Application Report

SPRAB37A–June 2010

Pulse Oximeter Implementation on the TMS320C5515 DSP Medical Development Kit (MDK)

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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 pulse oximeter 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 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.

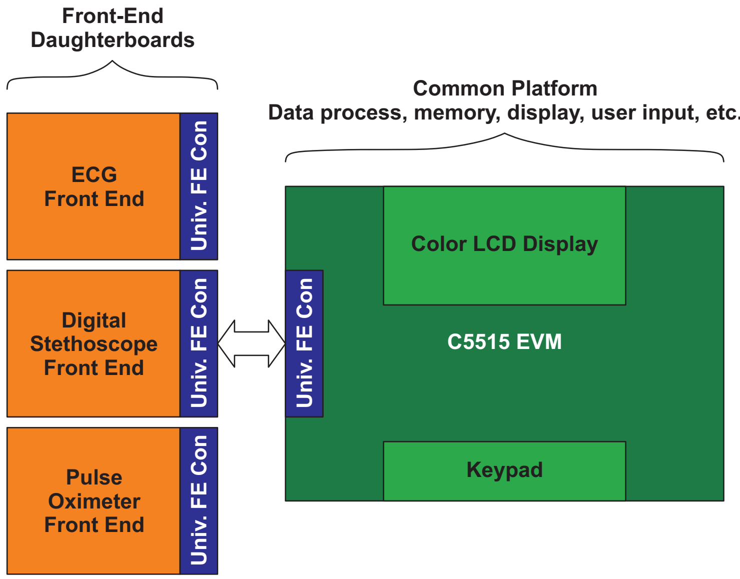


Figure 1. MDK Hardware Overview

1.2 MDK Pulse Oximeter System

Pulse oximeter measures the oxygen saturation in the blood, which is often referred to as % SaO2 or % SpO2. This parameter is defined as the ratio of oxyhaemoglobin (HbO2) to the total concentration of hemoglobin present in the blood (i.e., oxyhaemoglobin + reduced hemoglobin). Pulse oximetry utilizes the attenuation of the light at two different wavelengths where oxygenated hemoglobin and reduced hemoglobin offers significantly different absorption. The oxygen saturation of the arterial blood in the body can be calculated by measuring the light transmitted through the thin part of the patient's anatomy (usually a fingertip or earlobe), at two different wavelengths: one in the red (R) and the other in the near infrared (IR) part of the spectrum.

A plethysmogram displays the IR/R rays absorption of the blood. The absorption of the IR/R rays depends on the oxygen saturation of the blood, which depends on the pumping of the blood by the heart.

1.2.1 Key Features

The key features of the MDK pulse oximeter system are:

- % SpO2 detection and display on the C5515 EVM liquid crystal display (LCD) and PC
- Real-time display of the plethysmogram on the C5515 EVM LCD and PC
- Pulse rate display on the C5515 EVM LCD and PC
- Finger probe off detection and display

1.2.2 MDK Hardware

Several elements of the MDK pulse oximeter system are:

- C5515 EVM
- Pulse oximeter front-end board
- Finger probe 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 Devlopment Kit provided with your EVM.

Key components and interfaces of the C5515 EVM used in the MDK pulse oximeter system include:

- Texas Instrument's TMS320C5515 operating at 100 MHz
- User universal serial bus (USB) port via the C5515
- Inter-integrated circuit (I2C) /serial peripheral interface (SPI) electrically erasable programmable read-only memory (EEPROM)
- External memory interface (EMIF), I2C, universal asynchronous receiver/transmitter (UART), SPI interfaces
- SAR and general-purpose input/output (GPIO)
- Embedded IEEE Standard 1149.1-1990, IEEE Standard Test Access Port and Boundary-Scan Architecture (JTAG) controller
- Color LCD
- Keys (user switches)

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 Pulse Oximeter Front-End Board

Figure 2 shows a DB9 connector on the pulse oximeter front-end board for connecting the finger probe. The front-end board amplifies and digitizes the signals received from the finger probe. ADC (ADS8328) on the front-end board is configured for 500 sps with 16-bit data resolution.

The front-end board is interfaced with and powered by the C5515 EVM board through the universal front-end connector.

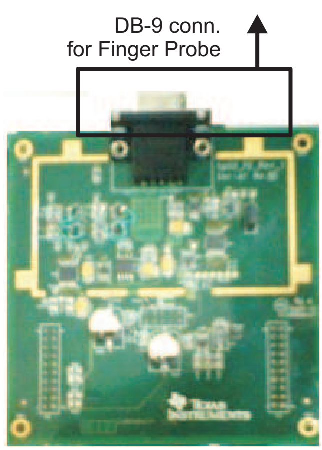


Figure 2. Pulse Oximeter Front-End Board

1.2.2.3 Finger Probe Sensor

The finger probe has a photo detector and two LED’s to transmit light across the fingertip: one red (R) and one infrared (IR). The wavelength of the red light is 660 nm and the wavelenthg of the infrared light is 895 nm.

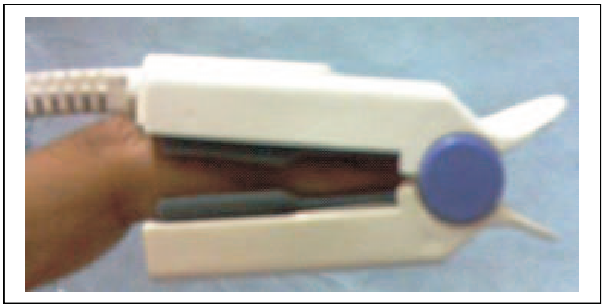


Figure 3. Index Fingertip Placed Inside Finger Probe

1.2.3 MDK Software

The software for the MDK pulse oximeter 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 IR and R signals from the front-end board and processes them. The LCD display on the C5515 EVM shows the %SpO2, plethysmogram and pulse rate. The processed signal is also provided to the PC application over the UART interface for display.

1.2.3.2 PC Application

The PC application, which has to be installed on the PC, can be used for viewing the %SpO2, plethysmogram, and pulse 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 pulse oximeter front-end board architecture.

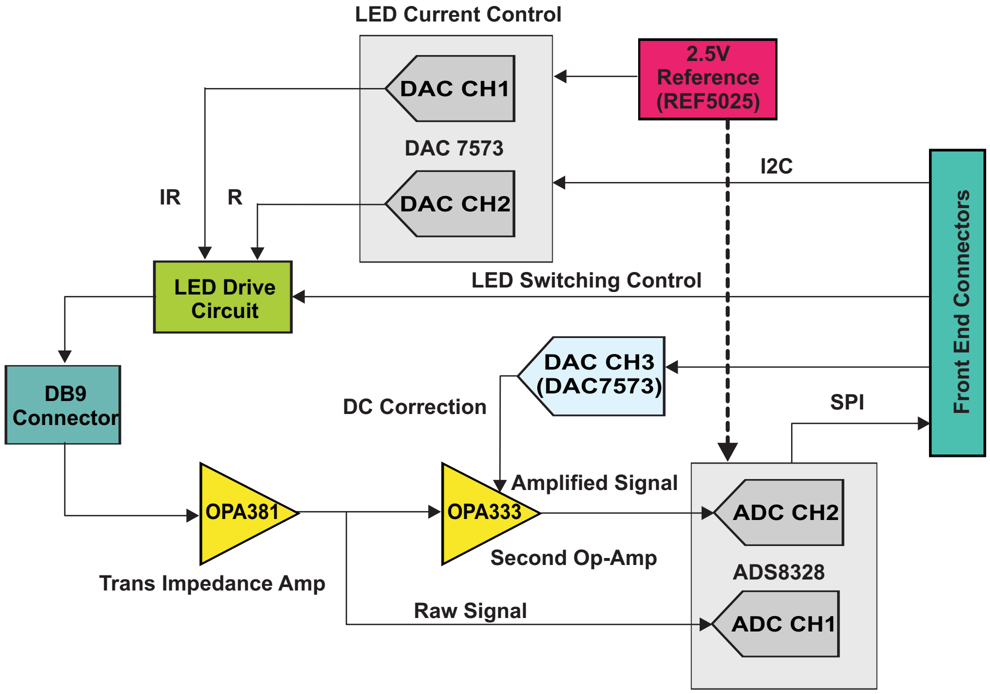


Figure 4. Pulse Oximeter Front-End Block Diagram

The front-end board contains the following stages:

- LED drive
- Signal conditioning
- Lead off detection
- LED intensity and DC offset control
- Signal acquisition
- Front-end connectors

2.1 LED Drive

The red and infrared LED's are switched on and off alternately. The LED's are switched ON in a pulsed fashion so that each LED is switched ON every 2 ms. The timing diagram for LED's are shown in Figure 5.

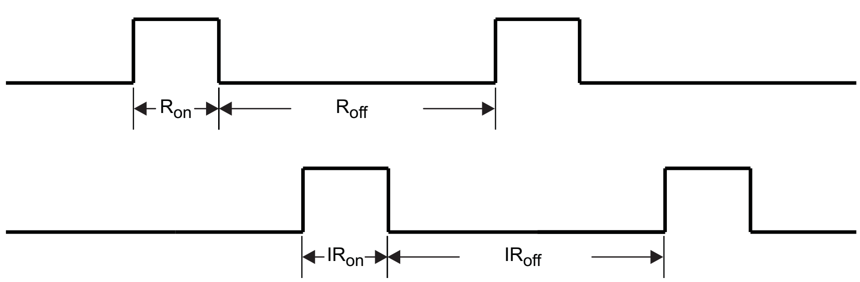


Figure 5. LED Timing Diagram

Where,

Ron/IRon = 450 µs

Roff/IRoff = 1550 µs

The DSP software on the C5515 EVM controls the On and Off switch of the *R* and *IR* LED. Figure 6 shows the LED switching control circuit diagram.

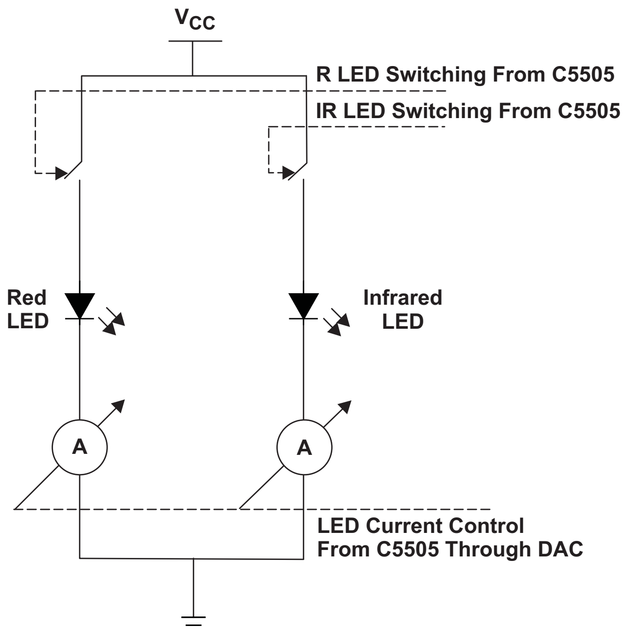


Figure 6. LED Switching Control

The LED current is controlled by the digital-to-analog converter (DAC) driven by the DSP C5515, depending on the R and IR intensity.

2.2 *Signal Conditioning*

The output from the photodiode of the finger probe is passed through a current-to-voltage converter (transimpedance amplifier). The raw voltage converted signal is amplified using a second stage amplifier whose gain is set to 5. The signals from these two stages are fed to two different channels of ADC.

2.2.1 Transimpedance Amplifier

The OPA381 is used as the trans-impedance amplifier. Low input bias current (50pA max), low input voltage noise, low input current noise and the wide bandwidth of OPA381 makes it the obvious choice for trans-impedance amplifier. Moreover this device has low power consumption and operates with a single low voltage supply (2.7 V~5.5 V).

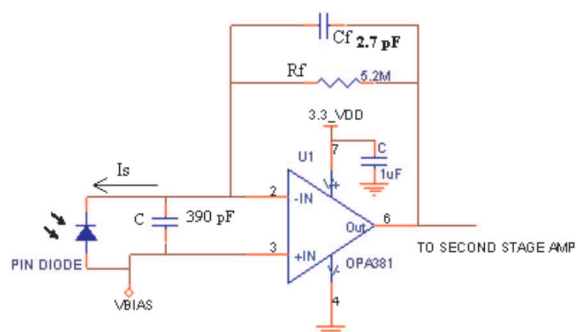


Figure 7. Transimpedance Amplifier

The OPA381 is used in inverting the configuration, where the non-inverting input is raised to a small voltage (0.3 V) for proper operation of the amplifier. At this stage, the level of the signal of the output is maintained within a preset limit by adjusting the intensity of the corresponding LED.

2.2.2 Feedback resistor (R_f)

The input signal from the photo detector is of the order of a few micro amps. A high-value feedback resistance (R_f) of the order of 5.2 M is used to convert the input current into an output signal of a few volts. At this stage, maximum gain is provided because adding more gain after the transimpedance stage generally produces poor noise performance. The signal-to-noise ratio (SNR) is improved with higher R_f since noise increases with the square root of R_f and signal increases linearly with R_f.

2.2.3 Feedback Capacitor (C_f)

Feedback capacitor (C_f) is used to minimize peak gain and improve stability. The use of C_f also limits bandwidth, reducing noise. A capacitance value of 2.7 pF is used as C_f. Larger values of feedback capacitance limit the operating bandwidth.

2.2.4 Second Stage Amplifier

The output from the first stage transimpedance amplifier passes through a second stage amplifier. OPA333 is used as the second stage amplifier (see .

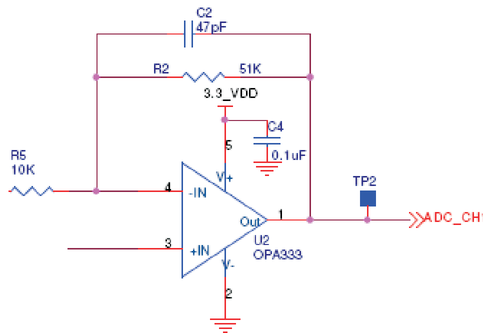


Figure 8. Second Stage Amplifier

The non-inverting input of the second stage amplifier is fed with an adjustable DC voltage so that the output of the second stage amplifier contains the complete AC component of the signal within the working range of the ADC. The second stage amplifier also provides a gain of 5 to the AC component of the signal. This adjustable DC voltage is generated by a DAC (DAC7573) programmed by the DSP C5515 using the I2C bus. Most of the DC component in the signal is removed with this correction.

At this stage, the output is fed to the second channel of ADC (ADC_CH1).

2.3 LED Intensity Control

The output of the transimpedance amplifier (for *R* and *IR*) is kept within fixed levels of the ADC. To keep the output at the fixed DC level, the intensity of the *R* and *IR* LED's are controlled using two channels of the DAC (DAC 7573). The DAC is controlled by the DSP C5515.

