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Design & Implementation of Pulseoxymeter to Measures the Oxygen Saturation in Blood

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ABSTRACT

Present paper deals with problem statement to develop a system which measures the oxygen saturation in the blood, so that we can incorporate this vital signal in our clinical diagnostic system. This signal is important to monitor the oxygen exchange in the lungs which indicates how well the arterial blood is oxygenated. Poor exchange may indicate respiratory failure. It has been realized that this information can be available via the non-invasive technique of pulse oxymetry, which is now a well-established technique in clinical settings. Both the theoretical principles and methodology of solution are presented in this paper.

KEYWORDS: Pulseoxymeter, Pulse Detector, Clinical Diagnostic System.

INTRODUCTION

Pulse oxymeter consists of hardware and software part to receive the pulsatile signal properly and to extract necessary information from it to calculate blood oxygen saturation respectively. So the project is divided in to two parts as hardware part and software part. In this report only hardware implementation is considered to obtain the pulsatile signal that consists of the necessary information in order to obtain the heart rate and blood oxygen saturation. If we can obtain this signal then the blood oxygen saturation and heart rate can be easily calculated using microcontroller.

As pulse oxymeter works on the principle of light absorbance and transmittance through the arterial bed, we need a light source to pass the light through small area like finger and photo detector to detect the light at other side. Easily available light source is light emitting diode and infrared diode. As a photo detector we have either photodiode or photo transistor. These are optoelectronic devices which convert incident light to electrical signal in the form of current. As we are interested in the voltage output we need a signal conditioning circuitry to convert the current to voltage and an amplifier to get the desired level of output along with filter to remove unwanted signal. This signal is pulsatile in nature and in analog form. So by using analog to digital convertor (ADC) thedetected pulsatile signals from red and infrared LEDs are converted to digital form and using microcontroller the oxygen saturation will be calculated which can be displayed on liquid crystal display (LCD). The sensor LEDs are required to be pulsed alternately withthe help of LED driver circuitry. The pulses required to pulse the LEDs are derived from the microcontroller.

This explains the theoretical background and the solution on implementation of pulse oxymeter using the knowledge of electronics and signal processing.

DESIGN PROCEDURE OF PULSE OXYMETER

As the pulse oxymetry works on the principles of light transmittance/ absorbance, therefore we need a light emitter (LED circuitry) to emit light through the area of interest (finger) and a photo detector in order to convert this transmitted incident light into an electrical signal. Also it was discussed earlier that this electrical signal will be a current that corresponds to light intensity. However, since we wish to work with voltages as opposed to current we will need to convert this current into a corresponding voltage. This can be easily accomplished via a current-to-voltage convertor. Also signal amplification and filtering is required to amplify the weak signal and to remove unwanted signals. All these stages are shown by signal conditioning block in the diagram.Figure below shows all these steps using a block diagram.

