ELEC2104 Lab Project - Pulse Oximeter

Gabriel Ralph: 470205736
Liam Weichandt: 500463727

Product Background

Being able to read the blood oxygen level in a medical setting is an essential part of monitoring the health of a patient. A pulse oximeter provides a non-invasive way to monitor the oxygen saturation of the patients' blood. This is significant because monitoring the saturation of blood in the body can help indicate underlying medical problems such as problems in the circulatory and respiratory systems. Therefore, we see its use in a range of medical settings.

There are a range of already existing pulse oximeters that are widely used which generally consist of a clip which contains a optical sensor circuit which will attach to either a finger, toes or ear. The output of this circuit is then sent to a filtering and amplification circuit.

The reason an optical sensor circuit is used is because the pulse oximeter works based on light-absorption characteristics of haemoglobin in blood. The higher percentage of oxygen in the blood, the more infrared light will be absorbed compared to red light when passing the light through the skin tissue. This is measured by observing the intensity of the received light using the optical sensor circuit. The volume of blood of the patient is a function of the arterial pulse. Blood absorbs most the light passing through the tissue and hence the intensity of the light is inversely proportional to the volume of blood present in the tissue. Because of this the signal received is small and experiences significant noise. This is why the filtering and amplification sections of the circuit are required. The haemoglobin oxygen saturation can then be found by observing the light absorbed by two different wavelengths, and hence the use of both the red and IR LED.

The ratio of normalised absorbance is calculated to account for the different absorbance coefficients of both oxyhemoglobin and its deoxygenated form. From the ratio of normalised absorbance, the blood oxygen level can be calculated.

Circuit Overview

Component List:

- Infrared LED (IR LED) Sharp GL4800E0000F
- Surface mounted red LED
- LPT804 silicon photo transistor
- $10\mu F$ Capcacitor
- $470\mu F$ Capcacitor
- 2x Diodes IN914
- Resistors: 2x 100 Ohm, 22k Ohm, 4.7k Ohm, 1K Ohm, 33K Ohm, 100K Ohm
- LM358AN OP Amp
- Custom PCB as per specifications in the design section

The circuit can be separated into two separate modules, the first being the optical sensor circuit which includes the red and IR LED's and the photo transistor. And the second being the filtering and amplifying circuit. The order of operation of the system goes as follows:

Optical Sensor $\rightarrow$ Filter $\rightarrow$ Amplification $\rightarrow$ Data collection/ Processing

The first module uses the combination of red and IR LED's and the phototransistor to produce a signal when a finger is placed in-between either of the LED's and the phototransistor that is inversely proportional to the volume of blood present in the tissue it passes through. Only one photo-transistor is required for both LED signals as the signals are turned on at separate times. Because this signal is small and contains a large amount of unwanted noise, the second module is needed to amplify and filter the signal.

The second module consists of a combined low pass and high pass filter to achieve the desired bandwidth of 0.5Hz to 3.5Hz which allows heart rates of 30BPM to 180BPM. It also includes amplification of the signal with a theoretically calculated gain of 98.

The final circuit design is located in the Design section of the report which includes the PCB component layout and circuit.

Design

Calculation of R_1 and R_2 Values

For the design chosen, a bandwidth of 0.5Hz to 3.5Hz was chosen as it allows a slight larger range, reducing the chance of not being able to detect the required signals. The only downside to this is that a small amount of extra noise could be introduced, however from testing, this was minimal.

$$R_1 = \frac{1}{f_{LOW} * \pi * C_1}$$

$$R_2 = \frac{1}{f_{HIGH} * \pi * C_2}$$

From the calculations above:

$$R_1 = 32kOhms$$

$$R_2 = 97KOhms$$

Which with these two resistor choices, gives a desirable gain of:

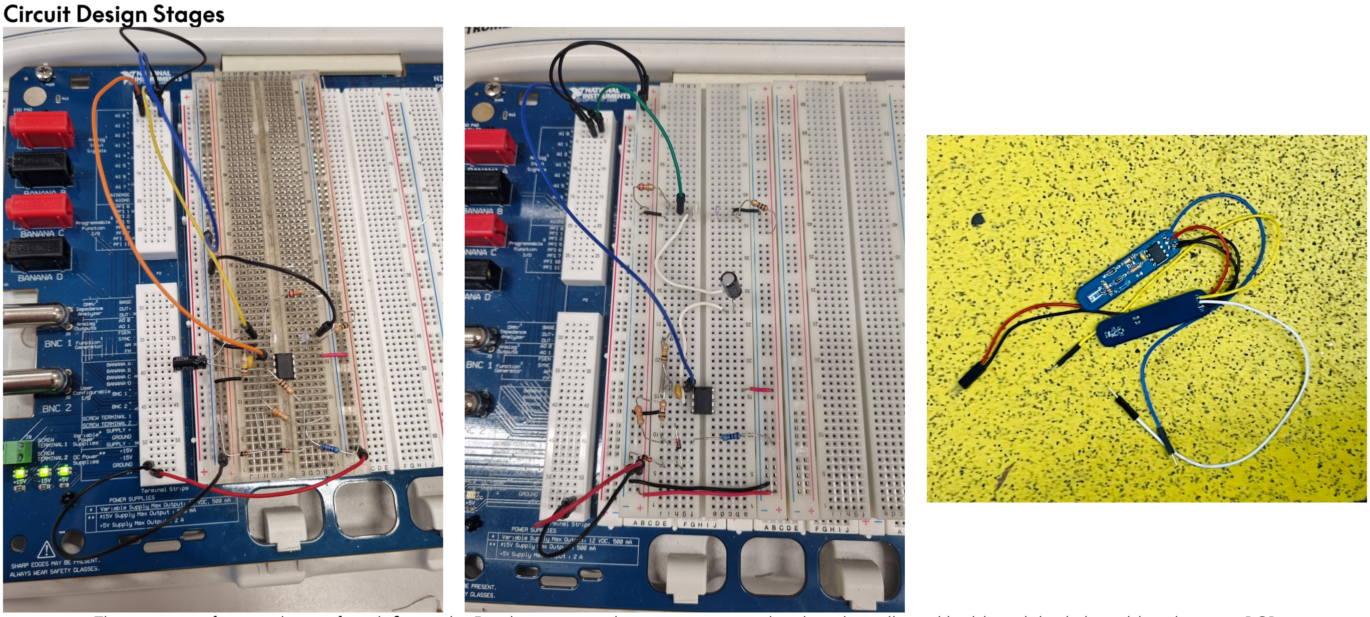
$$Gain = 98$$

From the resistors we were limited too, we chose to use the following resistors in the circuit:

$$R_1 = 33kOhms$$

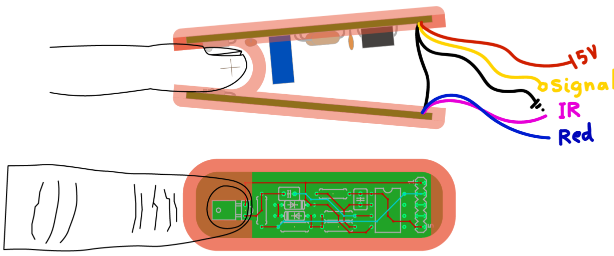
$$R_2 = 100kOhms$$

Circuit Design Stages

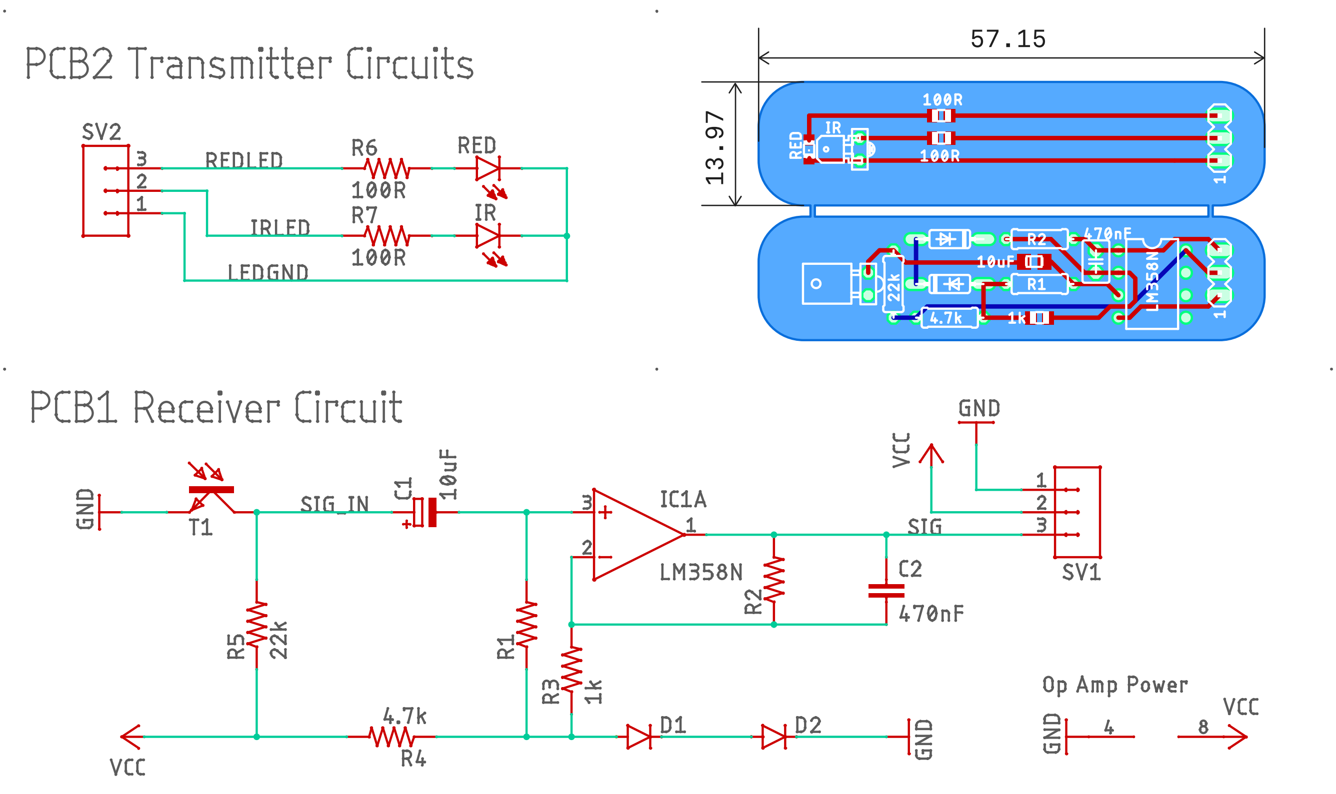


Three stages of circuit design, from left to right. First being a rough test stage, second a clean breadboard build, and third, the soldered custom PCB.

The circuits depicted below were taken from the assignment specifications and created in EAGLE CAD. The transmitter circuit was placed on one board and the receiver on another with the transmitter LEDs inline with the receiver phototransistor. The boards where then joined with small taps that could be snapped after manufacturing. In this way the pcb would form the top and bottom panels of a clip that could attach to someone's finger. The circuit board was manufactured by Seeed Studio.