Figure 9 shows the current LED control mechanism.

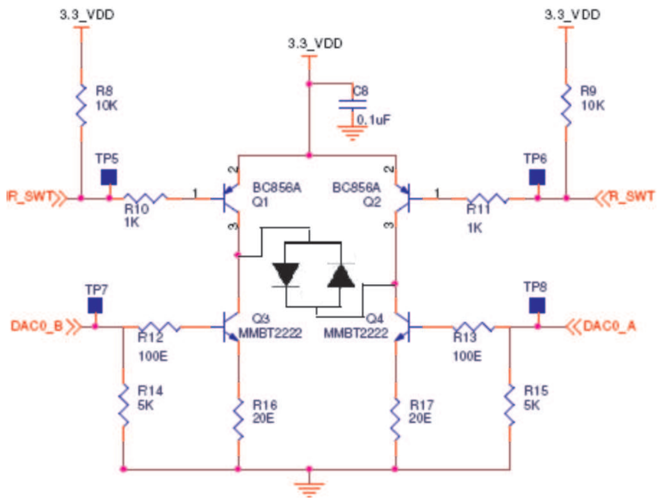


Figure 9. LED Switching and Intensity Control

The red LED glows when transistor, Q2, is switched ON by the DSP. The current through the LED is controlled by Q3. The current through Q3 and the LED intensity is controlled by the base drive to Q3 by changing the DAC output voltage (DAC0_B). Similarly, transistors Q4 and Q1 are used to switch and control the infrared LED intensity. GPIO's are used to switch on/off Q1 and Q2.

2.4 Signal Acquisition Using ADC

The low-power, dual-channel ADC (ADS8328) is used for data acquisition. The analog voltage supply range for ADS8328 is 2.7 V – 5.5 V. Figure 10 shows the block diagram of ADS8328.

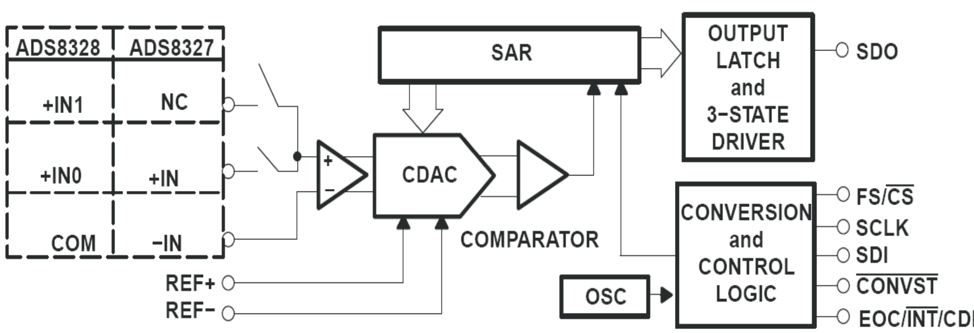


Figure 10. Block Diagram of ADS8328

The signals at the output of the transimpedance amplifier, ADC_CH0. and the second stage amplifier, ADC_CH1, are acquired using two different channels of ADC.

The following configuration is used for the ADC:

Host to ADC Interface	SPI
Sampling frequency	500 Hz
Data format	16-bit linear
ADC mode used	Manual mode
Reference voltage	2.5 V

ADC acquisition is synchronized with the timer to achieve 16 bit 500 samples per second per channel. The ADC is interfaced to the C5515 DSP using the SPI bus.

The ADS8328 is interfaced to the C5515 DSP as shown in Figure 11.

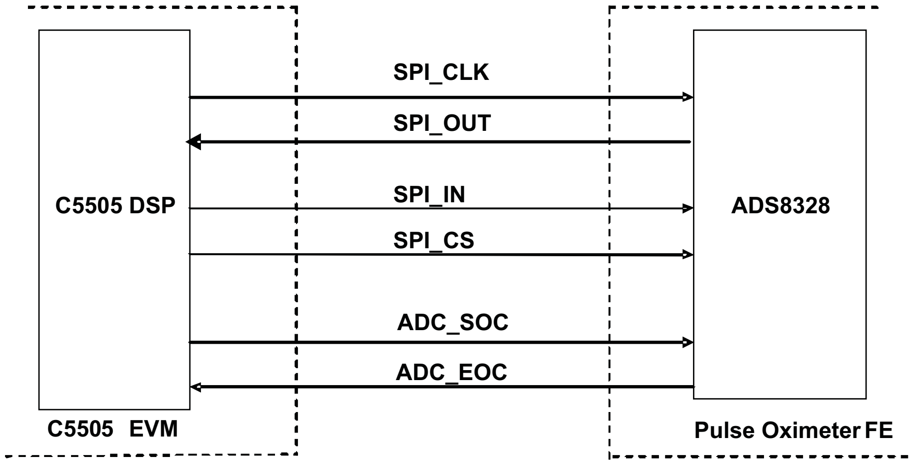


Figure 11. Block Diagram of the Interface Between C5515 DSP and ADS8328

2.5 *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.

2.5.1 J20 Connector Interface at C5515 EVM

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

2.5.2 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 pulse oximeter front-end board.

2.5.3 J22 Connector Interface at C5515 EVM

This connector carries GPIOs, SPI, and I2C connections 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	Signal Assigned
1	ADC_EOC
3	SPI_CLK
6	ADC_CON/ST
7	SPI_CS
8	R_SWT
11	SPI_IN
12	IR_SWT
13	SPI_OUT
16	I2C_SCL
20	I2C_SDA

3 DSP Subsystem

The DSP software running on the C550X EVM takes the digitized signal from the front-end board and processes it. The DSP receives SpO2 signals from channel0 and channel1 of the ADC corresponding to the LED that is switched on at that instant (red or infrared). The signal from channel 0, referred to as raw signal, is the output of the first stage transimpedance amplifier; the signal from channel 1 of the ADC, referred to as amplified signal, represents the output of the second stage amplifier. The raw signal level controls the intensity of the LED so that the signal remains within a preset limit. This helps to achieve linearity and good resolution from the ADC for the calculation of the SpO2 values. The amplified signal is used to calculate the % SpO2, plethysmogram, and pulse rate.

The software is designed to handle the following activities:

- LED switching
- LED intensity control
- Data acquisition: through ADC
- DC offset setting
- Signal processing: noise filtering, DC estimation, AC separation
- Parameter extraction (% SpO2, pulse rate)
- LCD display control

The LED switching block is responsible for switching IR and R LED's ON and OFF. The intensity of the IR and R LED is controlled by the LED intensity control block. The pulse rate and % SpO2 detection module detects the % SpO2 and pulse rate values using the filtered IR and R signals. The display module displays the detected parameters on the EVM LCD and the plethysmogram. The detected parameters are also sent to the PC through the UART interface.

Figure 12 shows the high-level architecture of DSP subsystem.

