

ECG Implementation on the TMS320C5515 DSP Medical Development Kit (MDK) with the ADS1298 ECG-FE

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ABSTRACT

The TMS320C5515 DSP Evaluation Module (EVM) provides a development platform to TI medical customers, third parties, and other developers. This application report focuses on ECG implementation on the TMS320C5515 DSP Evaluation Module with the ADS1298 ECG-FE.

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this document.

NOTE: Disclaimer Statement: This ECG development kit is 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.

This application report may not include all of the details necessary to completely develop the design. It is provided as a reference and only intended to demonstrate the ECG application.

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1 Introduction

A number of emerging medical applications such as electrocardiography (ECG), digital stethoscope, and pulse oximeters require DSP processing performance at very low power. The TMS320C5515 digital signal processor (DSP) is ideally suited for such applications.

The TMS320C5515 is industry's lowest power 16-bit processors helping conserve energy at exceptional levels and enabling longer battery life. With 240 MIPS performance, up to 320KB on-chip memory, higher integration (including a hardware accelerator for FFT computation), C5515 provides low power foundation for a range of signal processing applications, including voice recorder, musical instruments, portable medical solutions and other consumer electronics in industrial and security applications.

To enable the development of a broad range of medical applications on the C5515, Texas Instruments has developed an MDK based on the C5515 DSP. A typical medical application includes:

- An analog front end, including sensors to pick up signals of interest from the body
- Signal processing algorithms for signal conditioning, performing measurements and running analytics on measurements to determine the health condition
- User control and interaction, including graphical display of the signal processing results and connectivity to enable remote patient monitoring

1.1 Medical Development Kit (MDK) Overview

The MDK is designed to support complete medical applications development. It includes the following elements:

- Analog front-end boards (FE boards) specific to the key target medical applications of the C5515 (ECG, digital stethoscope, pulse oximeter), highlighting the use of the TI analog components for medical applications
- C5515 DSP EVM main board
- Medical applications software including example demonstrations

[Figure 1](#) shows an overview of the MDK hardware, consisting of individual analog front-end boards for ECG, digital stethoscope, pulse oximeter, and the C5515 DSP EVM. Any of the analog front-end boards can be connected, one of at a time, to the C5515 EVM using universal connectors on the front-end boards and the EVM. The analog front-end boards connect to the appropriate sensors for the ECG, digital stethoscope or the pulse oximeter, and perform analog signal conditioning and analog-to-digital (A/D) conversion of the signals from the sensor. Then, the digital signal is sent to the C5515 EVM where the C5515 DSP performs signal processing algorithms for the application. The DSP is also responsible for managing user control and interaction including graphical display of the signal processing results. The signal processing results can also be transferred from the C5515 EVM to a PC for further display, analysis, and storage using the PC application software that is provided with the MDK.

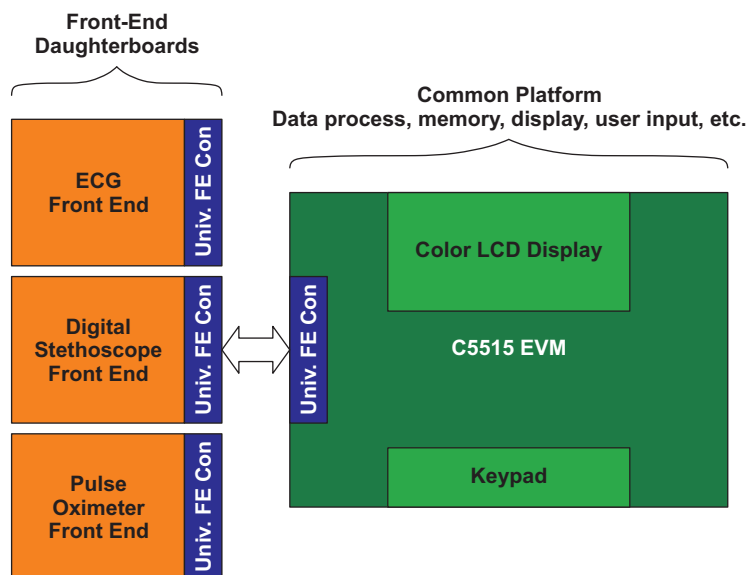


Figure 1. MDK Hardware Overview

1.2 MDK ECG System

1.2.1 Hardware Requirement

The following items are required for the MDK ECG system. Each item should be purchased separately.

- A TMS320C5515 DSP EVM
- An [ADS1298ECG-FE board](#)
- An ECG cable (see [Appendix A](#) for details)

1.2.2 TMS320C5515 DSP EVM

Key components and interfaces of the TMS320C5515 EVM include:

- TMS320C5515 fixed-point low-power DSP
- On board embedded JTAG emulation to enable the true plug-and-play functionality through just an A-to-mini B -USB cable and compatibility of external JTAG emulation interface
- TLV320AIC3204 32-bit programmable low power stereo codec
- OLED color LCD display (128x128 pixels)
- Stereo line in (2) /out (1), headphone out (1) and microphone in (L/R)
- Integrated Flash and mobile SDRAM
- I2C and SPI EEPROMs
- High speed USB 2.0 slave port
- MMC/SD slot and RS232 interface
- 10 user defined push button switches
- AFE connectors for ECG, SpO2, and Digital Stethoscope Front-End boards
- External oscillator socket
- Battery Holder (For 2 AAA, not included)
- +5V universal power supply

For more details, visit <http://support.spectrumdigital.com/boards/evm5515/revb/>.

1.2.3 ADS1298 ECG Front-End Board

For the ADS1298 ECG-FE board, see the [ADS1298ECG_FE User's Guide \(SBAU171A\)](#).

The ADS1298 is interfaced to the C5515 DSP as shown in [Figure 2](#).

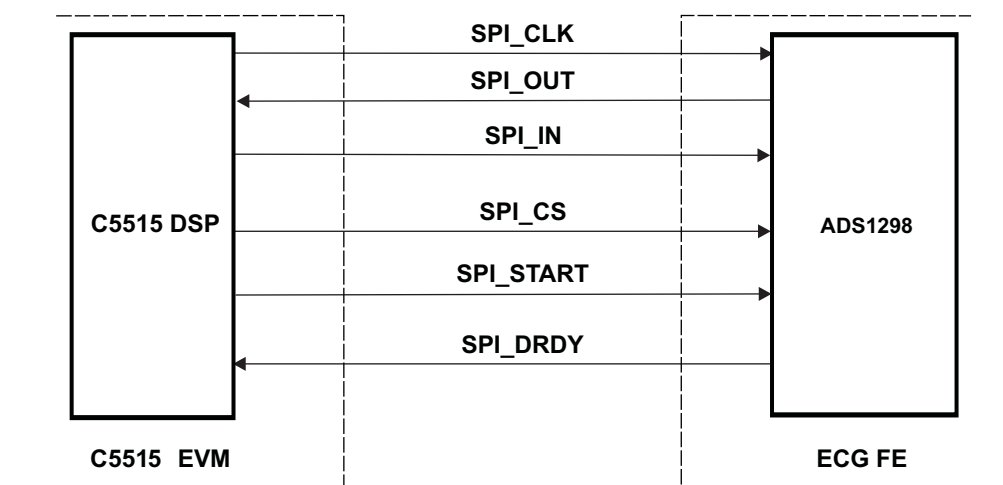


Figure 2. Interface Between ADS1298 and the C5515

1.2.4 Front-End Connector

The front-end board is connected to the EVM through the universal front-end connector, which consists of three connector interfaces with legends on the EVM: J10, J13, and J14.

