Project Report

Group 14

Yancheng Lin 510022956

Joel Lummis 500465318

Contents

Product Background

A pulse oximeter is a critical tool in healthcare, particularly for monitoring vital signs. Its primary function is to measure oxygen saturation levels in the blood, providing crucial insights into a patient's respiratory health. The device operates by emitting light through a tissue, typically a finger, and then detecting the amount of light absorbed by oxygenated and deoxygenated hemoglobin.

This project delves into the intricate design and implementation of an oximeter system, with a primary focus on achieving precision in sensor functionality. Careful installation and calibration of the sensor head are crucial to ensure stable and accurate readings. In addition to heart rate detection, the project aims to estimate blood oxygen levels using a dual-channel illumination approach. This multifaceted exploration involves electronic signal processing, amplifier and filter design.

This project report consists of five sections. We begin with a thorough circuit overview, covering the components of the pulse oximeter project. In section two, the design stage unveils the theoretical underpinnings, which include the design methods for two filters. In section three, we perform precise testing on sensor components, followed by amplifier and filter assessments. The culmination is comprehensive testing of the entire pulse oximeter system. A pivotal fourth section employs LabVIEW for data acquisition, offering insights into heart rate and oxygen levels through the Matlab. In section five, the report concludes with a candid reflection on troubleshooting, encapsulating the challenges met and conquered in this project.

1. Circuit overview

The circuit is designed to measure the oxygen saturation in a person's blood. As light absorption changes depending on if the blood is oxygenated, reading the light that passes through blood can indicate the level of oxygen within it. This is achieved through the following segments of the circuit.

Optical Sensor Integration:

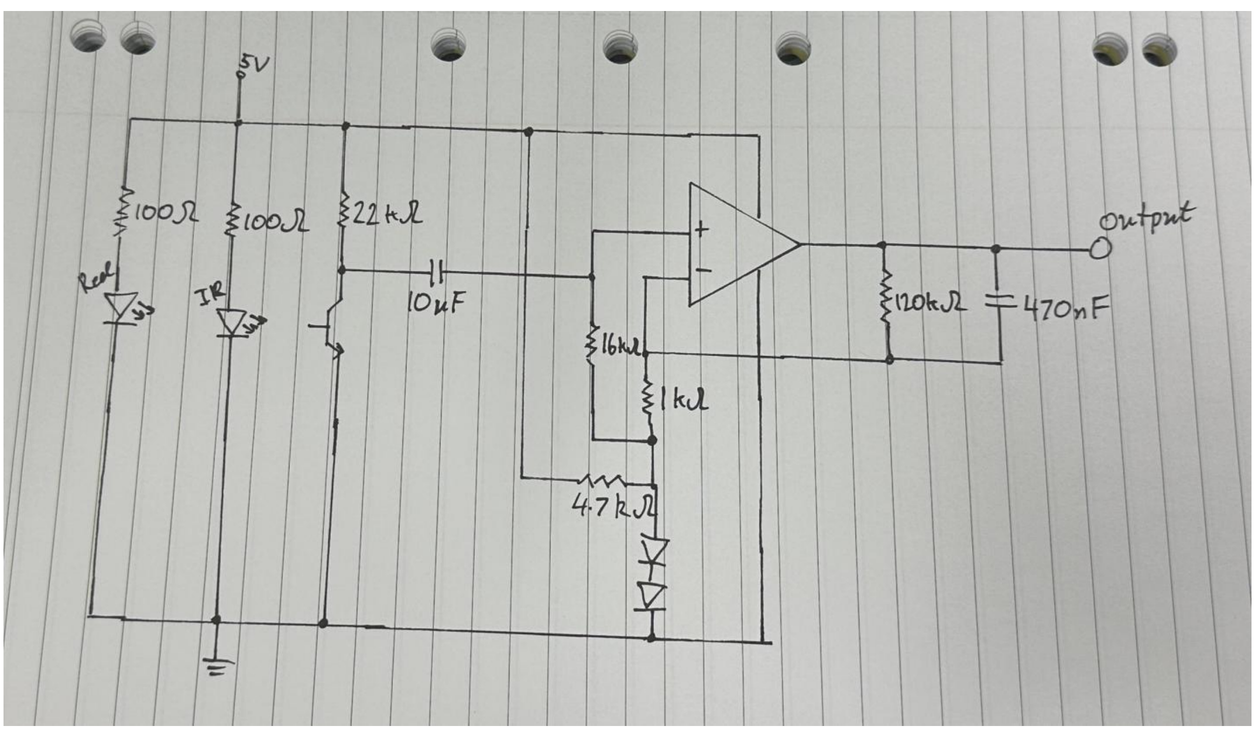
Firstly, the circuit requires a phototransistor to measure the levels of light emitted by either a red LED or IR LED after passing through blood. The sensor head houses these diodes and phototransistors.

Signal Processing and Filtering:

The signal received from the phototransistor must be cleaned of noise and limited to the relevant frequencies. A band pass filter consisting of a low pass and high pass filter is employed to isolate the desired frequency, while removing other frequencies and noise.

Amplification and Calibration:

The filtered signal is then amplified to enhance its strength and readability. This is done through operational amplifiers which provide the necessary gain to amplify only the wanted signals.



