. Within the *Live ECG\RESP* tab, the information about the lead status is shown in the upper right corner of the GUI. Within the *Analysis* tab, a pop-up window showing the status can be viewed by clicking on the **Show/Poll Lead-Off Status** button.

5 ADS1x9xECG-FE Hardware Introduction

The key features of the ADS1x9x analog front end demonstration board are:
- Based on MSP430F5529
- ADS1192 and ADS1292 suitable for six leads of ECG: Lead I, Lead II, Lead III, Lead aVR, Lead aVL, or Lead aVF
- ADS1292R suitable for one lead of ECG (Lead I) and respiration channel
- Low power consumption (350 Micro Watt/channel)
- Data Rate ranges from 125 SPS to 8 kSPS
- Unipolar Operation
- Lead off detection circuitry
- On chip oscillator and reference
- On chip RLD amplifier
- SPI data interface
- 8Gb NAND Flash support

The ADS1x9xECG-FE can be used as a demo board for standard six lead ECG and respiration channel using four electrode inputs. Defibrillator protection and patient protection circuitry are not provided on the ADS1x9xECG-FE board. The printed circuit board (PCB) and schematic are shown in Appendix C.

MSP430F5529 (U7) is the micro-controller used on the board. For more details of the MSP430F5529 please visit http://focus.ti.com/docs/prod/folders/print/msp430f5529.html

The following sections explain the main hardware components available on the ADS1x9xECG-FE.

5.1 Power Supply

ADS1x9x can operate from 2.7 V to 5.25 V analog supply (AVDD/AVSS) and 1.65 to 3.6V (DVDD) digital supply. In this design the ADS1x9x is operated at 3 V analog and 3.3 V digital.

The power for the board is derived from the USB input (P1) through a forward biased diode (D3) to avoid reverse current flow. The USB data bus is ESD protected using TI's ESD protection diode array TPD4E004DRYR (U2). The USB VBUS is fed to the integrated Li-ion linear charger and system power-path management module, BQ24032ARHLR (U8), which generates greater than 4.2V output (VCC_BAT). This output is then fed to TI's low-power linear voltage regulator, TPS73033 (U16), for generating regulated 3.3V for digital section of the board. The 3V supply for the analog section is derived from VCC_BAT using TI's low dropout voltage regulator TPS73201 (U10).

The inductors L3, L4, L5 and L7 are used to minimize the power supply noise induced by the power supply regulators.

The test points TP25, TP32 are provided to make sure the power supplied to the board is correct. The corresponding voltages are given in the table below. The analog power supply (ADS_AVDD) is also brought out on connector P3.

SI NO	Test Point	Description
1	TP25	3.3 V
2	TP32	ADS_AVDD, 3.0 V

5.2 Clock

The ADS1x9x includes an on-chip circuit which generates a 512 kHz clock, ±2% over temperature. For application requiring higher accuracy the ADS1x9x can also use an external clock signal. The demonstration kit provides the firmware option to select either an internal or external clock for testing. The demonstration kit also provides the option to generate an external clock for the ADC from the MSP430 or onboard oscillator.

Oscillators O2 (24MHz) and O3 (32.768 KHz) are used by the micro-controller.

Clock Type	R21	R24	Clock SEL
Internal Clock	Not Installed	Not Installed	Mount R77 to Drive "high" on ADC_CLK_SCL OR Set P2.3 of MSP430 to Drive "high" on ADC_CLK_SCL.
External Clock	Not Installed	Installed	Mount R76 to Drive "low" on ADC_CLK_SCL OR Clear P2.3 of MSP430 to Drive "low" on ADC_CLK_SCL.

5.3 Memory

ADS1x9xECG-FE has 8GB NAND Flash memory (U14) installed for data storage.

5.4 Accessing ADS1x9x Digital Signals

ADS1x9x SPI interface with MSP430 can be accessed through the test points given in the table below:

SI NO.	Signal	Test Points
1	ADC_CS	TP24
2	ADC_START	TP56
3	ADC_DOUT	TP47
4	ADC_SCLK	TP11
5	ADC_DIN	TP46
6	ADC_DRDY	TP52
7	ADC_RESET	TP53
8	CLK	TP42

5.5 GPIO Test Points

There are two GPIO connections between the ADS1x9x and the MSP430 micro-controller, which are accessible through the test points given in the table below:

SI NO.	Signal	Test Points
1	ADC_GPIO1	TP15
2	ADC_GPIO2	TP16

5.6 Analog Inputs

The ADS1x9xECG-FE gives the user the option to feed in the standard ECG/Respiration signals from a patient simulator to the DB9 connector (P5).

The output from any typical patient simulator can be directly fed into the DB9 connector. For all measurements in this user guide a Fluke medSim 300B simulator was used as shown in Figure 33.

Figure 33. Simulator Connection

5.7 USB Interface

The ADS1x9xECG-FE has a mini USB interface for PC application connectivity requiring a standard mini USB to USB cable for connection. ADS1x9xECG-FE is designed to work in the slave mode.

5.8 Onboard Key Interface

The ADS1x9xECG-FE board has four switches. Figure 34 details the position of each switch.
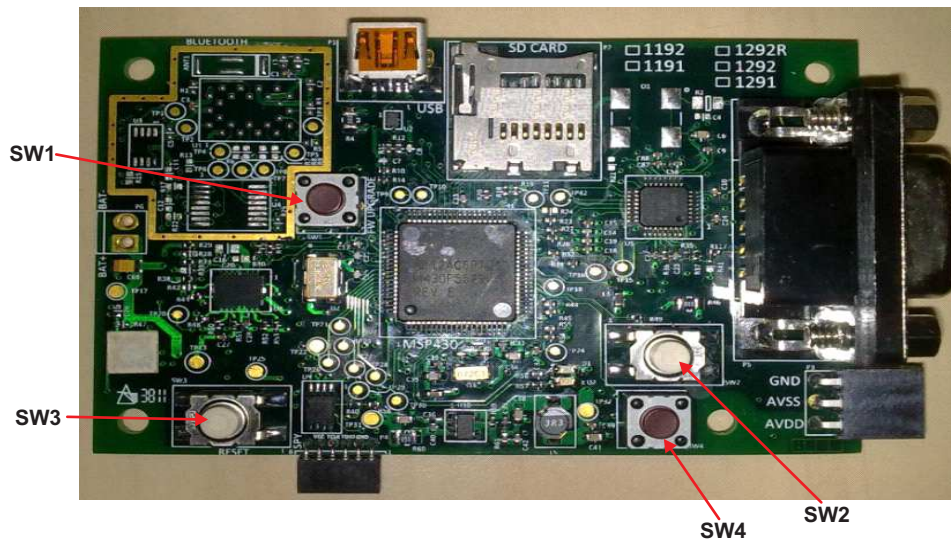
Figure 34. Switch Positions

The function of each switch is defined in the following table:

Switch Number	Description
SW1	This switch is used to enable boot strap loader (BSL) MSP430 firmware.
SW2	Unused
SW3	This switch is used for hard reset of the board. The board will reset and start again with the firmware loaded.
SW4	Unused

5.9   *Visual Indication*

The demonstration kit has two LEDs to indicate various operating states. The flashing green LED (D2) indicates the ADS1x9xECG-FE is in the idle state and steady blue LED (D1) indicates the micro-controller is busy in servicing requests from the PC application.

6   Evaluation of ECG and Respiration Specific Functions

The micro-controller receives the two-channel data from ADC through the SPI interface to send to the PC. The software is designed to handle the following activities:

- Data acquisition
- ADC Lead off detection
- DC signal removal
- Multi band pass filtering
- ECG lead formation
- QRS (HR) detection
- RR Detection
- USB communication
- Firmware upgrade through USB

The high level architecture of the firmware implementation for the ADS1292R is given below:
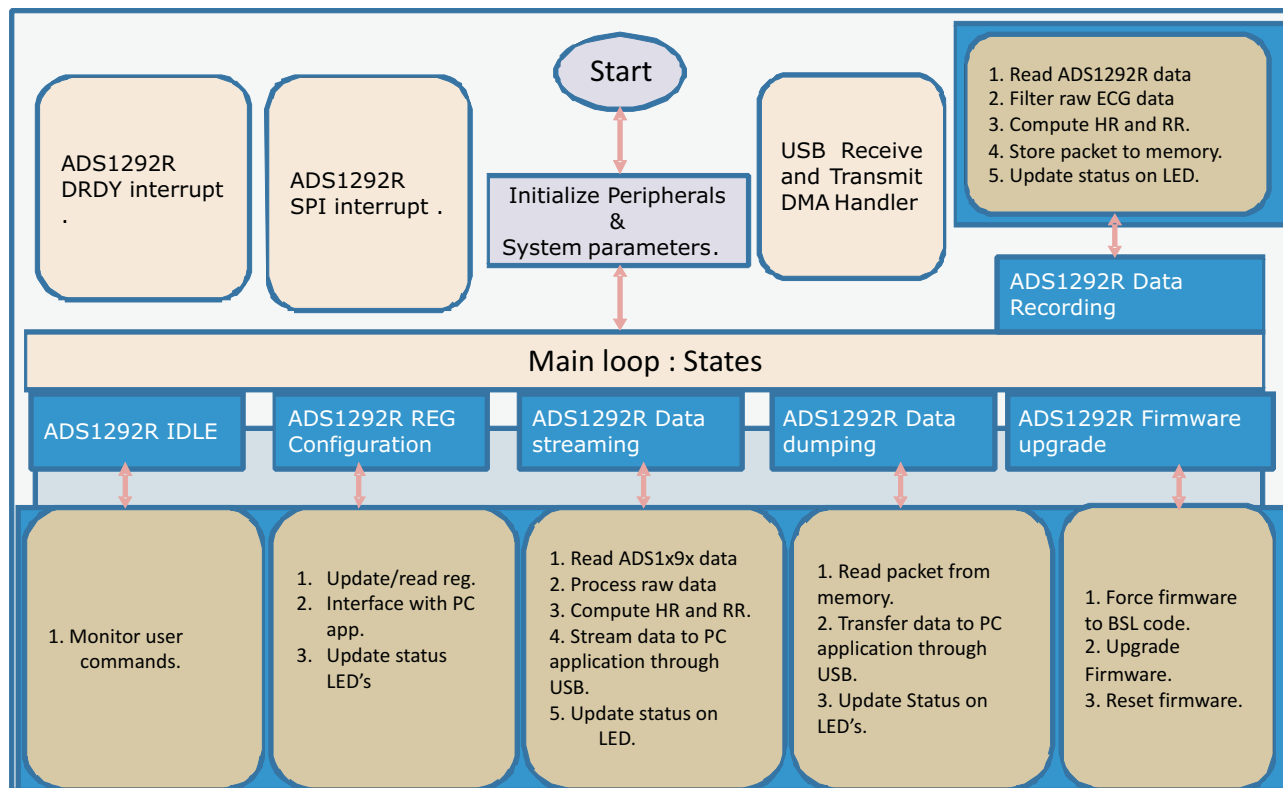
Figure 35. Firmware Architecture

The PC application consists of a LabVIEW front-end GUI with a back-end DLL written using C++. The DLL interfaces with the Windows USB driver and communicates to the demonstration kit. The LabVIEW front end GUI uses function calls to communicate with the demonstration kit through the DLL.

