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Development of an Oxygen Saturation Monitoring System by Embedded Electronics

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Electrical Engineering

by

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Saveetha University
Bachelor of Engineering in Electronics and Communication, 2012

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This dissertation is approved for recommendation to the Graduate Council.

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Abstract

Measuring Oxygenation of blood (SaO₂) plays a vital role in patient's health monitoring. This is often measured by pulse oximeter, which is standard measure during anesthesia, asthma, operative and post-operative recoveries. Despite all, monitoring Oxygen level is necessary for infants with respiratory problems, old people, and pregnant women and in other critical situations.

This paper discusses the process of calculating the level of oxygen in blood and heart-rate detection using a non-invasive photo plethysmography also called as pulsoximeter using the MSP430FG437 microcontroller (MCU). The probe uses infrared lights to measure and should be in physical contact with any peripheral points in our body. The percentage of oxygen in the body is worked by measuring the intensity from each frequency of light after it transmits through the body and then calculating the ratio between these two intensities.

Acknowledgments

I would like to express my heartfelt thanks to my advisor Dr. Vijay K. Varadan for granting me this opportunity to work in his prestigious lab and use the best of resources available at the University of Arkansas. His constant motivation and timely feedback helped me understand the basics of health care system and complete this project.

I would also like to thank my committee members Dr. Simon S. Ang and Dr. Roy C. McCann for their insightful thoughts, which helped me, tackle hard questions and understand the concepts better.

My thanks to Sharthak Munasib, Witness Martin, Mouli Ramasamy and others for being there for me and helped me stay in focus and was readily available during the hardships faced during the project. His timely opinions on tackling the problems assisted me complete this project successfully.

Dedication

I would be failing my duties if I do not mention the support provided by my family, friends and god who helped me through my hardships. With their wonderful support, prayers and motivated words that have led me to where I am today. I can say with absolute certainty that without you, I would not be here. I dedicate my work to you all.

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Chapter 1

1. Introduction:

1.1 Background

The human body requires and regulates with balance of oxygen in our blood. Oxygenation of Blood is often referred as Oxygen Saturation, which is the ratio of saturated hemoglobin to the total hemoglobin in the blood. Oxygenation occurs when an oxygen molecule enters the tissues of our body. Normal oxygen level in our body is 95 to 100 %. If the oxygen level is measured to be below 90%, it creates a condition called Hypoxemia [1] i.e., low concentration of oxygen in blood. Oxygen levels below 80% will affect primary organ functions. Pulse oximetry is a non-invasive method to measure and monitor oxygen saturation.

Mixed signal MSP430FG437 microcontroller is used because of its Ultra-low-power consumption and longer battery life in measurement applications. It consist of 16-bit timers, Pulse digitally controlled oscillator (DCO), 12-bit ADCs, 12-bit DACs, 48 I/O pins, LCD driver and many. The presence of DCO makes the device to become active from lower power modes less than $6\mu\text{s}$.

2. Blood Oxygenation:

Respiration is a vital process in human body. Body tissues require oxygen for aerobic respiration. Tissues gain all of their energy through respiration. The energy released through this process is used to store the synthesized adenosine triphosphate (ATP). This energy stored is responsible for distribution of oxygen to all the major parts of the body through our blood circulation flow.

Blood passes through pulmonary alveoli where carbon dioxide is released and the blood is oxygenated. This is called oxygenated process. The deoxygenated blood enters into the heart, it will be pumped out to lungs.

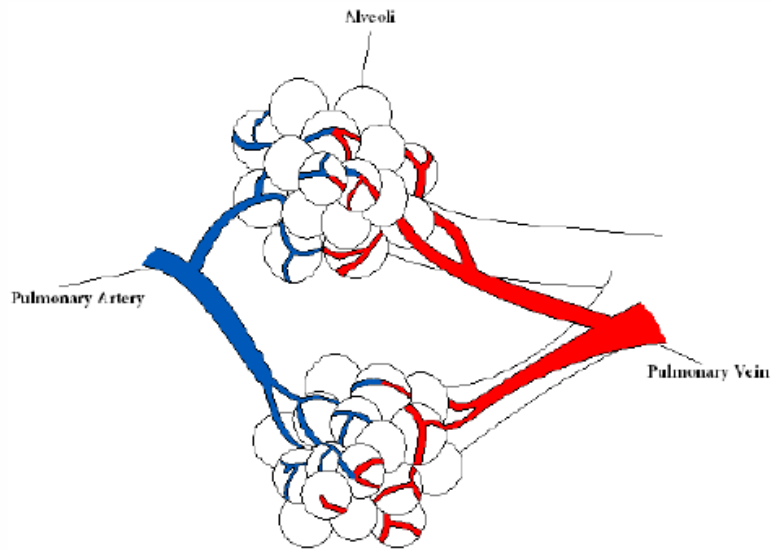


Fig.1 Oxygenation process in pulmonary alveoli

Hemoglobin, a protein in red cells gets attached to oxygen and forms oxyhemoglobin (HbO_2).

When these red cells reach body tissues, it absorbs all the oxygen within and the red cells becomes deoxyhemoglobin (Hb). The block diagram below explains the process clearly.

Deoxyhemoglobin once again reaches heart and the entire process is repeated and continued the same.

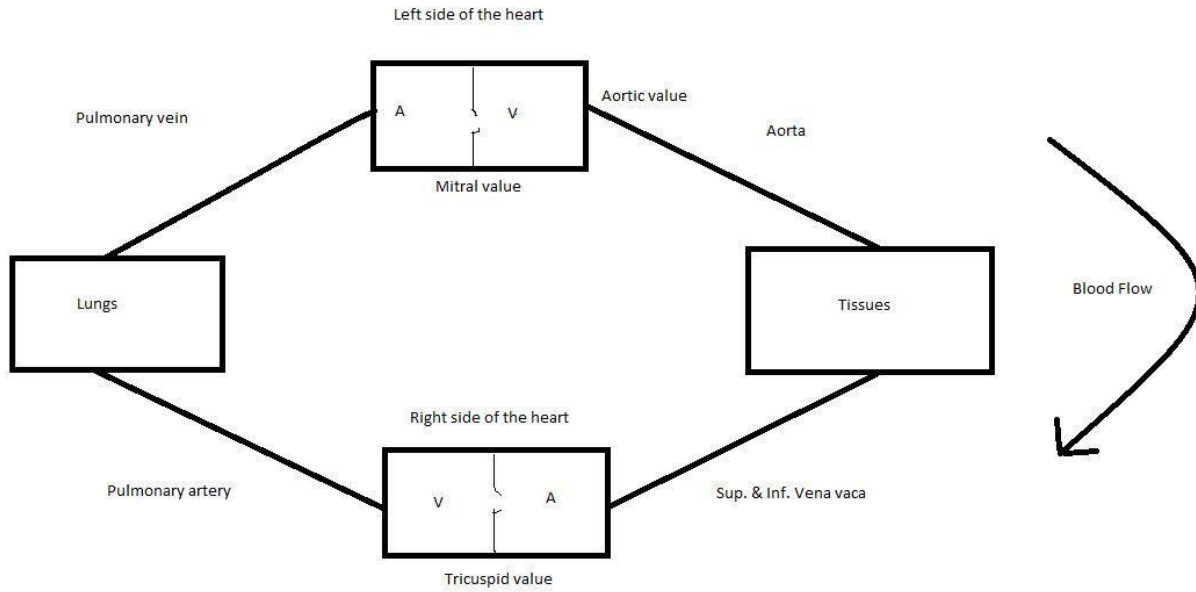


Fig.2 Block diagram of circulation of blood

3. Objective of the thesis:

The objective of the thesis is to design an electronic oxygen monitor using an embedded system. A Texas Instruments MSP 430 microcontroller was chosen for this project because of its low power consumption and faster wake up time.

Chapter 2

4. Theory of Operation:

The calculation of the level of oxygenation of blood (SaO_2) is measured by the intensities of light which has been attenuated by body tissue. Oxygenation of blood (SaO_2) is defined as the ratio between oxygenated hemoglobin level and the total hemoglobin level in our body tissue.

$$SaO_2 = \frac{HbO_2}{Total\ Hemoglobin\ Level}$$

The body tissues has non-linear characteristic. Our body tissues absorb different amounts of light depending on the oxygenation level of blood that is passing through.