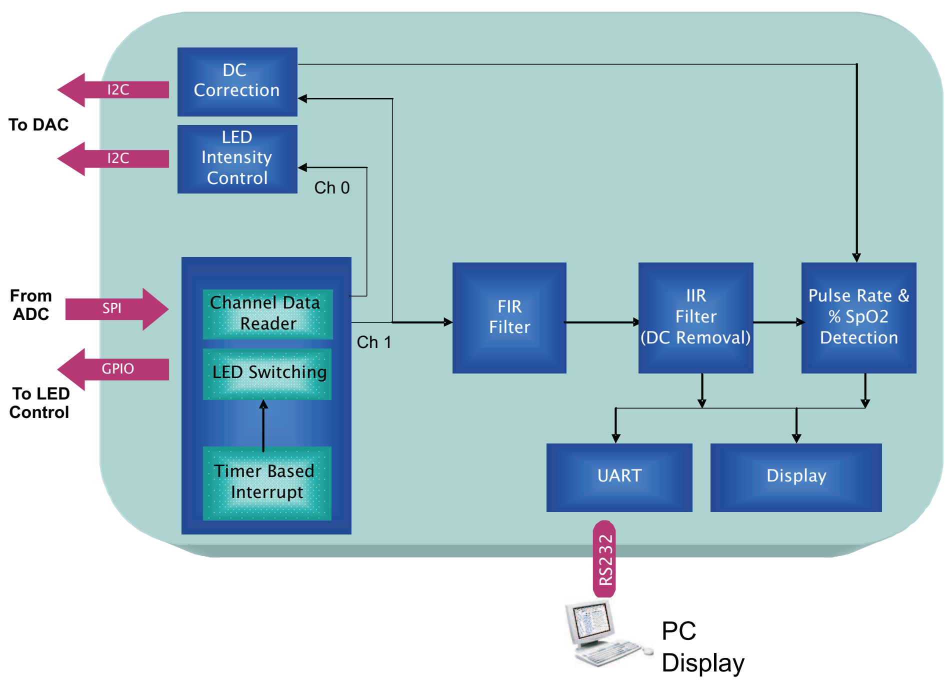


Figure 12. DSP Software Architecture

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

3.1 Data Acquisition

An interrupt is generated every 1 ms using a 1 ms timer. Using GPIO, the interrupt service routine (ISR) issues an ADC_CONV/ST signal to the ADC and waits for the ADC_EOC signal. After getting the ADC_EOC signal, the DSP acquires IR or R signals from the ADC; the IR and R signals are read, alternatively. During each read, both channel0 and channel1 are read. Each channel has 16-bit resolution. Effectively, two channels of IR signals and R signals are read once in every 2 msec (500 sps/Channel). The data acquisition is through SPI interface.

3.2 IR and R LED Intensity Control

The channel0 signal is fed to the LED intensity control logic. Based on the signal strength, this control unit sends the feedback signal to DAC on the front-end board through I2C. The feedback signal is of 12-bit resolution. The raw signal received for R wavelength is used to control the intensity control of R LED and vice versa.

3.3 IR and R DC Correction

The channel1 signal is monitored by a program that adjusts the DC offset of the second stage amplifier so that the AC signal remains within the acceptable working range of the ADC. The DC correction module detects DC level and sends the feedback signal to the DAC on the front-end board through I2C. The feedback signal is of 12-bit resolution.

3.4 FIR Filter

The channel1 signal is fed to the FIR filter for removing unwanted signals. The filter used is the FIR hamming window low-pass filter with order of 51, which provides a sharp cutoff at 10 Hz with attenuation of about 50 dB. The sampling frequency is 500 samples/second.

Buffer shifting convolution algorithm is used for the realization of the filter. The filter window is shifted for every filtered sample and to insert the new sample into the buffer as depicted in Figure 13.

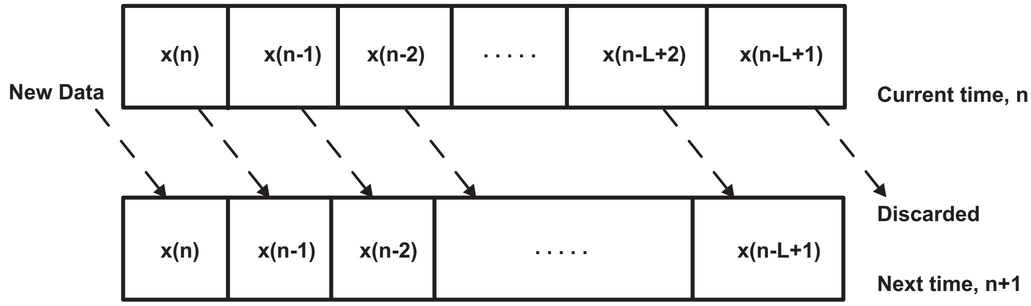


Figure 13. Buffer Shifting

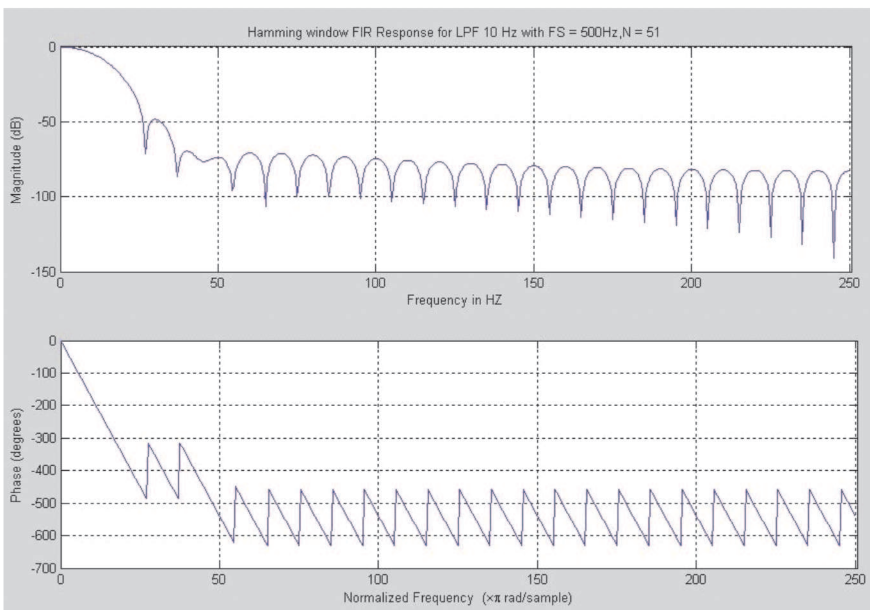


Figure 14. Results of LPF Implementation

3.5 IIR Filter for DC Removal

the filtered channel1 from the DC signal is 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 at 22 dB, the value of alpha is chosen 0.992.

Figure 15 shows the frequency response for the filter.

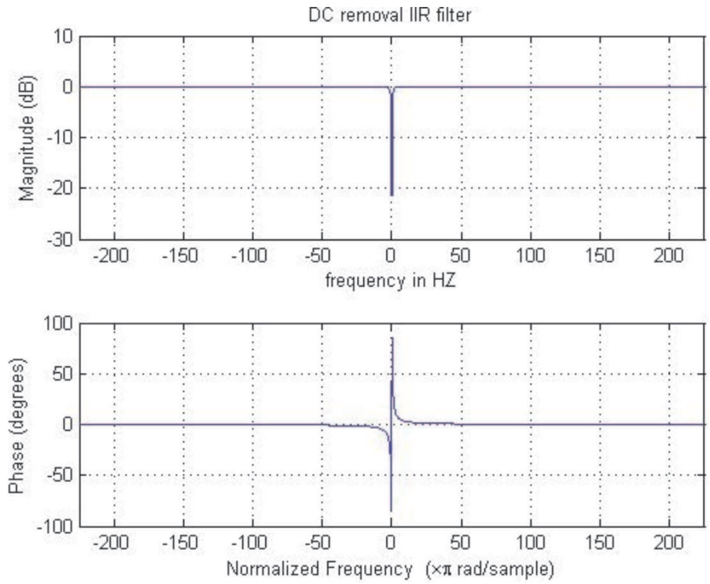


Figure 15. DC Removal Filter Response

Figure 16 shows the pole and zero location for IIR filter. Pole is locate at z = 0.992, and zero at 1 in Z plane.