1.2.4.1 J10 Connector Interface at C5515 EVM

This connector carries the 5 V, 3.3 V and 1.8 V from the C5515 EVM. These voltages act as the primary source for the ECG front-end board.

1.2.4.2 J13 Connector Interface at C5515 EVM

This connector carries GPIOs, I2C, SPI and interrupt (INT1) connections from the C5515 EVM to the front-end board. Pin mapping for the used interfaces are shown in [Table 1](#).

Table 1. J13 Connector Interface

Connector Pin Number	Signal Assigned
1	SPI_START
3	SPI_CLK
7	SPI_CS
11	SPI_IN
12	SPI_DRDY
13	SPI_OUT
15	I2C_INT
16	I2C_SCL
20	I2C_SDA

1.2.4.3 J14 Connector Interface at C5515 EVM

The mating for this connector is maintained, but no signals are used by the ECG front-end board.

2 DSP Subsystem

The DSP software, running on the C5515 EVM, takes the digitized signal from the front-end board and processes it the same. The DSP receives eight ECG lead data from the ADC through the SPI interface. The pacer samples are detected and removed from the ECG waveform. Filters are applied for removing the DC signal, 50/60Hz power line noise and unwanted signals. The filtered signal is used for detecting the heart rate and also for deriving 4 ECG leads (Lead III, aVR, aVL and aVF).

The software is designed to handle the following activities:

- Data acquisition through ADC
- Lead-off detection
- DC signal removal
- Multi band-pass filtering
- ECG leads formation
- QRS (HR) detection
- Display of ECG data
- UART communication

The following figure shows the high-level architecture of DSP subsystem.

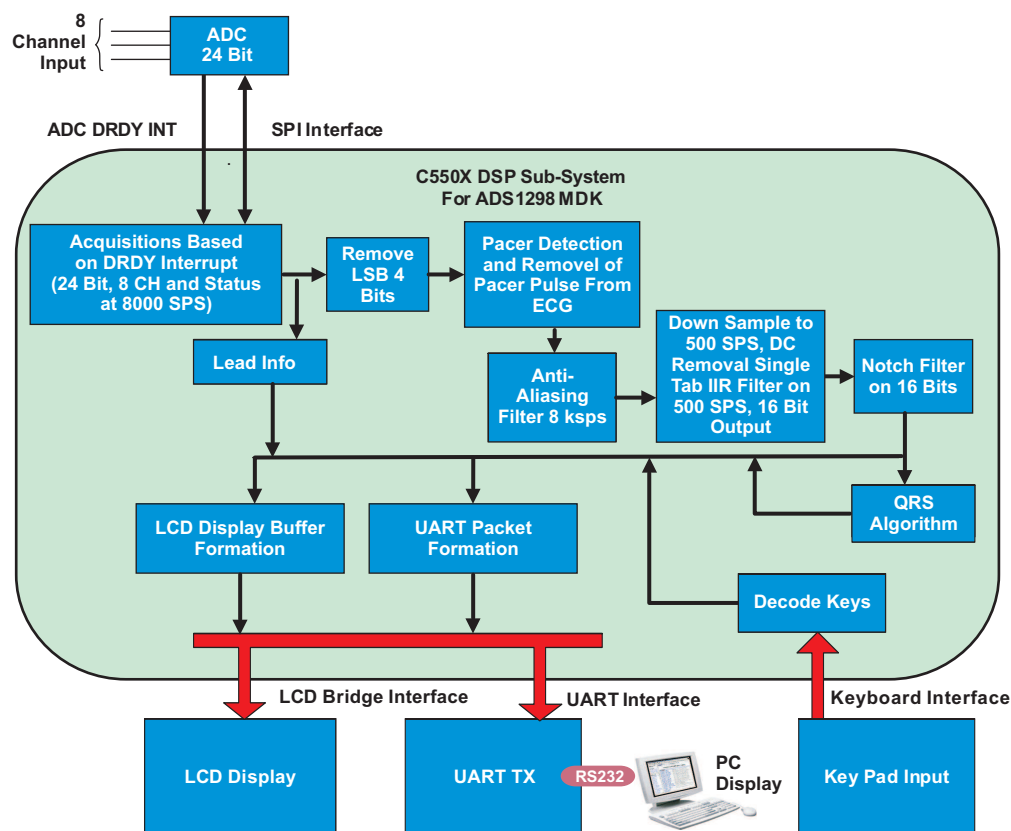


Figure 3. DSP Software Architecture

The various blocks of the DSP subsystem are described in the following sections.

2.1 Data Acquisition

ADS1298 is configured to generate DRDY interrupt after every 125 microsecond to achieve 8KSPS sampling rate. The C5505 DSP Interrupt Service Routine (ISR) reads the 24-bit lead status and 8-channel 24-bit data from the ADC through the SPI interface. The acquired data is provided to the pacer detection module after scaling down to 20 bits.

2.2 Lead-Off Detection

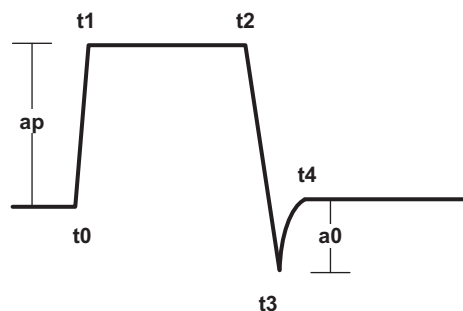
The lead-off detection module extracts the ECG electrode status information from the data packet. The first 24 bits of the data packet contains the values listed in [Table 2](#).