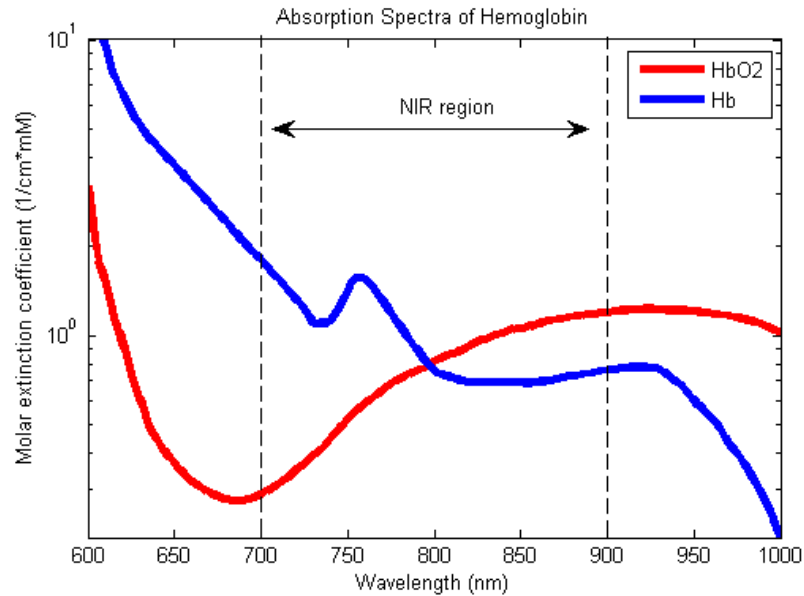


Fig.3 Absorption spectra of Hemoglobin both oxygenated and deoxygenated [2]

5. Photoplethysmography:

Photoplethysmography (PPG) is a non-invasive optical technique, used to measure blood volume changes and percentage of oxygen saturation of tissues. The basic form of Photoplethysmography (PPG) contains few components like, a light source, photo detector. It operates in two wavelengths, Red light spectra (660 nm) and near to infrared (940 nm) wavelength. The light source will spot the target skin and the photo detector will measure all the small variances in the light intensities.

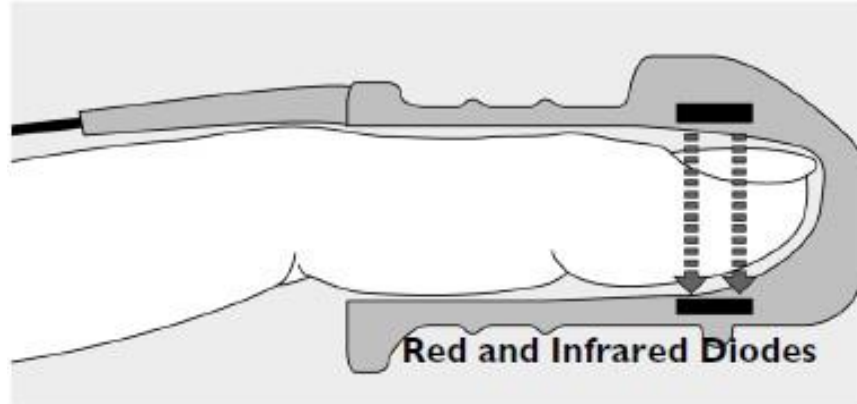


Fig.4 working diagram of SpO_2 sensor

To speak, there are two principles to consider while designing a pulse oximeter to measure, for a better safer and effective device. The Photoplethysmography (PPG) signal helps in determining of the volume of blood in vessels and cardiac cycle. The AC component is distinguishable by the amount of blood.

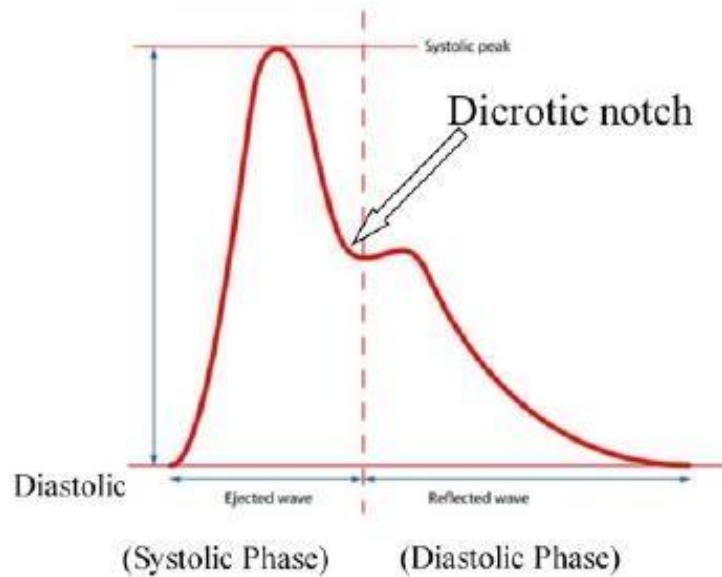


Fig.5 PPG signal form [14]

5.1 Pulsatile Flow:

A flow with periodic variations is called as pulsatile flow. [5] Per se measuring the oxygen saturation. Starting with observing the time difference over the volume of blood changes while the other tissues are to be constant. This is called as a period of cardiac cycle. The absorbance is subtracted from its nadir, thus calculating the absorbance from the cycle in and out. This principle provides the physiology of arterial system from other tissues. [3]

5.2 Differential Spectral Absorbance:

The spectral absorbance is observed between the total hemoglobin, (i.e., oxyhemoglobin and deoxyhemoglobin). These molecules are absorbed under infrared and red light regions. Absorbing under infrared (IR) light, they both exhibit same fraction of light. However absorbing under red region, oxyhemoglobin is weaker than that of deoxyhemoglobin.

By calculating the difference in absorbance of both regions of light simultaneously, we may calculate the differential spectral absorbance of the blood.

6. Beer- Lambert's Law:

Beer-lambert's law states that the absorbance of light as it passes through a sample is proportional to the thickness of the sample and the concentration of the absorbent.

According to Beer-lambert's law: [18]

$$-dl \propto I[C]dt$$

Where, dl = infinitesimal change in intensity of light

C = concentration of the sample

dt = small change in thickness

Figure 6 explains the beer-lambert's law in detail.

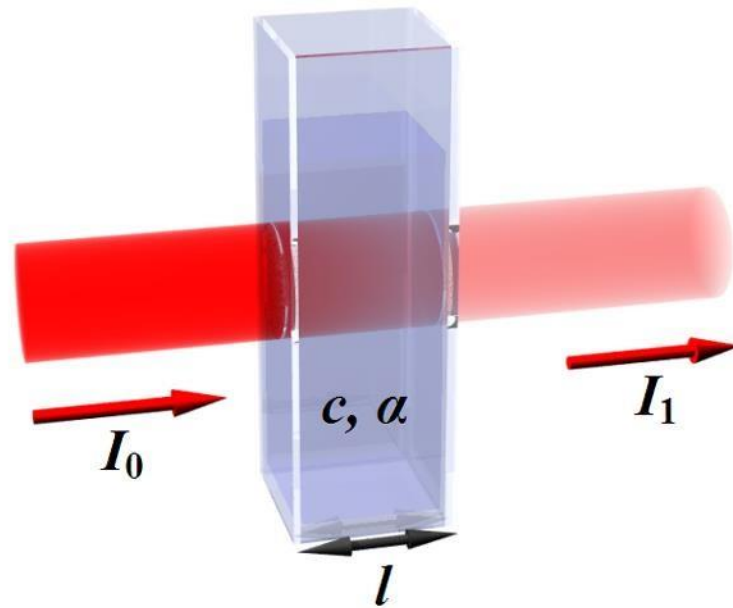


Fig.6 Beer-lambert's law

For the larger sample, the Beer-lambert's law can be written as

$$I = I_0 e^{-\alpha [c] d}$$

7. Calibration of Pulse Oximeters:

Early pulse oximeters worked under the principle of Beer- lambert law. It is defined as the attenuation of light to the properties of the material through which the light travels. But the law does not take account the multiple scattering of light by Red Blood cells (RBC). Since the present pulse oximeters works with the differential spectral absorbance technique, the effect of

scattering is partially compensated. As we know that the scattering is directly dependent to wavelength.

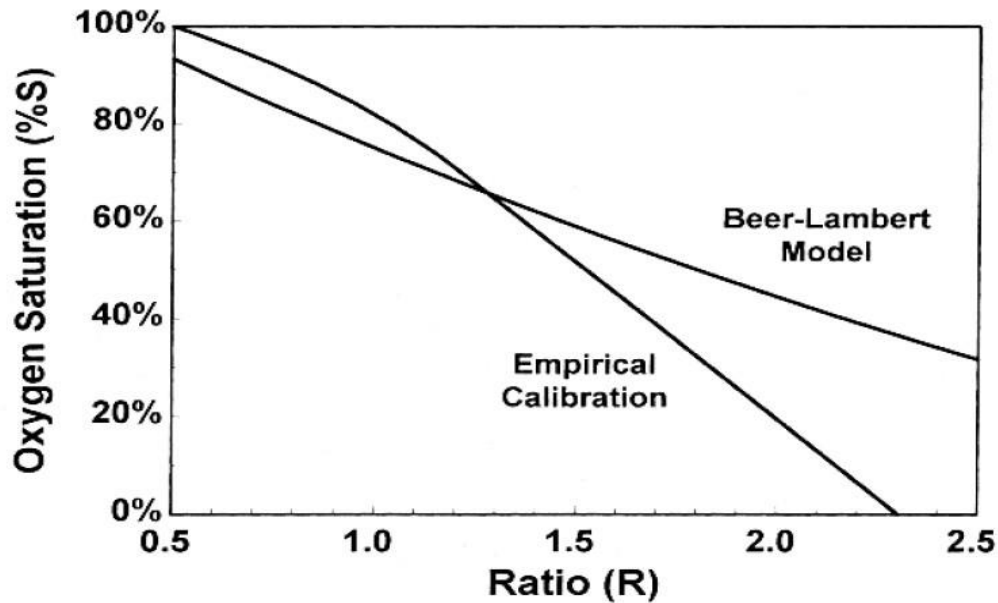


Fig.7 Relationship between ratio and oxygen saturation

8. Limitations of Pulse Oximeter:

As we know, Pulse oximeter works on the principle of Beer-Lambert's law. The Beer-Lambert's law doesn't always apply the oxygen saturation during empirical calibration. Since the law does not only considers the characteristic of the incident light. The calibrations needed to obtain in empirical model are limited to 75% to 80% [19], above this specified limit the pulse oximetry cannot be more accurate.