There are two general operating modes available in the system.

1. Evaluation Mode (Analysis Mode)
2. Live Data Streaming Mode

6.1 *Evaluation Mode (Analysis Mode)*

The Analysis Mode is used for the following requests:

1. Register setting
2. Register read
3. Data acquire

Firmware configures the ADC registers with default values during power on. Users can change the register settings through the PC application GUI. The register setting request from the PC is processed by the firmware and the appropriate register set command will be sent to the ADC.

During the data acquire request, the firmware will process the number of samples to be acquired as set in the GUI. The firmware instructs the ADC to start the data conversion in continuous mode. Based on the sampling rate configured, the ADC generates data ready pulses (DRDY) which are used by the micro-controller to indicate when to read data back. The data is stored in the onboard flash memory and later sent to the PC application in individual packets. Each packet contains 8 samples which are 24bits in length.
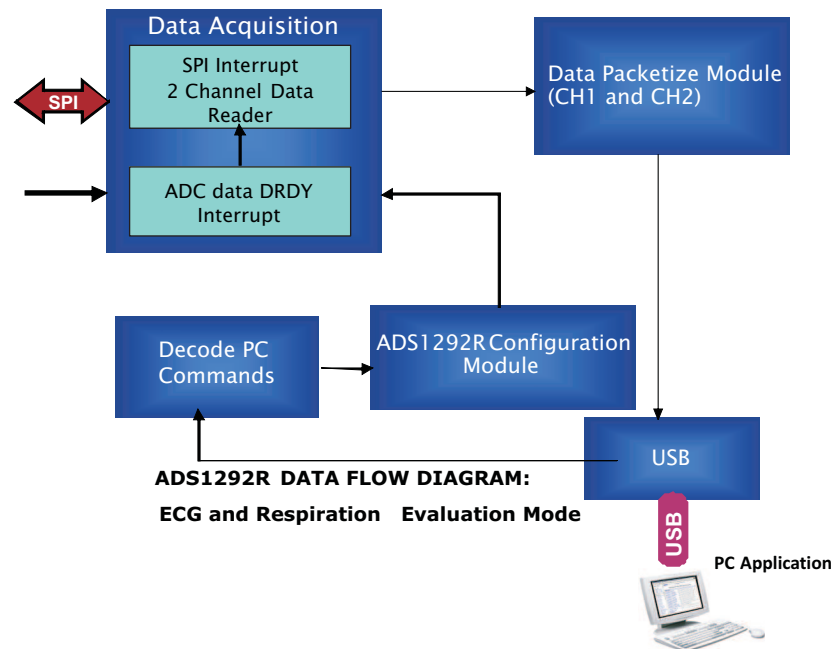
Figure 36. Evaluation Mode Data Flow for ADS1292R

6.2 *Live Data Streaming Mode*

The Live ECG / Live Respiration data streaming can be started from the PC application *Live ECG \ RESP Display* tab by clicking **Start Data Streaming**. The PC application will set the sampling rate to 500SPS before requesting the firmware to start the live data streaming.

The firmware will instruct the converter to run in continuous conversion mode, monitoring the DRDY interrupt for notification as to when new data is ready. Based on the interrupt, the firmware reads the data from the ADC.

The firmware applies the following filters on the data read:

1. DC removal IIR filter
2. Multiband-pass FIR filter with 50/60 Hz notch (user selectable) or band-pass filter

The filtered signal is used for detecting the heart rate, respiration rate and deriving ECG leads. Filters are applied only for live data streaming mode.

The system data flow diagram for live data stream mode is given in Figure 37.
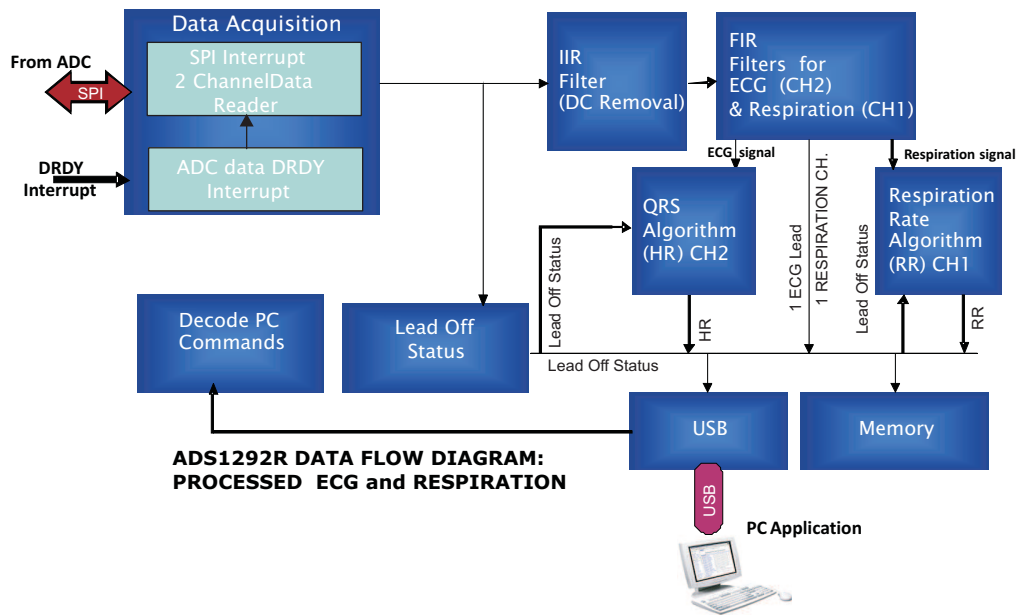
Figure 37. Live Data Stream Mode Data Flow for ADS1292R

6.2.1   Filters

IIR Filter - DC signal removal

1st Order IIR filter is used to remove the DC component from the acquired data. The following transfer function is used for the filter:

$$H(z) = \frac{Y(z)}{X(z)} = \frac{1 - z^{-1}}{1 - az^{-1}}$$

(1)

To provide DC attenuation at 22dB, the value of alpha is chosen as 0.992. The IIR filter output is scaled down to 16-bit and then provided to the FIR filter. The frequency response for the IIR filter is shown in Figure 38.
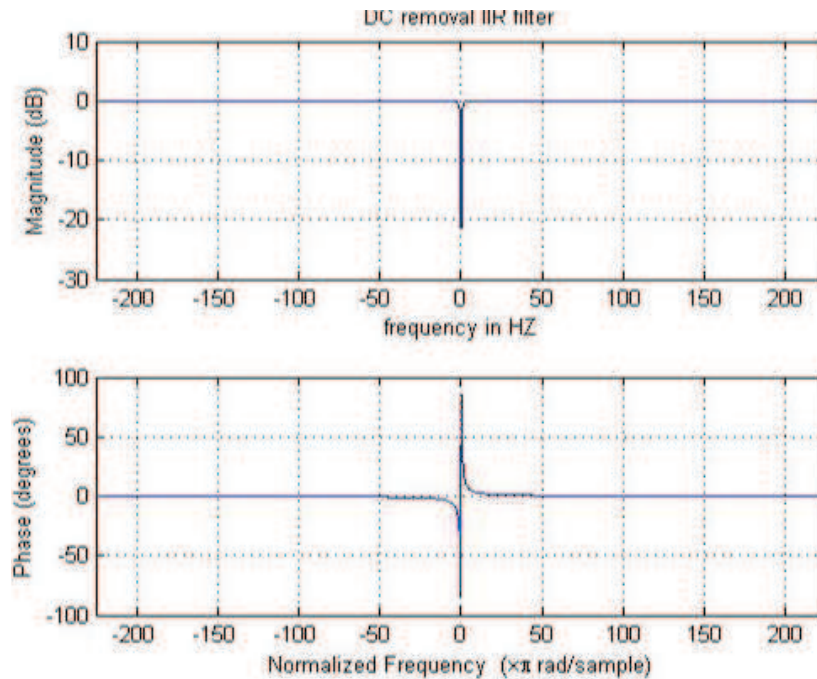
Figure 38. Frequency Response for the IIR Filter

Multiband-pass Filter

Multiband-pass filter (MBF) is used for removing unwanted signals and power line noise from the live data.

The MBF digital filter is a 161 order FIR filter with Hamming window having cut-off at 150Hz and notch at 50/60 Hz. The notch frequency is selectable from the PC application. This filter provides a very sharp cut-off around 150 Hz with attenuation more than 30 dB at the stop band. The notch at 50/60 Hz provides attenuation of more than 30 dB. Sampling frequency is 500 samples/ second.

The frequency response of the filter with a 50 Hz notch is shown in Figure 39, Figure 40, and Figure 41.
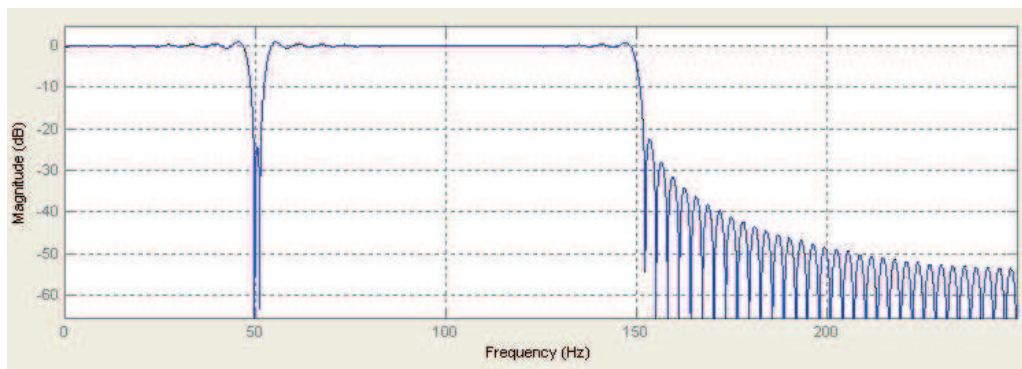
Figure 39. Frequency Response for the MBF Filter (Full View)
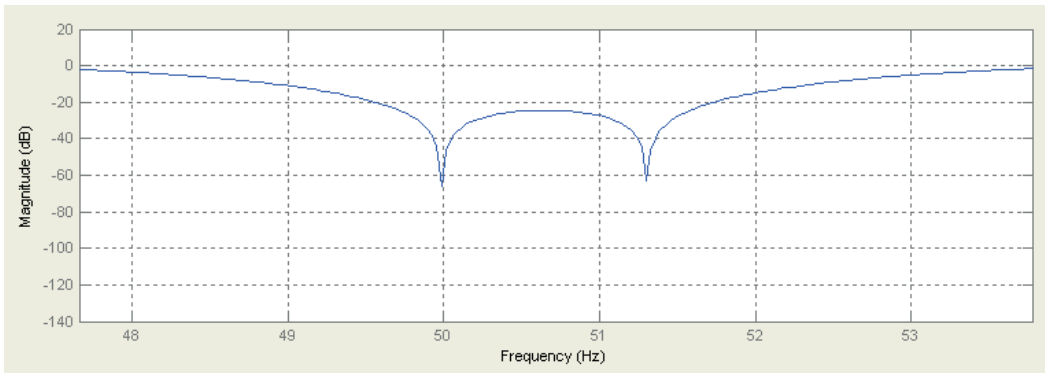
Figure 40. Frequency Response for the MBF Filter (50Hz Notch)
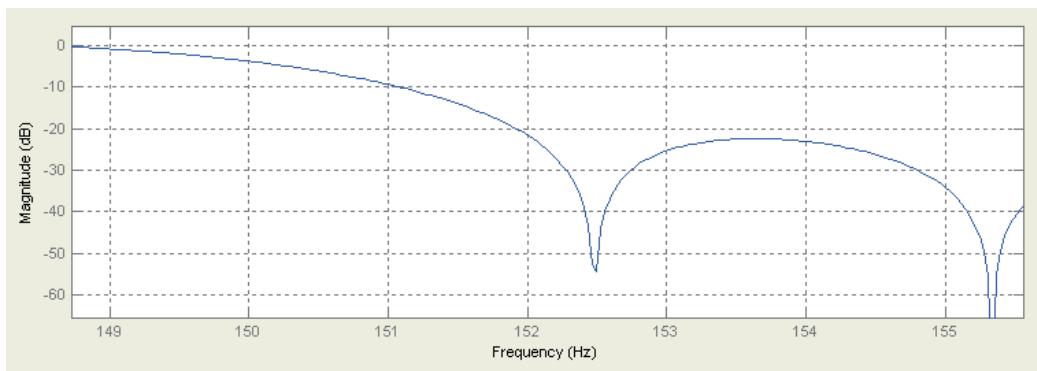
Figure 41. Frequency Response for the MBF Filter (Sharp cut off Around 150Hz)

