

Digital Stethoscope Implementation on the TMS320C5515 DSP Medical Development Kit (MDK)

Vishal Markandey

ABSTRACT

The medical development kit (MDK) provides a development platform to TI medical customers, third parties, and other developers. This application report focuses on the C5515 MDK; however, the analog front ends that are included can also be used with other platforms.

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: Do not use this medical development kit for the purpose of diagnosing patients.

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 digital stethoscope 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 C5515 is a member of TI's C5000™ fixed-point DSP platform. 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 evaluation module (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 conversion (ADC) 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 graphic 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.

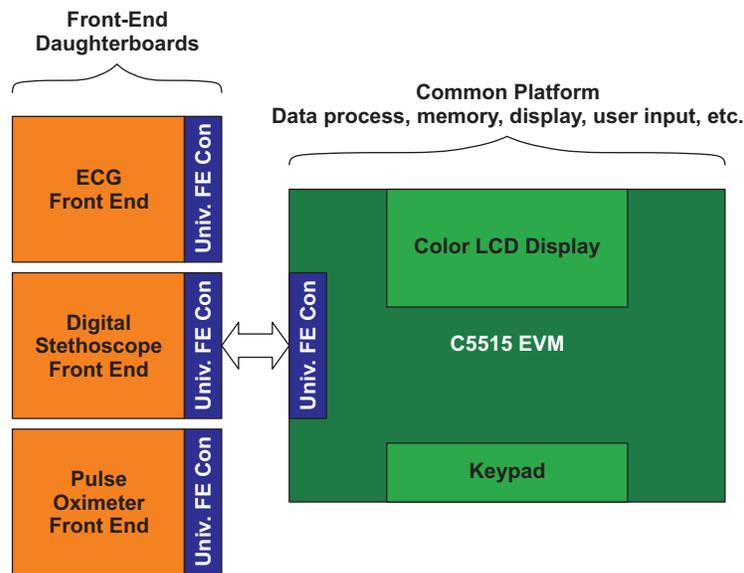


Figure 1. MDK Hardware Overview

1.2 MDK Digital Stethoscope System

The digital stethoscope system uses the front-end board and sensor to capture the acoustic sound waves of the heart and lungs. This board contains the necessary circuitry for signal conditioning and acquiring signals from the sensors. The analog signals are amplified and digitized before transmitting them to the DSP on the EVM for further processing, analysis, and display.

1.2.1 Key Features

The key features of the MDK digital stethoscope system are:

- Audio output for heart and lung sounds in three selectable modes:
 - Bell mode (20 Hz to 220 Hz)
 - Diaphragm mode (50 Hz to 600 Hz)
 - Extended mode (20 Hz to 2000 Hz)
- Heart rate display in bell and diaphragm mode on liquid crystal display (LCD) and PC application
- Five step volume control with mute option on the C5515 EVM
- Real-time display of heart sound waveform on the PC application
- Store, zoom and playback of heart sound waveform on the PC

1.2.2 MDK Hardware

The main elements of the MDK digital stethoscope system are:

- C5515 EVM
- Digital stethoscope front-end board
- Sensor

1.2.2.1 C5515 EVM

The EVM comes with a full compliment of on-board devices that suit a wide variety of application environments.

For further details on the C5515 EVM, see the Medical Development Kit provided with your EVM.

The EVM operates from a + 5 V external power supply or battery and is designed to work with TI's Code Composer Studio™ integrated development environment (IDE). Code Composer Studio communicates with the EVM board through the external emulator, or on-board emulator.

1.2.2.2 Digital Stethoscope Front-End Board

Figure 2 shows the digital stethoscope front-end board. The front-end board has three 2.5mm mono jack connectors to connect the microphones and one 2.5 mm stereo jack to connect the head phone. The front-end board can be interfaced with the EVM board through a universal front-end connector. The C5515 EVM board supplies power to the front-end board through the universal front-end connector. The front-end board is interfaced with the C5515 EVM by using I2C and I2S interfaces.

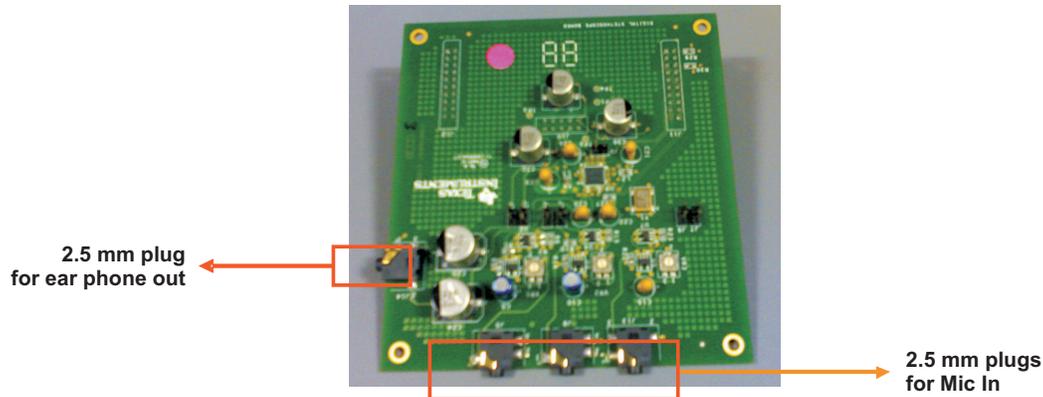


Figure 2. Digital Stethoscope Front-End Board

The codec (TLV320AIC3254) on the front-end board is configured for 12 KHz sampling with 16-bit data resolution. I2C interface is used for configuring the TLV320AIC3254 audio codec and I2S interface is used for codec data transfer.

1.2.2.3 Sensor

The sensor mainly has three parts:

- Diaphragm
- Condenser microphone
- 2.5 mm audio plug

Sound waves from the acoustic amplifier (diaphragm) are fed to the condenser microphone. The sound waves hitting the condenser microphone change its capacitance by changing its impedance, which produces a voltage swing proportional to the amplitude of the input sound waves. The voltage swing of the signal also depends on the bias voltage given for the microphone. A microphone bias voltage of 1.25 V is produced by the audio codec.

The coupling of the acoustic sensor to the microphone is critical to pick up noise free sound signals from the human body.

An acoustic diaphragm can be coupled to the microphone as shown in Figure 3. Place the microphone as close as possible to the diaphragm; the microphone should be connected to a 2.5 mm plug to connect the 2.5 mm jack to the front-end board. The electric wire that connects the microphone to the plug is made long enough to ensure that there is sufficient length to place the sensor on the subject.



Figure 3. Sensor Coupled Microphone

1.2.3 MDK Software

The software for the MDK application includes:

- C5515 software application
- PC application

1.2.3.1 C5515 Software Application

The hardware is initialized by the DSP on the EVM. The DSP reads the digitized signals from the audio codec via the I2S interface and processes it.

The processed digitized signals are sent back to the front-end board for conversion to analog signals and play back. The signal is also provided to the PC application over the UART interface for display.

The LCD display on the C5515 EVM shows the mode of operation of the digital stethoscope: volume indication bars, heart rate display and bell or diaphragm mode.

1.2.3.2 PC Application

The PC application, which has to be installed on the PC, can be used for viewing the heart waveform and heart rate values. It also provides options to zoom, store and playback the signals transmitted from the EVM. The PC application can operate in two modes: online and offline.

2 Front-End Architecture

Figure 4 shows the digital stethoscope front-end board architecture.