(Figure 1: a circuit overview for the Pulse Oximeter)

2. Design stage

2.1 Optical Sensor

The pulse oximeter's sensor head integrates a pair of light-emitting diodes (LEDs) and a photo-transistor. In this section, we will demonstrate data testing for this component in the pulse oximeter project. The lab document provides us one method to alternate the IR LED and red LED signals. Another possible method involves using a dedicated analog switch or relay for each LED. These switches or relays can be controlled to open or close the circuit for the specific LED, allowing the signals to be directed to a shared amplifier.

Based on datasheets, the turn on voltage and forward current for the IR LED are 1.2V and 0.02A, and 1.8 V and 0.02A for the red LED. The formula for the current is (Vdc-Von)/R. Therefore, the biasing current for IR LED is equal to (5V-1.2V)/100 ohm=0.038A. The biasing current for the red LED is equal to (5V-1.8V)/100 ohm=0.032A. Both values of biasing current are higher than 0.02A (forward current).

2.2 Amplifier

In this section, the circuit consists of two main stages, which include a high-pass filter and a low-pass filter. The high-pass and low-pass filter frequencies have been set in such a way that a band-pass filter is built to magnify the 1 Hz - 3 Hz signal. Building on the theory, where the high-pass filter has a lower cut-off frequency and the low-pass filter has a higher cut-off frequency, we can determine the resistor values for both filters. The computation procedure is presented below:

As the desired frequency lies within 1-3 Hertz, the bandpass filter must allow these frequencies through while cutting off frequencies above and below that range. As the capacitors are constant in this case, only the resistor value must be changed to determine the filter frequency. The high pass filter must allow for frequencies above 1Hz, which results in the following equation:

$$1 = \frac{1}{2\pi R_1 C_1}$$

$$R_1 = 16k\Omega$$

Similarly, the low pass filter must allow for frequencies below 3Hz which results in a resistor value show below

$$3 = \frac{1}{2\pi R_2 C_2}$$

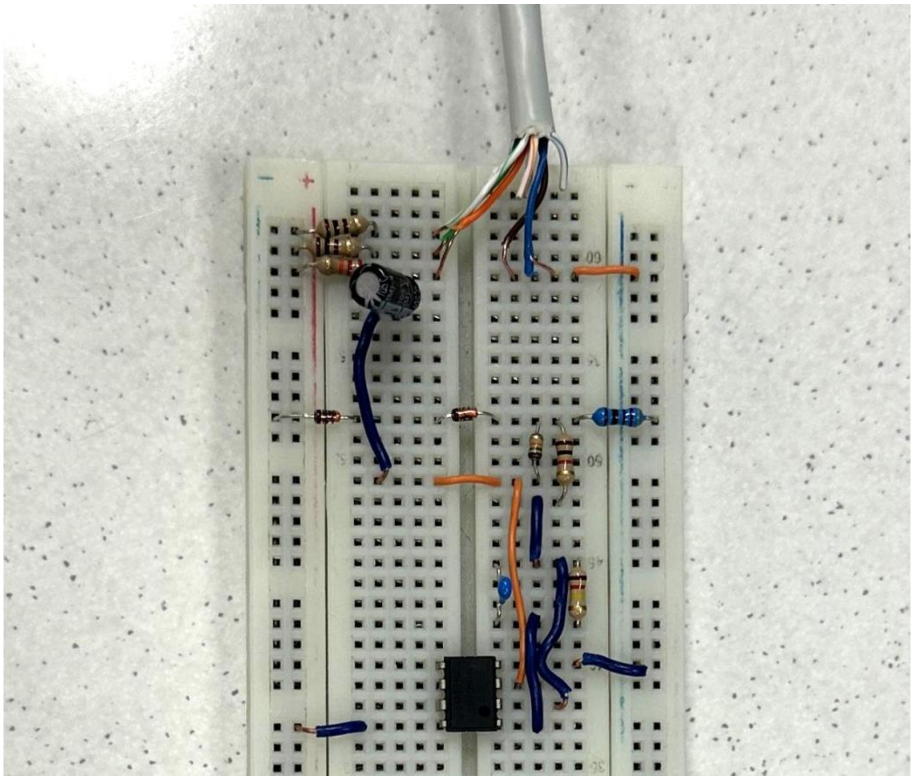
$$R_2 = 112k\Omega$$

For the resistor values in both the high pass and low pass filter, the closest available resistors are 15KΩ and 120KΩ. Now that the filters isolate only the desired frequency range, with a bandwidth of 2Hz, the signal must be amplified. The gain of this amplification takes the form of the following equation