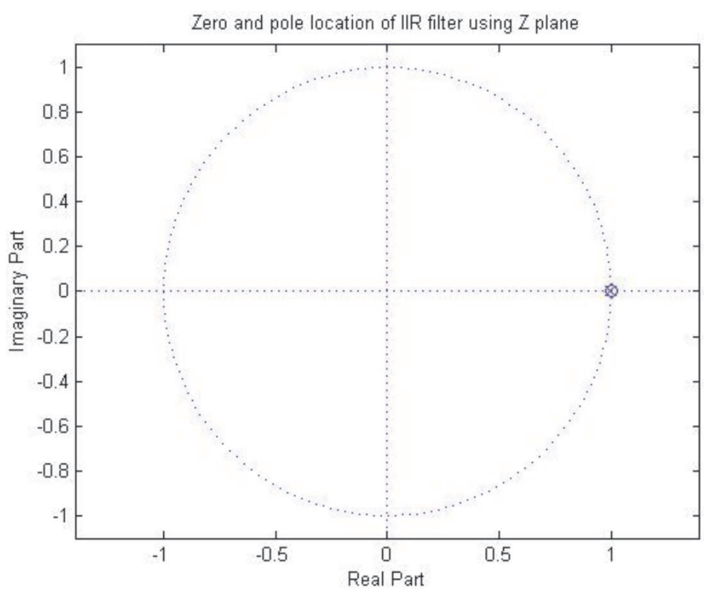


Figure 16. Pole and Zero Location for IIR Filter

Figure 17 shows the 1 Hz signal response via the DC removal filter.

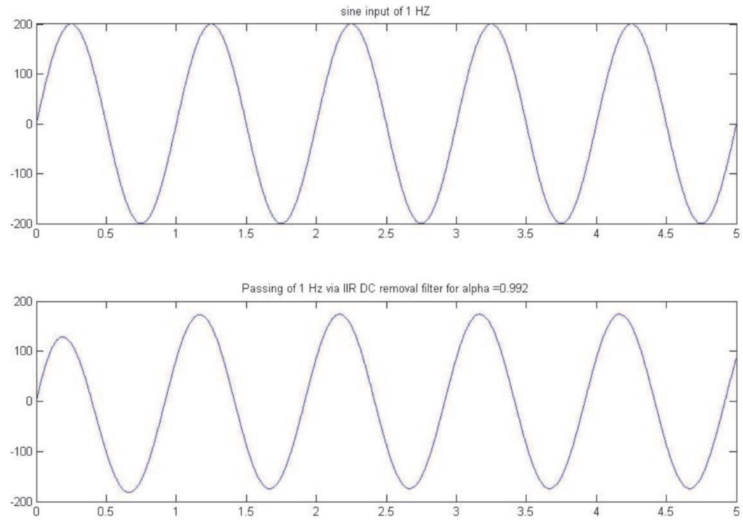


Figure 17. Signal Response via DC Removal Filter

3.6 Pulse Rate Detection

The pulse rate detection is done using the IR AC signals. The IR signals minimum and maximum threshold values are determined using the following formula:

Max Threshold = 40% below the maximum IR value

Min Threshold = 40% above the minimum IR value

These threshold values get updated if there is any change in the amplitude level of the IR signals.

The pulse rate detection algorithm detects the numbers of samples between two consecutive threshold (max) crossing points. The algorithm then calculates the pulse rate using the following formula.

Pulse Rate = (60 * Sampling Rate) / Number of samples between threshold crossing points

3.7 % SpO2 Detection

From the AC sample values obtained for the R and IR signals, the RMS values for the IR and R signals are detected over a period of three heart beats. The RMS values are passed through a square root algorithm providing a value proportional to the peak-to-peak signal. The ratio of R and IR signals are calculated and a table look-up is used for obtaining the SpO2 values.

3.8 Display

The LCD display shows the plethysmogram, pulse rate and finger probe status. It is controlled using the SW8 key on the EVM as mentioned in Section 7.1.1. Pressing the key on the EVM generates an interrupt, which is communicated to the DSP through a SAR interrupt. The interrupt service routine for the key press takes care of the corresponding action for the interrupt.

3.9 Universal Asynchronous Receiver/Transmitter (UART)

The data sent to the PC through UART has both R and IR signals; these signals are sent at 250 sps. A synchronization frame (Header) of 5 bytes is also sent to the UART interface every 2 s. The pulse rate, probe status, and % SpO2 values are sent through UART along with the SpO2 header.

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

SpO2 Header

FF	FF	00	00	FF	<Probe Status + % SpO2>	<Pulse Rate>

SpO2 Data

Low 8-bits IR	High 8-bits IR	Low 8-bits R	High 8-bits R

4 PC Application

The PC application is used for viewing the pulse oximeter waveform and pulse oximeter 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 pulse oximeter data is plotted in real-time as a scrolling display
- Offline mode: the recorded pulse oximeter data, SpO2 files, can be played back

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 the serial port, it parses the stream of bytes to different variables like the SpO2 value, infrared, red sample values, and probe status. The SpO2 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 SpO2 waveforms, and update the SpO2 saturated value and heart rate on the screen. This timer elapses every 60 ms; in each elapsed event 15 samples are plotted on the screen. Figure 18 shows a sample PC application snapshot.

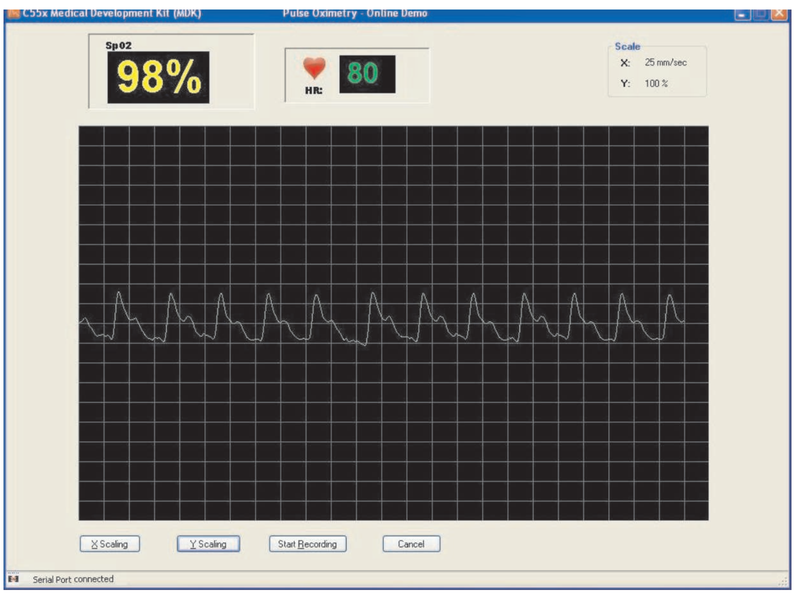


Figure 18. PC Application Snapshot

5 Installation

5.1 Components and Accessories Required

The following components and accessories are required for the MDK pulse oximeter installation.