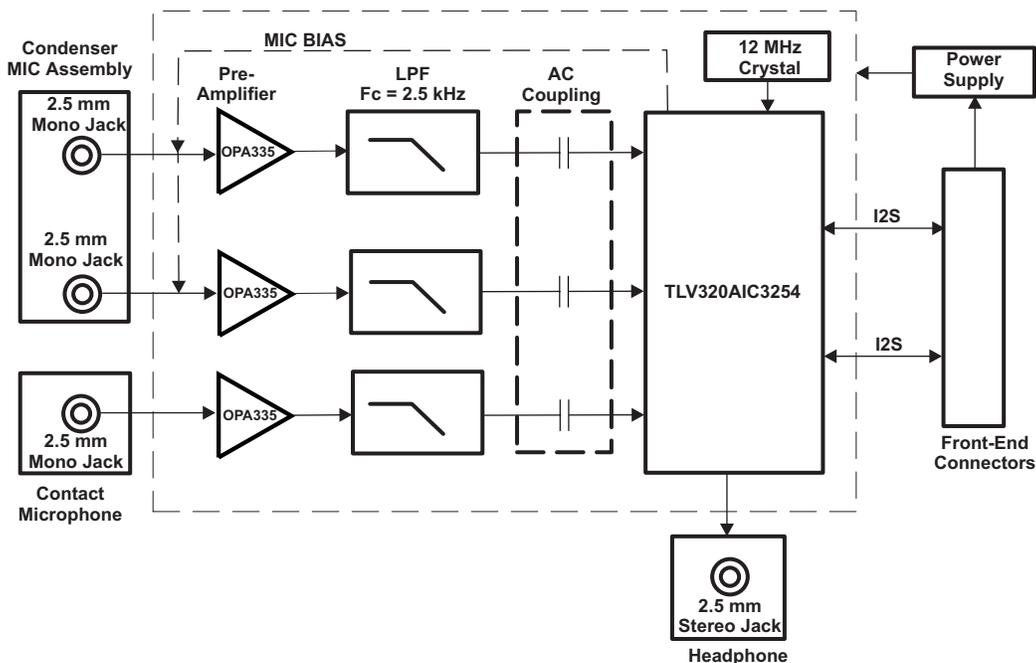


Figure 4. Stethoscope Front-End Block Diagram

The front-end board contains the following stages:

- Pre-amplifier
- Low pass filter
- AC coupling block
- Audio codec
- Front-end connector

2.1 Pre-Amplifier Stage

The input signal from the sensor is very feeble; therefore, a pre-amplifier stage is included to increase the input signal with a gain factor of 31. The pre-amplifier, with external mic bias circuitry, is implemented as shown in Figure 5.

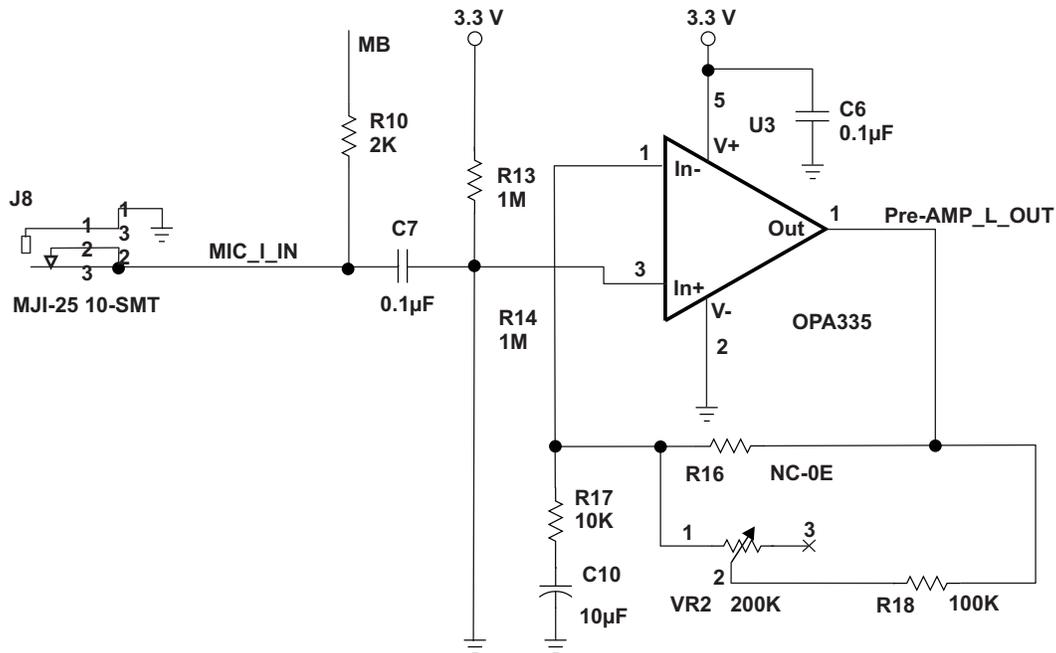


Figure 5. Pre-Amplifier Stage With Gain 31

2.2 Low-Pass Filter

A low-pass filter is provided to remove high-frequency noise and also to act as an anti-aliasing filter. Since a Sigma-Delta ADC (Codec) is chosen, requirements on the analog anti-aliasing filters are minimal. This is because over sampling relaxes the requirements on the base-band anti-aliasing filter; therefore, a simple first-order active low-pass filter is sufficient. Figure 6 shows the design of the low-pass filter.

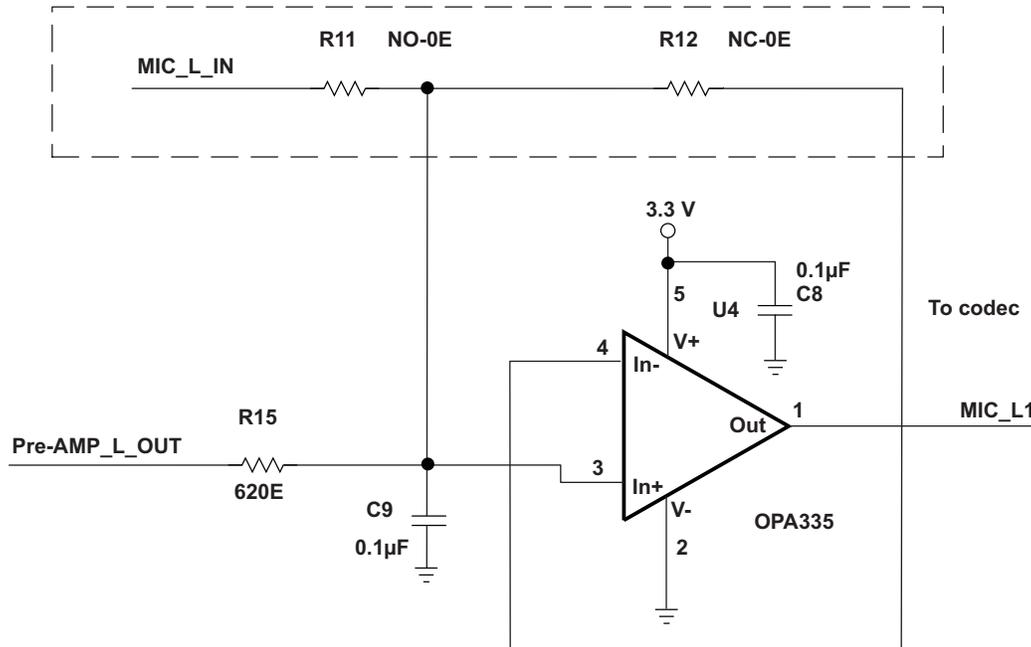


Figure 6. First-Order Low-Pass Filter

The values for R and C are calculated according to the following equation:

$$F = 1 / (2 * 3.14 * R * C)$$

Where

F = Cut-off frequency required (2500 Hz) - based on the maximum frequency range of supported modes

R = 620E

C = 0.1 µF

2.3 Audio Codec

The TLV320AIC3254 audio codec is a flexible, low-power, low-voltage stereo audio codec with programmable inputs and outputs. The voltage supply range for TLV320AIC3254 is 1.5 V - 1.95 V (analog) and 1.65 V - 1.95 V (digital). Figure 7 shows the block diagram of the TLV320AIC3254 audio codec.