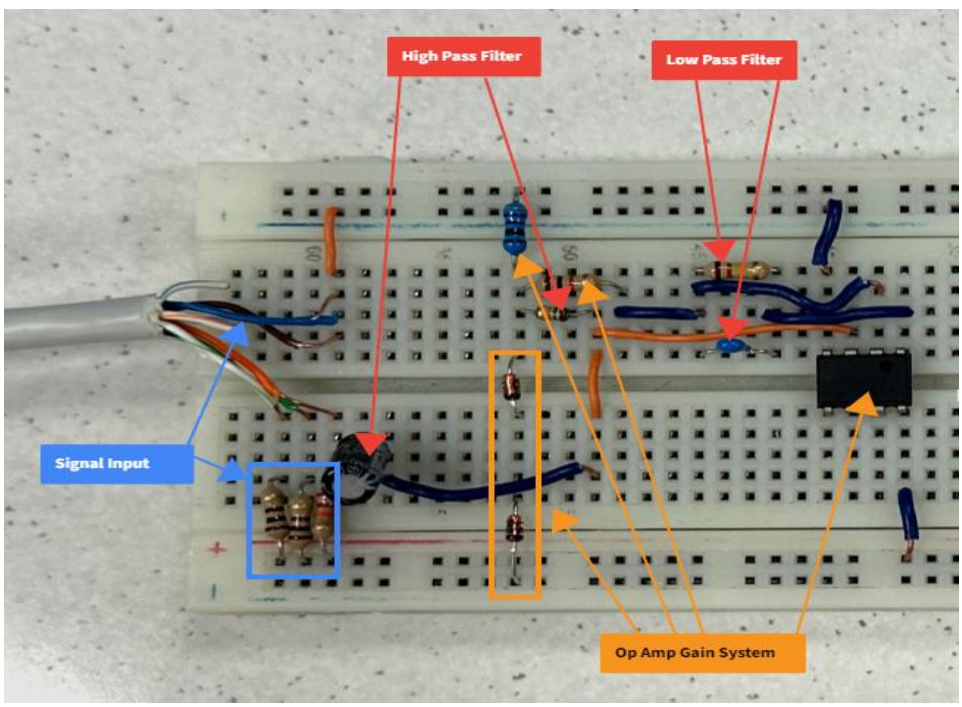
$$V_{Gain} = 1 + \frac{R_2}{R3}$$

$$V_{Gain} = 113$$

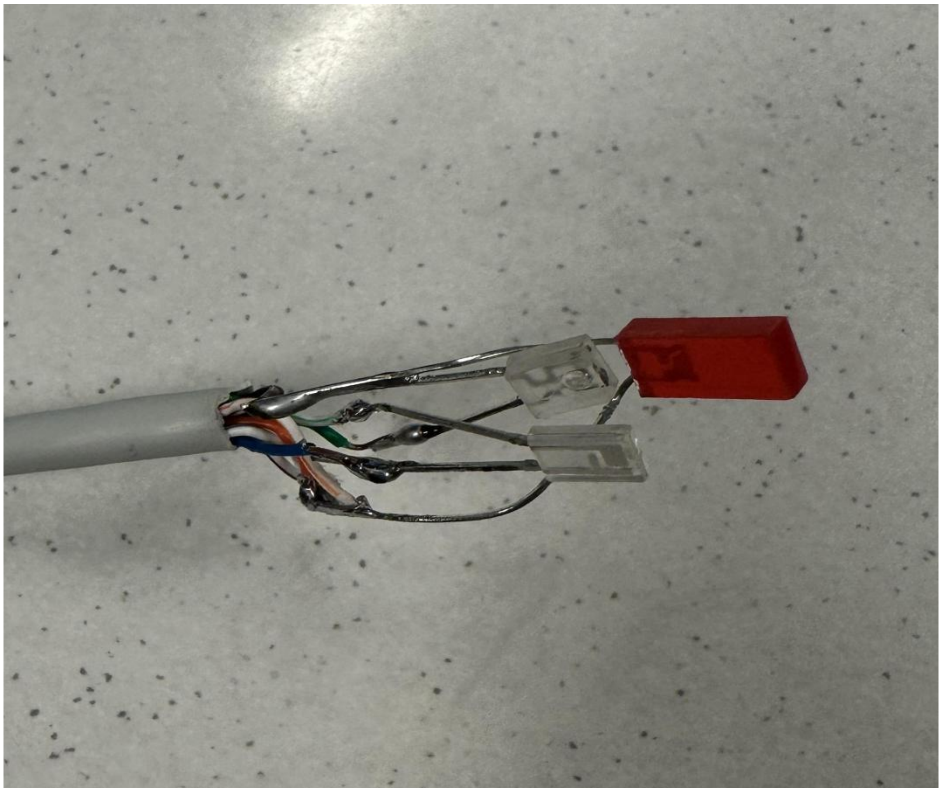
After the signal has been amplified, it now can be plotted on an oscilloscope and read to establish the blood oxygen levels. The completed prototype circuit can be seen in the following figures.



(Figure 2a: Prototype Filter and Amplifier)



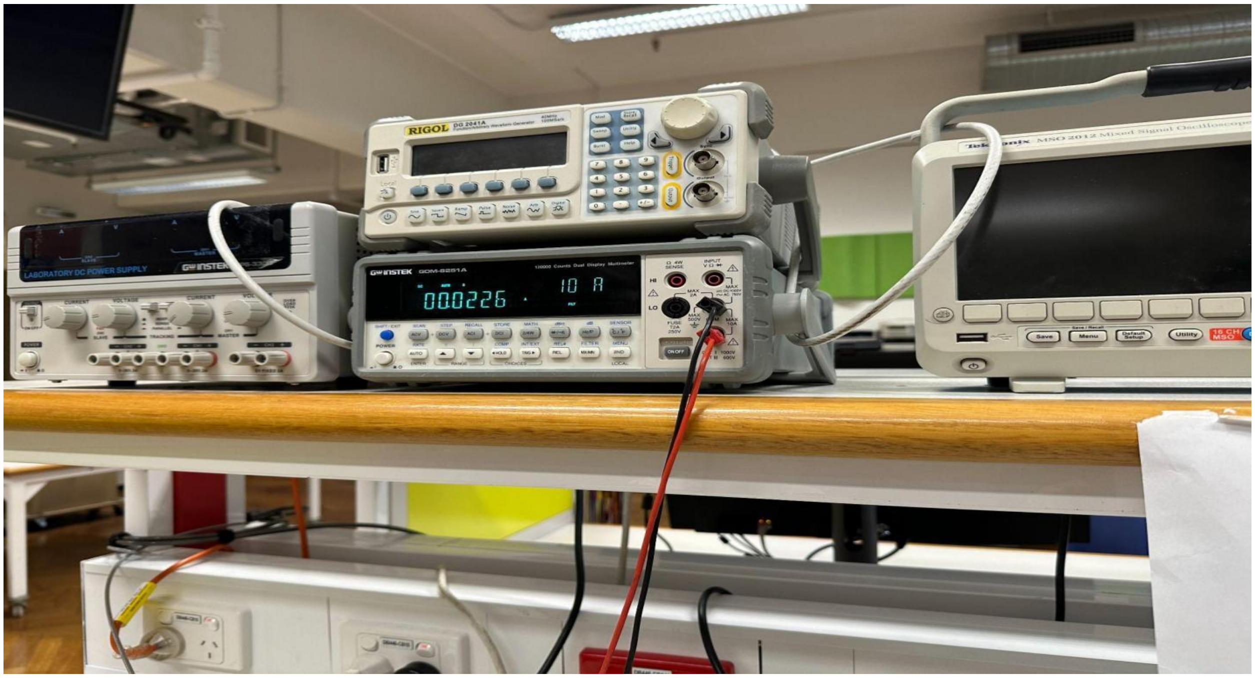
(Figure 2b: Annotated Prototype Filter and Amplifier)