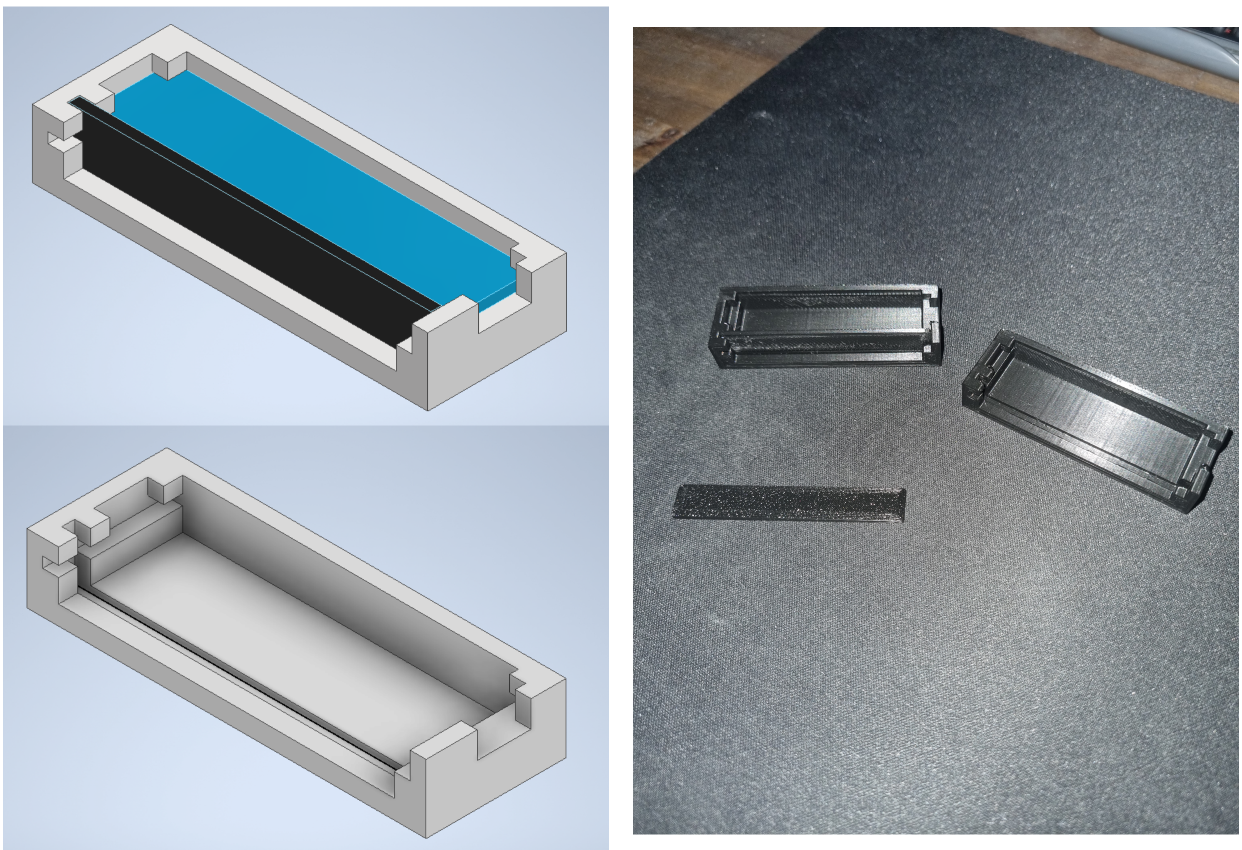


Initial case design and PCB integration.



Schematic diagram
and printed circuit board (PCB)
(dimension in mm).

PCB Case Design
A custom casing for the custom PCB was designed in AutoDesk Inventor to house the PCB while leaving the LED, IR LED and photo transistor exposed to ensure reading can be taken. The PCB slides into the casing and is then locked secure with a key. The entire case including the key was 3D printed to the exact specifications of the PCB.



PCB Case Designs in Autodesk Inventor and 3D Printed. From the left, the first image is of just the PCB case. The second image is of the PCB case with the PCB represented in blue and the key represented in black. The third image is of the final 3D printed PCB case and key.

Testing

Test - Biasing Circuit for LED, IR LED and Photo Transistor
The following test circuit was built to test the use of the LED and IR LED with a photo transistor. The digital write tool was used to set digital pints 0 and 1 to turn both the LED and IR LED on individually. The following resistor values were used as shown in the diagram.
$R_1 = R_2 = 100 Ohms$, $R_3 = 22kOhms$
Measuring the output voltage of the photo transistor, testing in different conditions gave the following results shown on the right.