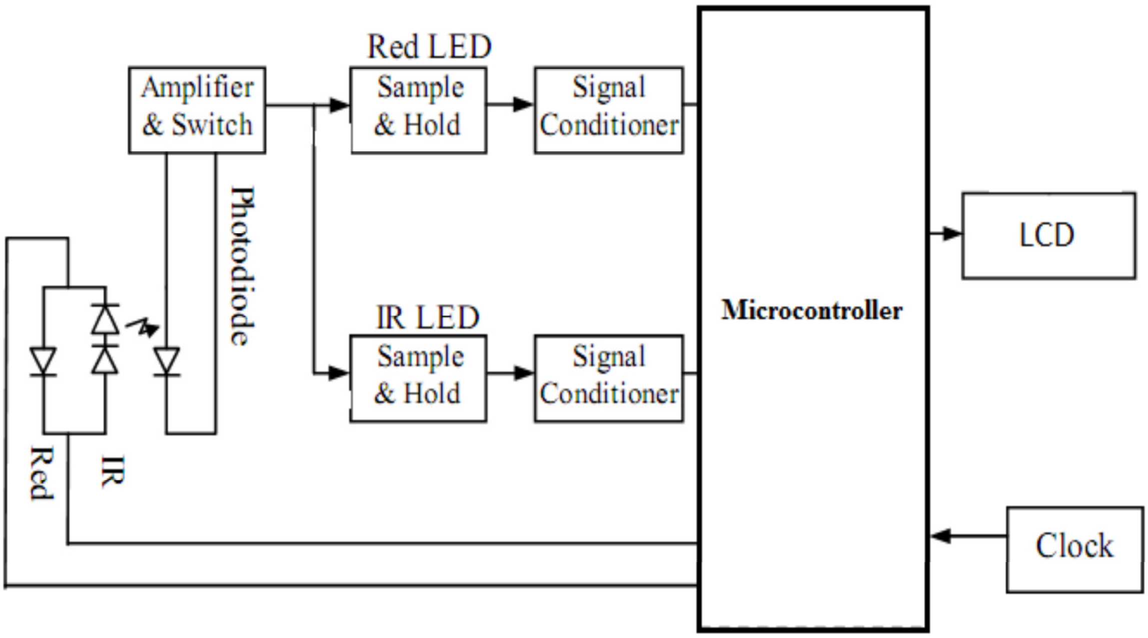

Figure 1.Initial block diagram of pulseoxymeter

As an initial step in the design of pulseoxymeter we are interested in detecting the pulsatile signal, following description gives the idea about the sensor detector combination in a finger clip and circuit used for signal conditioning. Finger clip need to be properly made to avoid the ambient light interference. Also it should support the light emitting and detecting diodes properly. There are two approaches to developing anoxymeter probe. The first is called transmittance the second is called reflectance.The difference isin the way the elements within the probe are positioned as shown in figure 2 below. A transmittance probe has two LEDs on one side and a photodiode (light detector) on the other. The tissue to be imaged (commonly a finger or an ear) is inserted between the two. A reflectance probe has the LEDs and the photodiode on the same side. It must be placed over a point with underlying bone. Light is emitted by the LEDs passes through tissue and blood vessels, reflects off bone and passes through the tissues again and is then detected. It is to be noted that a significant amount of light will reflect off the skin in the reflectance setup and unlike in the transmittance setup this light will be detected. Thus reflectance probes have a high offset and a lower signal-to-noise ratio than the transmittance probes. Reflectance setups also require a significantly greater amount of light. Thus either more LEDs or more photodiodes need to be used.

Transmittance probes are commonly placed on a finger or ear and are very convenient to attach and remove. Reflectance probes can be placed on the forehead or the sternum. Their advantage is that regardless of the patient's size (infants to very large adults) the attachment site is always similar. Both the transmittance and the reflectance probes are used clinically though the transmittance probe is more common due to the simplicity of signal analysis and convenience of attachment. Figure below shows the two approaches used in pulseoxymeter probe.

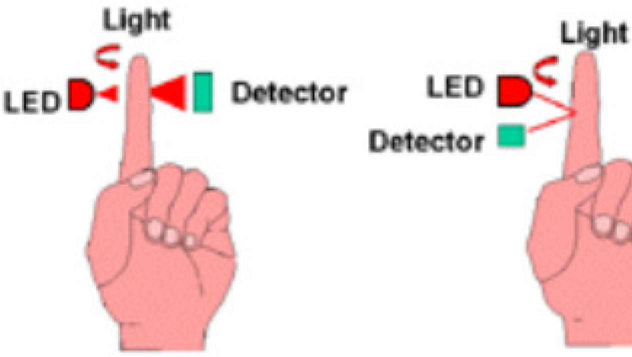

Figure 2.Sensor detector orientations in pulseoxymeter probes

As described earlier pulse oxymetry works on the principles of light transmittance/ absorbance therefore we need a photo emitter (LED circuitry) to emit light through the area of interest (finger) and a photo detector (phototransistor/ photodiode/ LDR) in order to convert this transmitted incident light into an electrical signal. Also it was discussed earlier that this electrical signal will be a current that corresponds to light intensity (the higher value of current the greater the light intensity). Since we wish to work with voltages as opposed to currents we will need to convert this current into a corresponding voltage. This can be easily accomplished via a current-to-voltage convertor. This design can then give us an output signal that corresponds to a pulsatile signal which we can use to extract the oxygen saturation reading. This system described above can be obtained via the following block diagram, figure 3 which shows the LED circuitry, photo detector circuitry and the current-to-voltage convertor each represented by a block.