Table 2. Lead-off Detection Module Values from ECG Electrode Status

Bit Position	Information / Value
23	Always 1 (not used)
22	Always 1 (not used)
21	Always 0 (not used)
20	Electrode V6 status (1 = Electrode fail, 0 = Electrode connected)
19	Electrode V1 status (1 = Electrode fail, 0 = Electrode connected)
18	Electrode V5 status (1 = Electrode fail, 0 = Electrode connected)
17	Electrode V4 status (1 = Electrode fail, 0 = Electrode connected)
16	Electrode V3 status (1 = Electrode fail, 0 = Electrode connected)
15	Electrode V2 status (1 = Electrode fail, 0 = Electrode connected)
14	Electrode LL status (1 = Electrode fail, 0 = Electrode connected)
13	Electrode LA status (1 = Electrode fail, 0 = Electrode connected)
12	Not used
11	Not used
10	Not used
9	Not used
8	Not used
7	Not used
6	Not used
5	Electrode RA status (1 = Electrode fail, 0 = Electrode connected)
4	Always 0 (not used)
3	Not used
2	Not used
1	Not used
0	Not used

2.3 Pacer Detection

The pacer detection algorithm detects the pacer pulse by detecting the slew rate of the ECG waveform. The pacer pulse slew rate must be greater than 10 V/Sec. (i.e., 1.25 mV between sample to sample for 8 kSPS).



ap: Pacer pulse amplitude +/- 700mV to +/- 2 mV

ap+a0: Amplitude peak valley

t0: Start of pacer pulse

t1-t0: Slew rate (10 V/sec)

t2-t1: Pacer pulse duration (0.1 mSec to 2 mSec)

The minimum duration between two consecutive pacer pulses is 100 mSec.

The previously listed conditions are checked in the pacer detection algorithm to determine a pacer pulse. The current version of the software has a fixed sampling frequency of 8 kSPS.

2.4 Anti-aliasing Filter

The anti-aliasing low-pass filter with a cutoff frequency of 150 Hz is implemented by using 51 taps of the FIR filter to remove high frequency noise from the ECG lead data. This filter provides attenuation of 30dB at stop band.

The simulation result for the LPF is shown in the following figure.

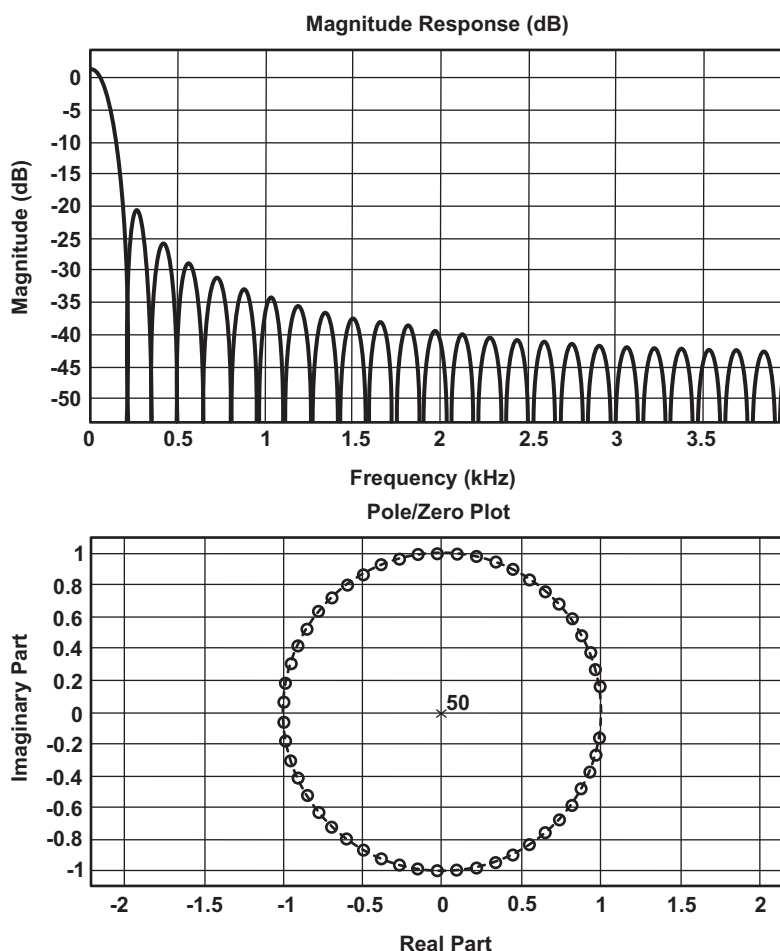


Figure 4. LPF Frequency Response

2.5 IIR Filter - DC Signal Removal

The DC signals from the eight ECG leads are removed by using the first-order IIR filter. The following transfer function is used for the filter:

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

To provide DC attenuation of 22 dB, the value of alpha is chosen as 0.992. The IIR filter output is downscaled to 16 bits and then provided to the finite impulse response (FIR) filter.

Figure 5 shows the frequency response for the filter.

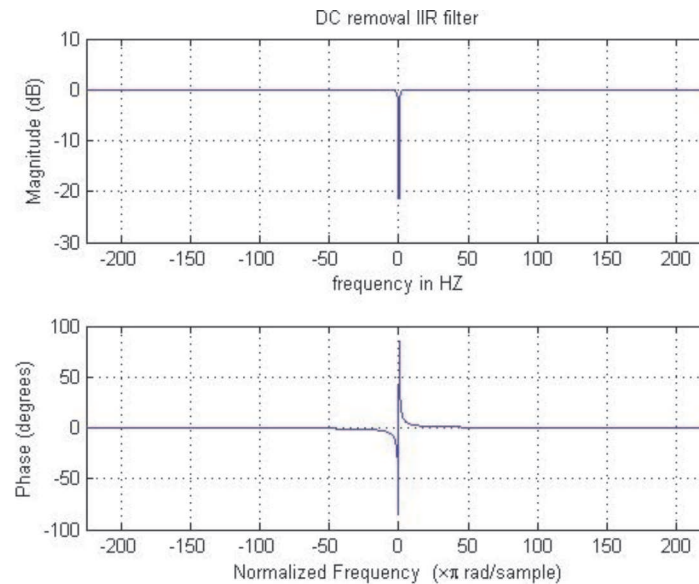


Figure 5. DC Removal Filter Response

Figure 6 shows the pole and zero location for the IIR filter. The pole is located at $z = 0.992$ and zero at 1 in the Z plane.

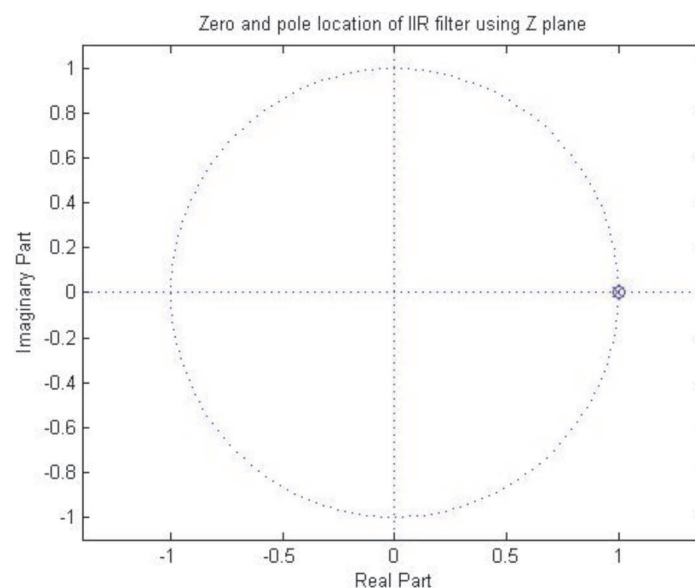


Figure 6. Pole and Zero Location for IIR Filter

Figure 7 shows 1 Hz signal response via the DC removal filter.