When placing a finger between the photo transistor the following biasing current were recorded:
LED:

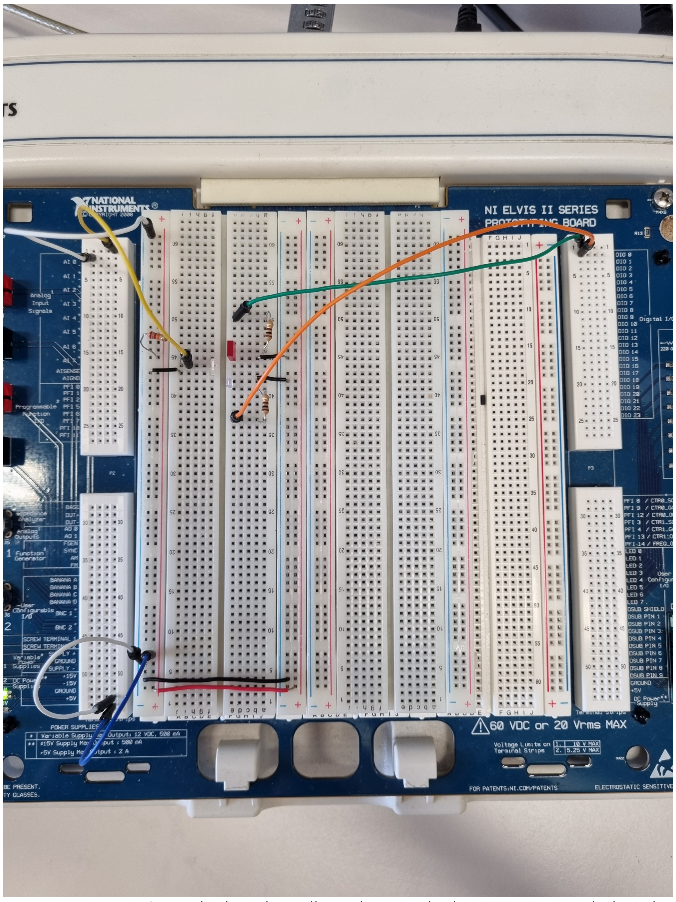
$$0.0205A$$

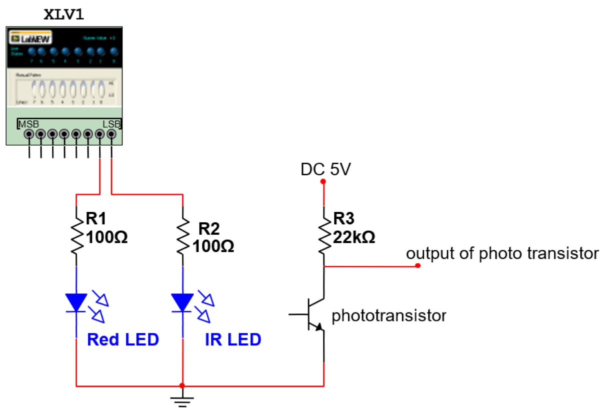
IR LED:

$$0.02409A$$

Photo Transistor, IR LED and LED close to each other:
Open Air:
Both Off: 15.46mV
LED On: 4.57mV
IR LED on: 1.13mV
Hand Covering:
Both Off: 5.15mV
LED On: 4.51mV
IR LED on: 0.966mV

Photo Transistor, IR LED and LED far away from each other:
Open Air:
Both Off: 17.23mV
LED On: 17.07mV
IR LED on: 1.43mV
Hand Covering:
Both Off: 15.0mV
LED On: 8.23mV
IR LED on: 1.13mV