Motion artifact is another factor that limits the efficiency of the pulse oximeter. It is one of the significant sources of error. The pulsatile flow of blood determines the oxygen saturation. Thus any action which affects the pulsatile flow of the blood will greatly affect the reading [19].

There are many conditions in ill patients which results in error. Table.1 shows some sources of errors [22].

Error Sources	Effects on SpO₂	Responses
Hypotension	Possible loss of signal	Correct underlying problem (e.g. give fluid challenge, lighten anesthesia), vasopressors
Vasoconstriction (reduction of blood flow to arterial bed)	Possible loss of signal, reduction of SpO ₂	Change to more central site
Hypothermia (reduction of blood flow: seen in Pts. w/Raynaud's disease)	Possible loss of signal, reduction of SpO ₂	Keep patient and extremities warm
Shivering/muscle twitching	Changes in pulse size, possible loss of signal	Warm and/or sedate patient
Carboxyhemoglobin	Falsely high SpO ₂ reading	Increase ventilation, eliminate rebreathing
Methemoglobinemia	Falsely low readings approaching 85%	Administer methylene blue
Venous pulsations	Falsely low SpO ₂ readings	Change site
Blood pressure cuff on monitored arm	Loss of signal decreases SpO ₂	Change site
Arterial lines on monitored arm	Loss of signal decreases SpO ₂	Avoid use of arteries in monitored are
Intense bright light (e.g., fiber optic fluorescent lights)	Lower SpO ₂ readings	Avoid exposure of photodiode to light

Table.1 Sources of errors [22]

Chapter 3

9. Micro controllers:

The micro controllers used belong to the family of MSP430, well known for their ultra-low power consumption and other peripheral features. In our experiment we have used MSP430FG437 mixed signal microcontroller. The below table describes the difference between MSP430FG437 with their family microcontrollers.

Device	Flash (KB)	SRAM (KB)	ADC12 Channel	DAC12 Chanel	Comp_A Channel	USART	LCD	I/Os	Package Type
FG439	60	2	12	2	16	Yes	Yes	48	80 PN 113ZCA
FG438	48	2	12	2	16	Yes	Yes	48	80 PN 113ZCA
FG437	32	1	12	2	16	Yes	Yes	48	80 PN 113ZCA

Table.2 MSP430 device comparison

9.1 Pin diagram

The pin of MSP430437 microcontroller consists of 80 pins. This is a pin diagram.

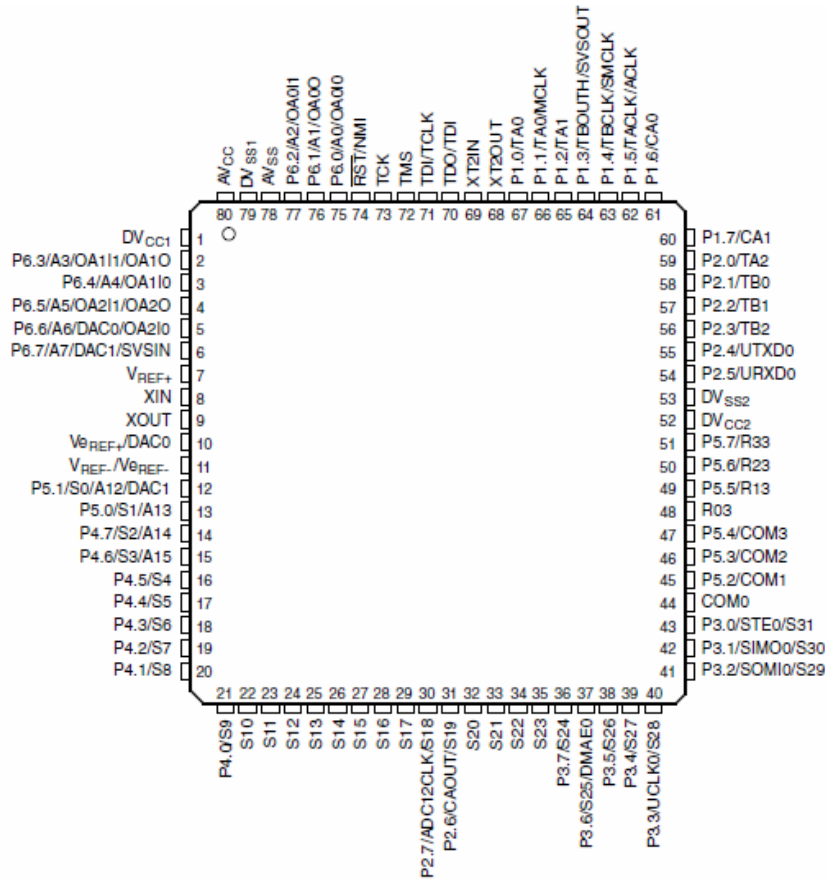


Fig.8 Pin assignment diagram of MSP430 microcontroller [10]

And also contains 113 ZCA package.

**ZCA PACKAGE
(TOP VIEW)**



Fig.9 113 ZCA package of MSP430 microcontroller [10]

10. Circuit design Implementation:

The circuit system of Pulse oximeter using MSP430FG437 micro controller is implemented with many filters, DAC ADC, LED, amplifiers, multiplexer, LCD display and many. The light source feed with the finger probe which is connected to the circuit as an input.

The LEDs used in the circuit are multiplexed at 500 times per second. This multiplexed LED alternatively excite the PIN diode. The output from the PIN diode is amplified by the various amplifiers in the circuit. The Analog to Digital Converter (ADC) samples the output from amplifiers. After the Analog to Digital Converters (ADC) samples the output form the amplifiers, it is the Micro Controller Unit (MCU) software’s responsibility to separate the feed to both red region waveform and infrared region waveform.

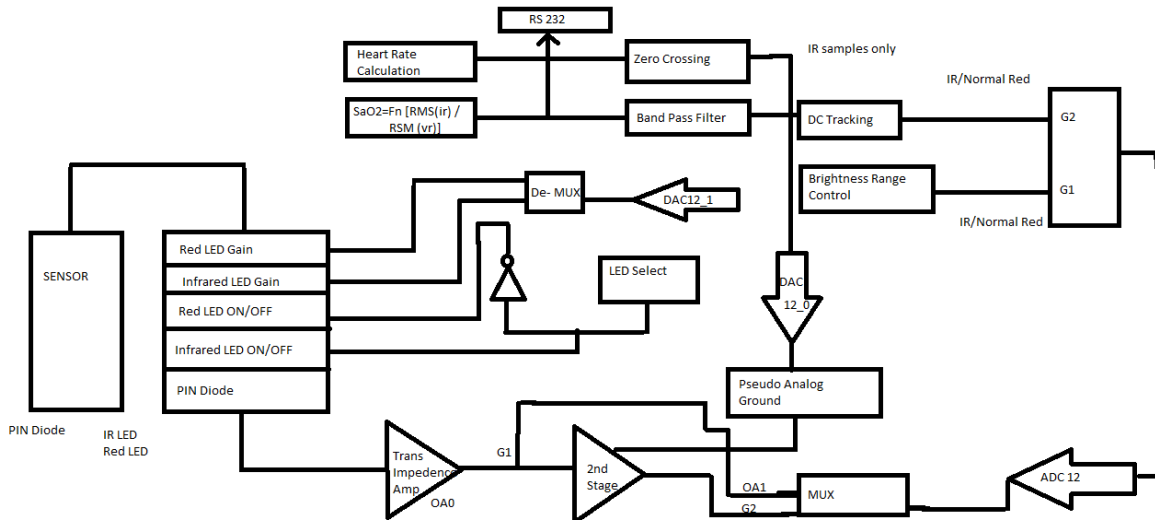


Fig.10 Circuit system of pulse Oximeter

The oxygen saturation level will be displayed on the LCD display. The finger probe acts as the input feeder which is integrated with photo sensors and PIN diode. The probe is connected to the system via D-type 9 pin connector.

10.1 Generate LED Pulses:

The Pulse oximeter works with two LEDs. The finger probe is integrated with red wavelength LED and infrared (IR) wavelength LED. In the Nellcor compatible probe used, these two LEDs are connected back to back with each other. The H- bridge circuit helps to turn ON these LEDs. Figure.11 elaborates and explains the H- bridge circuit.