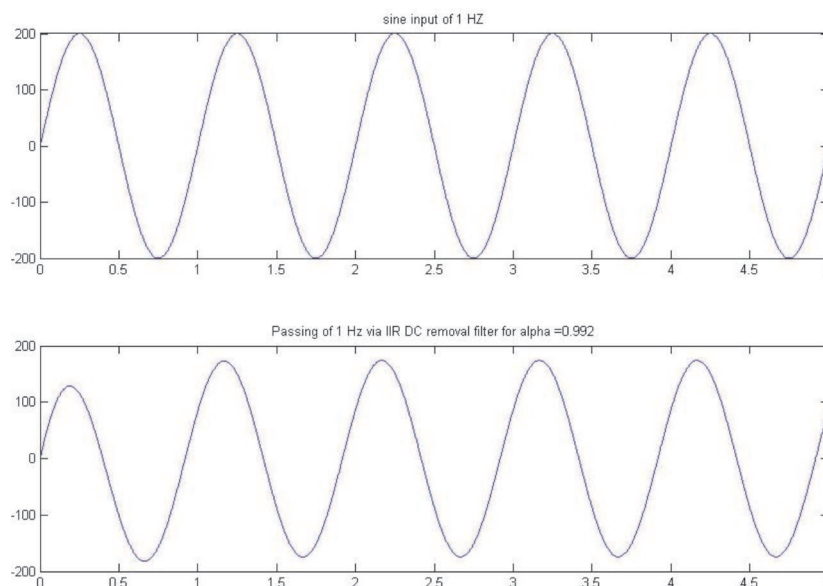


Figure 7. 1Hz Signal Response via DC Removal Filter

2.6 Notch Filter

The FIR band stop filter (BSF) is used to remove power line noise from the ECG data.

The BSF used is 351 order FIR filter with hamming window having cutoff at 47Hz to 53 Hz or 57Hz to 63 Hz. The BSF is compile-time programmable. This filter provides sharp cutoff at 50/60 Hz with attenuation of 60dB at stop band.

The simulation result for the BSF is shown in the following figure.

2.7 ECG Lead Computation

Eight ECG lead data from the notch filter is fed to the ECG lead formation module. This module computes the remaining four ECG lead data using the following formula:

$$\text{Lead III} = \text{Lead II} - \text{Lead I}$$

$$\text{Lead aVR} = -\text{Lead II} + 0.5 * \text{Lead III}$$

$$\text{Lead aVL} = \text{Lead I} - 0.5 * \text{Lead II}$$

$$\text{Lead aVF} = \text{Lead III} + 0.5 * \text{Lead I}$$

2.8 QRS (HR) Detection Algorithm

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

The following steps are involved for calculating heart rate:

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

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

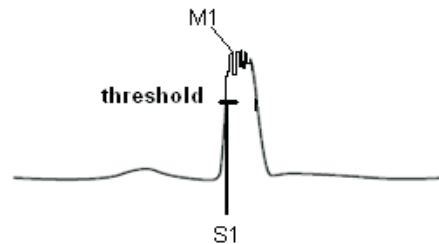
Where, $y0(n)$ is the first derivative.

$x(n + 1)$ is the sample value for $(n + 1)$ th sample

$x(n - 1)$ is the sample value for $(n - 1)$ th sample

The initial 2sec of the first derivatives in a buffer are stored and the maximum value (P) in this buffer are obtained.

2. Calculate the threshold as $0.7 * P$.
3. Compare each of the first derivative values calculated with the calculated threshold.
4. Mark the ECG sample index (S1) of that particular sample, whenever a derivative crosses the threshold.
5. Detect the QRS peak 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. Skip the next 50 samples (SKIP_WINDOW = 50) to take care of the minimum RR interval that can occur in case of maximum detectable heart rate (i.e., 240 BPM), after detecting a QRS peak.
7. Detect the next five QRS peaks by repeating steps 3 to 6.
8. Calculate the RR interval as the number of samples between two consecutive QRS peaks.
9. Calculate heart rate using the following formula:

$$\text{HR per Minute} = (60 * \text{Sampling Rate}) / (\text{Average RR interval for five consecutive RR intervals})$$
10. Recalculate threshold from the QRS peak values detected.

2.9 LCD Display

The LCD display shows the ECG, heart rate, pacer location and lead off status. The display is controlled using SW7 and SW8 keys on the EVM as mentioned in [Section 6.1.1](#). When user presses the keys on the EVM (SW7 and SW8) interrupt get generated. The key press gets communicated to DSP through SAR interrupt. The interrupt service routine for the key press takes care of the corresponding action for the interrupt.

2.10 Universal Asynchronous Receiver/Transmitter (UART)

The data sent to the PC through UART has eight ECG lead data; these signals are sent at 250 sps/lead. The PC application derives the remaining four ECG leads using the Lead I and Lead II data. A synchronization frame (header) of 5 bytes is also sent to the UART interface every 1 s. The packet number, heart rate, and lead status values are sent along with the ECG header. The header is followed by interleaved samples of eight ECG leads. The interval between the two ECG data packets is 500 μ s. The packet number gets incremented for every new sample sent.

The UART configuration is set as 115200 bps, 8 bits data, 1 stop bit and no parity.

ECG Header

00	80	00	80	00	Packet Number	Heart Rate	Lead Status (Low)	Lead Status (High)
----	----	----	----	----	---------------	------------	-------------------	--------------------

ECG Data

Current Channel Low 8 Bits	Current Channel High 8 Bits
----------------------------	-----------------------------

3 PC Application

The PC application is used for viewing the ECG waveform and ECG values. It also provides options to zoom, store and playback the signals.

The PC application has two modes of operation: online and offline.

- Online mode: the ECG data is plotted in real-time as a scrolling display
- Offline mode: the recorded ECG data is displayed for analysis

Two timers run on the application for online mode: acquisition and display timer.

The acquisition timer is set for 100 ms intervals and reads the data from the serial port. After fetching the data from serial port, it parses the stream of bytes to different variables like packet number, heart rate, lead-off status and to the ECG data object containing the digital value of eight leads ECG samples. The four non-acquired leads, Lead III, aVR, aVL and aVF data, are derived from Lead I and Lead II as follows:

Lead III = Lead II - Lead I

aVR = - Lead II + 0.5 * Lead III

aVL = Lead I - 0.5 * Lead II

aVF = Lead III + 0.5 * Lead I

The ECG data object for each sample is stored in a queue buffer.