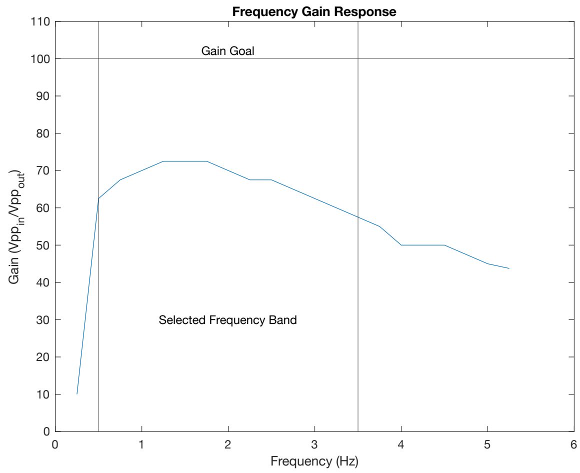
Circuit built on breadboard to test the biasing circuit including the LED, IR LED and photo transistor. Circuit on the right from report spec.

Test - RC High Pass Filter and Op Amp Circuit
Using the function generator with a frequency sweep to test the response of the RC High Pass Filter and Op Amp Circuit. The data in the table on the right was collected by performing a frequency sweep from ranges 0Hz to 5.25Hz with an 250mHz increment with $V_{pp} = 20mV$.

This gave a measured gain of:

$$Gain = 70$$

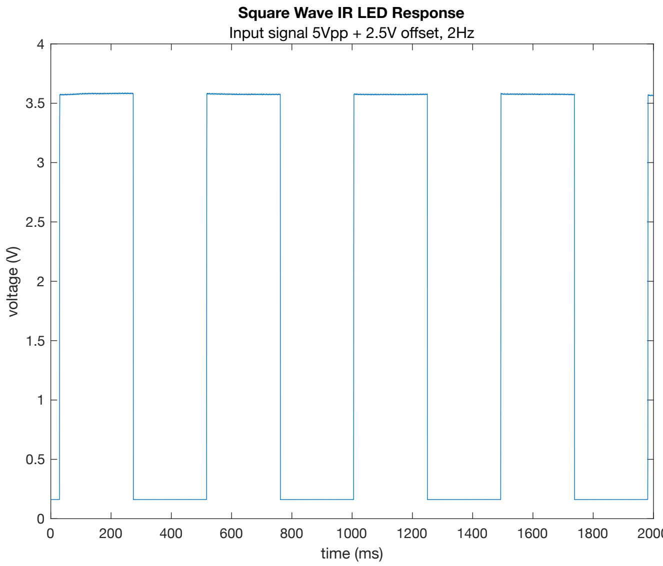
Which deviated from the theoretically calculated gain of 98 slightly. This could be due to multiple reasons, for example, the changed resistor values as there was not the specific resistors specified from the theoretical calculations.



Data Acquired from multimeter plotted when running a frequency sweep from the function generator on the RC High Pass filter and OP Amp circuit

Test - Entire Circuit with Function Generator
Using the Function Generator to simulate a finger test the bandwidth and voltage gain while using an IR LED. This demonstrated cleary the desired result, simulating a finger pulse. The following settings were used for the function generator:

$SquareWave$
$V_{pp} = 5V$
$f = 2Hz$
$V_{Offset} = 2.5V$
Graph: "Square Wave IR LED, 5Vpp, 2Hz, 2.5V



Plot of results from testing Function Generator simulating finger with Square Wave at 2Hz