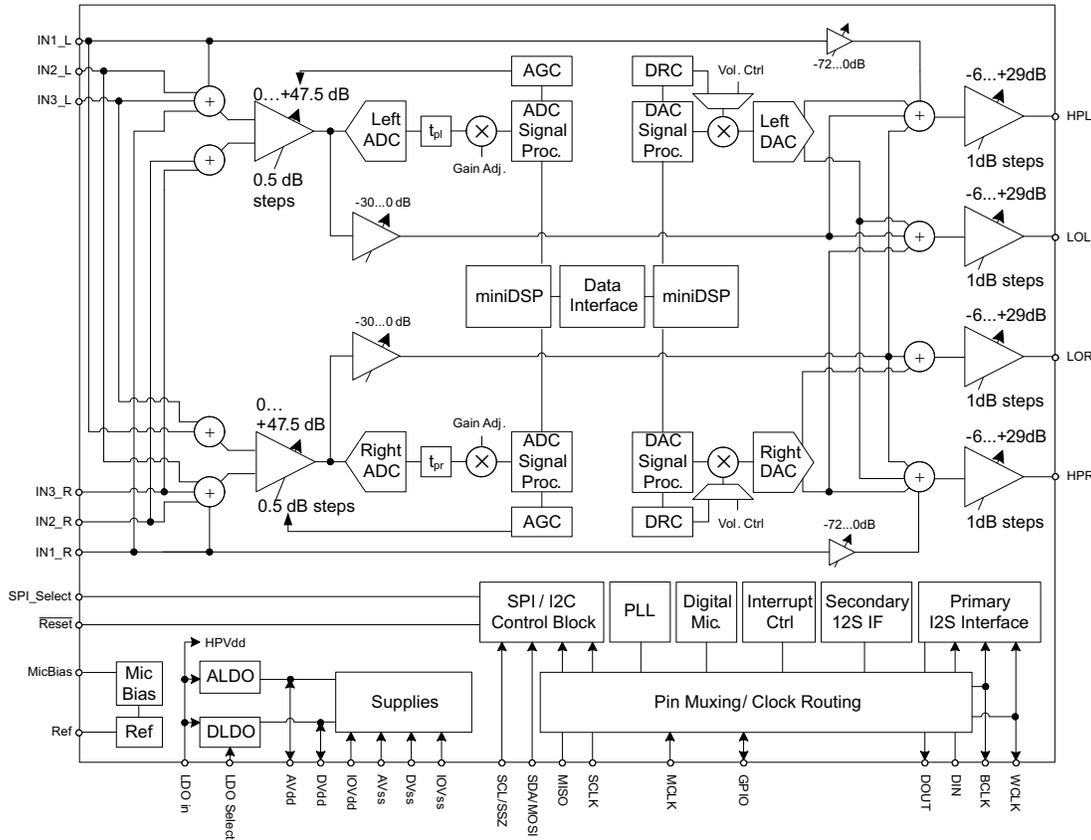


Figure 7. Block Diagram of TLV320AIC3254

The record path for the TLV320AIC3254 contains programmable input channel configurations covering single-ended and differential setups, as well as floating inputs or mixed input signals. It also includes a digitally controlled stereo microphone preamplifier and an integrated microphone bias. Programmable filter blocks are available that can remove audible noise that may be introduced by mechanical coupling.

The playback path offers signal processing blocks for filtering and effects, true differential output signals, flexible mixing of the digital-to-analog converter (DAC), and analog input signals as well as programmable volume controls.

The codec is interfaced to the C5515 DSP using the I2C bus to configure the codec. The audio codec uses the the following configuration:

ADC gain	0 dB
Host to audio Codec interface	I2S
Sampling frequency	12 KHz
Data format	16-bit linear
Audio output gain (DAC)	Selectable by the user through the key pad, and the possible gain values are -6, -3, 0, 3 and 6 dB's

The AC coupled signal is fed to the left channel of the Delta-Sigma ADC of the audio codec; ADC output is 12 ksp/s. The DSP reads these digitized signals from the audio codec via the I2S interface.

The processed digital audio output from the DSP is fed back to the DAC of the audio codec. From there, the audio codec amplifies the signal based on the selected DAC gain and outputs it to the headphone.

Figure 8 shows the AIC3254 interfaced to the C5515 DSP.

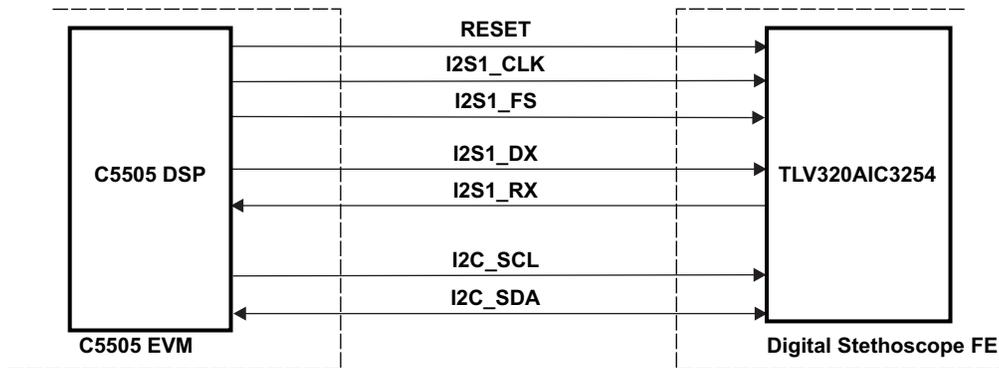


Figure 8. Block Diagram of the Interface Between the C5515 DSP and TLV320AIC3254

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: J20, J21, and J22.

2.4.1 J20 Connector Interface at C5515 EVM

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

2.4.2 J21 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 digital stethoscope front-end board.

2.4.3 J22 Connector Interface at C5515 EVM

This connector carries GPIOs, I2S, I2C, SPI and interrupts from the C5515 EVM to the front-end board. Pin mapping for the used interfaces are shown in Table 1.

Table 1. J22 Connector Interface

Connector Pin Number ⁽¹⁾	Signal Assigned
2	FE DETECT
5	I2S1 CLK
6	FE DETECT
9	I2S1 FS
14	I2S1 RX
16	I2C_SCL
19	I2S1 DX
20	I2C_SDA

⁽¹⁾ Other connector pins are not used.

2.5 Hardware Configuration

2.5.1 Jumper Settings

There are three audio input channels to the front-end board. Connector J5 and J8 can input microphone signals, whereas connector J13 inputs the contact microphone signal. Jumper settings are provided on the front-end board to select the required audio channel to the TLV320AIC3254 codec. Table 2 identifies the jumper settings available on the front-end board.

The version of the software provided with the kit only supports the selection of audio input through connector J8 to channel 2 left input of codec (J4 should be closed).

The codec supports both I2C and SPI mode for configuration. Jumper J9 should be closed to select the I2C mode for configuration. The I2C mode is only supported with the version of software provided with the kit.

Table 2. Jumper Settings for the Front-End Board

Identification	Connection	Description
Jumper J1	Closed ⁽¹⁾	Select microphone input J5 to channel 1 right input of codec
	Open	Deselect microphone input J5 to channel 1 right input of codec
Jumper J2	Closed ⁽¹⁾	Select microphone input J8 to channel 1 left input of codec
	Open	Deselect microphone input J8 to channel 1 left input of codec
Jumper J3	Closed ⁽¹⁾	Select microphone input J5 to channel 2 right input of codec
	Open	Deselect microphone input J5 to channel 2 right input of codec
Jumper J4	Closed (default)	Select microphone input J8 to channel 2 left input of codec
	Open	Deselect microphone input J8 to channel 2 left input of codec
Jumper J6	Closed ⁽¹⁾	Select contact microphone input J13 to channel 3 right input of codec
	Open	Deselect contact microphone input J13 to channel 3 right input of codec
Jumper J7	Closed ⁽¹⁾	Select contact microphone input J13 to channel 3 left input of codec
	Open	Deselect contact microphone input J13 to channel 3 left input of codec
Jumper J9	Closed (default)	I2C mode select for configuring the codec
	Open ⁽¹⁾	SPI mode select for configuring the codec (Not supported)

⁽¹⁾ Support requires modification in software

2.5.2 Resistor Gain Setting

The hardware amplifier gain can be selected using the potentiometer VR2 provided on the front-end board. The minimum gain provided is 11; this can be obtained by selecting the VR2 position at minimum. The maximum gain provided is 31; this can be obtained by selecting VR2 position at maximum.

3 DSP Subsystem

The DSP software, running on the C5515 EVM, takes the digitized signal from the front-end board and processes it. The processed heart sound waveform is sent back to the front-end board for conversion to analog signals and playback. The signals are also provided to the PC application over UART interface for display.

Figure 9 shows the high-level architecture of the DSP subsystem.