The display timer is set to an interval of 60 ms and is used to plot the ECG wave forms, and update the heart rate and lead-off status information on the screen. This timer is elapsed every 60 ms; in each elapsed event 15 samples of the leads are plotted on the screen.

4 Installation

4.1 Hardware Installation

1. Mount the ADS1298 ECG FE board on top of the C5515 EVM at connectors J10, J13 and J14. Ensure that there is a firm connection between the front-end board and the EVM.

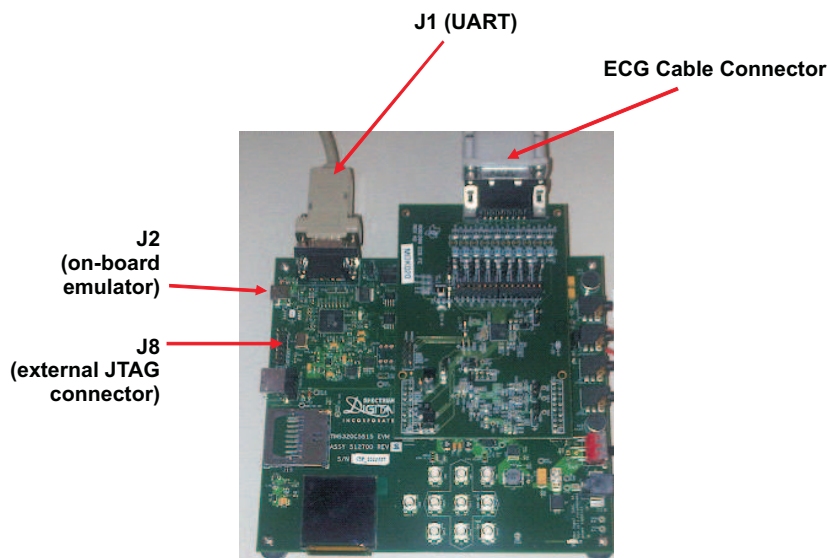


Figure 8. ECG Front-End Mounted on the C5515 EVM

2. Connect the serial cable (UART) to the DB9 connector (J1) of the C5515 EVM and the other end to the serial port of the PC, for viewing the signals on the PC application.
3. Connect the ECG cables to DB15 connector J1.
4. Connect the other end of the ECG cable (there are 10 leads) to an ECG simulator.
5. The J2 (on-board USB emulator connector) or J8 (external JTAG connector) can be used for the

debugging purpose.

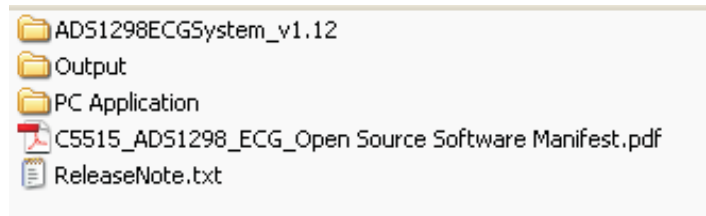
NOTE: The ECG simulator has 10 connector points that are assigned to different electrodes, i.e., RA, RL, LA, etc. Ensure that the ECG leads are connected to the corresponding connectors on the simulator.

4.2 Software Installation

4.2.1 Download the ECG Software for the ADS1298

Visit <http://code.google.com/p/c5505-ezdsp/> and download ADS1298_ECG_MDK.

1. Click "ADS1298_ECG_MDK" under C5515 EVM column and download "ADS1298_ECGSystem_C5515EVM.zip" file.
2. Unzip the ADS1298_ECGSystem_C5515EVM.zip.
3. The zip file includes:
 - ADS1298ECGSystem_V1.12: C5515 DSP ECG Software project folder
 - Output: this folder has the executable file, ECGSystem.out
 - PC Application: ECG PC User Interface Software folder
 - C5515_ADS1298_ECG_Open Source Software Manifest.pdf
 - ReleaseNote.txt



4.2.2 PC Application Installation Steps

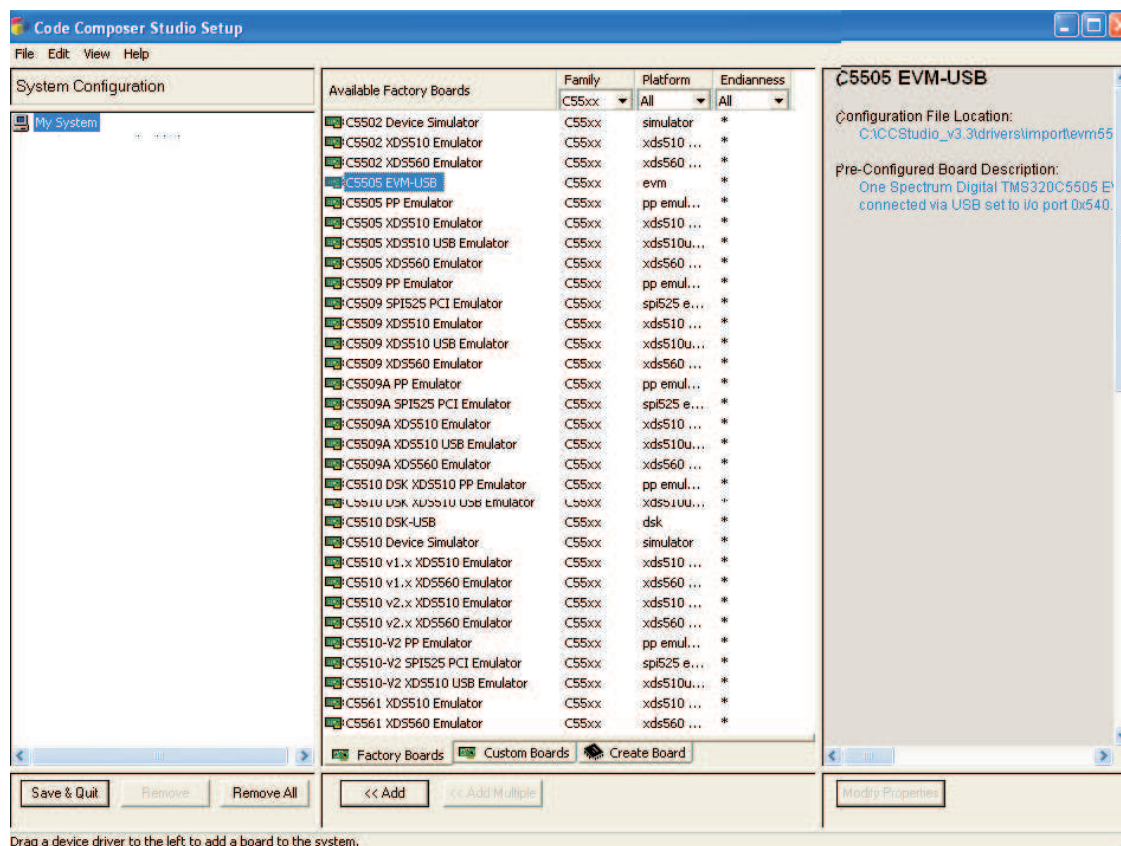
Prior to installing the PC application, ensure that .NET 2.0 framework is installed on the system. .NET 2.0 redistributable framework can be downloaded from the following URL:

<http://www.microsoft.com/downloads/details.aspx?familyid=0856eacb-4362-4b0d-8edd-aab15c5e04f5&displaylang=en>.