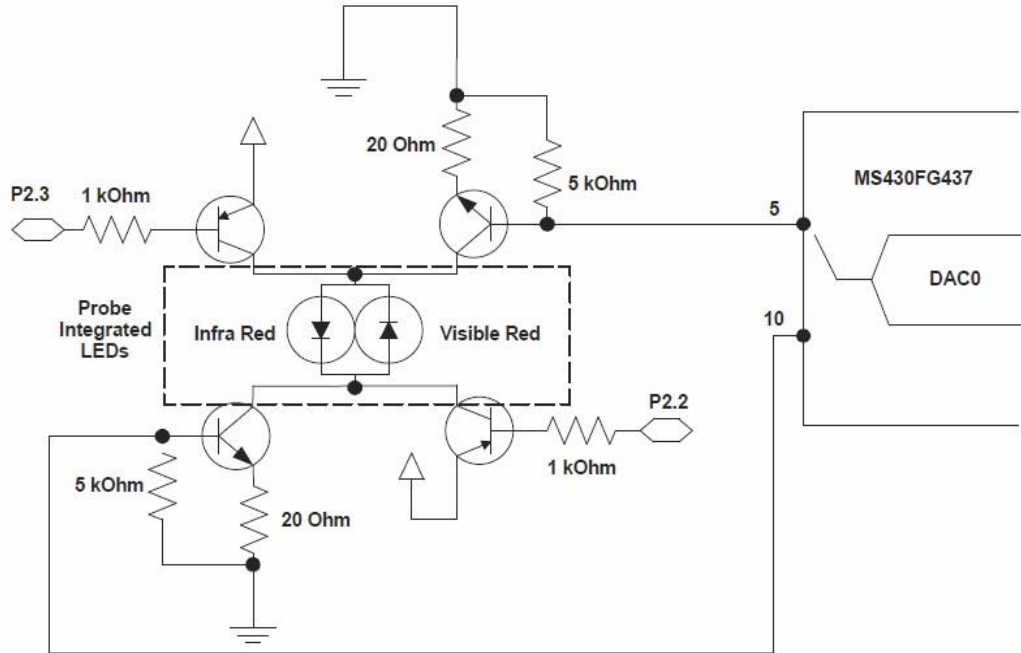


Fig.11 H-bridge LED drive circuit [11]

The Digital to Analog Converter (DAC), DAC0 in the MSP430FG437 micro controller controls the current via LEDs. The Digital to Analog converter (DAC) can be connected to Micro Controller Unit (MCU) through software control in DAC register. Port 2.2 and Port 2.3 are the complimentary ports which controls the complimentary circuits.

When the pin is not connected to the output of Digital to Analog Converter (DAC), DAC0 signal then it is set to 1 or 0 i.e., active high or active low. The pulldown resistor is connected to base of every transistor to ensure OFF when the transistor is not selected.

10.2 Pulse Oximetry Sensor:

The Pulse oximeter with MSP430FG437 is designed to work with the Nellcor compatible finger probe. The sensor is connected with D-type 9 pin connector. It consists of photo sensor cathode, Trans impedance offset, red and IR port. The both end of the impedance is connected

with impedance. This D-type 9 pin connector looks like the RS232 port. The Nellcore compatible finger probe's connector pins are explained in the diagram below.

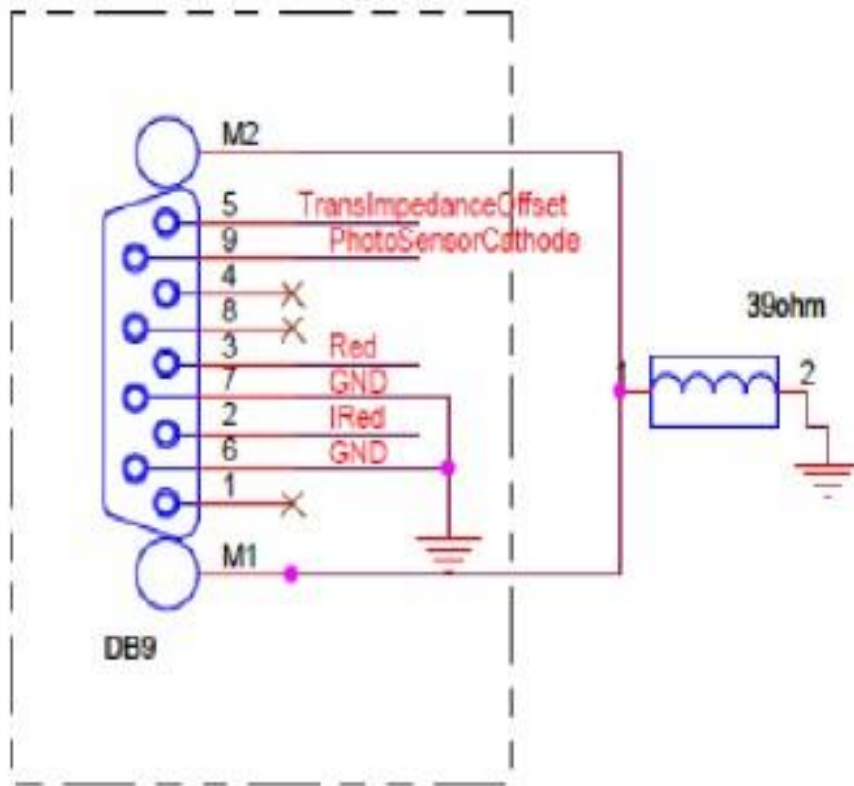


Fig.12 D-type 9 pin Connector

10.3 Filters:

Filters are classified into active and passive filters. As the name says, the passive filter contains passive elements like resistors, capacitors and other passive elements. The active filter contains active elements like transistors, OP-AMPS and others. Filters are divided into high pass filters; low pass filters and band pass filters.

The high pass filters allows frequencies more than the cut-off frequencies (f_c) and the low pass filter does the exact opposite to the high pass filter. I.e. it allows only the lower frequencies to that of the cut-off frequencies (f_c). Figure 13 shows an active low pass filter.

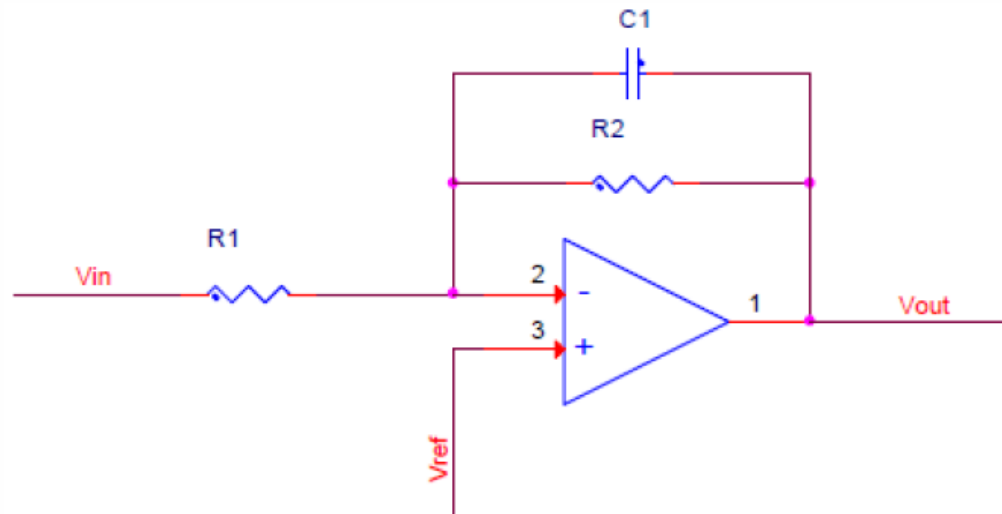


Fig.13 Low-Pass Filter

The frequency response of an active low pass filter is explained in the figure below.

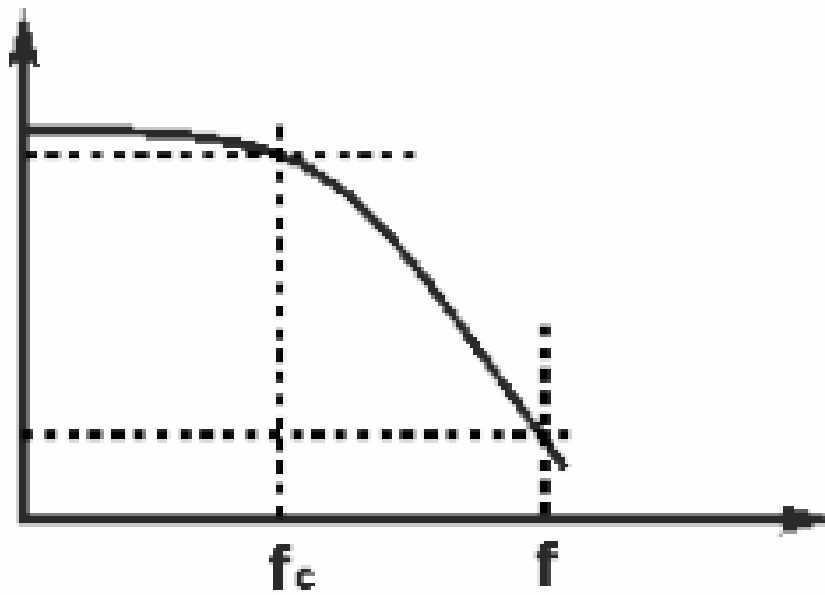


Fig.14 Frequency response of Low –pass filter

The cut-off frequency of an active low pass filter can be determined by the time constant

$$f_c = \frac{1}{2\pi\tau}$$

Where, $\tau=RC$

So the f_c can be written as

$$f_c = \frac{1}{2\pi RC}$$

Band pass filter is a filter which has the characteristics of both low pass filter (LPF) and high pass filter (HPF) together. The band pass filter can be also called as pass band, since it allows signal of certain frequencies to pass through.