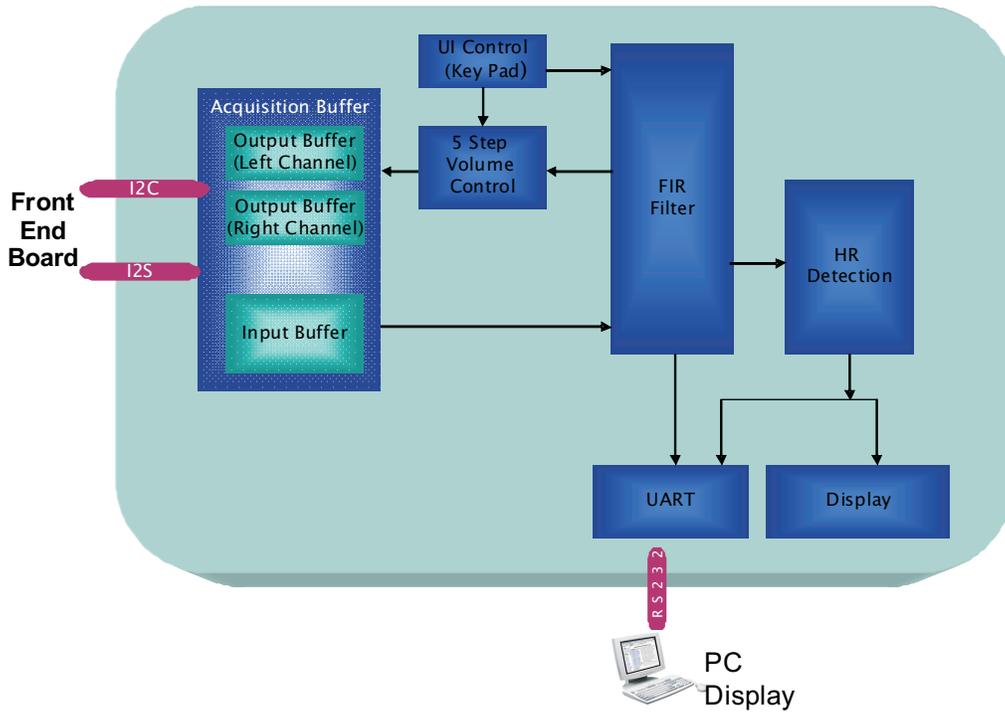


Figure 9. DSP Software Architecture

Figure 10 shows a simplified system flow chart for the DSP software.

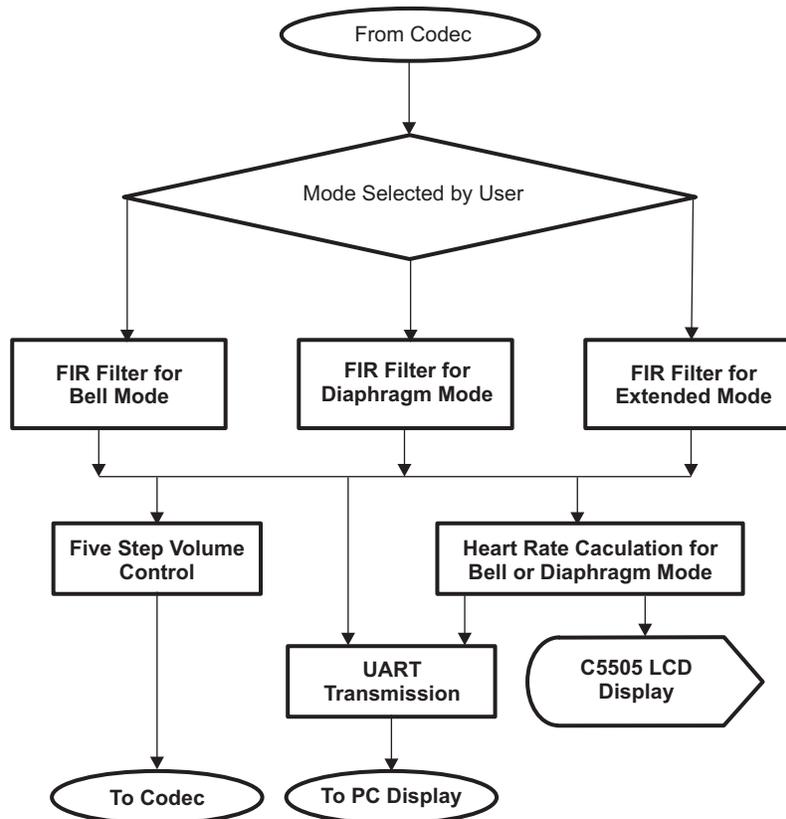


Figure 10. System Flow Chart

The following list describes the system flow for the DSP subsystem:

- Based on the mode selected, digital signals from the front-end board are fed to the corresponding filter
- FIR BPF (Hamming window) filter with order 161 is used to remove noise and unwanted signals
- The filtered output is fed back to the codec on the front-end board
- Filtered output is also passed to the PC application over UART interface for display and storage
- Heart beat detection algorithm is applied for bell and diaphragm modes
- Heart rate, operating mode, and volume level are displayed on the LCD screen

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

3.1 Data Acquisition

ADC output data from the front-end board is stored into two 128-word input buffers using a ping-pong mechanism by utilizing the direct memory access (DMA) of the C5515 DSP. Processed data from the DSP, for both left and right channels, is output to four 128-word output buffers using the ping-pong mechanism.

3.2 FIR Digital Filter

The digital stethoscope has three different finite impulse response (FIR) filters implemented for the three operating modes. The filter being used is the FIR hamming window band pass with order of 161, which provides a sharp cutoff with attenuation of about 50dB. The sampling frequency is 12000 samples/second.

Buffer shifting convolution algorithm is used for the realization of the filter.

The band pass frequency range for bell, diaphragm, and extended modes is shown in the following list:

- Bell mode - 20 Hz to 220 Hz
- Diaphragm mode - 50 Hz to 600 Hz
- Extended mode is 20 Hz to 2000 Hz

Figure 11 shows the sound waveform before and after applying the filter for the bell mode.

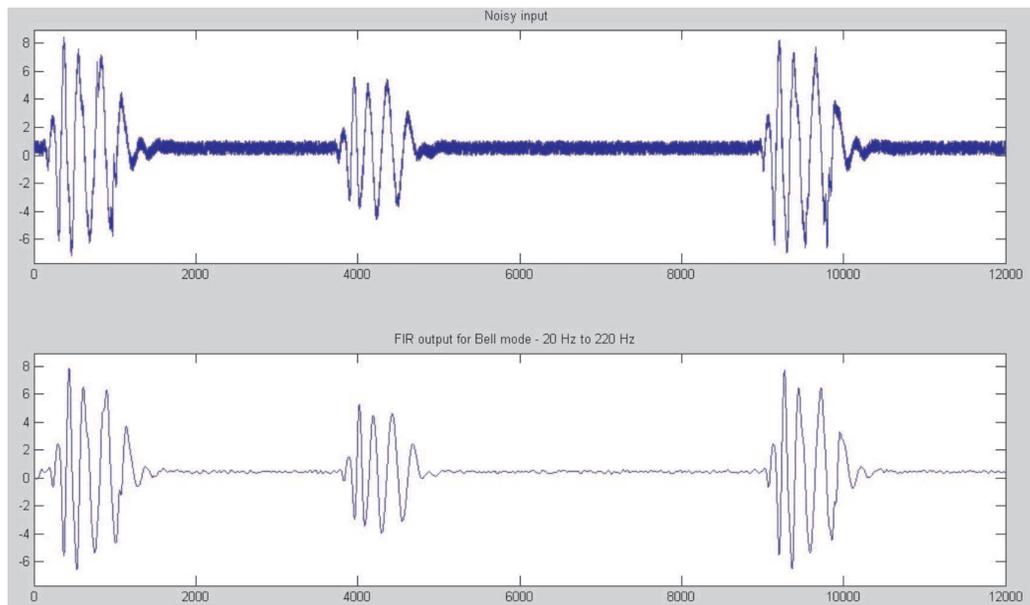


Figure 11. Signal Before and After FIR Filter for Bell Mode

Figure 12 shows the sound waveform before and after applying the filter for the diaphragm mode.

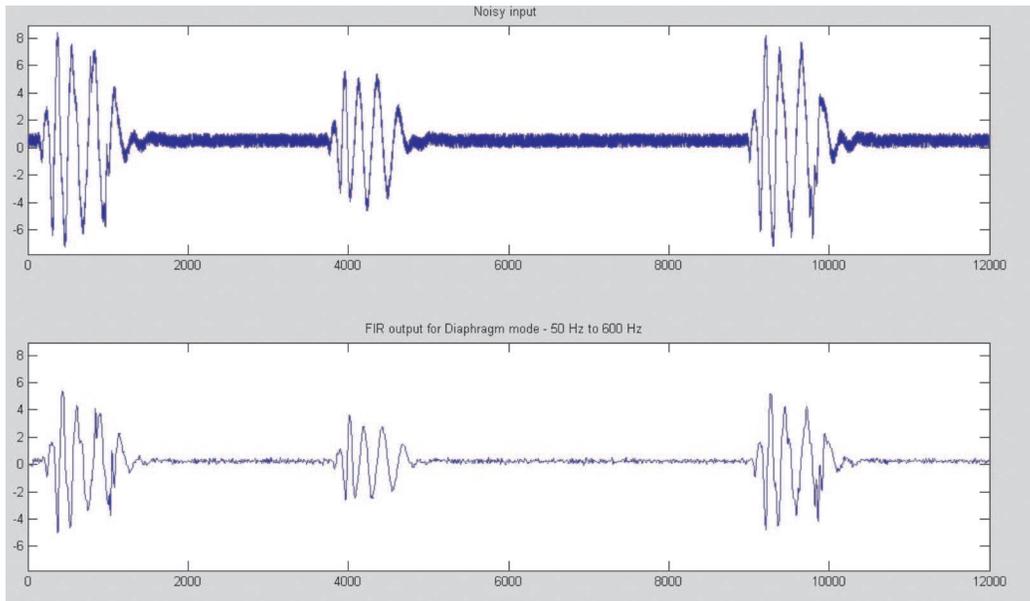


Figure 12. Signal Before and After FIR Filter for Diaphragm Mode

Figure 13 shows the sound waveform before and after applying the filter for the extended mode.