Band Pass Filter
PC application allows the selection of a 161 order muscle artifact filter, which has a passband of 0.67 Hz to 40 Hz. This filter provides a sharp cut-off at 40 Hz with attenuation of 30 dB at the stop band. The frequency response for the filter is shown in Figure 42.
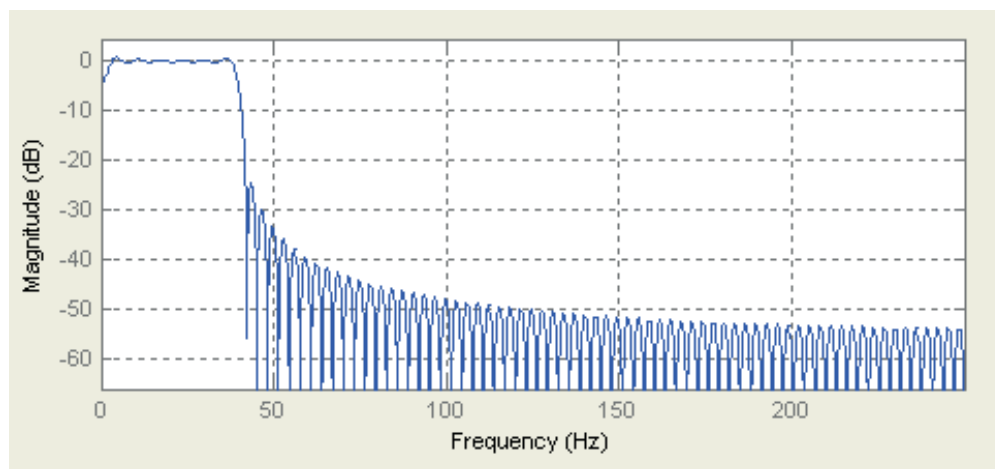
Figure 42. Frequency Response for the Band Pass Filter

6.2.2   Lead Derivation

The demonstration kit is configured to generate two ECG leads (Lead I and Lead II) from the four electrodes using two channels of the ADS1192 and ADS1292 data. The other four ECG leads are computed from Lead I and Lead II using the following equations:

Lead III = Lead II - Lead I

Lead aVR = - Lead II + 0.5 * Lead III

Lead aVL = Lead I - 0.5 * Lead II

Lead aVF = Lead III + 0.5 * Lead

The ADS1292R demonstration kit is configured to generate one ECG lead (Lead I) and one respiration channel from the four electrodes using the two channels.

6.2.3   QRS and Respiration Rate Detection

QRS detection is based on first derivative of the Lead I ECG signal and threshold. Once five consecutive QRS are detected, the heart rate is calculated by taking average of the five RR intervals.

The following steps are involved for calculating heart rate:

1. Calculate first derivative of the Lead I ECG signal samples. The first derivative for any sample is calculated as

    $y0(n) = |x(n+1) - x(-1)|$

    Where,
    y0(n) is the first derivative.
    x (n+1) is the sample value for (n + 1) th sample.
    x (n - 1) is the sample value for (n - 1) th sample.

2. The initial two seconds of the first derivative is stored in a buffer and the maximum value (P) in this buffer is obtained.

3. Calculate the threshold as 0.7 x P.

4. Whenever a derivative crosses the threshold, the ECG sample index (S1) of that particular sample is marked.

5. The QRS peak is detected by scanning the next 40 derivatives (MAXIMA_SEARCH_WINDOW = 40) and obtaining the maxima (M1) .This maxima (M1) value is stored in another buffer.
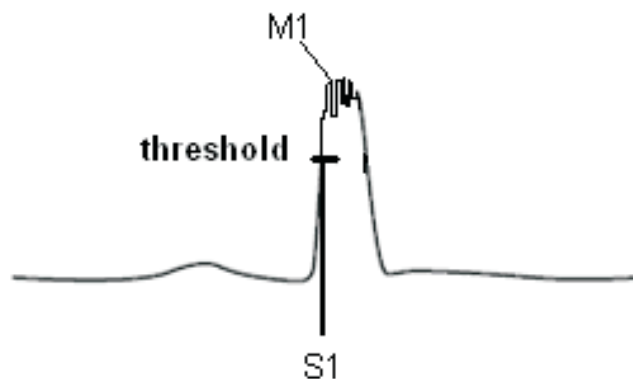
6. After detecting a QRS peak, the next 50 samples (SKIP_WINDOW = 50) are skipped to take care of the minimum RR interval that can occur in the case of maximum detectable heart rate (i.e. 240 BPM).

7. Next five QRS peaks are detected by repeating steps 4 to 7.

8. RR interval is calculated as the number of samples between two consecutive QRS peaks.

9. Heart rate is calculated using the below formula HR per Minute = (60 * Sampling Rate)/ (Average RR interval for 5 consecutive RR intervals)

10. Threshold also gets recalculated from the QRS peak values detected.

Respiration rate for boards with the ADS1292R installed is calculated from the respiration waveform using the similar algorithm mentioned above.

USB Receive and transmit module
The processed ECG and Respiration data including the heart rate, lead-off status, and respiration rate is communicated to the PC, packet by packet, through the ECG interface. The packet contains 14 samples of data, each being 16bits in width.

7   USB-Based Firmware Upgrade

The firmware on the ADS1x9xECG-FE can be changed from the PC application by selecting the **Firmware Upgrade** option on the PC application. At the end of the firmware upgrade, the system issues a reset command and will reload with new firmware. The firmware upgrade process steps are represented in the below screen shots:

1. Select PC application menu *File> Load Firmware*
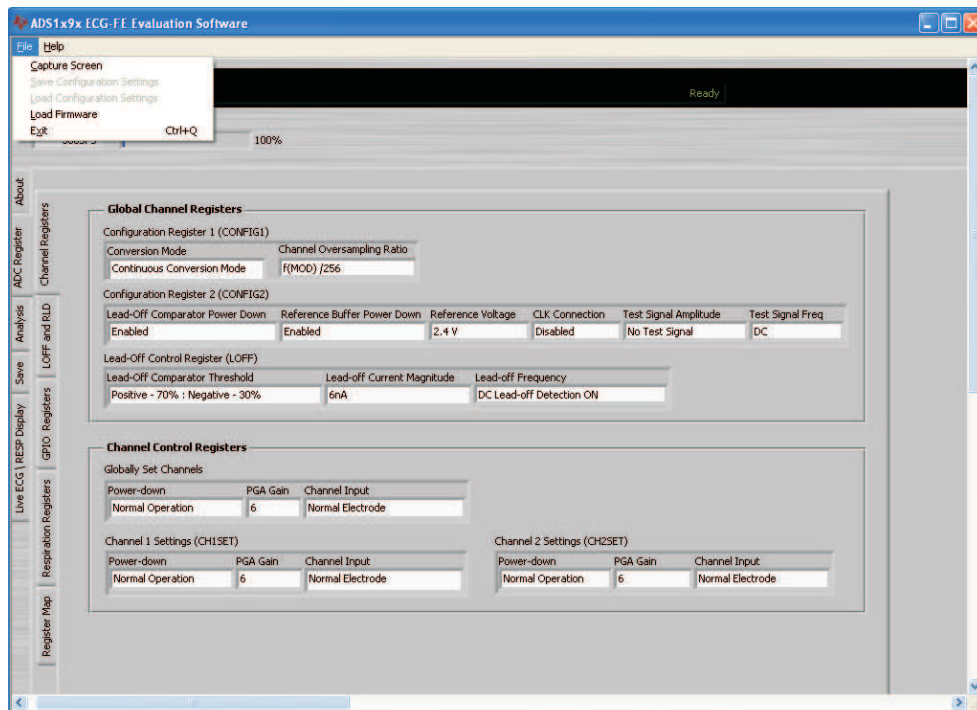
Figure 43. PC Application Firmware Upgrade - 1

2. The firmware upgrade application window and the application will detect the connected ADS1x9xECG-FE.
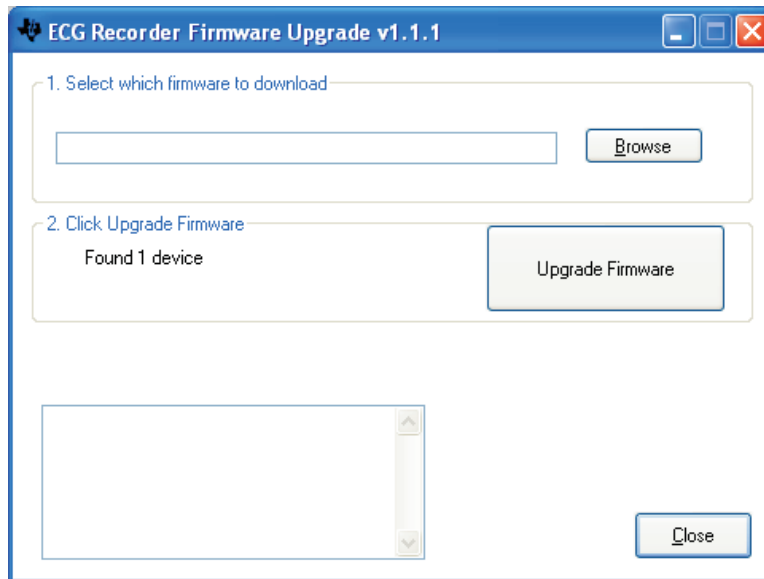
Figure 44. PC Application Firmware Upgrade - 2

3. Browse and select the firmware binary file (.txt file) and click "Upgrade Firmware"
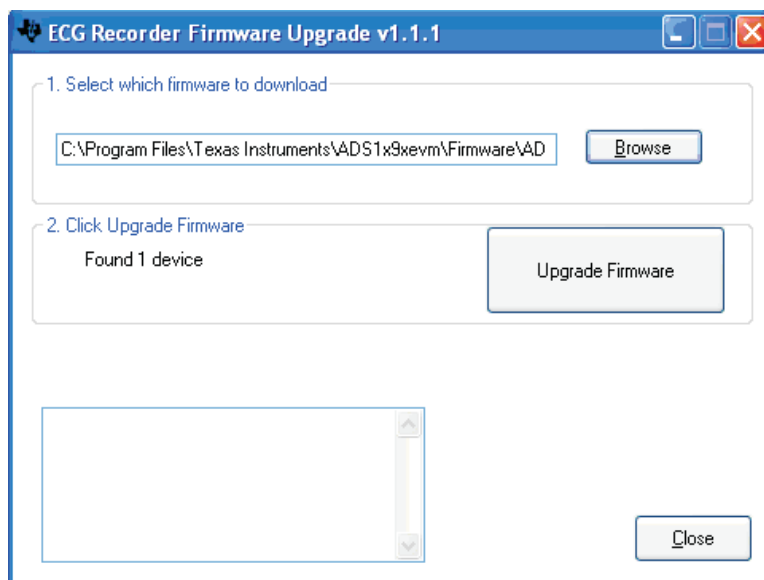
Figure 45. PC Application Firmware Upgrade - 3

> **NOTE:** The default firmware will be available at *C:\Program Files\Texas Instruments\ADS1x9xevm\Firmware*.

