

# Pulse Oximetry

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Pulse Oximetry is a method of monitoring the heart rate and the level of oxygen in the blood stream of a human body. It is mostly used in hospitals but is gradually finding its way into home use and becoming popular with family GPs. It uses optical sensors and light emitting diodes emitting light at different wavelengths through a finger tip where the transmitted light is detected using an optical sensor. Based on the principle of oxygenated haemoglobin having a higher absorption coefficient for infrared light than deoxygenated haemoglobin while deoxygenated haemoglobin absorbs more red light, by taking the ratio of absorbed red light to infrared light, the oxygen saturation level can be obtained.

The possibility of making such a prototype was studied and electronic circuits were developed to take measurements of transmitted light at the two different wavelengths. The results obtained showed a typical photodetector was capable of detecting transmitted light through a human finger with variations in voltage amplitude at two wavelengths for calculation of oxygen saturation percentage. The heart beat was detected simultaneously along with the oxygen saturation and displayed in real time on an oscilloscope. The frequency obtained showed the heart.

## Introduction

For many years, electronics have been built into medical instruments but mainly focused on large expensive equipments such as CAT and MRI scanners used in clinics and hospitals. Recently, there has been an increased desire for medical instruments that can be used at home as

well as in clinics. The advantage of using medical instruments at home allows the patient to monitor their health constantly without the need to visit the clinic for a check up. This is especially useful for the elderly where it can be difficult for them to make visits to the clinics, so the development of small, reliable, accurate medical devices is now accelerating in the current market.

These small instruments have to be energy efficient and patient friendly in both physically and technically. Creating such devices can be challenging, especially now that the state of the art medical products are non-invasive so it does not intimidate the patient when using the device.

“The ability to create smaller, portable, non-invasive test equipment that provides quick, accurate results have led to the development of pulse oximeters, personal heart rate monitors and blood glucose meters.” <sup>[1]</sup>

All these devices are optoelectronic sensor based, meaning it produces an electrical signal that it is directly proportional to the amount of light hitting on the active surface area. There are many electronic sensors which meet this criteria but they are not as common as the semiconductor photodiode. The photodiode has been at the core of light sensing for many years but today's designers are looking for functionality integrated around the photodiode providing much improved performance, sensitivity and reliability.

The Pulse Oximeter is a medical device which measures the percentage of oxygen in the patient's blood. With the aid of optoelectronic sensors, it has made pulse oximetry a feasible medical method. Before the invention of pulse oximeter, medical tests had to rely on blood samples taken from patients to determine blood oxygen content,

but the results obtained were not in real-time. Early pulse oximeters were large, heavy devices and priced around £5500. With modern technology, better LEDs, and integrated optoelectronic sensors the newly developed pulse oximetry systems became real-time, accurate and a non-invasive method of measuring blood oxygen content.

### Principles of Pulse Oximetry

A typical Pulse Oximeter uses the basic principle of a pair of small LEDs operating at two different wavelengths; one red LED with a wavelength of 660nm, the other, an infrared LED with a wavelength of 910nm. The LEDs are designed to be placed opposite a photodiode that detects the light from the LEDs. Absorption on each wavelength differs significantly for the oxyhaemoglobin and deoxygenated haemoglobin. Therefore from the difference of the absorption of the red and infrared light the ratio between oxy/deoxyhaemoglobin can be calculated. As the amount of blood in the capillaries depends on the actual blood pressure, which varies around the heart the heart pulse cycle, the heart rate can also be measured.

Haemoglobin is an active oxygen carrying part of the erythrocyte (red blood cells); it is a compound of iron (hem) and four polypeptide chains (group of polymers made up of long amino-acid chains). Each chain is linked to one atom of iron, each of which can carry four molecules of oxygen. Each molecule of oxygen has two atoms of oxygen so each haemoglobin molecule can carry eight atoms of oxygen.