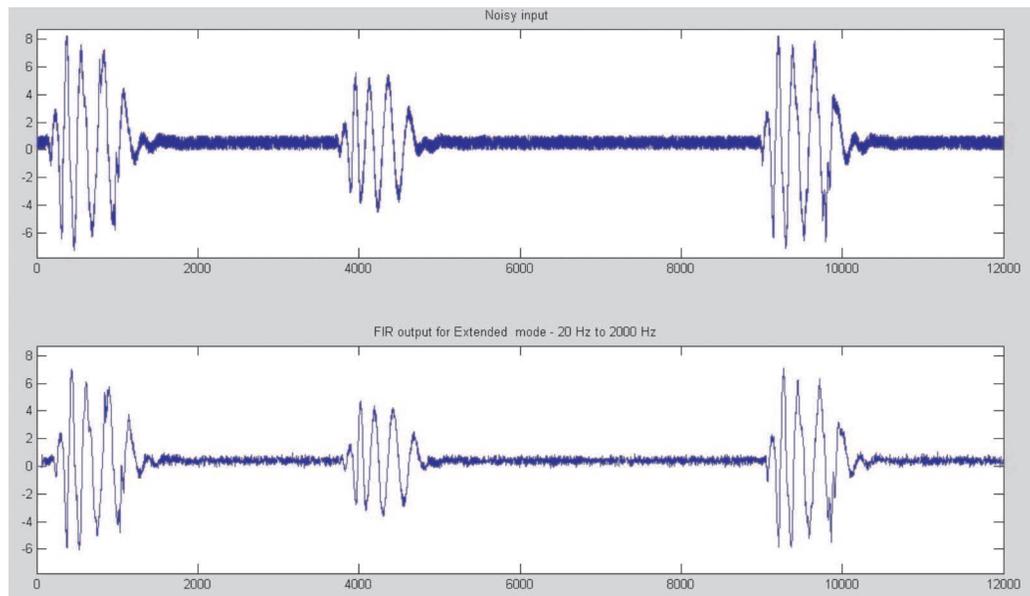
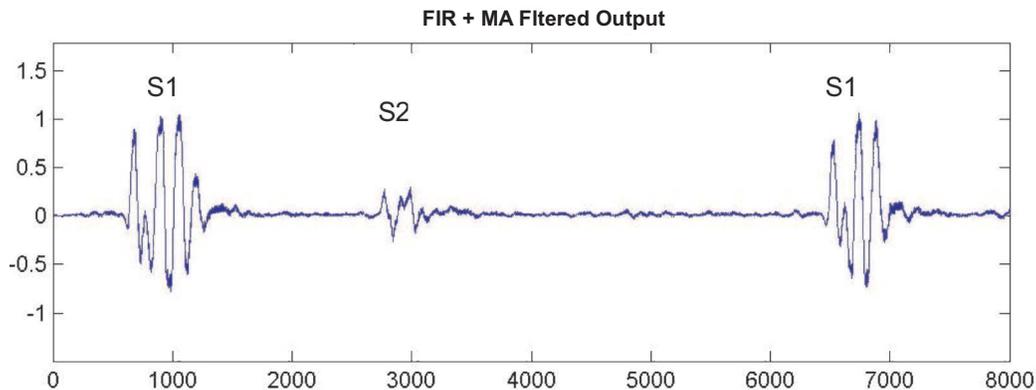


Figure 13. Signal Before and After FIR Filter for Extended Mode

3.3 Heart Beat Detection

Heart rate detection algorithm has the following steps:

1. Smoothen the FIR filter output by using the 5 tap moving average filter.
2. Detect the S1 (first heart sound) by calculating the maximum slope of the smoothened waveform.
3. Disable the S1 detection logic for 100 msec.
4. Measure the number of samples between two consecutive S1's.
5. Calculate the heart rate using the following formula:
 - (a) $HR = ((\text{Sampling Rate} * 60) / \text{Number of samples between two consecutive S1's})$
 - (b) Where, sampling rate = 12000 Hz
6. Apply eight data point moving average logic to compute the average heart rate.



$$HR = (\text{Sampling Rate} * 60) / \text{Number Sample Between 2 S1 Peaks}$$

Figure 14. Heart Waveform Showing S1

The moving average filter is implemented using a recursive algorithm. The order of the moving average filter used is 5. The following equation shows the moving average window:

$$y[i] = \frac{1}{M} \sum_{j=0}^{M-1} x[i+j]$$

Where

M – order of filter

x[i] – i th input sample

y[i] – i th filtered output

3.4 UART Transmission

The filtered output (at data rate 12000 sps) is decimated to 3000 sps and sent to UART for transmission. Decimation is implemented by averaging four samples.

The following parameters are sent over UART to the PC application every one sec.

- Heart rate
- Operating mode
- Volume

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

3.5 LCD Display

The LCD display shows the MDK application: volume indication bars, modes of operation, heart rate display, and bell or diaphragm mode. A sample LCD screen is shown in Figure 15.

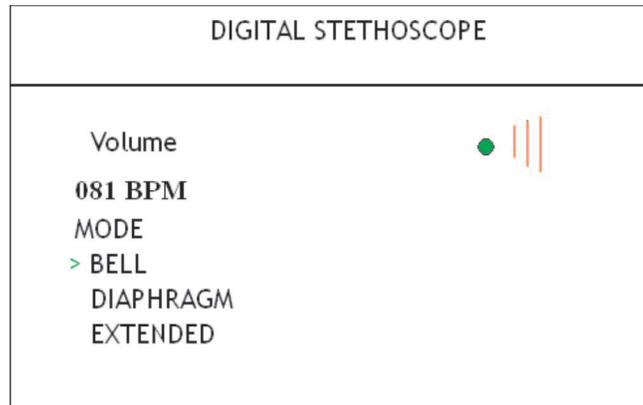


Figure 15. LCD Screen

The LCD display on the EVM is controlled using the SW7, SW10, SW12 and SW13 keys. For each of these key, an interrupt is generated and communicated to the DSP through the SAR interrupt.

4 PC Application

The PC application is used for viewing the heart waveform and heart rate 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 digital stethoscope signals are plotted in real-time
- Offline Mode: the recorded stethoscope wave files are played back

The PC application uses two timers in the online mode of operation: acquisition timer and display timer.

The acquisition timer is set for 100 ms interval for reading the data from the serial port. After retrieving the data from the serial port, it parses the stream of bytes for different variables such as mode of operation, heart rate, volume and steth sample value. The 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 for plotting the stethoscope wave form, and updating the mode of operation, heart rate, and volume information on the screen. This timer elapses every 60 ms; in each elapsed event 18 samples are plotted on the screen. Figure 16 shows a sample PC application snapshot.



Figure 16. PC Application

5 Installation

5.1 Components and Accessories Required

The following components and accessories are required for the MDK digital stethoscope installation.

- C5515 EVM
- Digital stethoscope front-end board
- Code Composer Studio v3.3
- RS232 cable
- USB cable
- Stethoscope diaphragm coupled with condenser microphone
- Stereo headphone
- C5515 DSP application software
- PC application software

5.2 Hardware Installation

1. Mount the stethoscope front-end board on top of the C5515 EVM at connectors J20, J21 and J22. Ensure that there is a firm connection between the front-end board and the EVM.
2. Connect the USB cable between the PC and the C5515 EVM for the debug mode of operation.
3. Connect the stethoscope sensor plug at J8.

The front-end board has a 2.5 mm jack; the mechanical adapter supplied with the stethoscope kit can be used to connect the 3.5 mm plug. First, connect the adapter to the microphone plug, then; insert it into jack J8 of the front-end board.