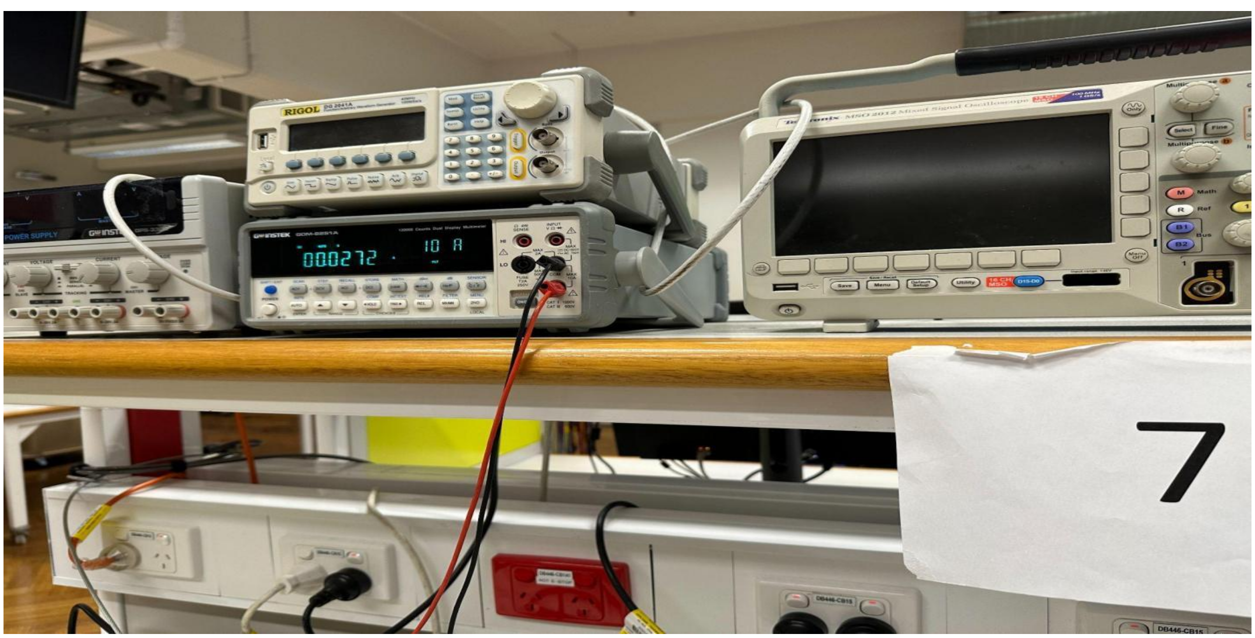
(Figure 2c: Prototype Optical Sensor Head)