4. Device will reset and come up with new firmware with itself.

8   Connector Interface

The following connectors used for external interface to ADS1x9x ECG recorder board.

- DB9
- USB mini connector

8.1   DB9 ECG Electrode Connector
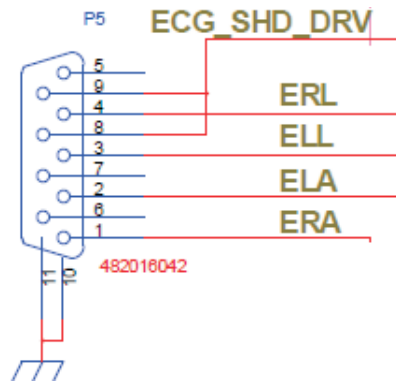
Figure 46. DB9 ECG Connector Pin Outs

NO	Signal	Description
1	ERA	
2	ELA	
3	ELL	
4	ERL	
5	NC	No Connect
6	NC	No Connect
7	NC	No Connect
8,9	ECG_SHD_DRV	

8.2   USB Mini Connector
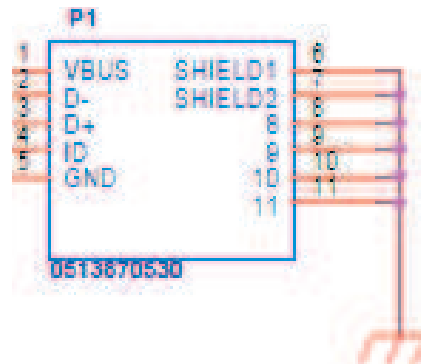
Figure 47. USB Mini Connector Pin Outs

NO	Signal	Description
1	VBUS	USB power 5 V
2	D–	USB DM
3	D+	USB DP
4	ID	NC
5	GND	GND

Appendix A ECG Cable Details

The DB9 ECG connector uses the following pin out.

Pin	Electrode Name
1	RA
2	LA
3	LL
4	RL
5	Open
6	Open
7	Open
8	Shield
9	Shield
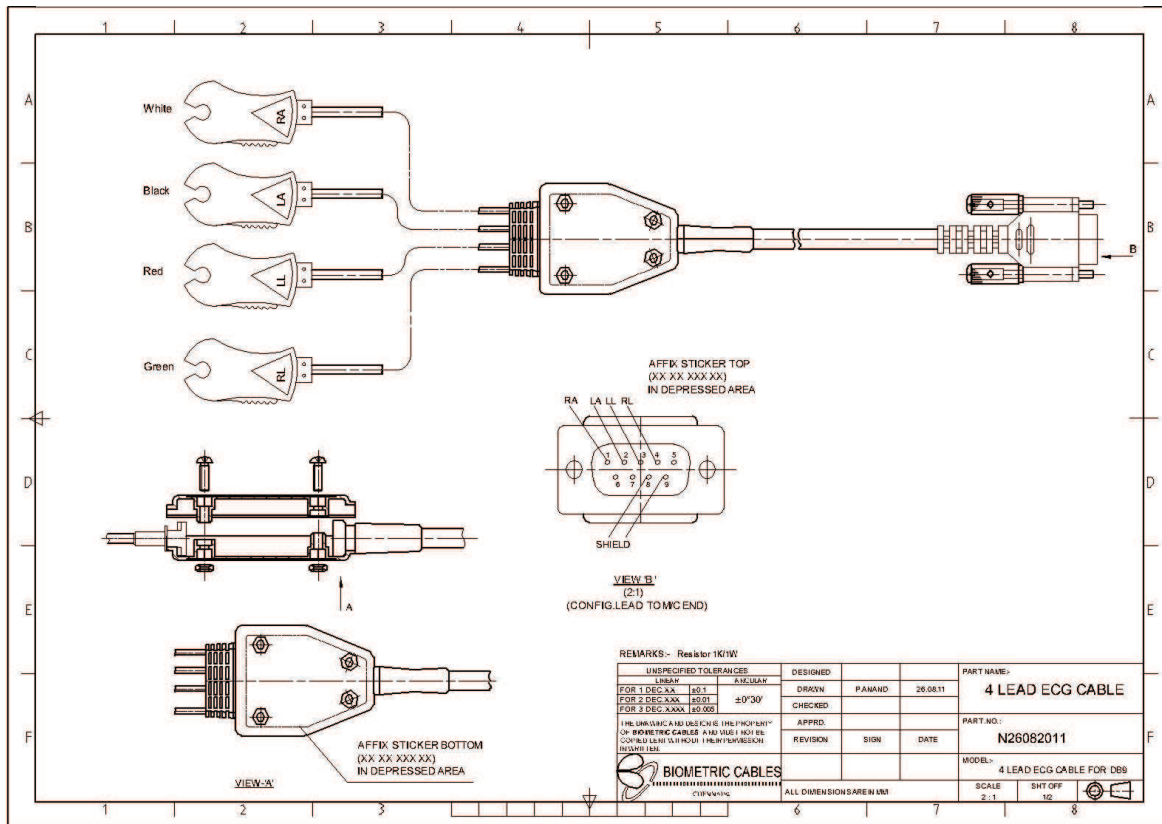
Figure 48. ECG Cable Drawing

The ECG cable can be ordered through http://www.biometriccables.com/ using the part number N26082011.

Appendix B ADS1x9x EVM Bill of Materials (BOM)

The following pages show the bill of materials table, landscaped for readability.

Table 1. Bill of Materials

Item	Quantity			Ref Des	Description	Manufacturer	Part Number
	ADS1292R	ADS1292	ADS1192				
1	1	1	1		Printed Wiring Board	TI	6525569
2	0	0	0	ANT1	Not Installed		
3	0	0	0	C1 ,C2, C3, C4, C5, C11, C12, C20, C26, C51, C54, C55, C57, C61, C69, C71, C73, C74, C78, C79, C80, C83, C89, C90, C91, C92	Not Installed		
4	10	10	10	C6, C34, C35, C36, C38, C41, C43, C65, C70, C85	CAP CER 10UF 6.3V X5R 20% 0603	AVX	06036D106MAT2A
5	4	4	4	C7, C8, C21, C25	CAP CER 10PF 50V NP0 RF 0402	AVX	04025U100CAT2A
6	18	18	18	C9, C13, C15, C19, C28, C31, C33, C39, C44, C52, C63, C64,C67, C72, C76, C77, C84, C87	CAP CER 0.1UF 16V X7R 0402	TDK	C1005X7R1C104K
7	2	2	2	C10	CAP CER 4700PF 10V 0402 LOW DIST	Taiyo Yuden	LMK105SD472KV-F
8	0	1	1	C24	CAP CER 4700PF 10V 0402 LOW DIST	Taiyo Yuden	LMK105SD472KV-F
	1	0	0		CAP CER 0.047UF 10V 10% X7R 0402	Murata	GRM155R71A473KA01D
9	8	8	8	C14, C18, C22, C27, C40, C58, C86, C88	CAP CERM 1.0UF 10% 6.3V X5R 0402	AVX	04026D105KAT2A
10	0	0	0	C16, C59, C62	Not Installed		
11	2	2	2	C17, C66	CAP CER 0.22UF 16V X7R 0402	Murata	GRM155R71C224KA12D
12	1	1	1	C23	CAP CER 1500PF 50V X7R 0402	AVX	04025C152JAT2A
13	2	2	2	C29, C30	CAP CER 12PF 5% 50V NP0 0402	AVX	04025A120JAT2A
14	1	1	1	C32	CAP CER 0.47UF 16V X5R 0402	TDK	C1005X5R1C474K
15	3	3	3	C37, C81, C82	CAP CER 2.2UF 4.0V X5R 20% 0402	AVX	04024D225MAT2A
16	2	2	2	C42, C75	CAP CERM 10000PF 5% 16V X7R 0402	AVX	0402YC103JAT2A
17	2	0	0	C45, C47	CAP CERM 2200PF 10% 50V X7R 0402	AVX	04025C222KAT2A
18	2	0	0	C46,C48	CAP CER 0.1UF 16V X7R 0402	TDK	C1005X7R1C104K
19	0	2	2		RES 0.0 OHM 1/10W 0402 SMD	Panasonic	ERJ-2GE0R00X
20	2	0	0	C49, C50	CAP CERM 2200PF 10% 50V X7R 0402	AVX	04025C222KAT2A
21	0	2	2		RES 0.0 OHM 1/10W 0402 SMD	Panasonic	ERJ-2GE0R00X
22	1	1	1	C53	CAP CER 4.7UF 6.3V X5R 0402	Murata	GRM155R60J475ME87D
23	2	2	2	C56, C60	CAP CERM 47PF 5% 50V NP0 0402	AVX	04025A470JAT2A
24	1	1	1	C68	CAP TANT 22UF 6.3V 20% 0805	AVX	TACH226M006XTA
25	1	1	1	D1	LED 470NM BLUE CLEAR 0603 SMD	Rohm	SMLE12BC7TT86
26	1	1	1	D2	LED 565NM GRN DIFF 0603 SMD	Lumex	SML-LX0603GW-TR
27	1	1	1	D3	DIODE SCHOTTKY 400MW 20V SOD123	Diodes Inc	SD103CW-13-F
28	0	0	0	D4	Not Installed		
29	0	0	0	L1, L2	Not Installed		

Table 1. Bill of Materials (continued)