Band pass filter is not ideal filter. The filter does not attenuate all the frequencies outside the specified range of frequencies. Figure 15 shows an active band pass filter.

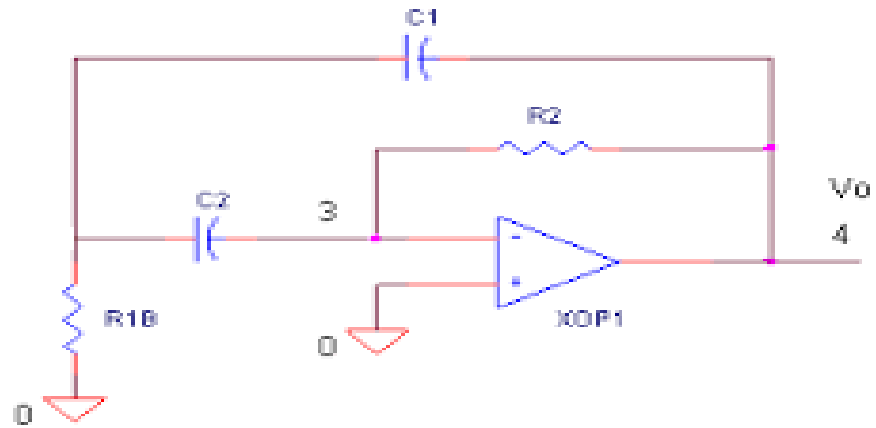


Fig.15 Band-pass Filter

The frequency response of an active band pass filter can be explained in the figure below.

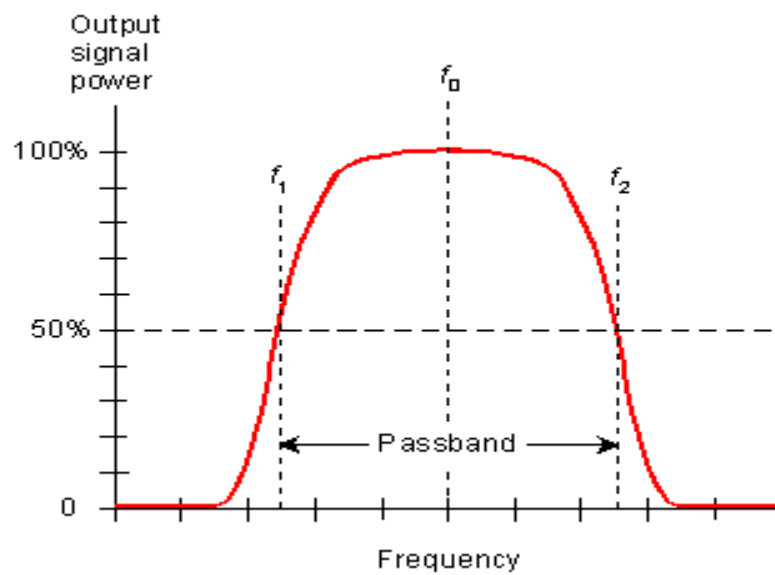


Fig.16 Frequency response of Band –pass filter

The bandwidth of band pass filter can be determined by the differences between the cut-off frequencies of both High pass filter and low pass filter.

Bandwidth (λ) = cut-off frequency of upper filter- cut-off frequency of lower filter

$$\text{Bandwidth } (\lambda) = f_{c,upper} - f_{c,lower}$$

10.4 Operational Amplifiers:

Micro Controller MSP430FG437 consists of three configurable operational amplifiers. An operational amplifier, OP-AMP is an amplifying circuit which amplifies the input signal in required terms of current or voltage.

An ideal Operational amplifier is not practically possible. The characteristics of an ideal operational amplifier (OP-AMP) includes, zero input off set voltage, zero noise, zero output impedance, infinite Common Mode Rejection Ratio (CMRR), infinite bandwidth, infinite gain. The figure 17 shows an ideal operational amplifier (OP-AMP).

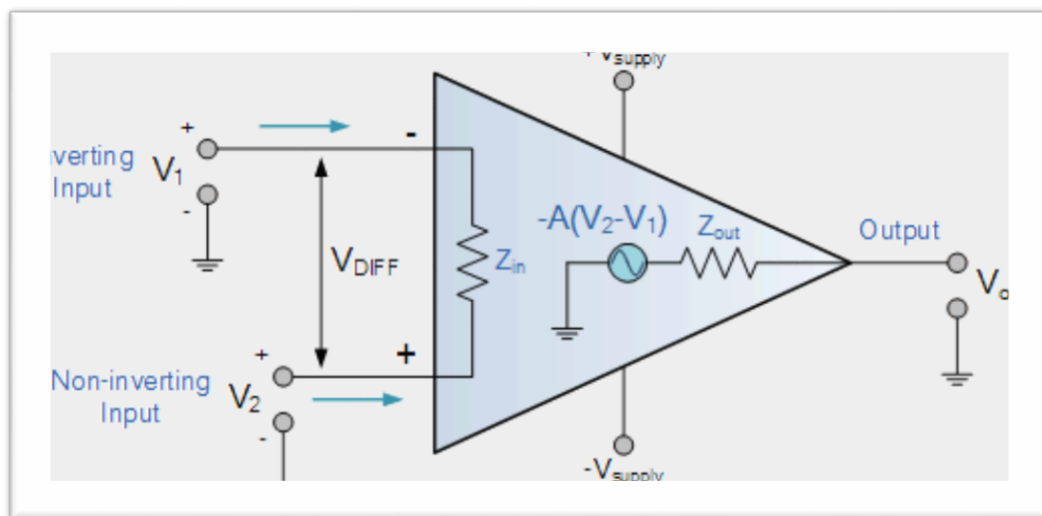


Fig.17 Ideal OP-AMP [22]

The active filters are designed for all the filters like low pass, high pass and band pass filters. They are named by the number of frequency dependent components they have. I.e. first order, second order, third orders and so on. However, the bandwidth and frequencies cannot be changed in the passive filters; they can be changed in Operational Amplifiers (OP-AMPs).

11. Sampling and Conditioning PIN diode signal:

The photo diode generates current from the received signal. The incoming signal will be weak. So the trans-impedance amplifier in the circuit will amplify to the requirement. OA0 is used to amplify the signal. Hence the current obtained is very small, it is must to amplify this signal. The output signal from OA0 contains both DC component and AC component. Figure 18 shows the control circuit of the PIN diode signal.

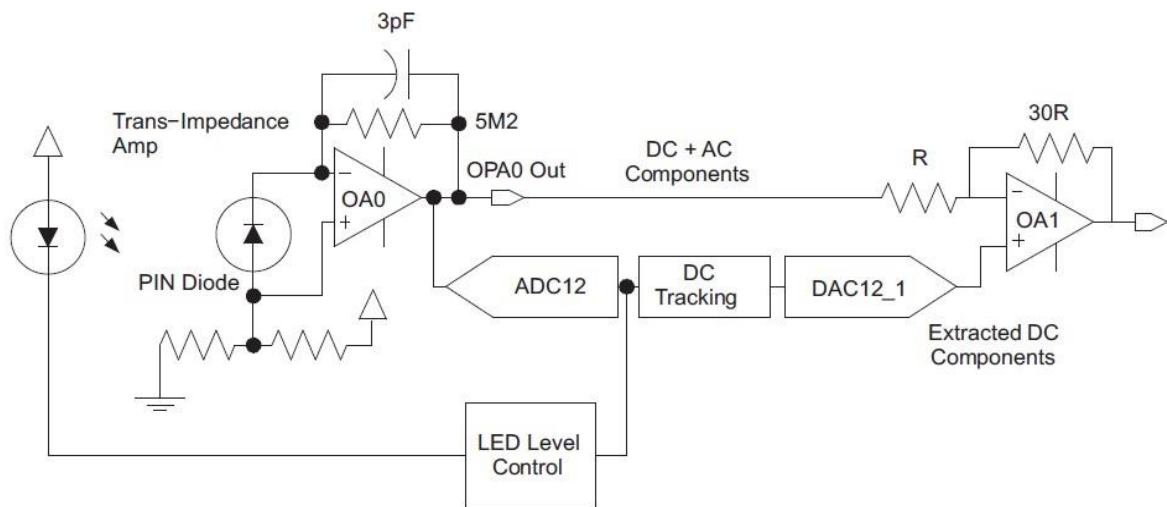


Fig.18 Control circuit of PIN diode [11]

The DC components are caused by the light scattering in the lesser oxygen places in our body. The AC components are caused by light modulation by the higher oxygen places and also by noise at 50-60 Hz. This AC output signal should be amplified. The other lights, the red light and the infrared light are separately controlled by preset range circuit. The amplified output signal from OA0 is fully extracted by OA1 stage.

12. Conditioning AC Components:

The Analog to Digital Converter (ADC) samples the output of OA1 at the rate of 1000sps. The samples of OA1 are extracted completely from the remaining DC components. The left DC is tracked by the IIR filter. Figure 19 shows the conditioning block diagram of AC components.