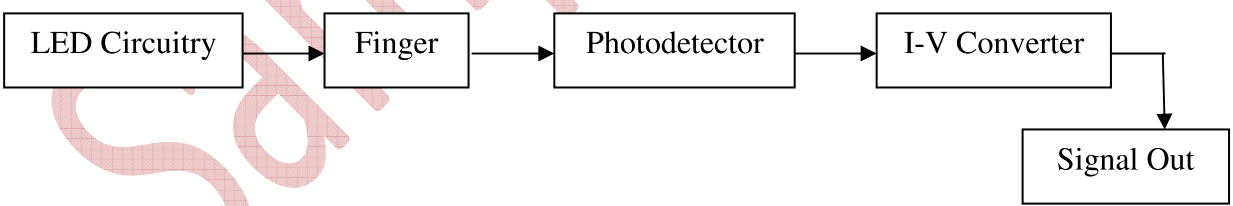

Figure 3.Block diagram of pulseoxymeter probe

Now we will present schematic diagrams of each block that can be implemented as shown in the following figures. Note that first each block will be presented separately and then the whole pulse oxymeter system will be presented.The following figure 4 is a schematic diagram of the LED circuitry involved in transmitting light through the finger. The 5 V power supply causes a current flow through the resistor and LED powering the LED and producing light. The purpose of the 150 Ω resistor is to regulate the current across the LED so that it does not burn out.

Figure 5 is a schematic diagram of both the photo detector (represented by a photodiode) and current-to-voltage convertor which is involved in detecting the transmitted light through the finger and converting that current into a voltage (note that there would be two of these circuitry's one for each red LED and IR LED). The incident light transmitted through the finger strikes the photodiode causing current to flow. This current then flows through the resistor and creates a voltage at the output port of the operational amplifier which is our desired signal of interest.