Trouble Shooting

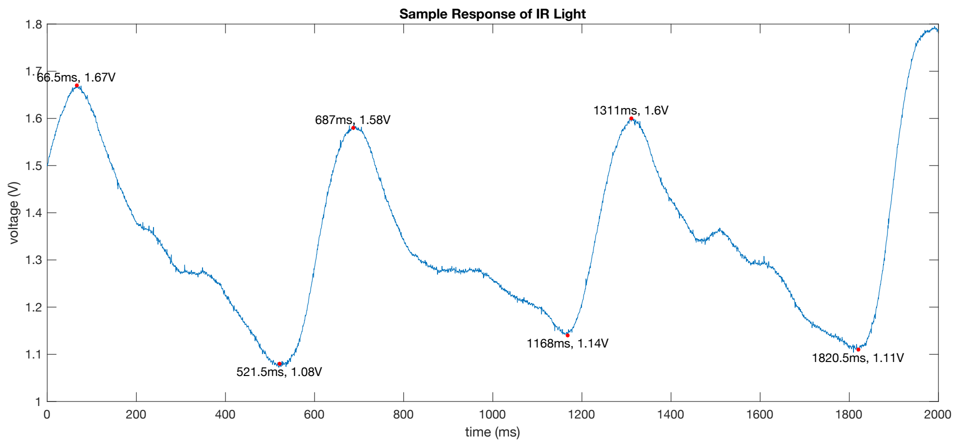
When designing any stage of the circuit, each individual section of the circuit was tested to ensure the circuit was working correctly before connecting it to the rest of the circuit. This is evident in all the photos provided in the testing section of the report. For example, the optical sensor with the LED, IR LED and phototransistor was connected and tested to ensure functional before connecting to the rest of the circuit.

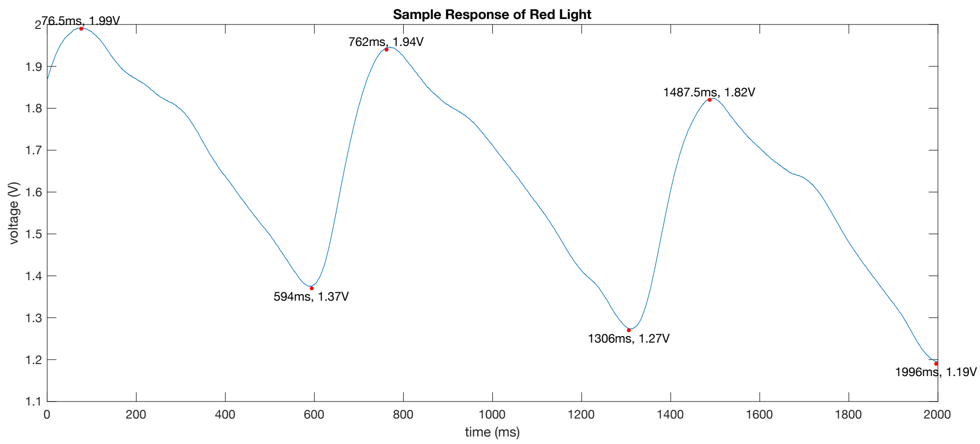
When it comes to testing of the PCB with components/ sections on the PCB. Each component was tested before being soldered onto the PCB to ensure it was not faulty. Then each section was soldered individually and tested before the rest of the circuit was soldered on and tested. This ensured that if any problem arises, the exact stage of the problem would be known.

Throughout the taking of data, the output of the phototransistor was consistently monitored to ensure the was no problems with the signal going into the filter and amplification part of the circuit.

Result and Performance Analysis

Using the IR LED with the circuit produced, the following heart-beat rate graphs were produced using the digital oscilloscope:





Graphs of the average of three samples taken for both the red LED and IR LED response. Each graph contains the circuit output signal

The average period recorded as the time between peek to peek and trough to trough was taken from all plotted points

$$\mu_{\text{period}} = 0.67\text{s}$$

From which the heart rate was calculated as:

$$\text{Heart Rate} = \frac{60}{\mu_{\text{period}}} = 90\text{BPM}$$

The blood oxygen level can be calculated by looking at the outputs from both the LED and IR LED when taking a sample. It can be calculated by taking the maximum and minimum values for the red and IR LED channels and then calculating the normalised absorbance ratio and blood saturation level.