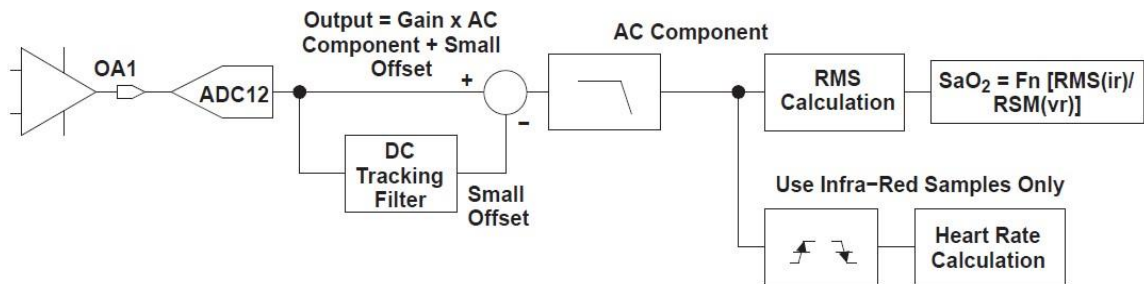


Fig.19 Block diagram of conditioning AC components [11]

In order to get the AC signal, the left DC component is subtracted from it, making it pure AC component digital signal. It is now passed through the low pass filters, which attenuates the unwanted elements and gives out the signal resembling the heartbeat.

13. DC Components tracking filters:

The DC components are filtered by Infinite Impulsive Response (IIR) filters. Though the filter filters the incoming feed of signal through, it still left with some of the outputs from the last output and the present output to give a new output value. When there is a change in the input, the output changes itself to the same as the input over a specific time interval. The DC tracking filter is explained lot by the IIR filter. Figure 20 shows the block diagram of an IIR tracking filter.

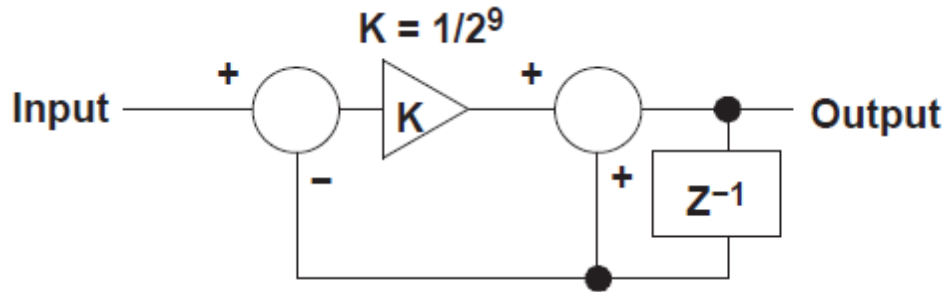


Fig.20 DC Tracking IIR Filter [11]

The rate of change of output “ids” controlled by coefficient “K.” When the input contains both AC and DC components together, the coefficient makes sure that the value of the K is changes very small to generate a time constant, which eventually cancels itself with the noise, leaving only the DC components. The dynamic range of the output is maintained if the calculations are made with double precision in 32 bits.

14. Time Multiplexing

The pulse oximeter uses multiplexer. It is multiplexed 500 times. Timer A is used to control the multiplex sequence and automatically starts the conversion of Analog to Digital data or signal. At CCR0 interrupt, it starts the following LED sequence.

- The DAC12_0 control bit sets or clears the data whichever is need according to the driven LED.
- This causes Port 2 to turn on the respective LED.
- Since clearing the DAC12_0 data, it assigns a new value with respect to the intensity of light
- It sets on DC tracking filter with DAC12_1 as the output for the respective LED.

The timing diagram for the Timer_A multiplexer is as below.

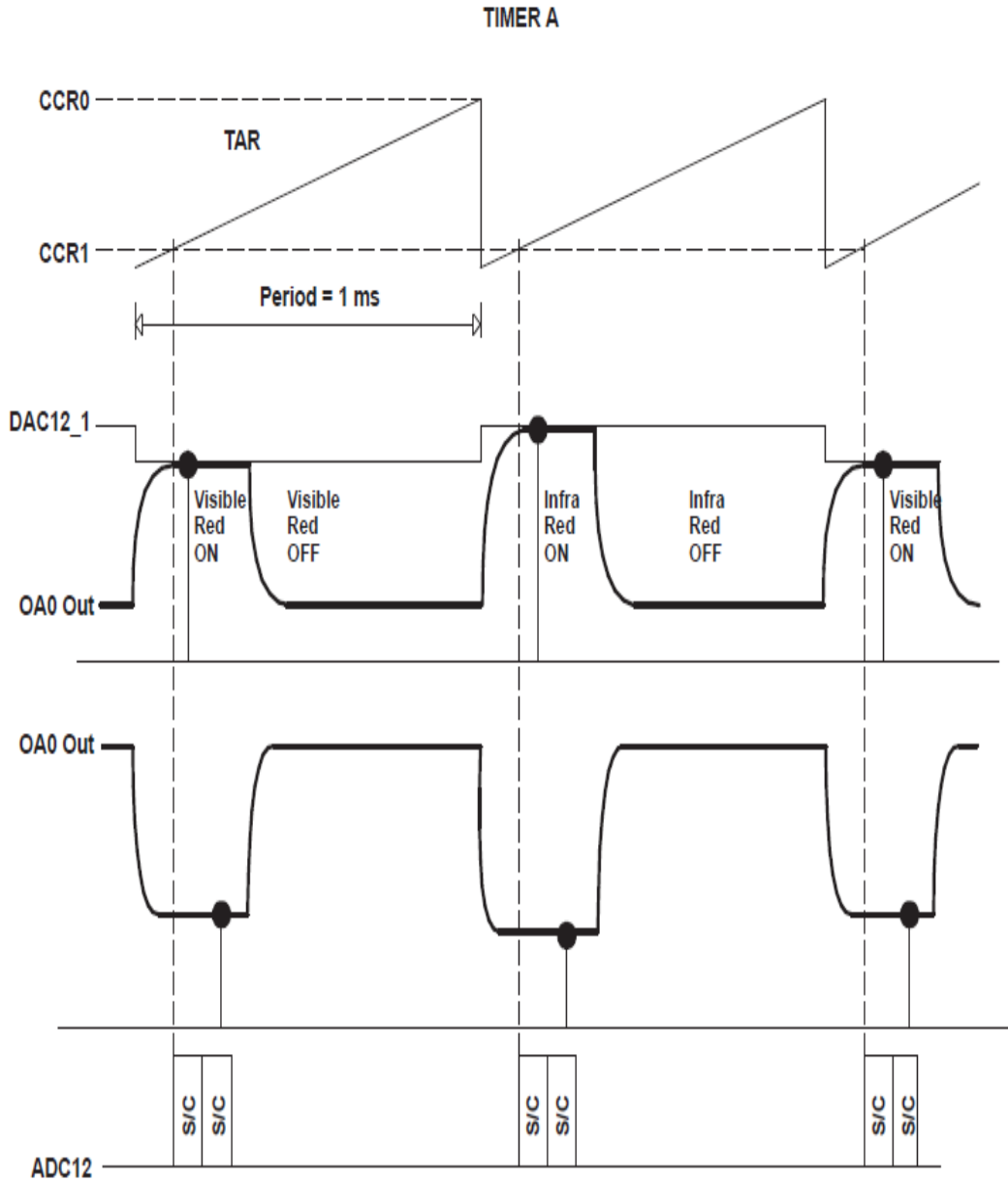


Fig.21 Time Multiplexing of Timer_A [11]

The difference between OA0 and DAC12_1 is amplified by OA1. When the intensity of the visible light is varied slowly, DAC12_1 will become a straight line, since the output OA0 equals

both intensities of light. Minimum two samples are required to calculate the oxygen level. One being the OA0 output and the other being the OA1, the oxygen level is calculated. To conserve power, the Analog- to –Digital converter (ADC) is intercepted to switch off the LED by clearing DAC12_0.

15. Joint Test Action Group (JTAG):

Joint Test Action Group (JTAG) is common name used for the IEEE 1149.1 standard test access port used for testing PCBs using boundary scan. In our thesis, we use MSP430FG437 with JTAG interface. The circuit diagram of the JTAG interface with the MSP430FG437 is shown in figure 22.

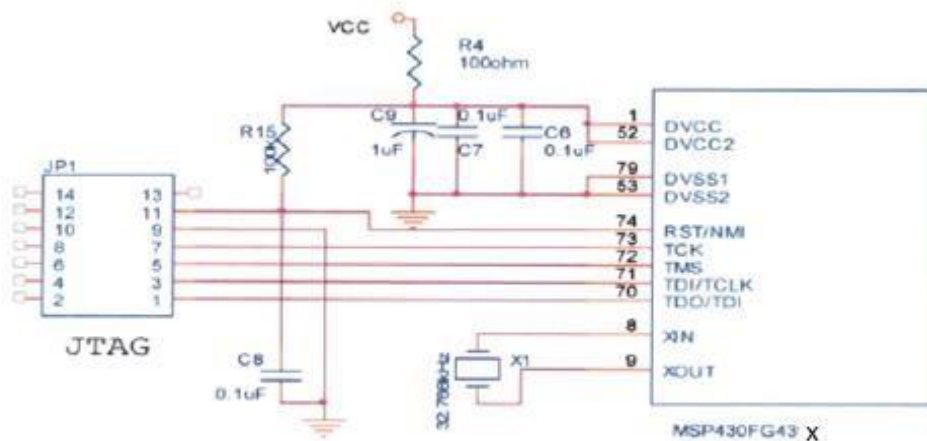


Fig.22 JTAG interface with MSP430FG43X

The JTAG interface uses dedicated signals which perform specific assigned tasks in the chip.