3 Data Testing

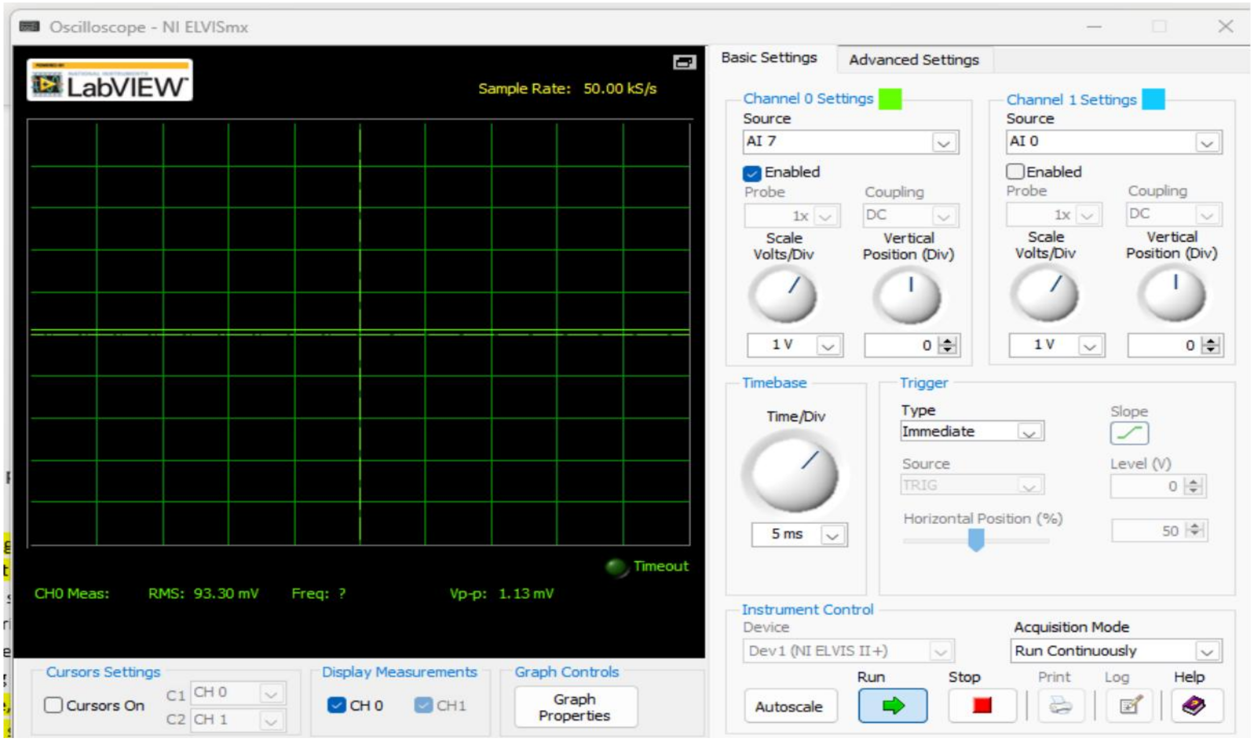
3-1. Sensor part testing



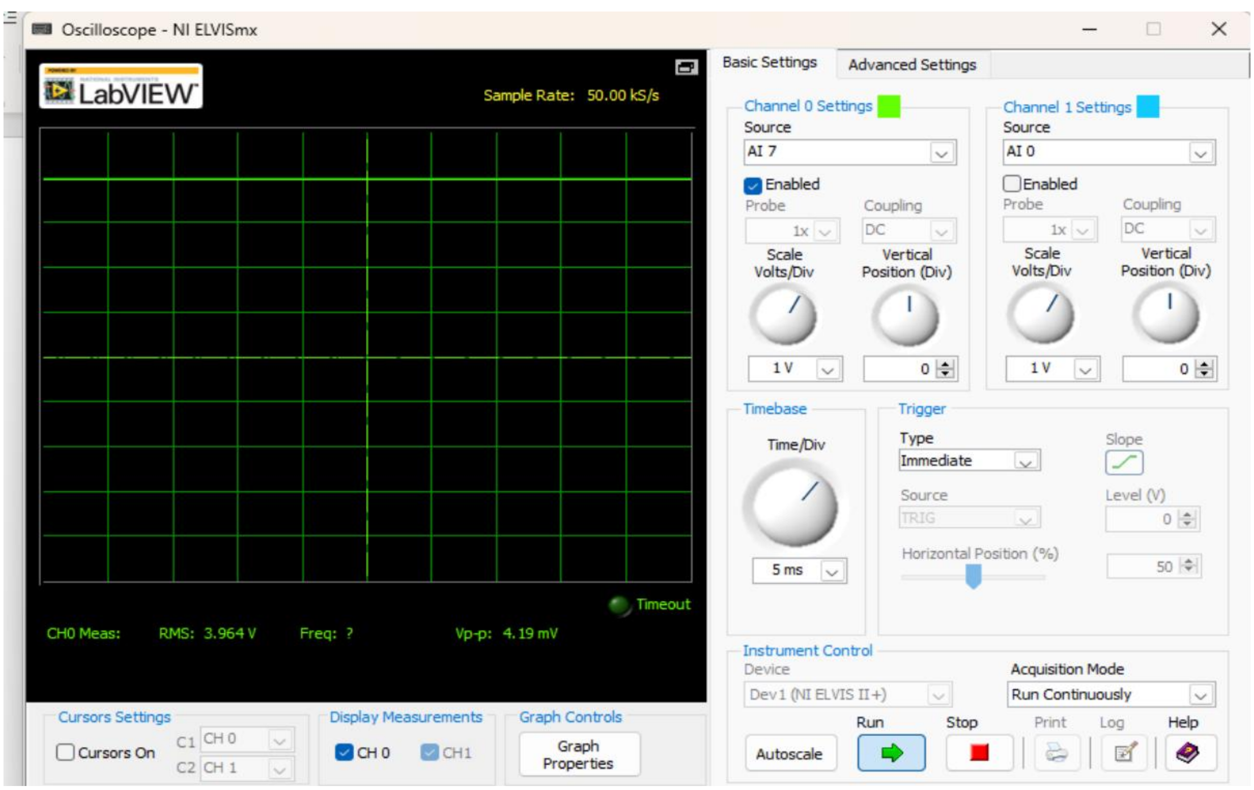
(Figure 3a: Current through the red LED measured by the multimeter)