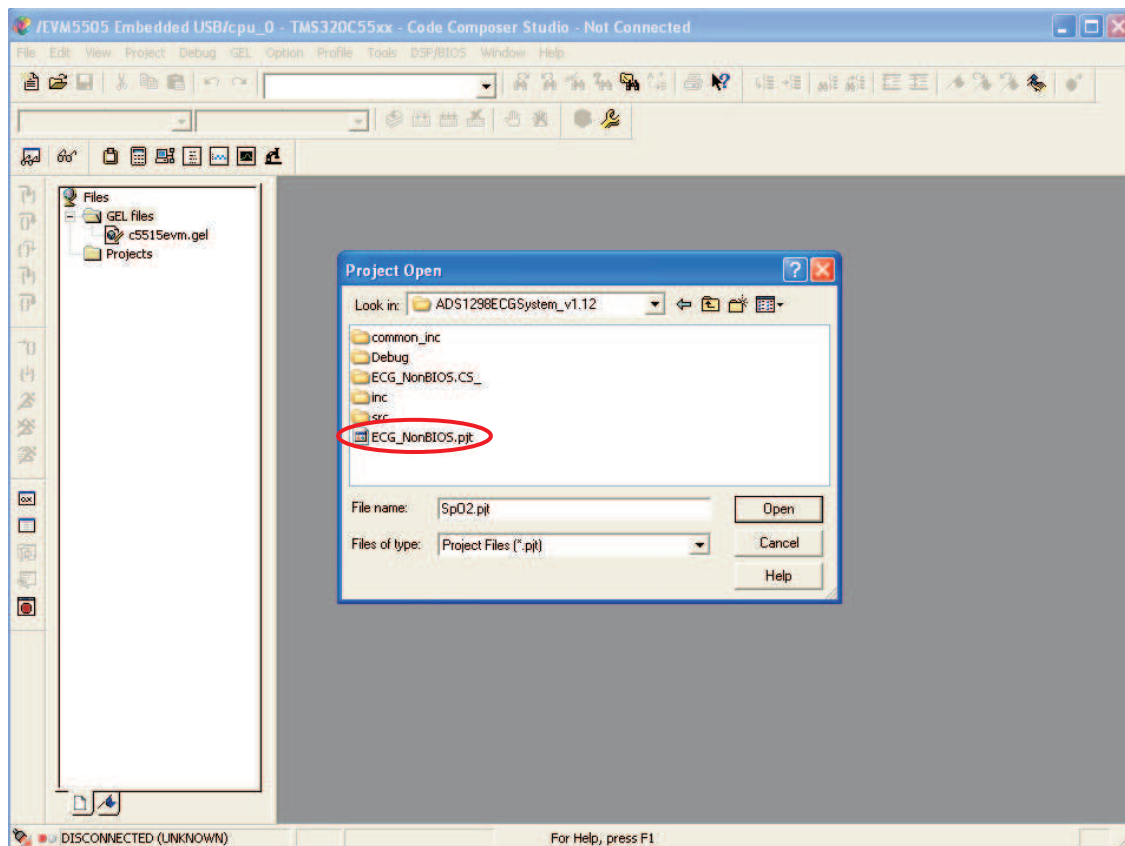
1. Open the *PCApplication* folder on the CD and double click on *C55x ECG Medical Development Kit.msi*.
2. Click *Next* on the welcome screen to continue the installation.
3. Browse to the folder where the application is installed. Select the installation mode for Everyone or Self and click *Next*.
4. Click *Next* on the Confirmation screen. This installs the application into the specified folder.
5. Click *Close* to complete and exit the installation.

5 Running the ECG Demo Application on the C5515 EVM

1. Texas Instrument Code Composer Studio 3.3 (CCS3.3) should be properly installed for the C5515 EVM prior to running the ECG software on the C5515 EVM.
2. Make sure to install the latest CCS driver from <http://support.spectrumdigital.com/>.
3. Open the Code Composer Studio Setup and choose the proper emulator for the C5515 EVM. It depends on the emulator being used. For the on-board USB emulator of the C5515 EVM, select "C5505 EVM-USB" from the "Available Factory Boards". Then, choose a gel file for the C5515 EVM. The gel file for the C5515EVM can be downloaded from this link, <http://support.spectrumdigital.com/boards/evm5515/revb/>. Save and close the Code Composer Studio Setup.



4. Properly connect the ECG cable, RS232 cable, and Emulator.
5. Power the C5515 EVM and connect the board to Code Composer Studio.
6. Open Code Composer Studio and click on *Debug* → *Connect* to connect CCS to the C5515 EVM
7. Click on *Project* → *Open* in Code Composer Studio and select the *ECGSystem.pjt* file in the "ADS1298ECGSystem_v1.12" folder.



8. Click on *File* → *ECGSystem.out* file in the "Debug" folder.
9. Execute the application.
10. Switch on the ECG simulator to view the ECG signal on the C5515 EVM. ECG waveforms will be displayed on the LCD screen of the C5515 EVM as shown in the following figure.

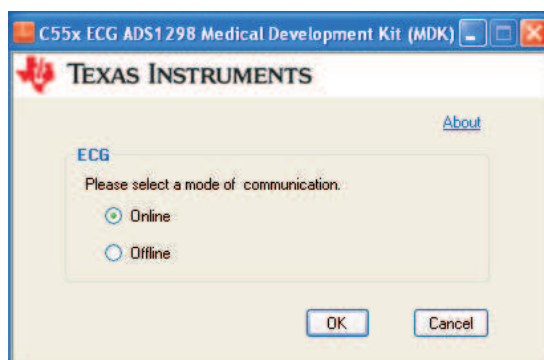


5.1 Running the PC Application

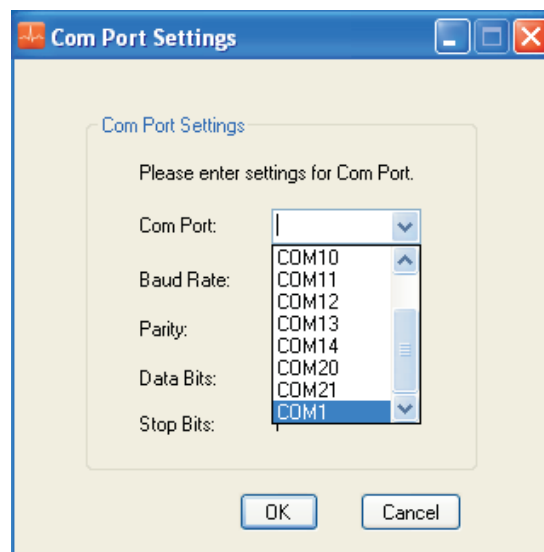
5.1.1 Online Mode

The following steps are required to view signals in online mode using the PC application:

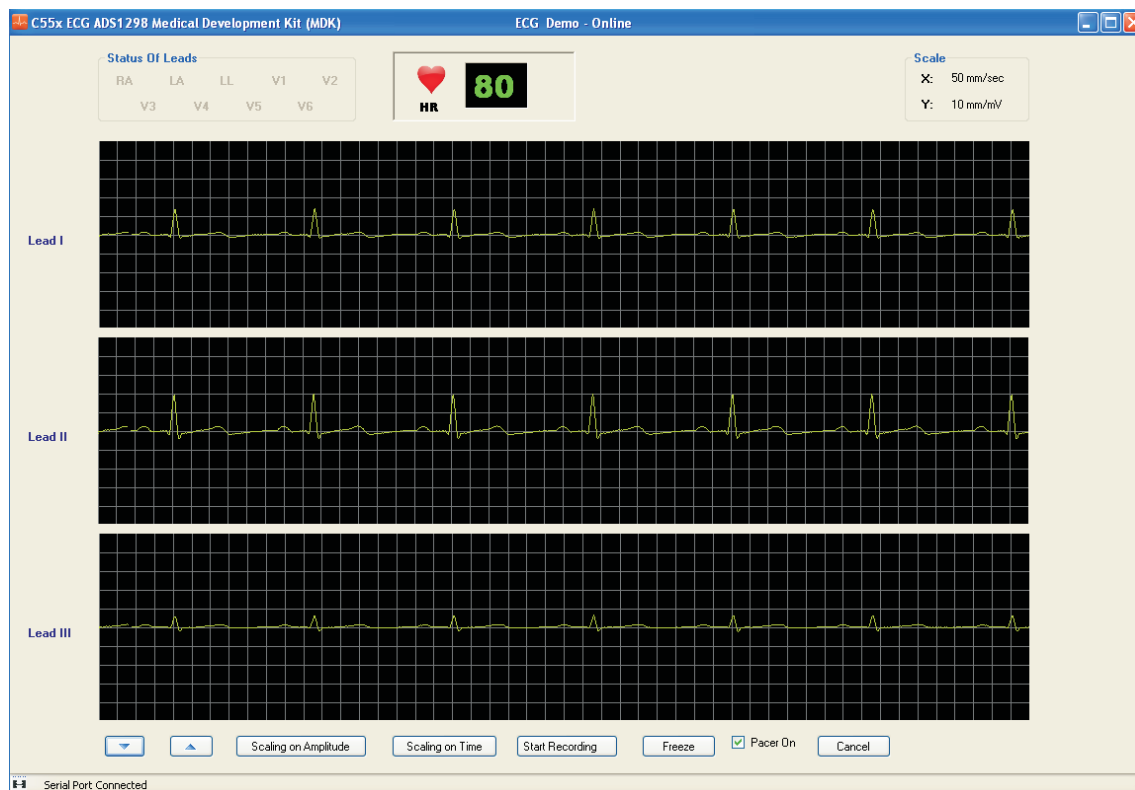
1. Ensure that the ECG Demo Application is successfully running on the C5515 EVM
2. Open the PC application (C55x ECG ADS1298 Medical Development Kit (MDK).exe).
3. Select online mode and click OK.



4. Select the available COM port and click OK (the port number can be different).



5. Signals transmitted from the C5515 EVM can be viewed on the PC application.



5.1.2 Offline Mode

The following steps are required to view signals in offline mode stored on the PC using the PC application:

1. Open the PC application (C55x ECG ADS1298 Medical Development Kit (MDK).exe).
2. Select offline mode and click OK.
3. Browse and select the previously saved .ecg file and click OK. (The ECG waveform can be recorded in the online mode using the "Start Recording" button.)
4. View the static ECG waveforms along with the heart rate and lead-off status on the PC application.

6 Options and Selections

6.1 On the C5515 EVM

6.1.1 ECG Display on the C5515 EVM Side

The ECG display on the LCD screen starts by showing the *ECG Monitor* followed by lead and heart rate; by default, ECG Lead II is displayed.

SW7 switch on the EVM can be pressed to view one channel after the other. Pressing the switch displays the next ECG lead in a cyclic manner: II, I, III, aVR, aVL, aVF, V1, V2, V3, V4, V5 and V6.

The SW8 switch on the EVM can be used for the zoom in and zoom out feature for the ECG waveform. Low, Medium (default) and High are the three levels of zooming provided.

If all 10 leads are connected, a green color dot is displayed at the lead status location on the EVM display. In case any one lead fails, the failed lead name is displayed at the lead status location. If more than one lead off is detected, a red color dot is displayed at the lead status location.

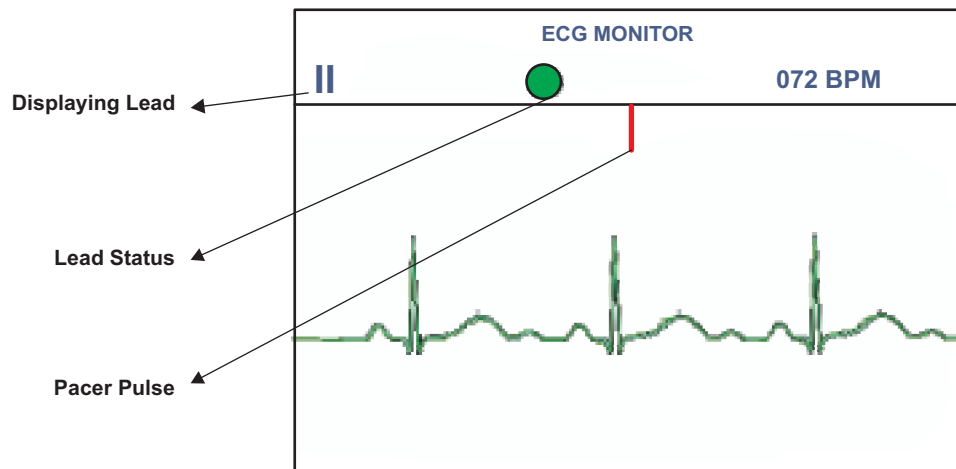


Figure 9. Display on the EVM LCD Screen

6.1.2 PC Application

The PC monitor application in online mode is as shown in Figure 10. By default 3 Leads are displayed simultaneously.