NOTE: If you want to sample heart sounds that are played on the PC, connect the line out from the PC to J8 of the stethoscope front-end board.

4. Connect the stereo headphone at J14 on stethoscope front-end board.
The front-end board has 2.5 mm jack; the mechanical adapter supplied with the stethoscope kit can be used to connect the 3.5 mm plug. First, connect the adapter to the headphone plug, then; insert it into jack J8 of the front-end board.
5. Connect the serial cable (UART) to the DB9 connector (J13) of the C5515 EVM and the other end to the serial port of the PC for viewing signals on the PC application.
6. Connect the power supply into power jack J7 on the C5515 EVM.
7. Keep jumper J4 and J9 in the closed position.
8. Place the sensor on the body to listen to heart and/or lung sounds.

5.3 Software Installation

5.3.1 System Requirements

The following installations are required to run the software provided with the MDK digital stethoscope kit.

- Code Composer Studio v3.3
- USB driver for Code Composer Studio v3.3
- NET 2.0 framework

Table 3 explains the content of the CD provided with the MDK digital stethoscope kit.

Table 3. Release CD Contents

S Number	Directory/File name	Contains
1	StethSystem_V_0_4.2	Project source code
2	Output	Contains two files: STETHSystem.out c5505evm.gel
3	PCApplication	Executable for PC application
4	BootImageCreation.zip	Folder that contains the following files: bootImage.exe convertBind0.bat convertEnc0.bat convertInsecure.bat programmer.out readme.txt
5	Document	Contains the following documents: ReleaseNote.txt Quick starter guide V6.0 doc

5.3.2 C5515 DSP Software (debug mode) Installation Steps

1. Copy the *c5505evm.gel* file from the CD to <CCS installation dir>/CC/GEL/.
2. Copy the *StethSystem* directory from the CD to a local directory on the PC where Code Composer Studio is installed.

5.3.3 C5515 DSP Software (standalone mode) Installation Steps

1. Copy the *BootImageCreation.zip* file from the CD to a local directory on the PC where Code Composer Studio is installed. This path needs to be used later for Flashing; ensure that there are no spaces in the path name.
2. Copy the *STETHSystem.out* file from the CD to the < BootImageCreation > folder.
3. Execute *convertInsecure.bat* from the <BootImageCreation> folder to create the new *InsecureBootImage.bin* file.
4. Open Code Composer Studio.

5. Power on the C5515 EVM.
6. Select Debug → Connect in Code Composer Studio to connect to the C5515 EVM.
7. Load *programmer.out* C5515 EVM from the < BootImageCreation > folder.
8. Select Debug → Run in Code Composer Studio.
9. Enter 241:<BootImageCreation Folder>\InsecureBootImage.bin and press OK in the popup window shown in Figure 17.

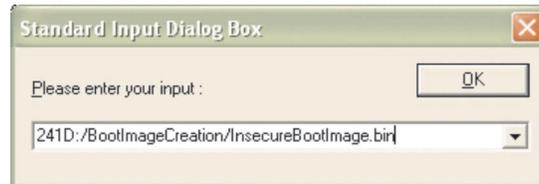


Figure 17. Input Dialog Box

10. Wait until *Programming Complete*.
11. Power off the C5515 EVM and disconnect.

5.3.4 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=0856eachb-4362-4b0d-8edd-aab15c5e04f5&displaylang=en>.

1. Open the *PCApplication* folder on the CD and double click on *C55x Steth 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.

6 Running the Demo Application

The digital stethoscope application can be run in two modes: standalone and debug.

- Standalone mode, for running from Flash memory
- Debug mode, for loading and debugging using Code Composer Studio

6.1 Running in Standalone Mode

1. Complete the installation steps provided in Section 5.3.
2. Power on the C5515 EVM using slide switch SW4.
3. Place the sensor to listen to heart and/or lung sounds.

6.2 Running in Debug mode

1. Complete the installation steps provided in Section 5.3.
2. Power on the C5515 EVM using slide switch SW4.
3. Open Code Composer Studio.
4. Click on Debug → Connect in Code Composer Studio to connect to the C5515 EVM.
5. Click on Project → Open in Code Composer Studio and select the *STETHSystem.pjt* file.
6. Click on File → Load .out file in Code Composer Studio. The .out file is located in the Debug directory.
7. Execute the application.
8. Place the sensor to listen to heart and/or lung sounds.

6.3 Running the PC Application

6.3.1 Online Mode

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

1. Connect the RS232 cable between the PC COM port and the C5515 EVM.
2. Complete the installation steps provided in [Section 5.3](#).
3. Open the PC application.
4. Select online mode and click OK.
5. Select the available COM port and click OK.
6. Signals transmitted from the C5515 EVM can be viewed on the PC application.

6.3.2 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.
2. Select offline mode and click OK.
3. Browse and select the previously saved .wav file and click OK.
4. Heart waveforms can be viewed on the PC application.

7 Options and Selections

7.1 On the C5515 EVM

7.1.1 Mode Selection

The operating mode can be selected depending on your diagnostic requirement. To switch between different modes, switch SW7 needs to be pressed at run time.

By default, the application works in bell mode. Pressing the switch changes the mode selection that can be viewed on the LCD screen and also on the PC application.

7.1.2 Volume Control

The volume of the output signal can be increased or decreased by pressing switch SW12 or SW13, respectively. The selected volume is indicated using the volume bar on the LCD screen by highlighting the yellow indicator bars. The default volume level will be 0 dB (3 yellow bars). A green dot on the LCD screen indicates that the volume is on as shown in [Figure 18](#).

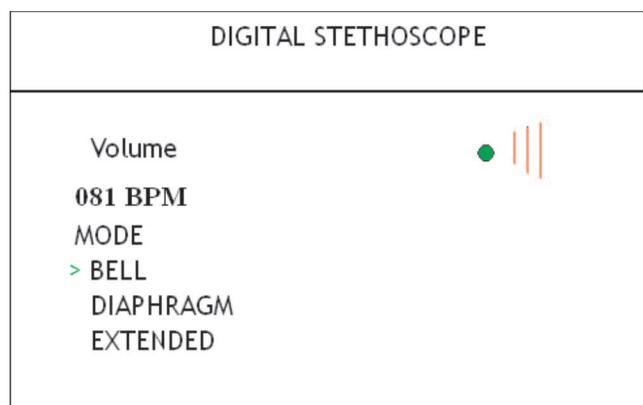


Figure 18. LCD Screen Showing Volume Level 0dB

7.1.3 Mute Option

The output sound can be muted and un-muted by pressing switch SW8 on the C5515 EVM. A red dot on the LCD screen indicates that the volume has been muted as shown in [Figure 19](#).

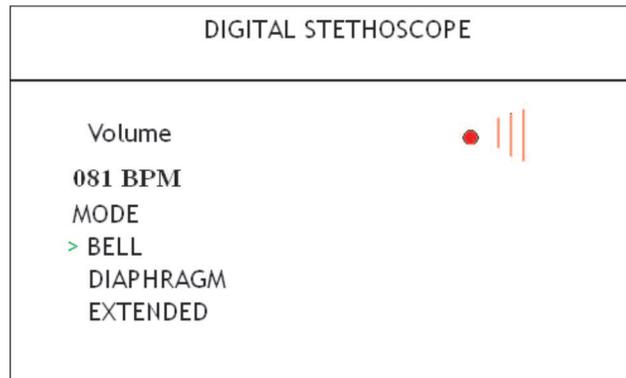


Figure 19. LCD Screen Showing Mute On

7.2 PC Application

The following features are provided on the PC application.

- **Zoom In** - This can be used to *zoom in* the heart sound display on PC application and to amplify the heart sounds while storing.
- **Zoom Out** - This can be used to *zoom out* the heart sound display on PC application and to reduce the amplification of heart sound while storing.
- **Start Recording** - This can be used to start the recording of the heart sound. During recording, this same button is used for the *Stop Recording* operation. Note that after the start recording option is selected, the zoom options get disabled.
- **Stop Recording** - This can be used to stop recording and save the heart sound as a .wav file. It can be played back using the PC application in offline mode, or also using media players.
- **Clear**: This can be used to clear the screen and start a fresh display of the waveform.
- **Cancel**: This can be used to close the form.