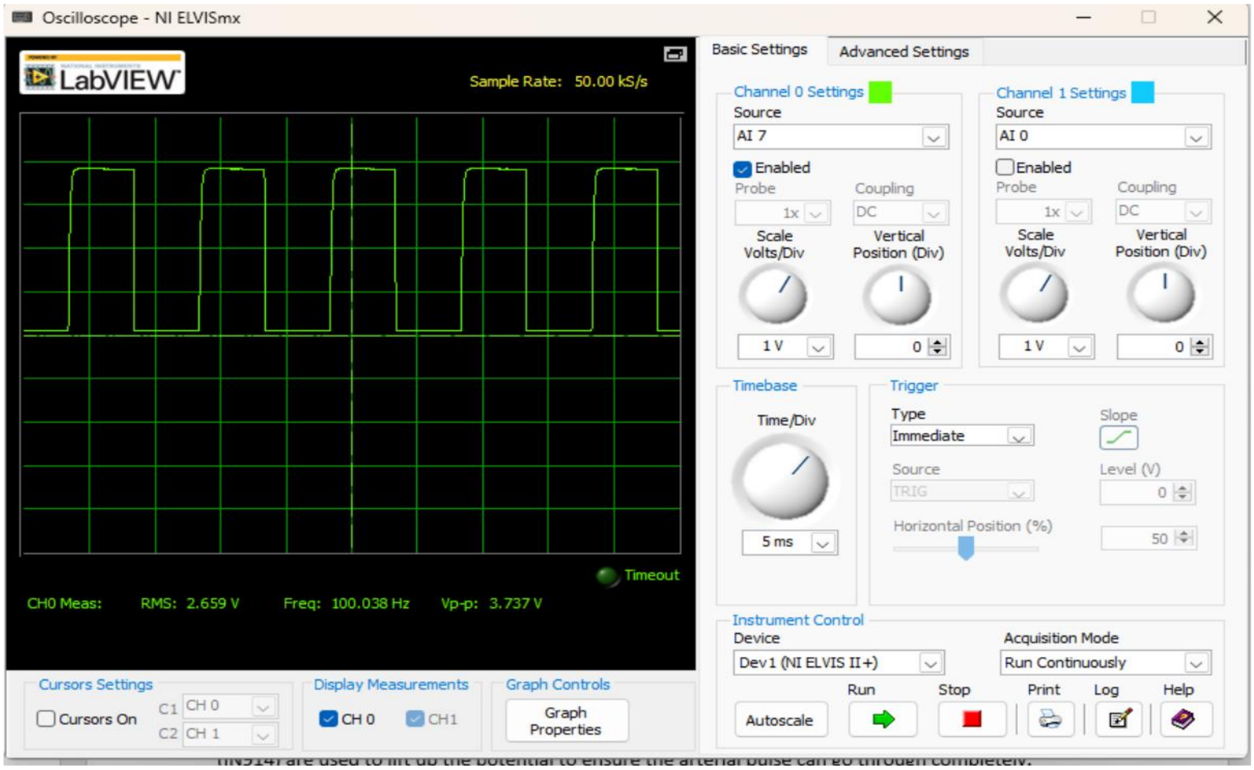
(Figure 3b: Current through the IR LED measured by the multimeter)



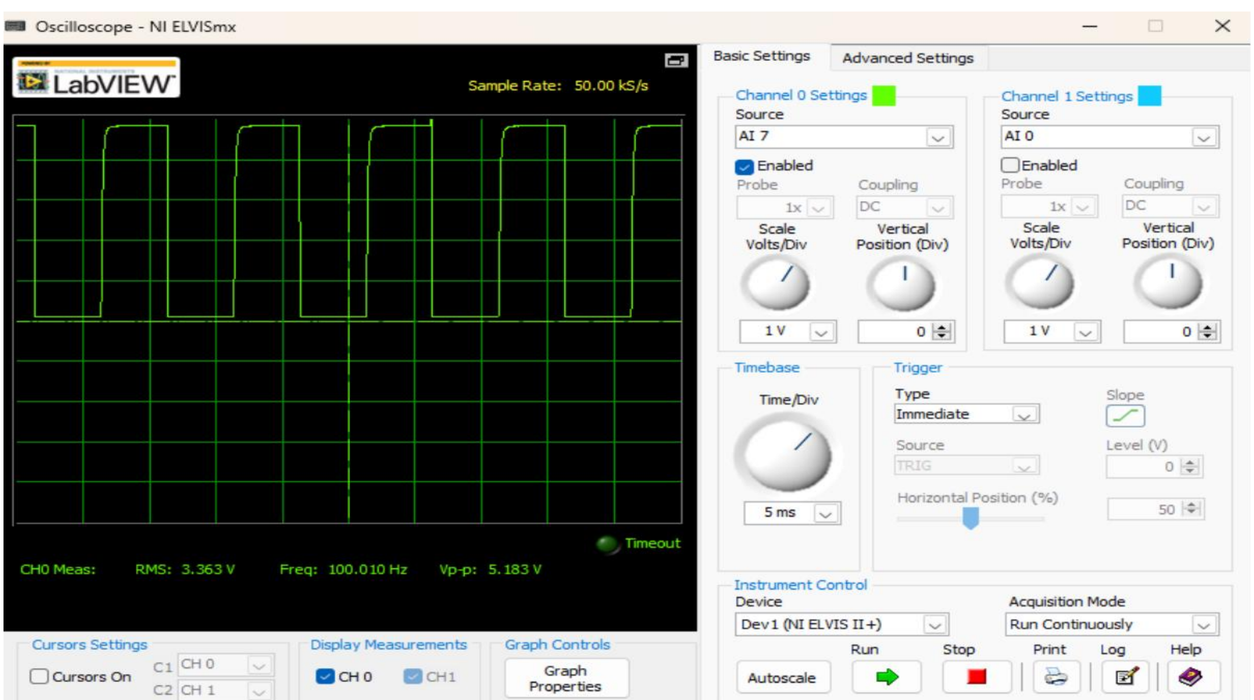
(Figure 3c: Voltage (Vout) at the collector of the photo transistor when LED on)