Oxyhaemoglobin refers to oxygen carrying haemoglobin and deoxygenated haemoglobin refers to non oxygen carrying haemoglobin. If all haemoglobin molecules bonded with an oxygen

molecule ( $O_2$ ), the total body of haemoglobin is said to be fully saturated (100% saturation). When haemoglobin unloads the oxygen molecule to tissue cells at capillary levels, the saturation progressively decreases and the normal venous saturation is about 75%. The normal saturation level is said to be between 87-97%.<sup>[2]</sup>

The two wavelengths are chosen for the reason that deoxygenated haemoglobin has a higher absorption at around 660nm and at 910m oxygenated haemoglobin has the higher absorption.

The oxygenated haemoglobin allows red light to transmit through and absorbs more infrared light while the deoxygenated haemoglobin allows infrared to transmit through and absorbs more red light. Usually a finger is placed between the source (LEDs) and the receiver (photodiode) acting as a translucent site with good blood flow. Once these absorption levels are detected from the finger the ratio of absorption at different wavelengths can be obtained.

Figure 1

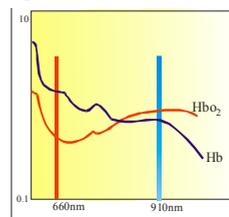


Figure 2

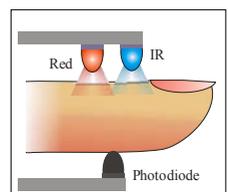


Figure 1. Absorption coefficient for two types

Figure 2. Basic idea of a pulse oximeter of haemoglobin at red and infrared wavelength.

The pulsatile waveform shown in figure 3 has both DC and AC components in it. The AC component includes the absorption from the non-pulsing arterial blood, the venous and capillary blood and the scattering and absorption due to the tissue and bone. [3] The DC components are always constant and rest on one another. Only the AC component is the pulsatile waveform that is of interest as it represents the pulsing of the blood in the arteries and each individual pulse can be seen.

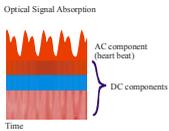


Figure 3. AC and DC pulsatile signals

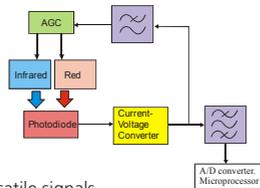


Figure 4. System flow diagram

## Development

The prototype started off with two light emitting diodes and a photodetector. The light normally switches from red to infrared and then back to red again, the two LEDs never shine simultaneously. A receiver circuit was used to detect the transmitted light using a photodiode which produces a current that is proportional to the intensity of the light. This signal is then converted into voltage using an op-amp configured as a current to voltage converter.

An automatic gain control (AGC) was implemented into the system as the AGC controls the intensity of the LEDs. This is required in order to keep the DC level constant regardless of the thickness of the finger. Ideally, when a thick finger is placed between the photodiode and the LEDs, the intensity of the LEDs incident onto the measuring surface will be brighter but with a thin finger, the input intensity will be dimmer. This is because a

thin finger blocks less light compared to a thick finger.

The system also required filters; the flow diagram shows a low pass filter and a band pass filter. The low pass filter only allows low frequencies, below 0.5Hz, to pass through. This is applied before the AGC so only the DC component is taken into the feedback loop.

The band pass filter with pass band of 0.5-3Hz is applied at the output of the current to voltage converter as only the frequencies within this range are required since the lowest a human heart rate can be is approximately 30 beats per minute and the highest around 200 beats per minute. These are both under extreme circumstances.

Oxygen saturation is referred as  $SpO_2$  as mentioned earlier. It is defined as the ratio of oxyhaemoglobin ( $HbO_2$ ) to the total concentration of haemoglobin ( $HbO_2 + \text{deoxyhaemoglobin}$ ). To measure the actual difference in absorption spectra of  $HbO_2$  and  $Hb$  two different wavelengths of light. Assuming the transmission of light through the blood stream is affected by the concentration of  $HbO_2$  and  $Hb$  and their absorption coefficients at the two measurement wavelengths, then the "light intensity will decrease logarithmically with path length according to the Beer-Lambert law". [4] As mentioned earlier there are DC and AC components in the signal transmitted through the finger, so the ratio R is defined as:

$$R = \frac{\log_{10}(I_{dc+ac} / I_{dc})_{\lambda_1}}{\log_{10}(I_{dc+ac} / I_{dc})_{\lambda_2}} \quad (1)$$

Using the AGC circuit in the instrumental design of pulse oximeter, it keeps the DC components of transmission signals the same, it can be eliminated from the formula and the new ratio becomes:

$$R = \frac{\log_{10}(I_{ac})_{\lambda 1}}{\log_{10}(I_{ac})_{\lambda 2}} \quad (2)$$

$I_{ac}$  = Light intensity at  $\lambda 1$  or  $\lambda 2$  where only AC level is present.