8 References

- *TMS320VC5505 DSP Medical Development Kit (MDK) Quick Start Guide* ([SPRUG01](#))

Appendix A Front-End Board Schematics

A.1 Front-End Board Schematics

The schematics for the digital stethoscope front-end board are shown below:

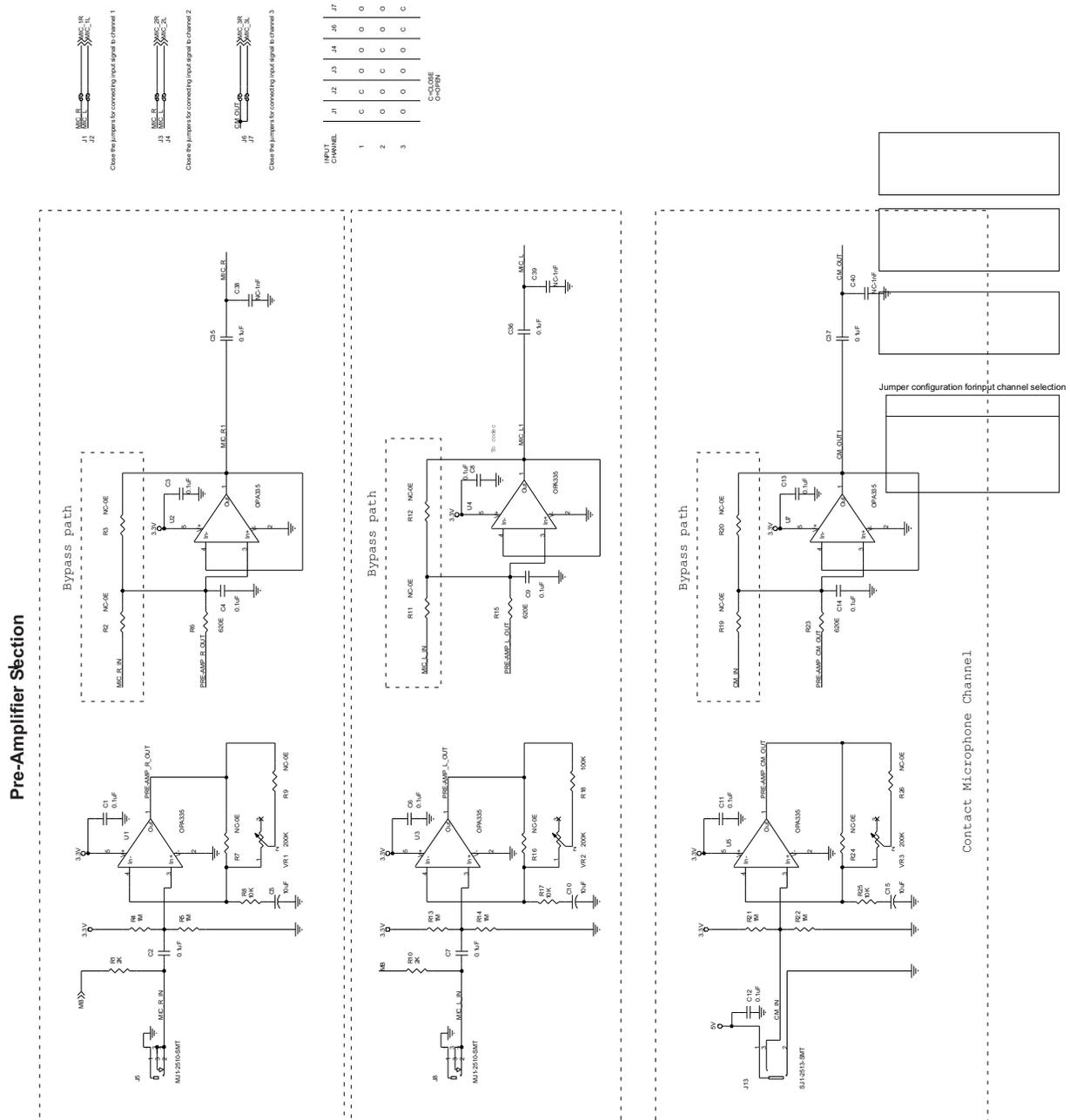


Figure 20. Pre-Amplifier

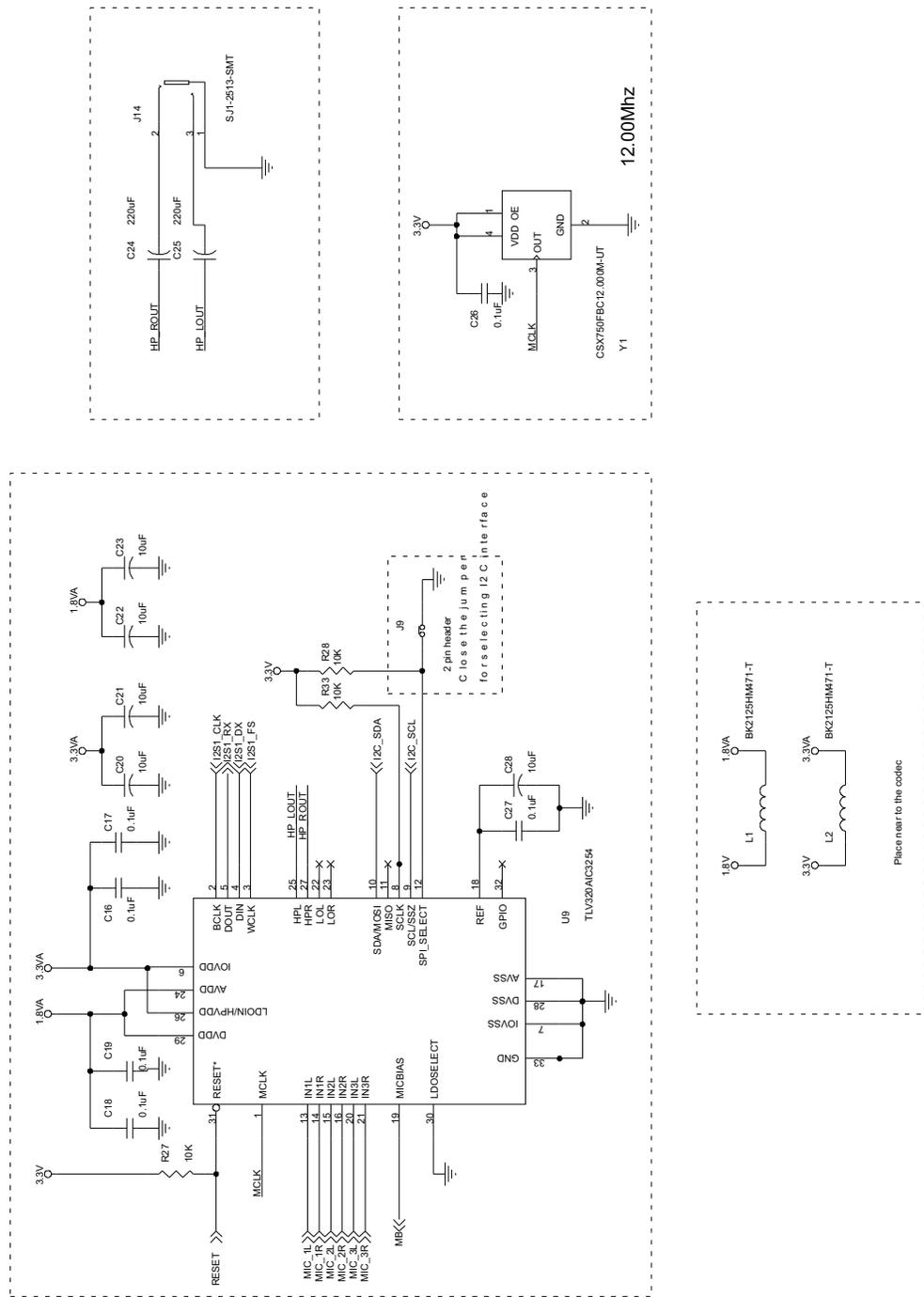


Figure 21. Codec Schematic

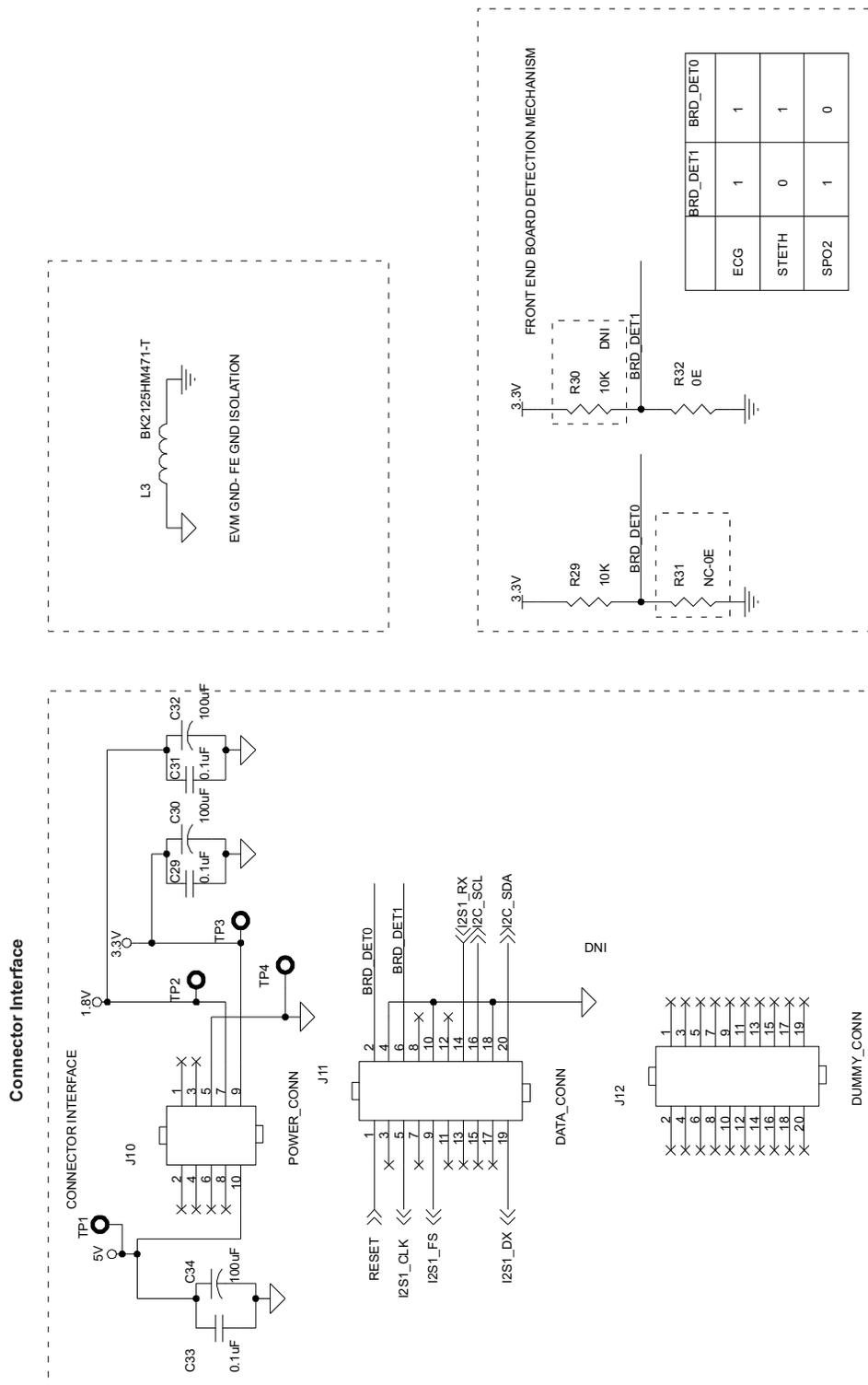


Figure 22. Connector Interface Schematic

Appendix B FE Board BOM

B.1 FE Board BOM

Table 4 provides the bill of material for the digital stethoscope front-end board.

Table 4. Bill of Material

Item	Quantity	Value	Reference	Description	Part Number	Manufacturer	DNI
1	24	0.1 μ F	C1,C2,C3,C4,C6,C7,C8,C9,C11,C12,C13,C14,C16,C17,C18,C19,C26,C27,C29,C31,C33,C35,C36,C37	CAP CERM 0.10 μ F 50 V 5% 0603 SMD	ECJ-1VB1C104K	Panasonic	
2	8	10 μ F	C5,C10,C15,C20,C21,C22,C23,C28	CAPACITOR TANT 10 μ F 16 V 10% RAD	T350E106K016AS	KEMET	
3	2	220 μ F	C25,C24	CAP 220 μ F 16 V ELECT FC SMD	EEV-FC1C221P	Panasonic	
4	3	100 μ F	C30,C32,C34	CAP ELECT 100 μ F 16 V TK SMD	EEE-TK1C101P	Panasonic	
5	3	NC-1 nF	C38,C39,C40	CAP CERM 0.10 μ F 50 V 5% 0603 SMD	ECJ-1VB1C104K	Panasonic	Yes
6	7	2 pin header	J1,J2,J3,J4,J6,J7,J9	CONN HEADER 2POS .100 VERT TIN	LOCAL	LOCAL	
7	2	MJ1-2510-SMT	J5,J8	SMT CONN AUDIO JACK MONO 2.5MM SMD	MJ1-2510-SMT	CUI	
8	1	POWER_CONN	J10	Elevated Female Header 5x2	BB02-KD102-T03-100000	Gradconn	
9	1	DATA_CONN	J11	Elevated Female Header 10x2	BB02-KD202-T03-100000	Gradconn	
10	1	DUMMY_CONN	J12	Elevated Female Header 10x2			
11	2	SJ1-2513-SMT	J14,J13	CONN AUDIO JACK STEREO 2.5MM SMD	SJ1-2513-SMT	CUI	
12	3	BK2125HM471-T	L1,L2,L3	FERRITE BEAD 470 Ω 0805	BK2125HM471-T	Taiyo Yuden	
13	2	2K	R10,R1	RES 2.00K Ω 1/10W 1% 0603 SMD	RC0603FR-072KL	Yageo	
14	13	NC-0E	R2,R3,R7,R9,R11,R12,R16,R19,R20,R24,R26,R31	RES ZERO Ω 1/10W 5% 0603 SMD	ERJ-3GEY0R00V	Panasonic	Yes
15	1	100K	R18	RES 100K Ω 1/10W 5% 0603 SMD	RC0603JR-07100KL	Yageo	