(Figure 3d: Voltage (Vout) at the collector of the photo transistor when LED off)



(Figure 3e: Voltage (Vout) at the collector of the photo transistor using function generator)



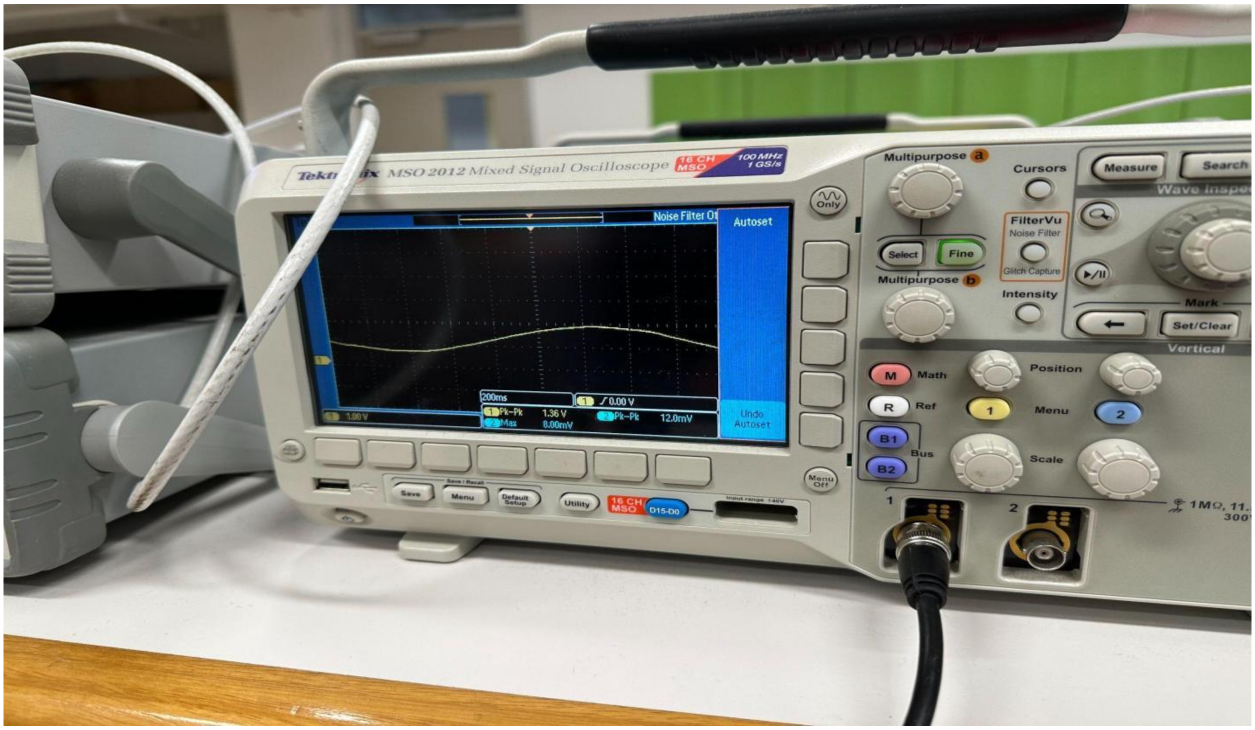
(Figure 3f: Voltage using function generator when cover the light by hand)

As shown in the figures 3a and 3b above, real currents through red LED and IR LRD are 0.0226A and 0.0272A respectively, which are less than calculated values. One possible reason is that there is an internal resistor in our lab device. Therefore, the DC voltage is less than 5V and real currents are less than calculated currents.