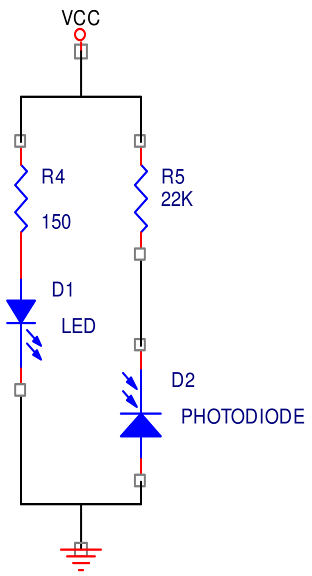

Figure 4.Circuit diagram of LED

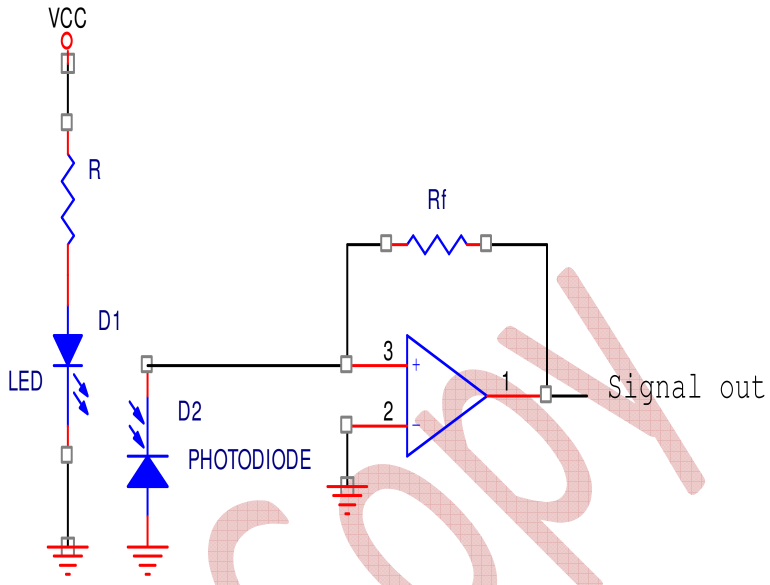

Figure 5.Initial Circuit diagram of pulse detector and Photo detector

FURTHER REFINEMENT

Although this system is very simple to implement and does produce a pulsatile signal but due to a number of issues further refined circuit is implemented. The issues pertaining to the signal are corruption by noise, low signal amplitude due to which we are unable to properly send/recover a signal from this simplistic system. Realization of this allows to implement a refined system that will deal with these issues and allow us to transmit/recover the signal with high fidelity. Figure 6 below is the block diagram for the refined system. It includes some post processing in order to deal with the numerous issues involved in transmission and recovering a pulsatile signal.

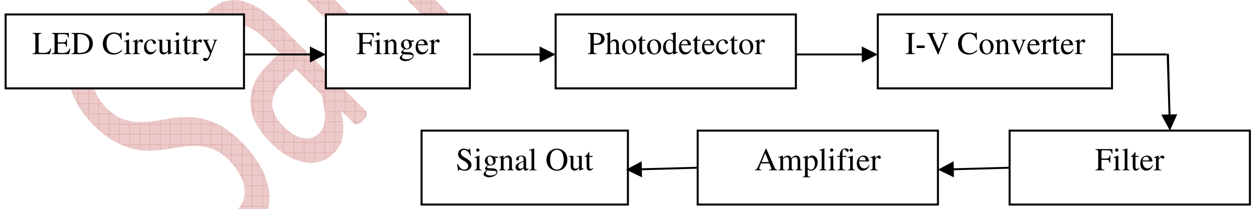

Figure 6.Refined block diagram of pulse detector

Figure 7 below shows the circuit diagram of refined circuit used in pulse detection.