- C5515 EVM with power supply
- Pulse oximeter front-end board (SpO2 FE)
- Code Composer Studio v3.3
- RS232 cable
- USB cable
- SpO2 probe
- C5515 DSP application software
- PC application software

5.2 Hardware Installation

1. Mount the pulse oximeter 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 SpO2 finger probe to the DB9 connector P1.
4. 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 the signals on the PC application.
5. Connect the power supply to the power jack, J7, on C550X EVM.
6. Power on the system using slide switch SW4 on the C5515 EVM.
7. Place the index finger inside the finger probe as shown in Figure 3.

5.3 Software Installation

5.3.1 System Requirements

The following installations are required to run the software provided with the MDK pulse oximeter kit.

- Code Composer Studio v3.3
- bios_5_32_01
- Spectrum Digital XDS510 USB driver for Code Composer Studio v_3.3
- .NET 2.0 frame work

Table 2 explains the content of the CD provided with the MDK pulse oximeter kit.

Table 2. Release CD Contents

S Number	Directory/Filename	Contains
1	SpO2System_V_5_0	Project source code
2	Output	Contains three files: SpO2System.out c5505evm.gel and C5515 XDS510USB Emulator.ccs
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 *SpO2System* 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 *SpO2System.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 19.

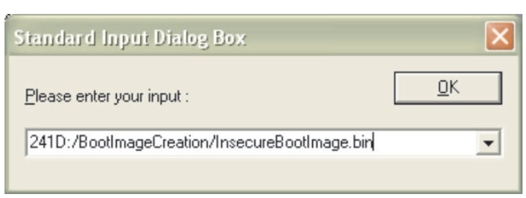


Figure 19. Input Dialog Box

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=0856eacb-4362-4b0d-8edd-aab15c5e04f5&displaylang=en.

1. Open the *PCApplication* folder on the CD and double click on *C55x SpO2 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 pulse oximeter 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 C5515 EVM using slide switch SW4.
3. Place the index finger inside the probe, as shown in Figure 3, to display % of SpO_2, pulse rate, and plethysmogram on the LCD screen.

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 *SpO2System.pjt* file.
6. Click on File → Load .out file in Code Composer Studio.
7. Execute the application.
8. Place the index finger inside the probe, as shown in Figure 3, to display % of SpO_2, pulse rate, and plethysmogram on the LCD screen.

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 5.3.4.
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 SpO2 file (.SpO2) and click OK.
4. View the static Plethysmogram along with the % SpO2 value and pulse rate on the PC application.

7 Options and Selections

7.1 On the C5515 EVM

7.1.1 Plethysmogram Display on the C5515 EVM Side

The SpO2 display on the LCD screen starts by showing the *pulse oximeter* followed by % SpO2 and pulse rate display as shown in the Figure 20.

The plethysmogram display starts after 3 s. The color of the waveform indicates the probe connectivity; a green line indicates that the probe is properly connected to the finger and a red line indicates that the probe is not connected properly.

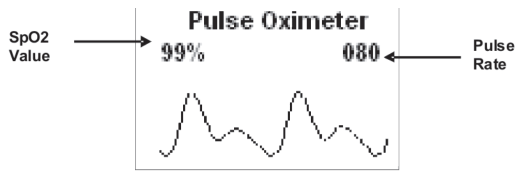


Figure 20. Display on the EVM LCD Screen

The SW8 switch can be used as zoom in and zoom out features for the plethysmogram. There are three levels of zooming that are provided: low, medium (default), and high.

7.1.2 PC Application

% SpO2 value and pulse rate display on the screen and the values gets refreshed every 2 seconds. Serial port connection (RS232) status with the device is displayed on the status bar.

The following features are available on the PC application.

- **Zoom In** - This can be used to *zoom in* the SpO_2 data displayed on the PC application and to amplify SpO_2 data while storing.
- **Zoom Out** - This can be used to *zoom out* the SpO_2 data displayed on PC application and to reduce the amplification of SpO2 data while storing.
- **Start Recording** - This can be used to start the recording of the SpO_2 data. 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 SpO_2 data as an .SpO2 file. It can be played back using the PC application in offline mode.
- **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 (SPRUGO1)

Appendix A Front-End Board Schematics

A.1 Front-End Board Schematics

The schematics for the pulse oximter front-end board are shown below.