## Results and Discussion

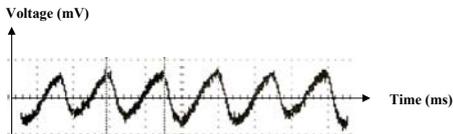


Figure 5: Pulse detected at finger tip.

Figure 5 shows the typical waveform produced when detecting the heart rate at the finger tip, for a normal person the frequency measured was 1.2Hz which corresponds to 72 beats per minute. The peak-peak voltage is taken for each wavelength incident on the finger. The values were then converted into light intensity prior to substituting into equation 2 to obtain the  $SpO_2$ . For a healthy person the  $SpO_2$  value is considered to be anything above 87%. For experimentation the heart rate and the  $SpO_2$  level were observed after different subjects had been exercising for a short period.

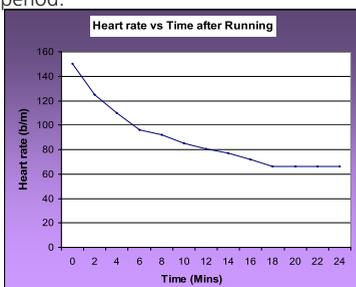


Figure 6. Heart rate observed after running.

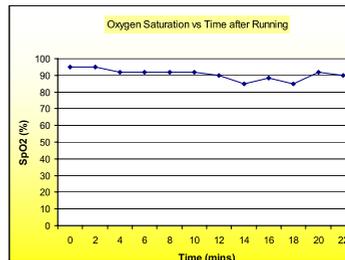


Figure 7: Oxygen level observed after the running of an athletic person.

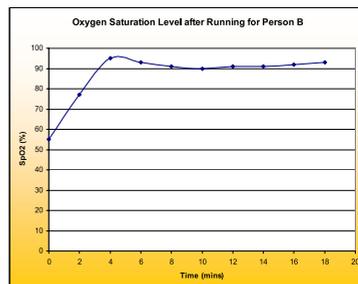


Figure 8: Oxygen level observed after the running of an unhealthy person.

Figure 6 shows how the heart rate gradually slowed down after the subject had completed a 10 minute run. For an athletic person, the heart rate is normally around 60 beats per minute at rest, so after a recovery time, the heart rate will return to this level. Figure 7, shows the oxygen saturation level of the same person after running. Overall the  $SpO_2$  level was not affected greatly by running mostly due to the fact that for an athletic person their oxygen level will not change much without anaerobic exercise such as sprinting.

For an unhealthy volunteer the observed  $SpO_2$  differed greatly compared to a healthy person. Figure 8 shows a significant difference at zero

minutes after the run, until four minutes after the subject was at rest, when their SpO<sub>2</sub> returns to the resting level.

## Conclusion

Results obtained showed a convincing conclusion that the system built can fully detect the heart beat and the SpO<sub>2</sub> can be obtained from the reading taken from the oscilloscope.

The result gathered from someone who had just been running, the heart beat displayed on the oscilloscope gradually slowed down with time so the system was able to show the heart rate of the patient in real time. However the SpO<sub>2</sub> result for that specific subject did not change after running since they were rather athletic already. Where with an unhealthy person, there was a significant drop in SpO<sub>2</sub> level where the subject had just finished their run and there was a shortage of oxygen supply to the cells in the body.

For further development the pulse oximeter can include more functions such as incorporating a memory system into the device so the patient can keep a record of their results for a period of time which then can be uploaded to either a home computer or a doctor's computer for further analysis of the results by the doctor.

## Acknowledgements

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## References:

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3. [www.oximeter.org/pulseox/principles.htm](http://www.oximeter.org/pulseox/principles.htm)
4. Dr Neil Townsend 2001, Medical Electronics, Michaelmas term