Those dedicated signals are as follows.

- TRST is a Test-Reset input, which initializes and disables the test interface.
- TCK is a Test Clock input, which controls the timings of the test interface independently from any other system clocks. TCK is pulsed by the equipment controlling the test and not by the tested device.
- TMS is the Test Mode Select input, which controls the transitions of the test interface.
- TDI is a Test Data Input, which supplies the data to the JTAG registers.
- TDO is the Test Data Output line, it is used to serially output the data from JTAG registers. It carries the sampled values from the boundary scan chain and propagates them to the next chip level.

The JTAG serves as a double purpose for programming as well as debugging the device. The target board MSp430FG437 JTAG interface is accessed using JTAG enabled application.

16. RS232- Driver/Receiver:

RS232 is short for Recommended Standard 232. It is a serial binary data signals port which connects Data Terminal Equipment (DTE) and Data circuit Terminating equipment (DTE). It is one of the most common port found in computers and laptops. RS 232 port ensures the connection between and host and the featured external circuit.

The Electronics Industries Association (EIA) as of 1969 defines standard RS-232 is as

- Electrical signal characteristics such as voltage levels, signal rate, timing and slew rate of signals, voltage withstand level; short circuit behavior and maximum load capacitance.

- Interface mechanical characteristics, pluggable connectors and pin identification.
- Functions of each circuit in the interface connectors.

The serial port hardware Universal Synchronous/Asynchronous Receiver/Transmitter (USART), controls the transmission bit rate, which converts the parallel data to series data. The relation with the RS 232 and the computer is asynchronous. As we know the digital devices widely use TTL or CMOS logic for their operation. By connecting the device to the RS 232 port, the RS 232 levels between 0-5 Volts. RS 232 has 9 pin configuration. The 9 pins are listed below.

- Carrier Detect (CD)
- Receive Data (RD)
- Transmit Data (TD)
- Data Terminal ready (DTR)
- Signal Ground (SG)
- Data Set Ready (DSR)
- Request to Send (RtS)
- Clear to Send (CtS)
- Ring Indicator (RI)

Figure 23 shows the block diagram of RS 232 interface with MSP430FG43X.

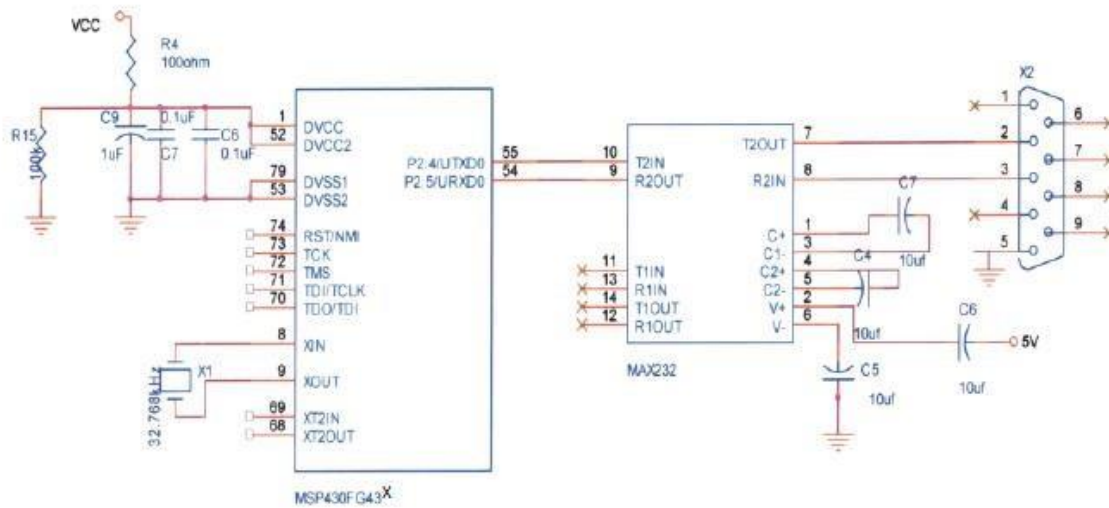


Fig.23 Block diagram of RS 232 interface with MSP430FG43X

17. Universal Synchronous/Asynchronous Receiver/Transmitter (USART):

The electrical signal characteristics are controlled by the line driver that converts from USART's logic to RS232's signals. The receiver converts the data the other way around.

There are two modes in USART. The control bit SYNC selects the required mode needed for the execution. Figure 24 shows the block diagram of USART.

- SYNC=0; asynchronous – UART – mode selected
- SYNC=1; synchronous – SPI – mode selected

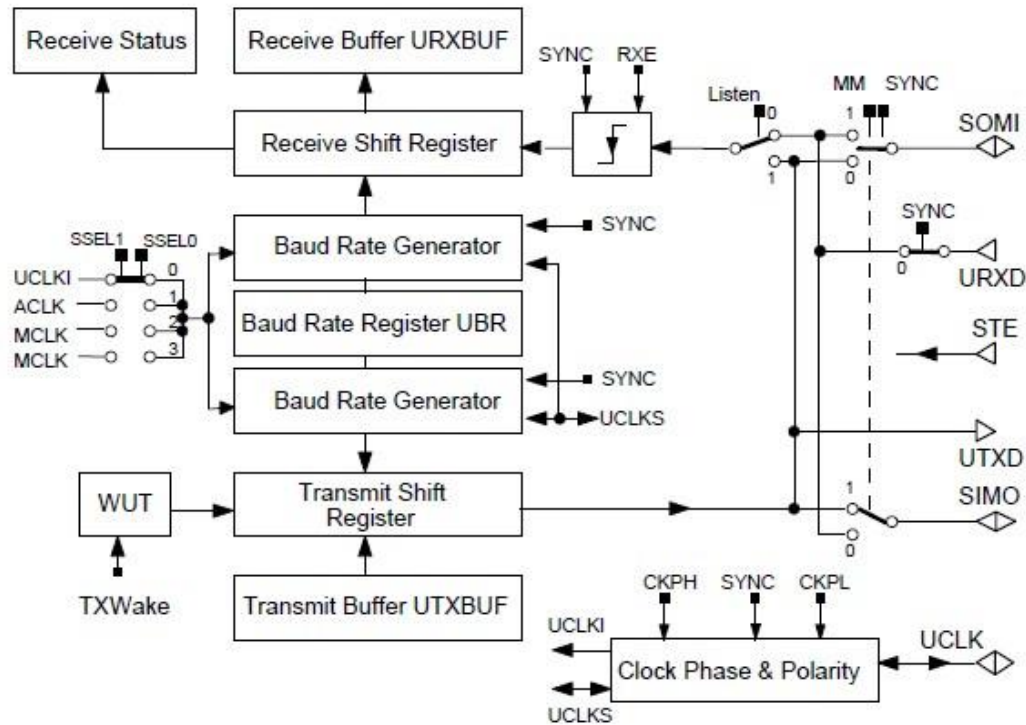


Fig. 24 Block diagram of USART [24]

The USART is connected to the computer system or the Central Processing Unit (CPU) as a byte peripheral. It connects the external system to the primary controller of the USART through external pins. The communication features of USART's serial asynchronous includes,

- Asynchronous modes, which includes address bit communication protocol.
- Shift registers serial data stream.
- Data transmitted or received with Least Significant Base (LSB) first.
- Programmable transmit and receive bit rate.
- Status flags.

The receiver in the asynchronous mode, synchronize itself to small frames with the specific timer allotted. The rest of the system does not use the same timer for sending and receiving the data over.

The USART in SPI mode connects the external system through three or four external pins. The USART's serial synchronous communication includes the follows.

- Control bit SYNC in control register UCTL is set to select synchronous mode.
- Supports three or four external pin.
- Selects master or slave mode of the USART
- Allocates separate shift registers for both transmitting and receiving data
- Uses double buffering
- Controls clock frequency in master mode
- Checks clock polarity and phase control

Chapter 4

18. Measurement of Pulse Oximeter:

The finger probe with the red and infrared lights is connected back to back with each other. Ports 2.2 and port 2.3 drive the circuit. The Digital to Analog Converter (DAC), DAC0 controls the incoming current through the LEDs. Both the LEDs are multiplexed at 500 times per second. Therefore the PIN diode gets excited alternatively to the light source from the input.

The photo diode generates a small amount of current from the absorbed light. The Operational Amplifier, OA1 and OA0 amplify the signal from the excited PIN diode. And the small amount of current is amplified by the Trans-impedance amplifier. The signal out from the Trans-impedance amplifier contains huge amount of DC component and smaller amount of AC components. The lesser oxygen bearing parts in our body causes the DC components and the AC components are caused by the higher oxygen bearing parts on our body. These AC components are caused by the light modulation and noise from ambient light at 50-60 Hz. The incoming photo signals are separated for red light and infrared light.

During the second stage of Operational Amplifier OA1, the AC component of Operational Amplifier OA0 is amplified. The Impulsive Intense Response (IIR) filter is used to track and find the DC components. This DC tracking filter receives the DC components and feeds it to the offset as an input to it. The differences between the two terminals are amplified and extracted only AC components. The left DC components are disposed or filtered out completely.