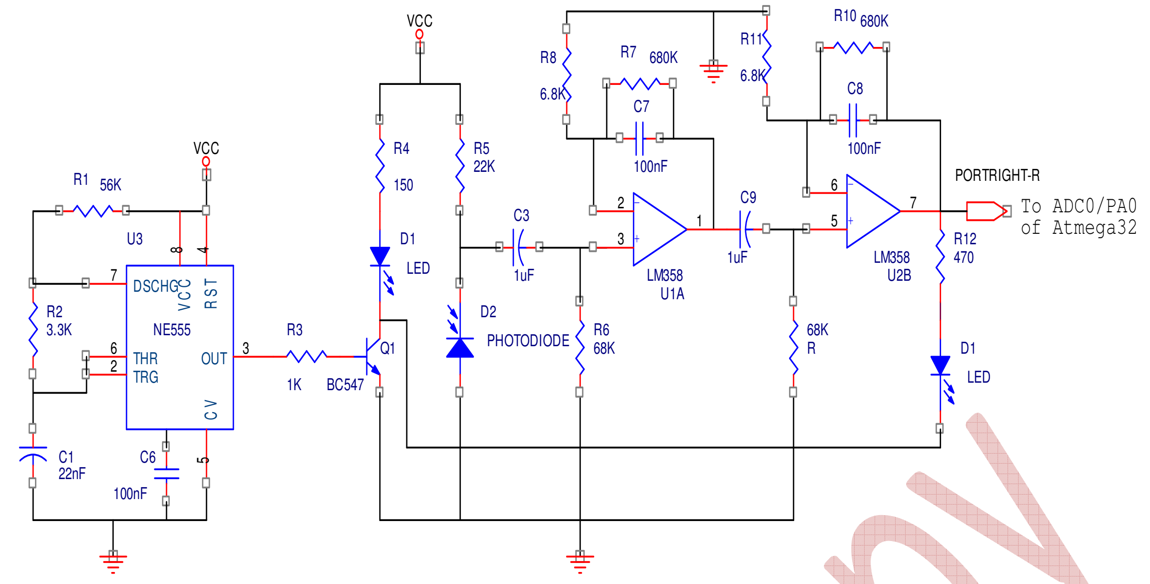

Figure 7.Circuit diagram of pulse detector circuit

The circuit basically consists of 1 KHz frequency generator build around IC555 which is used as astablemultivibrator. This 1 KHz signal is used to drive infrared LED using an NPN transistor. As pulses are received infrared LED transmits light which is received by the photo detector (photodiode). Output of photodiode consists of ac and dc signals as light passes through the finger which is placed in between infrared LED and photo detector. Capacitor at the input of amplifier blocks the dc signal and passes ac signal which is amplified by the2 operational amplifiers and a low-pass filter build around operational amplifier LM 358. Both the amplifier gain is set to 101to give a total gain of 10000.It is necessary to use a low pass filter in the circuit to filter out any unwanted high frequency noise. The cut-off frequency of the filter was chosen as 2.5Hz. LED at the output of second amplifier is used to indicate the pulses as the heart beats. The output at the second stage is in analog form connected to the ADC input of the microcontroller which then calculates the pulse rate and displays it on the LCD. Figure 8 below shows connections for microcontroller and LCD.

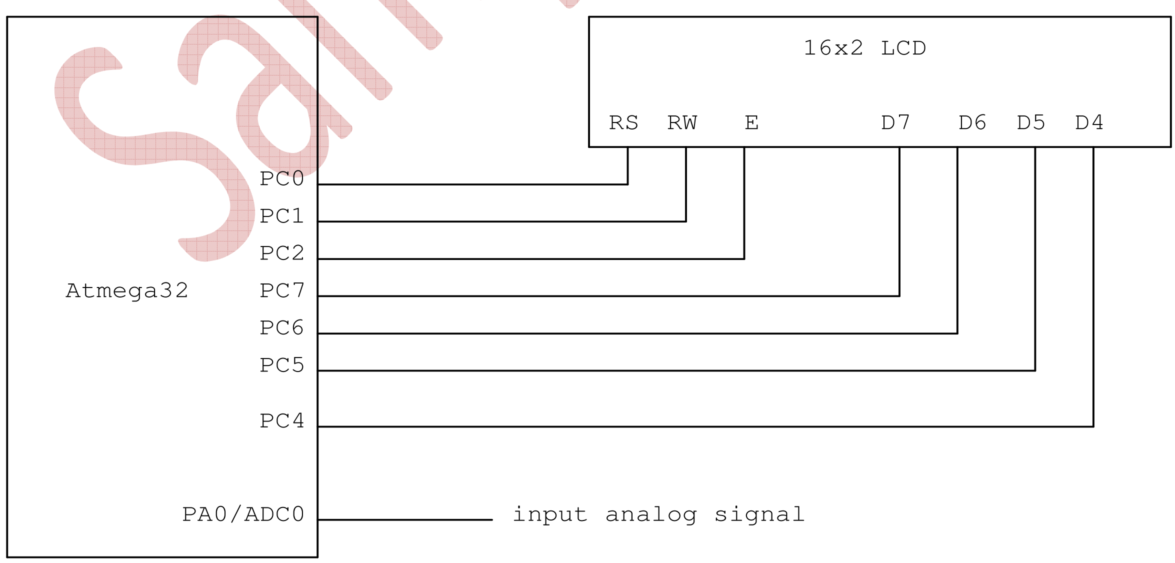

Figure 8.Block diagram of Microcontroller part of pulseoxymeter

DESIGN EQUATIONS

The astablemultivibrator frequency is given by-

Frequency = 1.44 / (R_1+ 2R_2)

= 1.1 KHz

The signal conditioning circuit consists of two active low pass filters with a cut-off frequency of about 2.5 Hz. The operational amplifier IC used in this circuit is LM358 a dual opamp chip. It operates at a single power supply and provides rail-to-rail output swing. The filtering is necessary to block any higher frequency noise present in the signal. The gain of each filter stage is set to 101 giving the total amplification of about10000. A 1 uF capacitor at the input of each stage is required to block the dc component in the signal. The equations for calculating gain and cut-off frequency of the active low pass filter are-

Gain of each stage = 1+ R_f / R_i

= 1+ 680k / 6.8K

= 101

Cut-off frequency of filter = $1 / 2\pi R_f C_f$

= $1/ 2\pi (680 \times 10^3 \times 0.1 \times 10^{-6})$

= 2.34Hz

The two stage amplifier/filter provides sufficient gain to boost the weak signal coming from the photo sensor unit and convert it into a pulse. An LED connected at the output blinks every time a heart beat is detected.