Item	Quantity			Ref Des	Description	Manufacturer	Part Number
	ADS1292R	ADS1292	ADS1192				
30	1	1	1	L3	FERRITE CHIP 120 OHM 2000MA 0603	Murata	BLM18PG121SN1D
31	2	2	2	L4,L7	FILTER CHIP 220 OHM 2A 0603	Murata	BLM18EG221SN1D
32	1	1	1	L5	INDUCTOR POWER 3.3UH 1.3A SMD	TDK	VLF4012AT-3R3M1R3
33	0	0	0	L6	Not Installed		
34	0	0	0	O1	Not Installed		
35	1	1	1	O2	CRYSTAL 24.0000MHZ 10PF SMD	Abracon	ABM3B-24.000MHZ-10-1-U-T
36	1	1	1	O3	CRYSTAL 32.768KHZ 12.5PF SMD	Abracon	ABS07-32.768KHZ-T
37	1	1	1	P1	CONN RCPT MINIUSB B 5POS SMD R/A	Molex Inc	513870530
38	0	0	0	P2	Not Installed		
39	1	1	1	P3	3 pin Connector	Samtec	SSW-103-02-S-S-RA
40	0	0	0	P4	Not Installed		
41	1	1	1	P5	CONN D-SUB RCPT R/A 9POS GOLD/FL	TE Connectivity	1734354-1
42	0	0	0	P6	Not Installed		
43	1	1	1	Q1	TRANSISTOR NPN 25V 50MA SOT-23	On Semi	MMBT5089LT1G
44	0	0	0	R1, R3, R5, R6, R7, R8, R9, R13, R15, R17, R21, R22, R24, R25, R28, R39, R41, R42, R47, R65, R67, R68, R74, R76, R78, R79, R80, R81, R83, R86, R88, R89, R90, R91, R92, R93, R96, R103	Not Installed		
45	0	0	0	R2	Not Installed		
46	7	7	7	R4, R46, R60, R97, R108, R111, R114	RES 0.0 OHM .33W 0805 SMD	Vishay/Dale	CRCW08050000Z0EAHP
47	2	2	2	R10, R36	RES 1.0M OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ105X
48	3	3	3	R11, R12, R20	RES 33 OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ330X
49	1	1	1	R14	RES 1.40K OHM 1/10W 1% 0402 SMD	Panasonic	ERJ-2RKF1401X
50	1	0	0	R16	RES 51K OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ513X
	1	1	1	R73			
	0	1	1	R85			
51	15	15	15	R18, R19, R29, R30, R31, R32, R33, R34, R38, R48, R52, R53, R77, R94, R95	RES 10K OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ103X
52	22	22	22	R23, R26, R27, R37, R40, R44, R45, R49, R51, R54, R55, R75, R84, R98, R99, R100, R102, R105, R106, R109, R110, R113	RES 0.0 OHM 1/10W 0402 SMD	Panasonic	ERJ-2GE0R00X
53	2	2	2	R35, R117	RES 100K OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ104X

Table 1. Bill of Materials (continued)

Item	Quantity			Ref Des	Description	Manufacturer	Part Number
	ADS1292R	ADS1292	ADS1192				
54	3	3	3	R43, R101,R107	RES 1.0K OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ102X
55	1	1	1	R50	RES 33K OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ333X
56	1	1	1	R56	RES 130 OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ131X
57	1	1	1	R57	RES 220 OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ221X
58	1	1	1	R58	RES 47K OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ473X
59	1	1	1	R59	RES 46.4K OHM 1/10W 1% 0402 SMD	Panasonic	ERJ-2RKF4642X
60	1	1	1	R61	RES 30.9K OHM 1/10W 1% 0402 SMD	Panasonic	ERJ-2RKF3092X
61	4	0	0	R62, R64, R66, R72	RES 10.0M OHM 1/16W 1% 0402 SMD	Panasonic	CRCW040210M0FKED
62	2	0	0	R63, R71	RES 0.0 OHM 1/10W 0402 SMD	Panasonic	ERJ-2GE0R00X
63	0	2	2		RES 51K OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ513X
64	2	0	0	R69, R70	RES 40K OHM 0.15W 0.1% 0603	Vishay/Thin Film	PAT0603E4002BST1
65	2	2	2	R82, R115	RES 100 OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ101X
66	0	0	0	R87	Not Installed		
67	1	1	1	R104	RES 4.7K OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ472X
68	1	1	1	R112	RES 10 OHM 1/10W 5% 0402 SMD	Panasonic	ERJ-2GEJ100X
69	2	2	2	R116, R118	RES 0.0 OHM 1/10W 0402 SMD	Panasonic	ERJ-2GE0R00X
70	2	2	2	SW1,SW4	SWITCH LT 6MM 160GF 5MM HEIGHT	Panasonic	EVQ-21505R
71	2	2	2	SW2,SW3	SWITCH TACT 2.36MM SILVR G-WING	C&K Components	KT11P2SM34LFS
72	0	0	0	TP1-TP60			
73	0	0	0	U1	Not Installed		
74	1	1	1	U2	4-Channel ESD-Protection Array	Texas Instruments	TPD4E004DRYR
75	0	0	0	U3	Not Installed		
76	0	0	0	U4	Not Installed		
77	1	0	0	U5	2 channel Analog to Digital Converter (24 bit with resp)	Texas Instruments	ADS1292RIPBS
78	0	1	0		2 channel Analog to Digital Converter (24 bit)	Texas Instruments	ADS1292IPBS
79	0	0	1		2 channel Analog to Digital Converter (16 bit)	Texas Instruments	ADS1192IPBS
80	1	1	1	U7	MSP Microcontroller	Texas Instruments	MSP430F5529IPNR
81	1	1	1	U8	Power-Path Management IC	Texas Instruments	BQ24032ARHLR
82	1	1	1	U9	2 bit Voltage Level Shfter	Texas Instruments	TXS0102DCTR
83	1	1	1	U10	3V Low-Dropout Regulator	Texas Instruments	TPS73201DBVT
84	0	0	0	U11	Not Installed		
85	0	0	0	U12	Not Installed		
86	0	0	0	U13	Not Installed		
87	1	1	1	U14	8Gb NAND Flash	Micron	MT29F8G08ABABAWP:B
88	0	0	0	U15	Not Installed		

Table 1. Bill of Materials (continued)

Item	Quantity			Ref Des	Description	Manufacturer	Part Number
	ADS1292R	ADS1292	ADS1192				
89	1	1	1	U16	3.3V Linear Regulator	Texas Instruments	TPS73033DBVR
90	0	0	0	U17	Not Installed		
91	1	1	1	U18	3.3V supervisors	Texas Instruments	TPS3825-33DBVT
Battery Assembly							
92	0	0	0	Connector on battery	CONN HOUSING 2POS .100 W/O RAMP	Molex	22012021
93	0	0	0	Connector on battery	CONN TERM CRIMP 18-24AWG TIN	Molex	8030303
94	0	0	0	Battery	4.2V Li Ion Battery	Power Stream	GM065080
95	0	0	0	Battery Cable	22 AWG red color cable		
96	0	0	0	Battery Cable	22 AWG black color cable		

Appendix C PCB Layout and Schematics

C.1   PCB Layout

The following pages show the PCB layout, landscaped for readability.
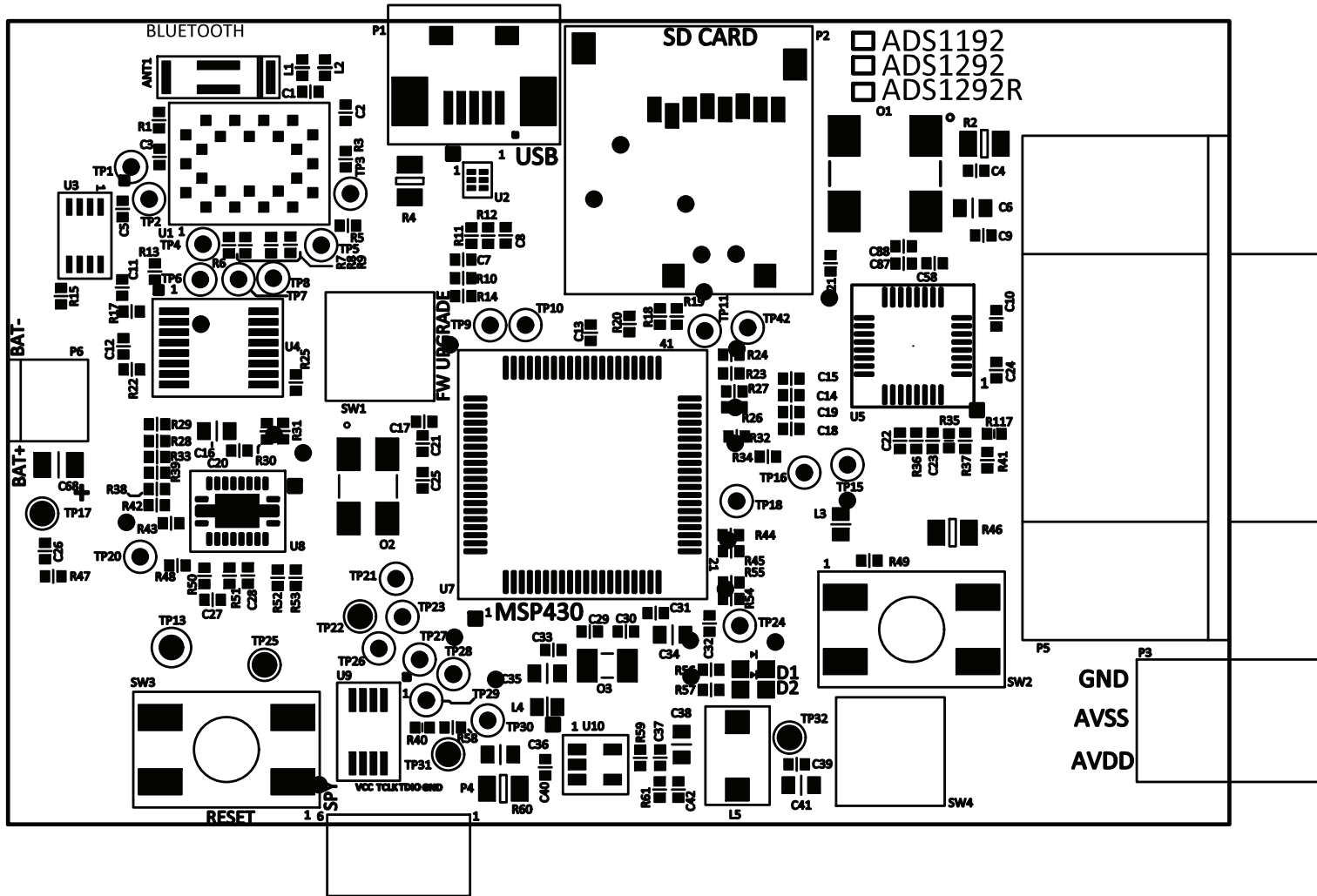
Figure 49. Top Layer Placement
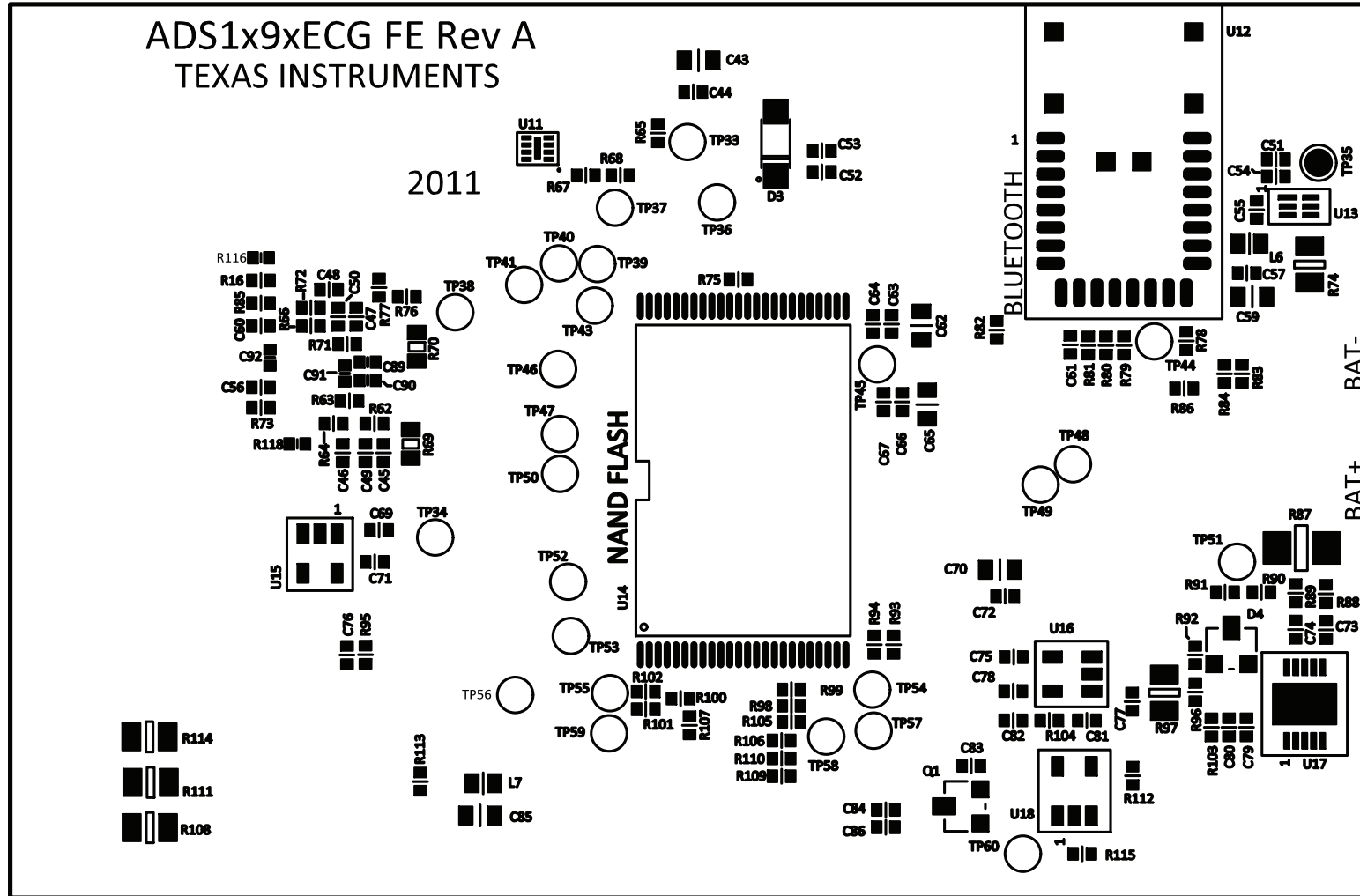
Figure 50. Bottom Layer Placement