The output from the both amplifiers are amplified and sampled. The output is sampled by ADC12. Here acts the MCU software and separates the red light with the infrared light. The

sequence is multiplexed. The timer_A controls the sequence and starts converting the data from to digital format. The conversion is done by Analog to Digital converter (ADC).

The signal to CCR0 is interpreted and a new LED sequence is sent with the control bit, the DAC12_0 makes sure that the LED is set on or cleared off accordingly to the requirement. If set on Port 2 turns on the corresponding LED sequence. If not the Analog to Digital conversion automatically starts. The circuit needs two samples for execution and calculate the oxygen level. These two samples are feed by an internal timer with the help of MSC bit in the control register.

The output from the Operational Amplifier OA1 is sampled at the rate of 1000 samples per second for both red light and infrared light. The DC tracking filter, IIR filter is used to track the DC components and eliminated to acquire true AC signal. This true AC signal is once again filtered and the unwanted noise is removed at >50 HZ.

The DC component values are removed from every wavelength of light, leaving only the AC part of the signal. This gives us the oxygenation level in the blood. The DC complement gives the pulse rate in number of heart beats in a specific time interval. The PIN diode sets its target by the DC level acquired with very small tolerance. The RMS value is calculated by averaging the square of a signal over a number of heart beats per cycle. Once the DC levels match, the value of oxygen saturation is calculated as follows.

$$R = \frac{\log (I_{ac}) \lambda_1}{\log (I_{ac}) \lambda_2}$$

So, the oxygen saturation is directly proportional to the RMS value. And the SaO₂ value is displayed on the 9 segment LCD display.

$$SaO_2 \propto R$$

Chapter 5

19. Test Results and Calculations:

As the part of the thesis work, the pulse oximeter is developed with specified elements. Numbers of data are collected during the process. The measurements are calibrated with utmost accuracy, eliminating minor errors. To conclude the measured reading with the developed prototype, the reading are taken separately with standard commercially available pulse oximeter in the market and compared with the readings taken with our prototype. The “EasyComforts Oxygen meter” is used as the commercially available pulse oximeter.

The table below shows the reading taken while in the morning at sitting position using the “EasyComforts Oxygen meter” pulse oximeter.

No. of reading (Sitting)	BPM (Commercial)	BPM (device)
1.	75	72
2.	78	79
3.	79	77
4.	77	78
5.	77	78
No. of reading (Standing)	BPM (Commercial)	BPM (device)
1.	76	76
2.	79	76
3.	75	76
4.	77	78
5.	78	77

Table.3 Reading taken with Pulse Oximeter in the morning

Now the measurements are taken with during evening as with the same scenario.

No. of reading (Sitting)	BPM (Commercial)	BPM (device)
1.	74	75
2.	77	75
3.	79	75
4.	75	73
5.	76	75
No. of reading (Standing)	BPM (Commercial)	BPM (device)
1.	71	71
2.	75	73
3.	74	73
4.	74	74
5.	74	76

Table.4 Reading taken with Pulse Oximeter in the evening

Since taking both the readings are taken under a common condition, now the readings are taken after an heavy cardiovascular activity.

No. of reading (Sitting)	BPM (Commercial)	BPM (device)
1.	110	112
2.	108	109
3.	106	109
4.	106	109
5.	104	104
No. of reading (Standing)	BPM (Commercial)	BPM (device)
1.	108	108
2.	106	108
3.	105	105
4.	105	104
5.	105	105

Table.5 Reading taken with Pulse Oximeter after an intense cardiovascular activity

Taking a bunch of data is taken. Now, the differences between the data are calculated and checked for obtained accuracy. Most of the commercially available devices claim to have an accuracy of ± 3 .

No. of Reading	Reading-1	Reading-2	Difference
1.	75	72	-3
2.	78	79	1
3.	79	77	-2
4.	77	78	1
5.	77	78	1

Table.6 Reading-1 Vs Reading-2

19.1 Theoretical validation:

From the waveform signals taken from the Oscilloscope, the parameters are noted down.

Those parameters are substituted in the SpO2 formulae.

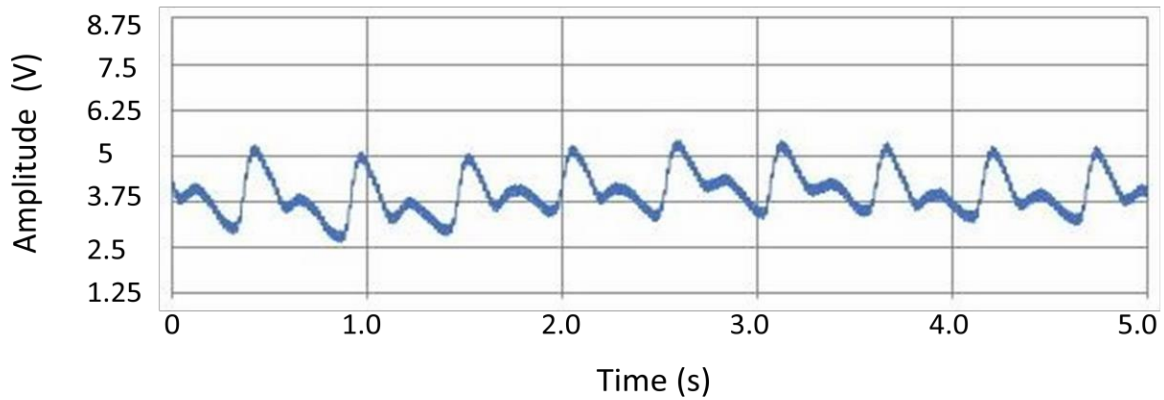


Fig.25 IR-LED data sample

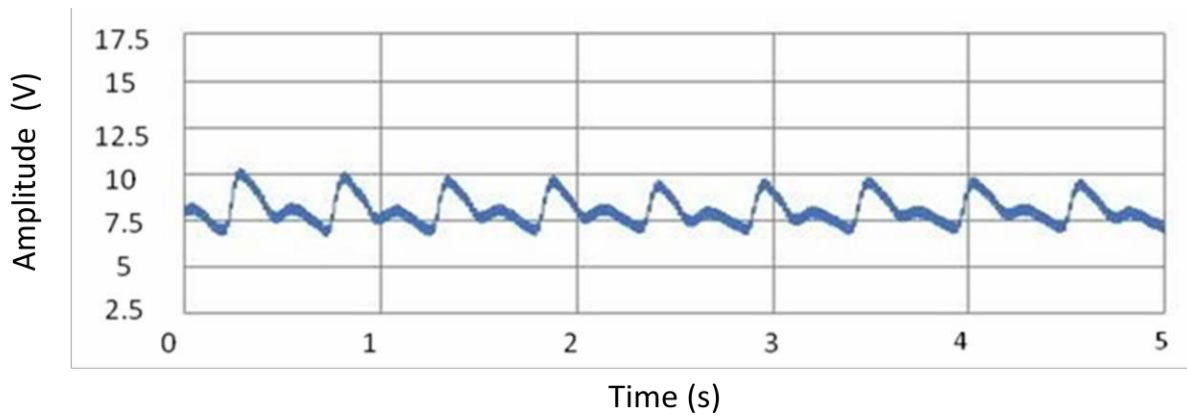


Fig.26 Red LED sample data

To check, the parameters are noted. It is found that

$$IR = 2.7, \Delta IR = 1.1$$

$$R = 2.5, \Delta R = 0.6$$

We know that,

$$SpO_2 = \frac{IR}{IR + R} \times \Phi \times 100$$

Where,

IR = Amplitude of infrared light

R = Amplitude of visible Red light

Φ = Light absorbing constant

To find Φ ,

We know that,

$$\Phi = \frac{\Delta X}{\Delta Y}$$

Where,

ΔX = Max amplitude of infrared light

ΔY = Min amplitude of visible red light

It is said that,

$$\Delta X = \log \frac{IR}{IR - \Delta IR}$$

And

$$\Delta Y = \log \frac{R}{R - \Delta R}$$

Substituting in the ΔX and ΔY formula we get,

$$\Delta X = \log \frac{IR}{IR - \Delta IR}$$

$$\Delta X = \log(2.7/1.6) = 0.2272$$

And now,

$$\Delta Y = \log \frac{R}{R - \Delta R}$$

$$\Delta Y = \log(2.5/1.9) = 0.1191$$

Substituting in Φ formula,

$$\Phi = \frac{\Delta X}{\Delta Y}$$

$$\Phi = (0.2272/0.1191) = 1.907$$

Finally finding SpO₂, is calculated by substituting all the obtained data in the below formula.

$$SpO_2 = \frac{IR}{IR + R} \times \Phi \times 100$$

$$SpO_2 = (2.7 / (2.7 + 2.5)) * 1.907 * 100$$

$$SpO_2 = 99.07\%$$

When compared to interpretation table the oxygen saturation content is considered to be normal.

20. Conclusion:

The primary aim of this thesis work is to develop an oxygen monitor system using embedded system. The developed oxygen monitor works properly.

Being calculated the SpO₂ value; the reading showed in pulse oximeter is also checked. Comparing the measurement obtained theoretically from the developed device, the oxygen monitor system is successfully developed using embedded electronics.

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