To measure the heart rate by sensing the change in blood volume in a finger artery while the heart is pumping the blood an infrared LED that transmits an IR signal through the fingertip of the subject is used a part of which is reflected by the blood cells. The reflected signal is detected by a photo diode sensor. The changing blood volume with heartbeat results in a train of pulses at the output of the photo diode the magnitude of which is too small to be detected directly by a microcontroller. Therefore a two-stage high gain active low pass filter is designed using two Operational Amplifiers (OpAmps) to filter and amplify the signal to appropriate voltage level so that the pulses can be counted by a microcontroller. The heart rate is displayed on a liquid crystal display. The microcontroller used in this project is ATMEGA32.

Heart rate is the number of heartbeats per unit of time and is usually expressed in beats per minute (bpm). In adults a normal heart beats about 60 to 100 times a minute during resting condition. The resting heart rate is directly related to the health and fitness of a person and hence is important to know. We can measure heart rate at any spot on the body where you can feel a pulse with your fingers. The most common places are wrist and neck. We can count the number of pulses within a certain interval (say 15 sec) and easily determine the heart rate in bpm.

CONCLUSION

This project describes a microcontroller based heart rate measurement system that uses optical sensors to measure the alteration in blood volume at fingertip with each heart beat. The sensor unit consists of an infrared light-emitting-diode (IR LED) and a photodiode placed side by side as shown in figure above. The IR diode transmits an infrared light into the fingertip (placed over the sensor unit) and the photodiode senses the portion of the light that is reflected back. The intensity of reflected light depends upon the blood volume inside the fingertip. So each heart beat slightly alters the amount of reflected infrared light that can be detected by the photodiode. With a proper signal conditioning this little change in the amplitude of the reflected light can be converted into a pulse. The pulses can be later counted by the microcontroller to determine the heart rate using microcontroller.

REWORK

By using above circuit though we can observe the heart rate by blinking LED at the output we are not able to observe the polyplethysmographic (PPG) signal at the output. This signal is required to calculate the oxygen saturation in the blood. So the original circuit is modified to extract the required PPG signal.

The low pass filter is changed to band pass filter having lower cutoff frequency of 0.5Hz and higher cutoff frequency of 5Hz and amplifier gain is kept variable with the help of potentiometer. Also the LED and photo detector which are exposed to the environment are now placed in closed box where we can only insert the finger so that photo detector can only be able to detect PPG signal and does not get affected by other noise signals.

While checking the circuit following observations are found-

1) As soon as the power is supplied to the circuit it shows some DC ripple at the output.
2) When finger is placed between LED and photo detectoroutput shows some signal change on CRO which indicates that there is some AC signal along with the DC noise of the order of few mill volt.
3) With the help of potentiometer the gain of the amplifier is varied so as to get considerable change in the signal strength.
4) Though amplifier increased the signal strength, the noise signal strength also increased.
5) With the help of CRO we tried to observe the complete waveform to see if it resemble to the expected signal but it was difficult to distinguish between noise and expected signal.
6) Small movement of the finger caused lot of noise signal generation so it is very necessary to keep the finger steady in the sensor probe.
7) After making necessary adjustments the signal activity remained same as before.
8) When tried by pulsing the sensor LED with square wave pulses of 1Hz to see any changes in the output, some signal change was observed in the form of regular interval pulses. But it is observed that similar kind of signal is still there though we remove the finger from the probe indicating that photo detector is still sensing some other signals though it is placed in shielded environment.

From this it is concluded that further sensor confinement is necessary to reduce noise at the output and to use the op-amp with offset null adjustment. Secondly to increase the required signal strength we have to try by extracting the signal by using multiple photo detectors and then combine their output so as to get increased signal strength. This again requires modification in the signal conditioning circuit as per the photo detector configuration.

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