C.2 Schematics

The schematics are appended to the end of this data sheet.

Block Diagram — ADS1x9xECG FE

- Battery
- Power Module
- USB → To PC Application
- Power
- BT Module
- Data
- 1.ADS1292R - 24 bit 2 Ch
  - -- 1 Ch ECG
  - -- 1 Ch Respiration
- 2.ADS1292 - 24 bit 2 Ch
  - -- 2 Ch ECG
- 3.ADS1192 - 16 bit 2 Ch
  - -- 2 Ch ECG
- I2C
- SPI
- USB
- UART
- JTAG
- GPIO
- SPI
- GPIO
- Flash Memory
- Micro SD
- LEDs & Keys
- Optional
- Must have modules
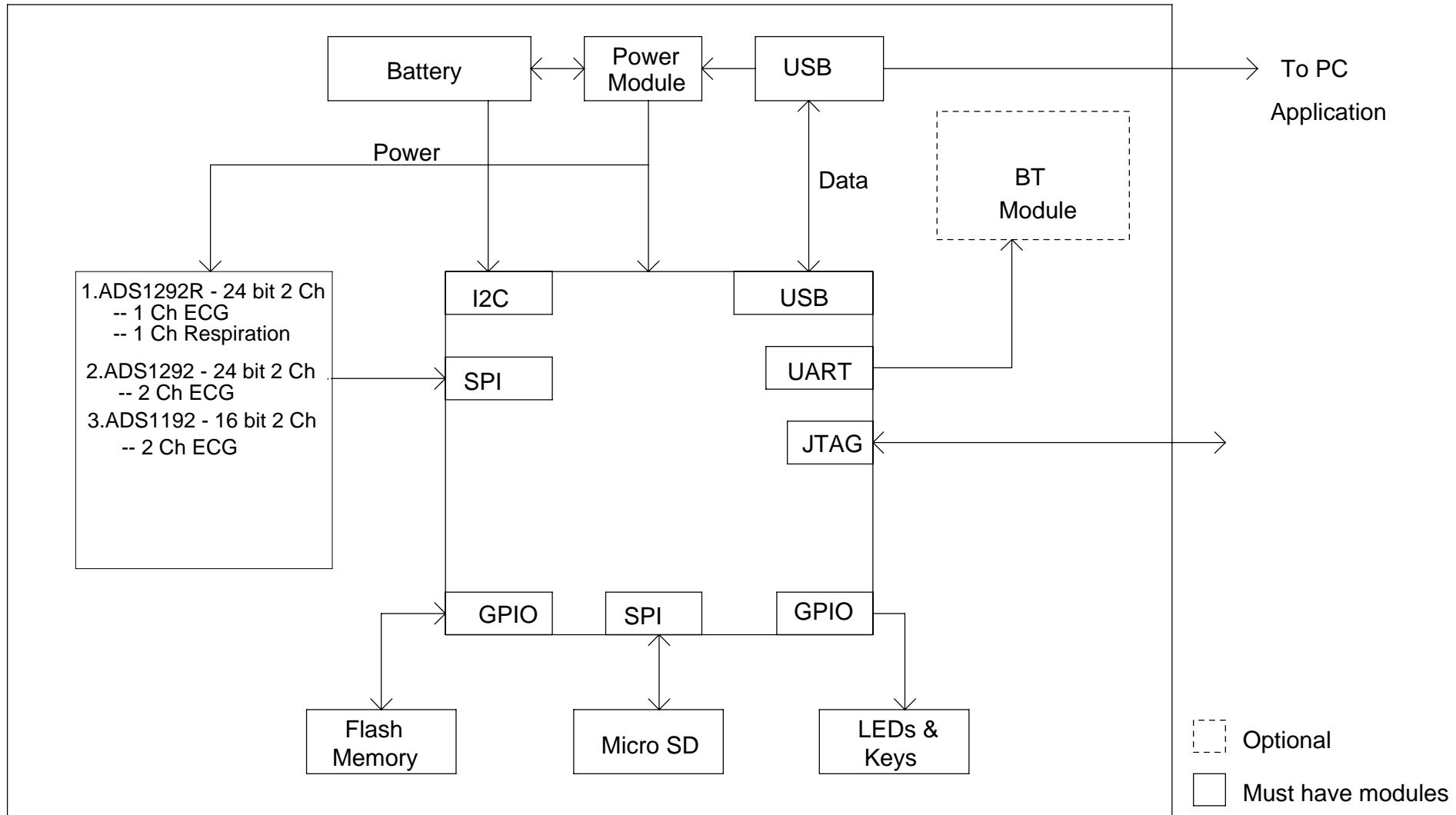
Title: Block Diagram
Size: B
Document Number: ADS1x9xECG FE
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Date: Thursday, August 04, 2011
Sheet 1 of 7

DNI

ADS_AVDD

C71
NI

ECG_SHD_DRV
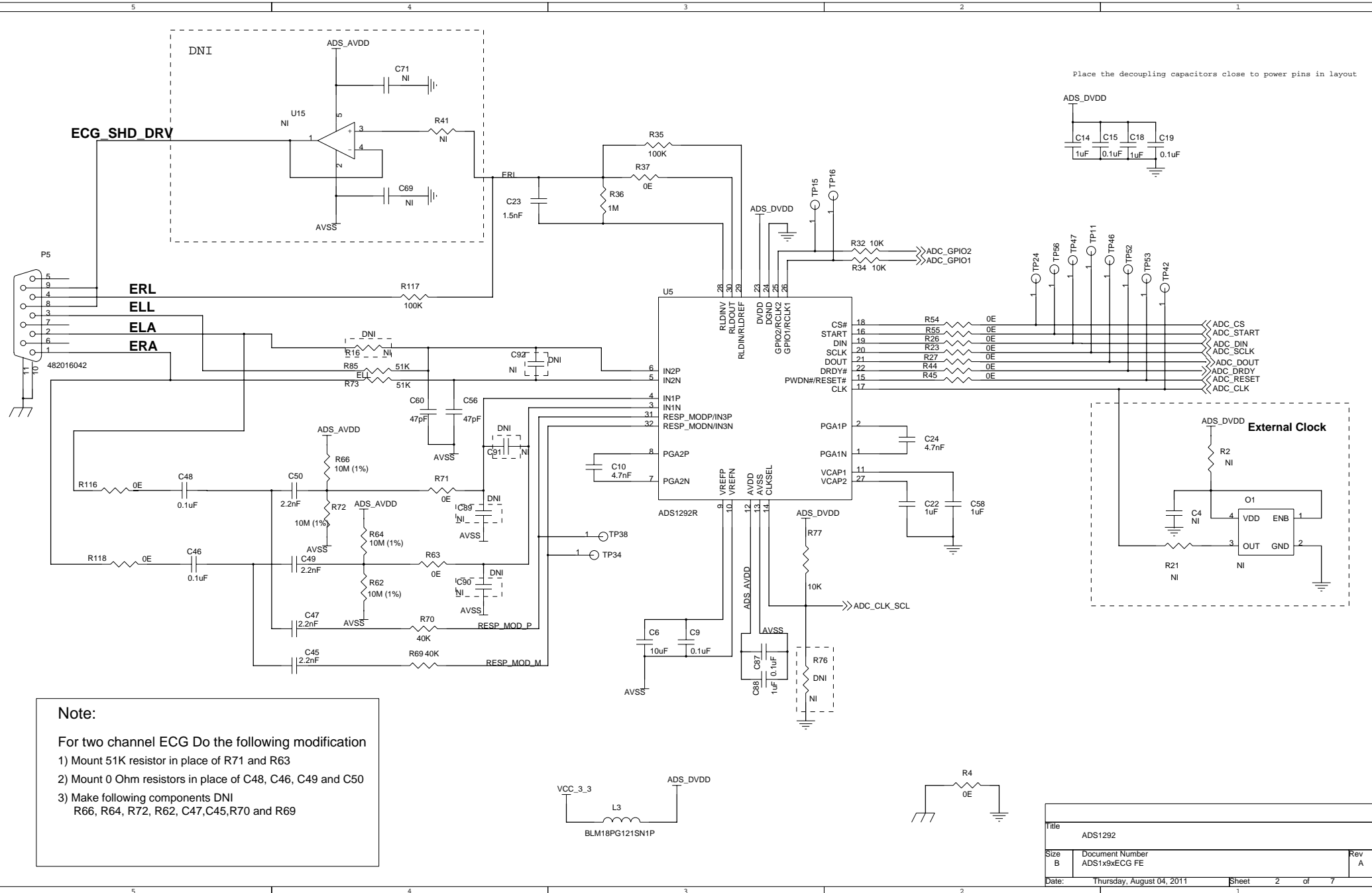
Place the decoupling capacitors close to power pins in layout