The sequence of the leads are I, II, III, aVR, aVL, aVF, V1, V2, V3, V4, V5 and V6. Lead-off status and heart rates are displayed on the screen and the value refreshes once every second. The serial port connection status (RS232) with the device is displayed on the status bar.

The following features are available on PC application.

- **Next (up arrow):** This button can be used to view the next 3 leads wave form.
- **Previous (Down arrow):** This button can be used to view the previous 3 leads wave form.
- **Scaling on Amplitude:** This button can be used to vertically “zoom in” and “zoom out” the ECG waveform display on PC application.
- **Scaling on Time:** This button can be used to horizontally “zoom in” and “zoom out” the ECG waveform display on PC application.
- **Start Recording:** This can be used to start the recording of ECG waveform. During recording this same button is used for “Stop Recording” operation. Note that after start recording option is selected, the zoom options get disabled
- **Stop Recording:** This can be used to stop recording and saving the ECG waveform as .ECG file. It can be played back using PC application in offline mode.
- **Freeze:** This button can be used to view a static waveform. Particular portion of the wave form can be viewed by moving Left and Right cursors in the Freeze option.
- **Unfreeze:** On pressing the same button the wave form will be in continuous scrolling mode.
- **Pacer ON:** By default “Pacer ON” is enabled. The pacer presence is shown in red on top of ECG waveform. If “Pacer ON” is disabled then pacer presence will not be shown.
- **Cancel:** This can be used to close the form.

Appendix A Sensors and Accessories

A.1 ECG Cable Details

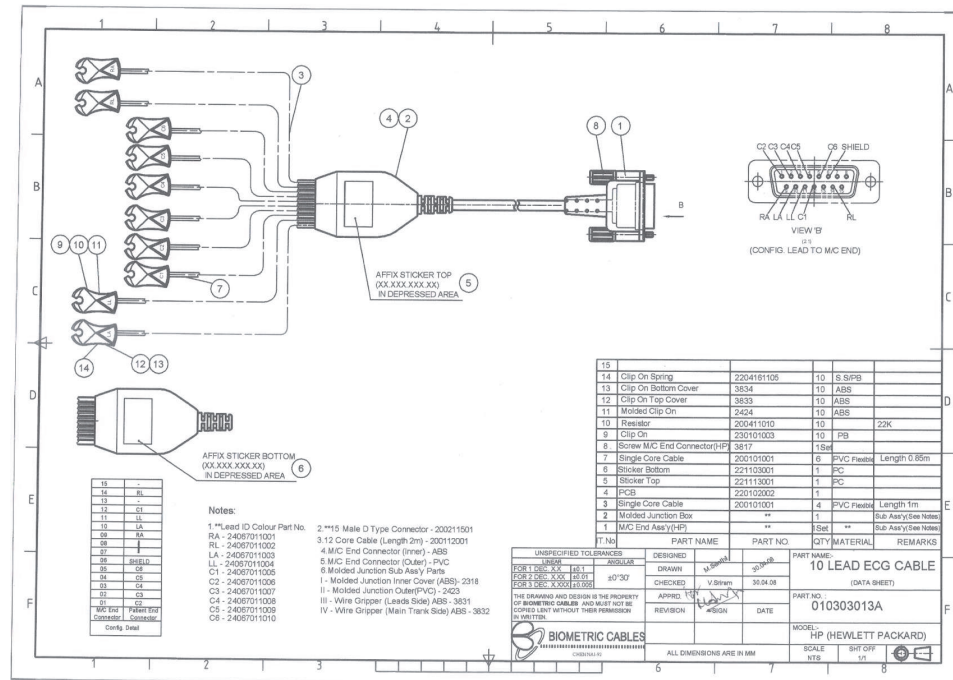


Figure 10. ECG Cable Details

Cable details: 10 lead ECG cable for philips/hp -snap, button (Part No: 010302013)
<http://www.biometriccables.com/index.php?productID=692>

Cable details: 10 lead ECG cable for philips/hp -Clip-on type (P/n-010303013A)
<http://www.biometriccables.com/index.php?productID=693>

Other compatible cables for MDK: HP/Philips/Agilent Compatible 10 Lead ECG cable

A.2 ECG Sensor

Sensor details: Disposable Electrodes - Medico Lead - Lok

Vendor name: Medico Electrodes International Link : <http://www.medicoleadlok.com/>

Other compatible parts: Any Ag/AgCl solid gel ECG electrode on the market.

Appendix B MEDICAL DEVELOPMENT KIT (MDK) WARNINGS, RESTRICTIONS AND DISCLAIMER

Not for Diagnostic Use: For Feasibility Evaluation Only in Laboratory/Development Environments.

The MDK may not be used for diagnostic purposes.

This MDK is intended solely for evaluation and development purposes. It is not intended for diagnostic use and may not be used as all or part of an end equipment product.

This MDK 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.

Your Obligations and Responsibilities

Please consult Section 1.1, **Important Disclaimer Information**, in the *ADS1298ECG_FE User's Guide (SBAU171A)* prior to using the MDK. Any use of the MDK outside of the specified operating range may cause danger to the users and/or produce unintended results, inaccurate operation, and permanent damage to the MDK and associated electronics. You acknowledge and agree that:

- You are responsible for compliance with all applicable Federal, State and local regulatory requirements (including but not limited to Food and Drug Administration regulations, UL, CSA, VDE, CE, RoHS and WEEE,) that relate to your use (and that of your employees, contractors or designees) of the MDK for evaluation, testing and other purposes.
- You are responsible for the safety of you and your employees and contractors when using or handling the MDK. Further, you are responsible for ensuring that any contacts or interfaces between the MDK and any human body are designed to be safe and to avoid the risk of electrical shock.
- You will defend, indemnify and hold TI, its licensors and their representatives harmless from and against any and all claims, damages, losses, expenses, costs and liabilities (collectively, "Claims") arising out of or in connection with any use of the MDK that is not in accordance with the terms of this agreement. This obligation shall apply whether Claims arise under the law of tort or contract or any other legal theory, and even if the MDK fails to perform as described or expected.

WARNING

If defibrillator is used for development purposes, use of medical grade EVM input power supply (Accessory Part Number: SL Power AULT Model MW173KB0503F01) is strongly recommended. Use of the Isolator (Accessory Part Number: MOXA Model Name: TCC-82) that isolates the MDK from the PC is also strongly recommended. These accessories provide additional supplemental protection to development users from high voltages that may be present when introducing defibrillator voltages during development simulation. There may also be other voltage transients sourced from the defibrillator to accompanying interface hardware such as a personal computer when used in conjunction with the ECG/EVM development hardware.

WARNING

To minimize risk of electric shock hazard, use only the following power supplies for the EVM module: Medical Development Applications: SL Power AULT Model MW173KB0503F01.

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