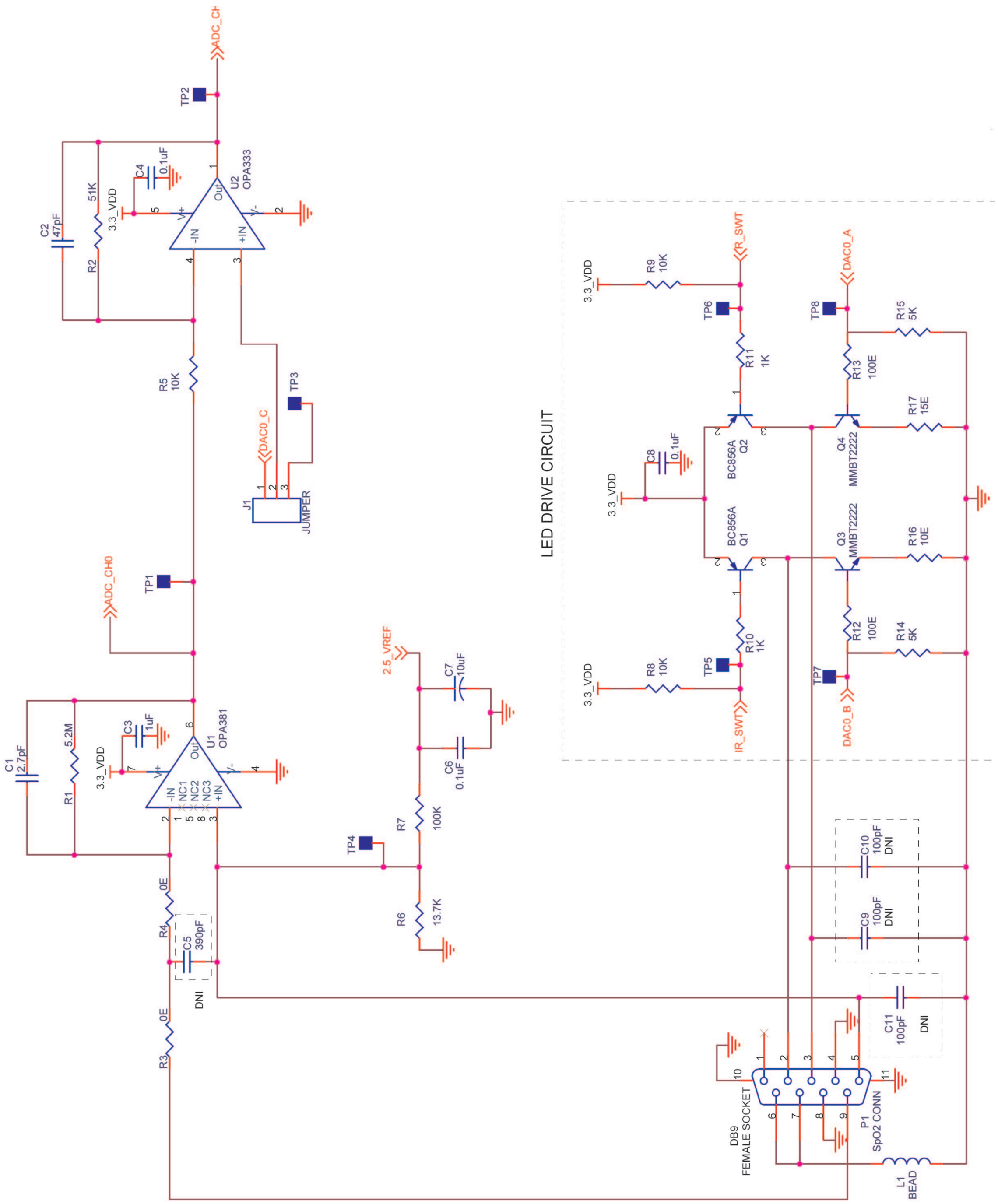


Figure 21. TRANS_IMP_AMP

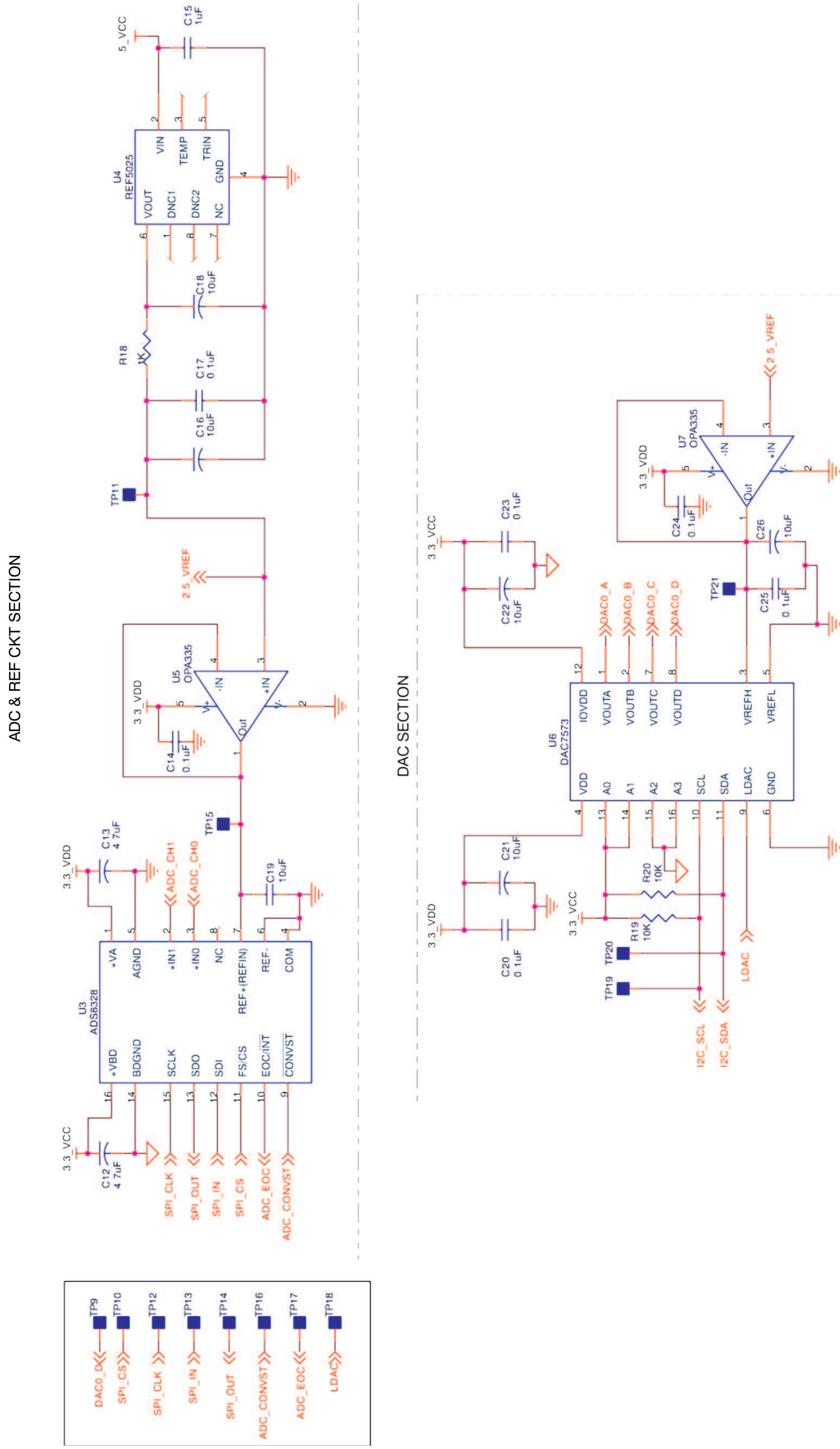


Figure 22. ADC_DAC

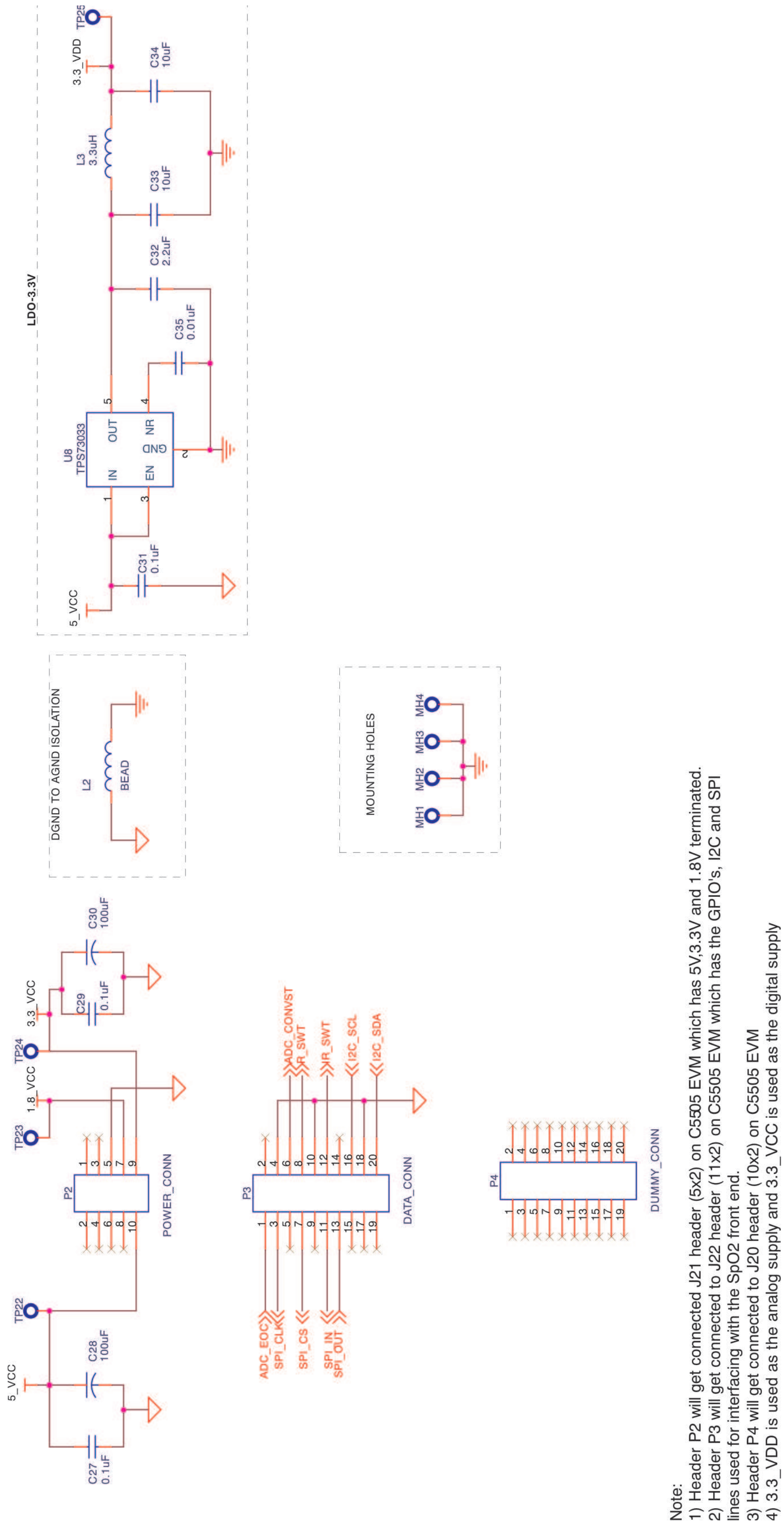


Figure 23. PWR_CONN_INTRFCE

Appendix B Front-End Board BOM

B.1 Front-End Board BOM

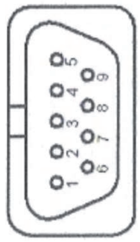
Table 3 provides the bill of material for the digital stethoscope front-end board.