ADS_DVDD

C14 | C15 | C18 | C19
1uF | 0.1uF | 1uF | 0.1uF

U15
NI

R41
NI

R35
100K

R37
0E

ERI

R36
1M

ADS_DVDD

TP15 TP16

R32 10K → ADC_GPIO2
R34 10K → ADC_GPIO1

C69
NI

AVSS

C23
1.5nF

P5
5
9
4
8
7
3
2
6
1
10

482016042

ERL
ELL
ELA
ERA

R117
100K

TP24 TP56 TP47 TP11 TP46 TP52 TP53 TP42

U5

28 30 29   23 24 25 26
RLDINV RLDOUT RLDIN/RLDREF   DVDD DGND GPIO2/RCLK2 GPIO1/RCLK1

R18 NI
R85 51K
R73 51K

C92 DNI
NI

ELL

6 IN2P
5 IN2N
4 IN1P
3 IN1N
31 RESP_MODP/IN3P
32 RESP_MODN/IN3N

CS# 18   R54 0E → ADC_CS
START 16   R55 0E → ADC_START
DIN 19   R26 0E → ADC_DIN
SCLK 20   R23 0E → ADC_SCLK
DOUT 21   R27 0E → ADC_DOUT
DRDY# 22   R44 0E → ADC_DRDY
PWDN#/RESET# 15 R45 0E → ADC_RESET
CLK 17   → ADC_CLK

C60 C56
47pF 47pF

DNI
C91 NI

AVSS

8 PGA2P
7 PGA2N

C10
4.7nF

PGA1P 2
PGA1N 1
VCAP1 11
VCAP2 27

C24
4.7nF

ADS_DVDD

External Clock

R2
NI

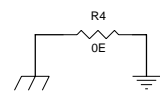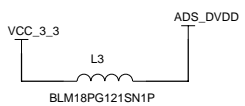ADS_AVDD

R66
10M (1%)

R116 0E
C48
0.1uF

C50
2.2nF

R72
10M (1%)

ADS_AVDD

R71
0E

C89
NI DNI

AVSS

ADS_1292R

C22 C58
1uF 1uF

ADS1292R

VREFP VREFN AVDD AVSS CLKSEL
10 9 12 13 14

ADS_DVDD

O1
4 VDD ENB 1
3 OUT GND 2

C4
NI

R21
NI

C46
0.1uF

R118 0E

AVSS
C49
2.2nF

R64
10M (1%)

R63
0E

C90
NI DNI

1 TP38
1 TP34

R77
10K

→ ADC_CLK_SCL

ADS_AVDD

C47
2.2nF

R62
10M (1%)

AVSS

R70
40K

RESP_MOD_P

C6 C9
10uF 0.1uF

AVSS

C87 0.1uF
C88
1uF

R76
DNI
NI

C45
2.2nF

R69 40K

RESP_MOD_M

Note:

For two channel ECG Do the following modification
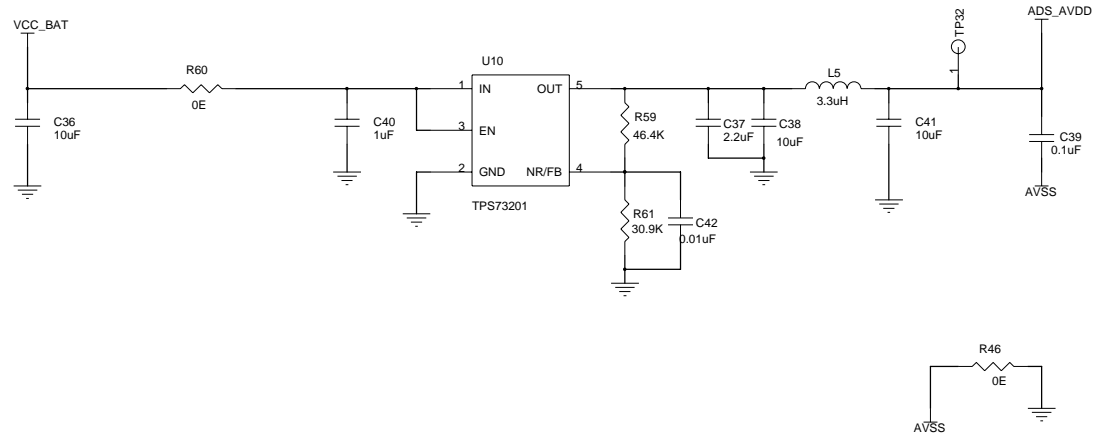
1) Mount 51K resistor in place of R71 and R63

2) Mount 0 Ohm resistors in place of C48, C46, C49 and C50

3) Make following components DNI
   R66, R64, R72, R62, C47,C45,R70 and R69

VCC_3_3   ADS_DVDD

L3

BLM18PG121SN1P

R4
0E

Title
ADS1292

Size
B

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VCC_BAT

R60
0E

C36
10uF

C40
1uF

U10

1 IN   OUT 5

3 EN

2 GND   NR/FB 4

TPS73201

R59
46.4K

R61
30.9K

C42
0.01uF

C37
2.2uF

C38
10uF

L5
3.3uH

TP32
1

C41
10uF

ADS_AVDD

C39
0.1uF

AVSS

R46
0E

AVSS

SD CARD

DNI

VCC_3_3

TP30 TP58 TP57 TP54 TP10 TP59

R101 1K R107 1K

FLASH_CE
FLASH_CE2
FLASH_CLE
FLASH_ALE
FLASH_WE
FLASH_RE
FLASH_RB
FLASH_RB2

R110 0E
R106 0E
R105 0E
R98 0E
R99 0E
R109 0E
R100 0E
R102 0E

C43 10uF
C63 0.1uF
C64 0.1uF

U14

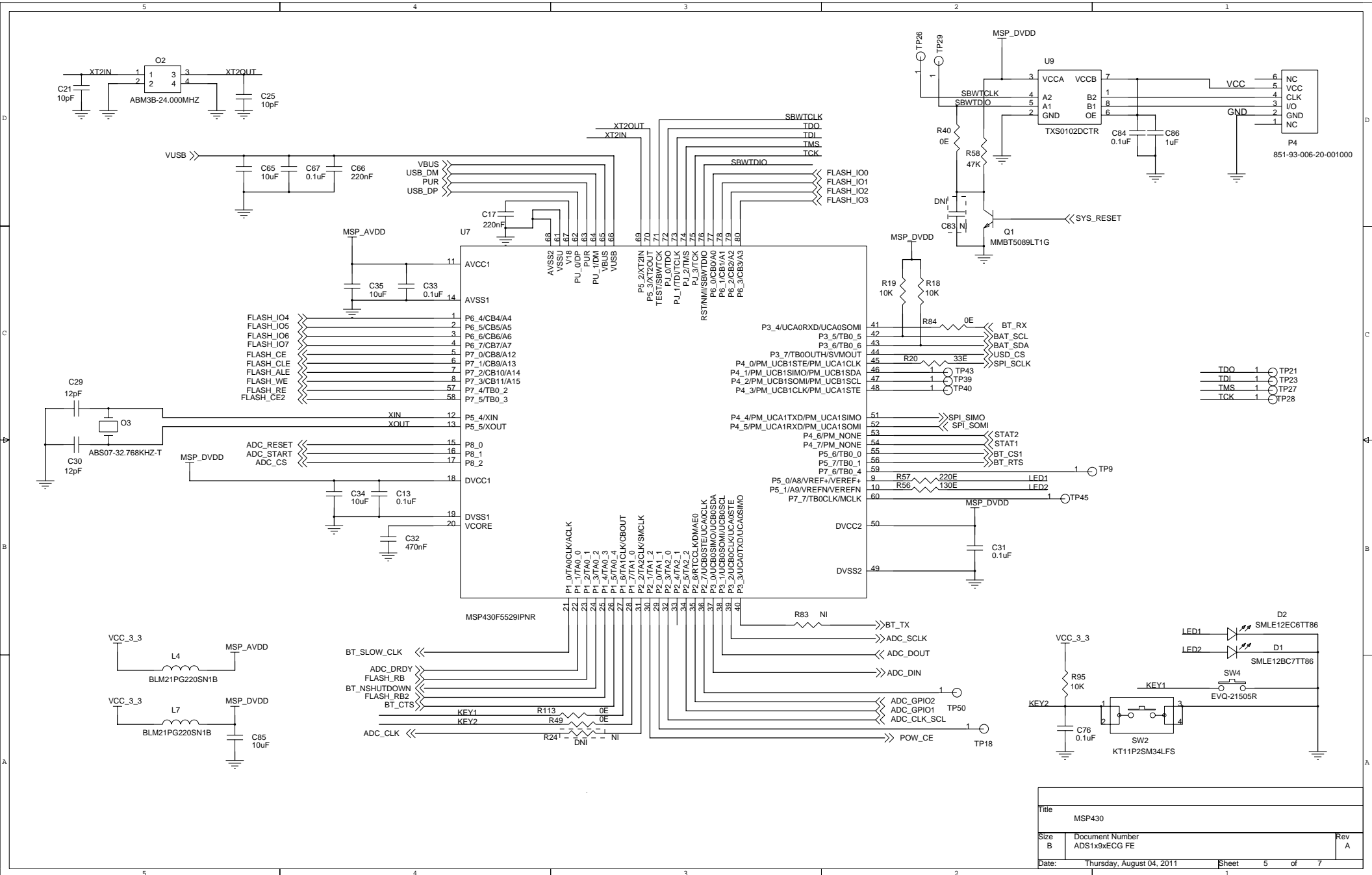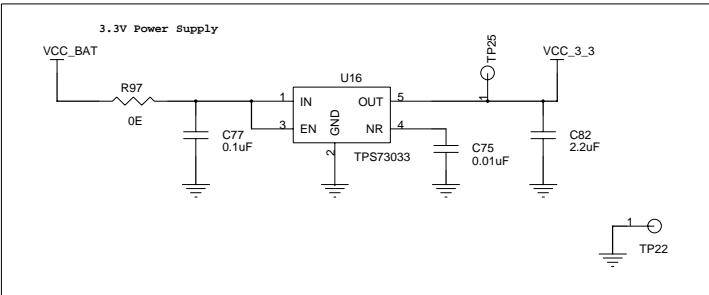|			
9	CE#	I/O0	29
10	CE2#	I/O1	30
16	CLE	I/O2	31
17	ALE	I/O3	32
18	WE#	I/O4	41
8	RE#	I/O5	42
7	R/B#	I/O6	43
6	R/B2#	I/O7	44