16	6	1M	R4,R5,R13,R14,R21,R22	RES 1.0M Ω 1/10W 5% 0603 SMD	RC0603JR-071ML	Yageo	
17	3	620E	R6,R15,R23	RES 620 Ω 1/10W 5% 0603 SMD	ERJ-3GEYJ621V	Panasonic	
18	8	10K	R8,R17,R25,R27,R28,R29,R30,R33	RES 10K Ω 1/10W 5% 0603 SMD	RC0603JR-0710KL	Yageo	
19	1	0E	R32	RES ZERO Ω 1/10W 5% 0603 SMD	ERJ-3GEY0R00V	Panasonic	
20	6	OPA335	U1,U2,U3,U4,U5,U7	IC OP AMP CMOS SGL SPLY SOT-23-5	OPA335AIDBVT	TI	
21	1	TLV320AIC3254	U9	IC STEREO AUDIO CODEC 1.8 V 32QFN	TLV320AIC3254	TI	
22	3	200K	VR1,VR2,VR3	POT 200K Ω 4MM SQ CERMET SMD	3314G-1-204E	Bourns, Inc	
23	1	CSX750FBC12.000M-UT	Y1	OSCILLATOR 12.0000 MHZ SMD	CSX750FBC12.000M-UT	CITIZEN	

Appendix C Sensors and Accessories

C.1 *Stethoscope Diaphragm*

Type: Acoustic Stethoscope Diaphragm

A typical acoustic stethoscope diaphragm details is as given below.

Vendor: 3M LITTMANN
Model Number: Classic II SE 2203

For further details and purchases, see the following URL:

<http://www.stethoscope-gallery.com/main/home.aspx>.

C.2 *Condensor Microphone*

Type: MICROPHONE OMNI DIRECT 6MM W/CAP

A typical condenser microphone details is given below.

Manufacturer: Panasonic
Vendor: Digikey
Model Number: WM-64C

For further details and purchases, see the following URL:

<http://parts.digikey.com/1/parts/858-microphone-omni-direct-6mm-w-cap-wm-64c.html>.

C.3 *2.5mm Audio Cable Assembly*

Type: Single Ended Audio cable

A typical audio cable details is given below.

Manufacturer: Tensility International Corp
Vendor: Digikey
Model Number: CA-2202

For further details and purchases, see the following URL:

<http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail&name=CP-2202-ND>.

Appendix D 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 the *TMS320VC5505 DSP Medical Development Kit (MDK) Quick Start Guide* ([SPRUG01](#)) 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

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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