Taking the average from the 3 samples for both the red and IR LED channels gave the following avaerage maximum and minimum values:

$$I_{IRL} = 1.1110$$

$$I_{IRH} = 1.6167$$

$$I_{RL} = 12.767$$

$$I_{RH} = 1.9167$$

Where I_{IRL} and I_{IRH} are the Low and High values respectively for the IR LED. I_{RL} and I_{RH} are the Low and High values respectively for the red LED.

The equation for normalised absorbance ratio (R):

$$R = \frac{ln\frac{I_{RL}}{I_{RH}}}{ln\frac{I_{IRL}}{i_{IRH}}} \approx \frac{i_{Rac}/I_{RDC}}{i_{RAC}/I_{RDC}}$$

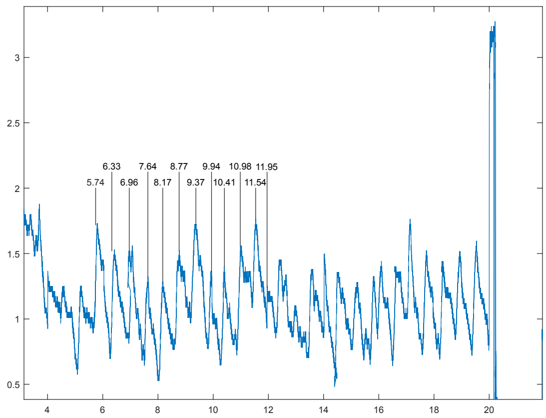
$$R = \frac{ln\frac{I_{12.767}}{I_{1.9167}}}{ln\frac{I_{1.1110}}{i_{1.6167}}} = 1.0807$$

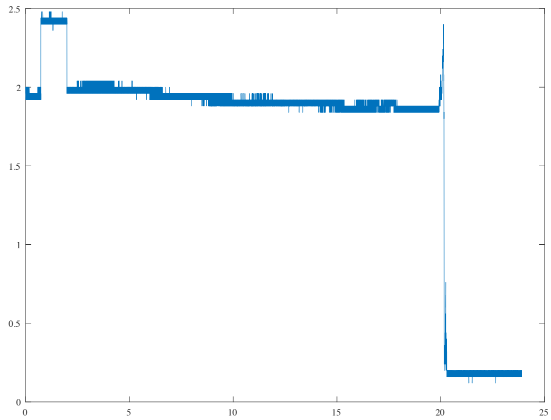
$$S_pO_2 = \frac{0.81 - 0.18R}{0.63 + 0.1R} * 100\%$$

$$S_pO_2 = \frac{0.81 - 0.18(1.0807)}{0.63 + 0.1(1.0807)} * 100\% = 82.187\%$$

LabView
Using the desk oscilloscope (Tektronix MSO 2012) and provided LabView interface for data collection a larger sample of the signals, the two graphs below were recorded and the BPM was calculated.

$$\text{Heart Rate} = \frac{60}{0.56} = 106\text{BPM}$$





The data obtained directly from LabView, the first graph is of the circuit output showing the heart beat rate. The second graph is of the corresponding output of the optical sensor circuit.

Conclusion

To conclude, the project lead to the successful creation and prototyping of a pulse oximeter. This pulse oximeter successfully was able to produce an output representing the heart beat rate of the finger, which could then be used to calculate accurate normalised absorbance ratios and the blood saturation level.
A high and low pass filter was successfully applied but the measured gain was less than what was designed for when theoretically calculated however it lied within reasonable range. Valid heart rate readings were able to be recorded using the sensor of which 90BPM and 106BPMwere found from the data. The recorded S_pO_2 value was slightly out of range from the usually range of $95 - 100\%$ however was still reliable. Overall the device was able to successfully detect the heart rate and the outcomes of the project provided significant insight into a real life applicable circuit and circuit design process.

Contribution

Liam Weichandt (SID: 500463727):
50% of project.
- Collected data measurements
- Created/designed custom 3D Printed PCB case
- Report write up
- Presentation slides

Gabriel Ralph (SID: 470205736):
50% of project.
- Custom PCB Design/ creation
- Created graphs from data
- Calculations from data