Table 3. Bill of Material

Item	QTY	Value	Reference	Description	Part Number	Manufacturer
1	1	2.7 pF	C1	CAP CER 2.7 pF 50V NPO 0805	08055A2R7BAT2A	AVX Corporation
2	1	47 pF	C2	CAP CERM 47 pF 5% 50 V NPO 0805	08055A470JAT2A	AVX Corporation
3	2	1 µF	C15,C3	CAP CERM 1.0 µF 10% 25 V X7R 0805	08053C105KAZ2A	AVX Corporation
4	12	0.1 µF	C4,C6,C8,C14,C17, C20,C23,C24,C25, C27,C29,C31	CAP CERM 0.10 µF 50 V 5% 0805 SMD	08055C104JAT2A	AVX Corporation
5	1	390 pF	C5	CAP CERM 390 pF 50 V 5% 0805 SMD	08055C391JAT2A	AVX Corporation
6	6	10 µF	C7,C16,C18,C21,C2 2,C26	CAP TANT LOESR 10 µF 16 V 10% SMD	TPSB106K016R0800	AVX Corporation
7	3	100 pF	C9,C10,C11	CAP CERM 100 pF 50 V 5% 0805 SMD	08055C101JAT2A	AVX Corporation
8	2	4.7 µF	C12,C13	CAP TANT LOESR 4.7 µF 16 V 10% SMD	TPSB475K016R0800	AVX Corporation
9	3	10 µF	C19,C33,C34	CAP CER 10 µF 16 V X5R 0805	EMK212BJ106KG-T	Taiyo Yuden
10	2	100 µF	C28,C30	CAP ELECT 100 µF 16 V TK SMD	EEE-TK1C101P	Panasonic
11	1	2.2 µF	C32	CAP CER 2.2 µF 25 V X7R 0805	08053C225MAT2A	AVX Corporation
12	1	0.01 µF	C35	CAP CERM 0.01 10% 50 V X7R 0805	08055C103KAT2A	AVX Corporation
13	1	JUMPER	J1	CONN HEADER 3POS .100 VERT TIN	22-28-4030	Molex
14	2	BEAD	L2,L1	FERRITE BEAD 470 Ω 0805	BK2125HM471-T	Taiyo Yuden
15	1	3.3 µH	L3	INDUCTOR POWER 3.3 µH 1.3A SMD	VLF4012AT-3R3M1R3	TDK Corporation
16	1	SpO2 CONN	P1	DB9 SpO2 Connector Female	5745988-4	Tyco Electronics
17	1	POWER_CONN	P2	Elevated Female Header 5x2	BB02-KD102-T03-100000	Gradconn
18	1	DATA_CONN	P3	Elevated Female Header 10x2	BB02-KD202-T03-100000	Gradconn
19	1	DUMMY_CONN	P4	Elevated Female Header 10x2	BB02-KD202-T03-100000	Gradconn
20	2	BC856A	Q2,Q1	PNP Transistor SOT23-3	BC856AMTF	Fairchild
21	2	MMBT2222	Q3,Q4	NPN Transistor SOT23-3	MMBT2222	Fairchild
22	1	5.2M	R1	High Precision Chip Resistor 5.2M Ω	CRCW08055M20DHEA	Vishay
23	1	51K	R2	RES 51KΩ 1/8W 1% 0805 SMD	CRCW080551K0FKEA	Vishay
24	2	0E	R4,R3	RES 0.0 Ω 1/8W 5% 0805 SMD	CRCW08050000Z0EA	Vishay
25	1	13.7K	R6	RES 13.7KΩ 1/8W 1% 0805 SMD	CRCW08051372FKEA	Vishay
26	1	100K	R7	RES 100KΩ 1/8W 1% 0805 SMD	CRCW0805100KFKEA	Vishay
27	5	10K	R5,R8,R9,R19,R20	RES 10.0KΩ 1/8W 1% 0805 SMD	CRCW080510K0FKEA	Vishay
28	3	1K	R10,R11,R18	RES 1.00KΩ 1/8 W 1% 0805 SMD	CRCW08051K00FKEA	Vishay
29	2	100E	R12,R13	RES 100 Ω 1/8 W 1% 0805 SMD	CRCW08051000FKEA	Vishay
30	2	5K	R14,R15	RES 5KΩ 1/8W 1% 0805 SMD	CRCW08055K00FKEA	Vishay
31	1	10E	R16	RES 10Ω 1/8W 1% 0805 SMD	CRCW08050100FKEA	Vishay
32	1	15E	R17	RES 15Ω 1/8W 1% 0805 SMD	CRCW08050150FKEA	Vishay
33	1	OPA381	U1	IC LOW PWR TRAN IMP AMP	OPA381AIDGKT	TI
34	1	OPA333	U2	IC OP AMP CMOS SGL SPLY SOT-23-5	OPA333AIDBVT	TI
35	1	ADS8328	U3	IC ADC 16 BIT 500-kSPS 16-TSSOP	ADS8328IBPW	TI
36	1	REF5025	U4	IC PREC V-REF 2.5 V LN 8-SOIC	REF5025AID	TI
37	2	OPA335	U7,U5	IC OP AMP CMOS SGL SPLY SOT-23-5	OPA335AIDBVT	TI
38	1	DAC7573	U6	IC QUAD 12 BIT LOW PWR DAC 16-TSSOP	DAC7573IPW	TI
39	1	TPS73033	U8	IC LDO REG HI-PSRR 3.3 V SOT23-5	TPS73033DBVR	TI

Appendix C Sensors and Accessories

C.1 SpO2 Finger Probe



Pin No.	Color	Connection
1		
2	RED	Connected to LED Cathode
3	BLUE	Connected to LED Anode
4		
5	WHITE	PIN Diode Anode
6		
7	OUTER SHIELD	GND
8		
9	ORANGE	PIN DIODE Cathode

LED: The probe uses a dual emitter LED from the UDT sensors (part number DLED-660/895-CSL-2), which has two LED’s of wavelength: 660 nm and 895 nm. These wavelengths are connected back to back in a single package with two leads brought out.

PIN Diode: The PIN diode used in the probe has an intrinsic layer between the n and p layer resulting in a lower junction capacitance, compared to a normal p-n diode. Because of this, the p-i-n photodiode response times are faster than the p-n junction photodiodes. The PIN diode used in this design is part number PIN-8.0-CSL from the UDT sensors. This pin diode has a capacitance of 25 pf and a dark current of 10 nA.

Vendor: Biometrics Cables

For further details and purchase, see the following URL:
http://www.biometriccables.com/index.php?productID=295

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* (SPRUGO1) 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.