12 VCC
37 VCC

FLASH_IO0
FLASH_IO1
FLASH_IO2
FLASH_IO3
FLASH_IO4
FLASH_IO5
FLASH_IO6
FLASH_IO7

VCC_3_3
R94 10K

11	NC6	NC19	40
14	NC7	NC20	45
15	NC8	NC21	46
23	NC9	NC22	47
24	NC10	NC23	48
19	WP#	NC14	28
		NC13	27
20	DNU1	NC11	25
21	DNU2	NC12	26
22	DNU3	NC5	5
35	NC17	NC4	4
34	NC16	NC3	3
33	NC15	NC2	2
39	NC18	NC1	1

R93 NI
DNI

TP55

13 VSS
36 VSS
38 PRE/VSS2

MT298G08AAAWP

R75 0E

TP33 TP36 TP37 TP41

VCC_3_3

R68 R67 R65
NI NI NI

C62 NI
C78 NI

P2

USD_CS	1	RSV1
SPI_SIMO	2	CS
	3	DI
	4	VCC
SPI_SCLK	5	CLK
	6	VSS
SPI_SOMI	7	DO
	8	RSV2

NI

U11

4 IO4
3 IO3
2 IO2
1 IO1

9 GND

NI

5 IO5
6 IO6
7 IO7
8 IO8

PUR

SW1
EVQ-21505R

R82 100E
5% tol

VUSB

R14
1.4K
1% tol

VBUS
USB_DM
USB_DP

R12 33E
R11 33E

D3 SD103AW-13-F

P1

1	VBUS	SHIELD1	6
2	D-	SHIELD2	7
3	D+		8
4	ID		9
5	GND		10
			11

0513870530

R10
1M
5% tol

C8 10pF

C7 10pF

U2

1 IO1
2 IO2
4 IO3
5 IO4

6 VCC GND 3

TPD4E004DRYR

C52 0.1uF

C53 4.7uF

O2
ABM3B-24.000MHZ
XT2IN
XT2OUT
C21 10pF
C25 10pF

VUSB
C65 10uF
C67 0.1uF
C66 220nF

MSP_AVDD
C35 10uF
C33 0.1uF

U7
MSP430F5529IPNR

AVCC1 11
AVSS1 14

FLASH_IO4 1 P6_4/CB4/A4
FLASH_IO5 2 P6_5/CB5/A5
FLASH_IO6 3 P6_6/CB6/A6
FLASH_IO7 4 P6_7/CB7/A7
FLASH_CE   5 P7_0/CB8/A12
FLASH_CLE 6 P7_1/CB9/A13
FLASH_ALE 7 P7_2/CB10/A14
FLASH_WE   8 P7_3/CB11/A15
FLASH_RE   57 P7_4/TB0_2
FLASH_CE2 58 P7_5/TB0_3

C29 12pF
O3
ABS07-32.768KHZ-T
C30 12pF

XIN   12 P5_4/XIN
XOUT 13 P5_5/XOUT

MSP_DVDD
ADC_RESET 15 P8_0
ADC_START 16 P8_1
ADC_CS   17 P8_2
           18 DVCC1

C34 10uF
C13 0.1uF

           19 DVSS1
           20 VCORE
C32 470nF

AVSS2 68
VSSU 61
V18   67
PU_0/DP 62
PUR   63
PU_1/DM 65
VBUS 64
VUSB 66

C17 220nF

P5_2/XT2IN 69
P5_3/XT2OUT 70
TEST/SBWTCK 71
PJ_0/TDO 72
PJ_1/TDI/TCLK 73
PJ_2/TMS 74
PJ_3/TCK 75
RST/NMI/SBWTDIO 76
P6_0/CB0/A0 77
P6_1/CB1/A1 78
P6_2/CB2/A2 79
P6_3/CB3/A3 80

XT2OUT
XT2IN
SBWTCLK
TDO
TDI
TMS
TCK
SBWTDIO

VBUS
USB_DM
PUR
USB_DP

FLASH_IO0
FLASH_IO1
FLASH_IO2
FLASH_IO3

P3_4/UCA0RXD/UCA0SOMI 41
P3_5/TB0_5 42
P3_6/TB0_6 43
P3_7/TB0UTH/SVMOUT 44
P4_0/PM_UCB1STE/PM_UCA1CLK 45
P4_1/PM_UCB1SIMO/PM_UCB1SDA 46
P4_2/PM_UCB1SOMI/PM_UCB1SCL 47
P4_3/PM_UCB1CLK/PM_UCA1STE 48
P4_4/PM_UCA1TXD/PM_UCA1SIMO 51
P4_5/PM_UCA1RXD/PM_UCA1SIMO 52
P4_6/PM_NONE 53
P4_7/PM_NONE 54
P5_6/TB0_0 55
P5_7/TB0_1 56
P7_6/TB0_4 59
P5_0/A8/VREF+/VEREF+ 9
P5_1/A9/VREFN/VEREFN 10
P7_7/TB0CLK/MCLK 60
DVCC2 50
DVSS2 49

BT_RX
BAT_SCL
BAT_SDA
USD_CS
SPI_SCLK
R84 0E
R20 33E
TP43
TP39
TP40

SPI_SIMO
SPI_SOMI
STAT2
STAT1
BT_CS1
BT_RTS
R57 220E LED1 TP9
R56 130E LED2 TP45
MSP_DVDD
C31 0.1uF

P1_0/TA0CLK/ACLK 21
P1_1/TA0_1 22
P1_2/TA0_1 23
P1_3/TA0_2 24
P1_4/TA0_3 25
P1_5/TA0_4 26
P1_6/TA1CLK/CBOUT 27
P1_7/TA1_0 28
P2_0/TA1_1 29
P2_1/TA1_2 30
P2_2/TA2CLK/SMCLK 31
P2_3/TA2_0 32
P2_4/TA2_1 33
P2_5/TA2_2 34
P2_6/RTCCLK/DMAE0 35
P2_7/UCB0STE/UCA0CLK 36
P3_0/UCB0SIMO/UCB0SDA 37
P3_1/UCB0SOMI/UCB0SCL 38
P3_2/UCB0CLK/UCA0STE 39
P3_3/UCA0TXD/UCA0SIMO 40

BT_SLOW_CLK
ADC_DRDY
FLASH_RB
BT_NSHUTDOWN
FLASH_RB2
BT_CTS
KEY1 R113 0E
KEY2 R49 0E
ADC_CLK
R24 DNI   NI

R83 NI BT_TX
ADC_SCLK
ADC_DOUT
ADC_DIN
ADC_GPIO2 TP50
ADC_GPIO1
ADC_CLK_SCL
POW_CE TP18

VCC_3_3
L4
BLM21PG220SN1B
MSP_AVDD

VCC_3_3
L7
BLM21PG220SN1B
MSP_DVDD
C85 10uF

TP26
TP29
MSP_DVDD
U9
TXS0102DCTR
VCCA VCCB 7
A2 B2 1
A1 B1 8
GND OE 6
SBWTCLK 4
SBWTDIO 5
R40 0E
R58 47K
DNI
C83 N
Q1
MMBT5089LT1G
SYS_RESET

VCC
GND
P4
851-93-006-20-001000
NC 6
VCC 5
CLK 4
I/O 3
GND 2
NC 1
C84 0.1uF
C86 1uF

MSP_DVDD
R19 10K
R18 10K

TDO 1 TP21
TDI 1 TP23
TMS 1 TP27
TCK 1 TP28

VCC_3_3
D2 SMLE12EC6TT86
LED1
LED2
D1 SMLE12BC7TT86
SW4
EVQ-21505R
KEY1
R95 10K
KEY2
C76 0.1uF
SW2
KT11P2SM34LFS

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Battery Fuel Gauge

DNI

PACK_P

TP51
TP20

R103
NI

C79
NI

U17
1 RBI   PGM 10
         GPIO 9
2 VCC   SRP 8
3 VSS
4 SCL   SRN 7
5 SDA   BAT 6
  VSS1
11

TP17
R47
NI

P6
1 BAT_P
2 BAT_M
NI

R89
NI

C74
NI

R87
NI

R88
NI
TP13

C73
NI

C80
NI

C26
NI

R92 NI   R96 NI
BAT_SCL
R91 NI   R90
BAT_SDA   NI

D4
NI

3.3V Power Supply

VCC_BAT   TP25   VCC_3_3

R97
0E

C77
0.1uF

U16
1 IN   OUT 5
3 EN   NR 4
  GND
2

TPS73033

C75
0.01uF

C82
2.2uF

TP22

Battery Management

DNI

C16   C20
NI   NI

U8
4 AC
         OUT3 15
         OUT2 16
         OUT1 17

TP31

C28
0.1uF

VCC_BAT

VBUS
C70   C72   C27 1uF   R51 0E
10uF   0.1uF

20 USB
14 TMR
   LDO 1
8 PSEL
9 CE
18 ACPG#
19 USBPG#_/_VBSEL

BAT2 6
BAT1 5   PACK_P

C68
22uF

TS 12   TS

POW_CE
POW_CE

ACPG
USBPG

ISET1 10   ISET1
ISET2   ISET2

STAT2   STAT2   3 STAT2   DPPM 13
STAT1   STAT1   2 STAT1   VSS 11
                    TP
BQ24032ARHLR   21

R50

33K

TP49 TP48

VCC_3_3

R42 NI TS   R48 10K
R29 10K ISET1   R43 1K
R39 NI ISET2   R28 NI
         PSEL   R33 10K

DNI   DNI
DNI

R52 10K ACPG
R53 10K USBPG
R38 10K POW_CE
R30 10K STAT2
R31 10K STAT1

3.3V Voltage Supervisor

VCC_3_3

C44
0.1uF

SW3

R104
4.7K

U18
5 VDD   RESET# 1
4 MR#   RESET 3
  GND
2

TP60

R115
100E
SYS_RESET

1   3
2   4
KT11P2SM34LFS

R112
10E

C81
2.2uF

TPS3825

ADS_AVDD

R108 0E

P3
SSW-103-02-S-S-RA

3
2
1

AVSS
R111 0E

R114 0E

DNI

Title Bluetooth Module

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R86	R13	Description
Mount	Do Not Mount	When PANI315 Bluetooth module is used (Default)
Do Not Mount	Mount	When A1101R09A Bluetooth module is used

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EVM Warnings and Restrictions

It is important to operate this EVM within the input voltage range of 0 V to 5 V and the output voltage range of 0 V to 5 V .

Exceeding the specified input range may cause unexpected operation and/or irreversible damage to the EVM. If there are questions concerning the input range, please contact a TI field representative prior to connecting the input power.

Applying loads outside of the specified output range may result in unintended operation and/or possible permanent damage to the EVM. Please consult the EVM User's 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, some circuit components may have case temperatures greater than 30° C. The EVM is designed to operate properly with certain components above 30° C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.

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