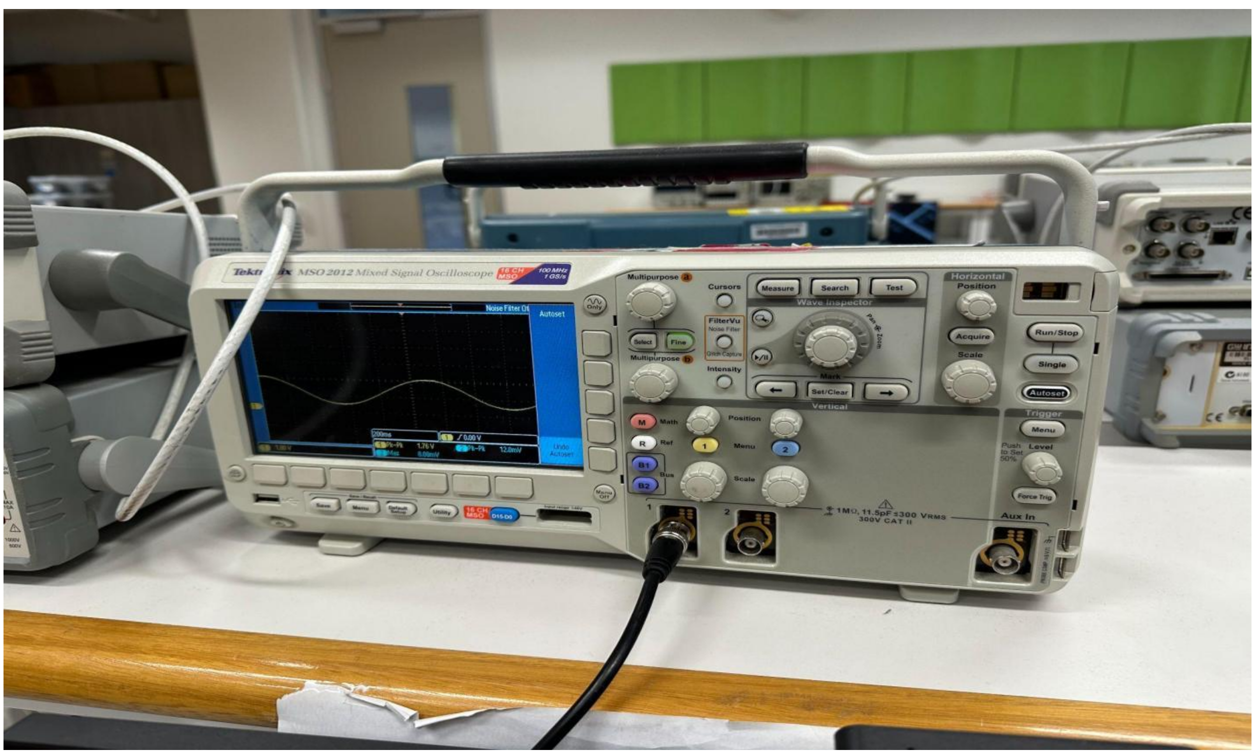
As shown in figures 3c and 3d above, voltage (Vout) at the collector of the photo transistor is near to 0V (93.3mV) when LEDs are on. When LEDs are off, the Vout (in RMS) is near 3.964V. After that, we used a signal from the function generator to power on LEDs in order to test the circuit more clearly. We set up a square wave from FG as 5Vpp with 2.5DC offset. Adding a DC offset to the square wave ensures that the photo-transistor is biased properly. This offset ensures that the photo-transistor operates within its linear region, allowing for a more accurate and controlled response to the modulated light signals. As shown in the figure 3e above, the Vpp is near to 3.737V when LEDS are off. When covering the light by hand, the Vpp has a significant increase (from 3.737 Vto 5.183 V) as shown in the figure 3f.

In general, it seems that our circuit for the optical sensor is consistent with the theory. When LEDs are off, the photo-transistor registers a higher voltage. When on, the Vpp decreases, reflecting light absorption by arterial pulsations. Covering the sensor reduces ambient light interference, enhancing signal accuracy. This ensures a focused response to modulated light signals, improving reliability.

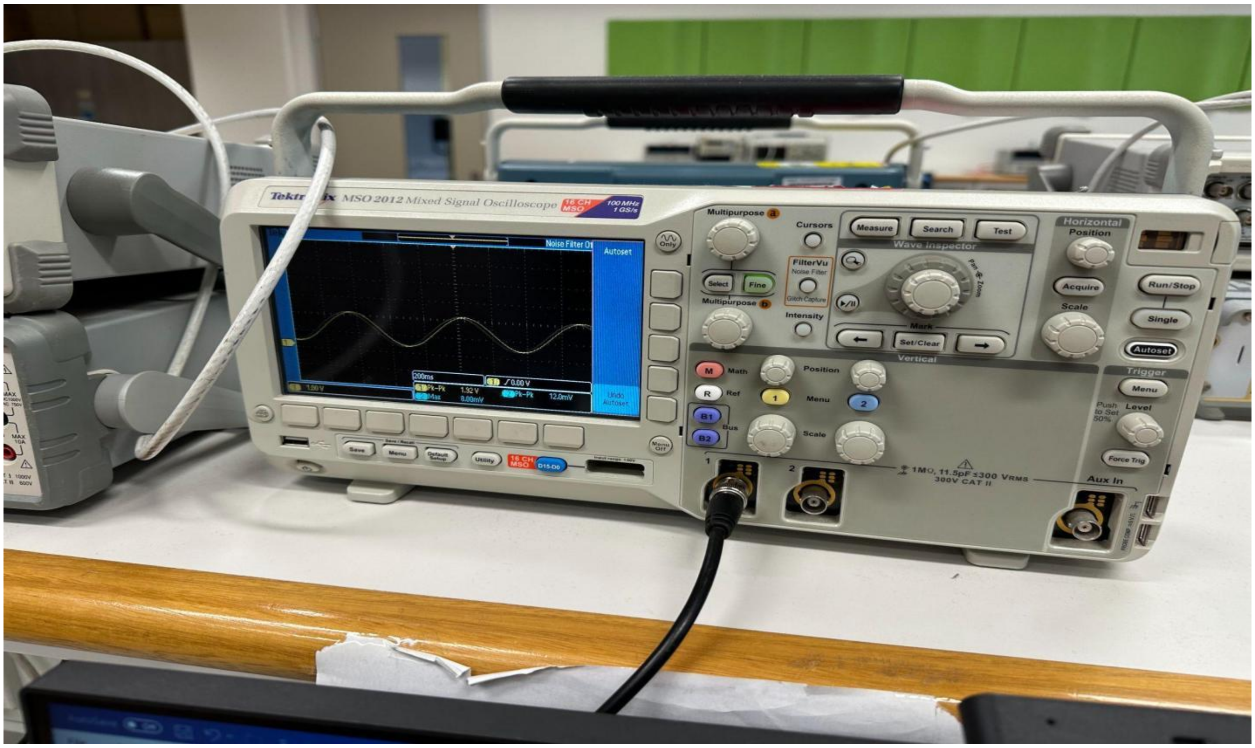
3-2. Amplifier/filter part testing



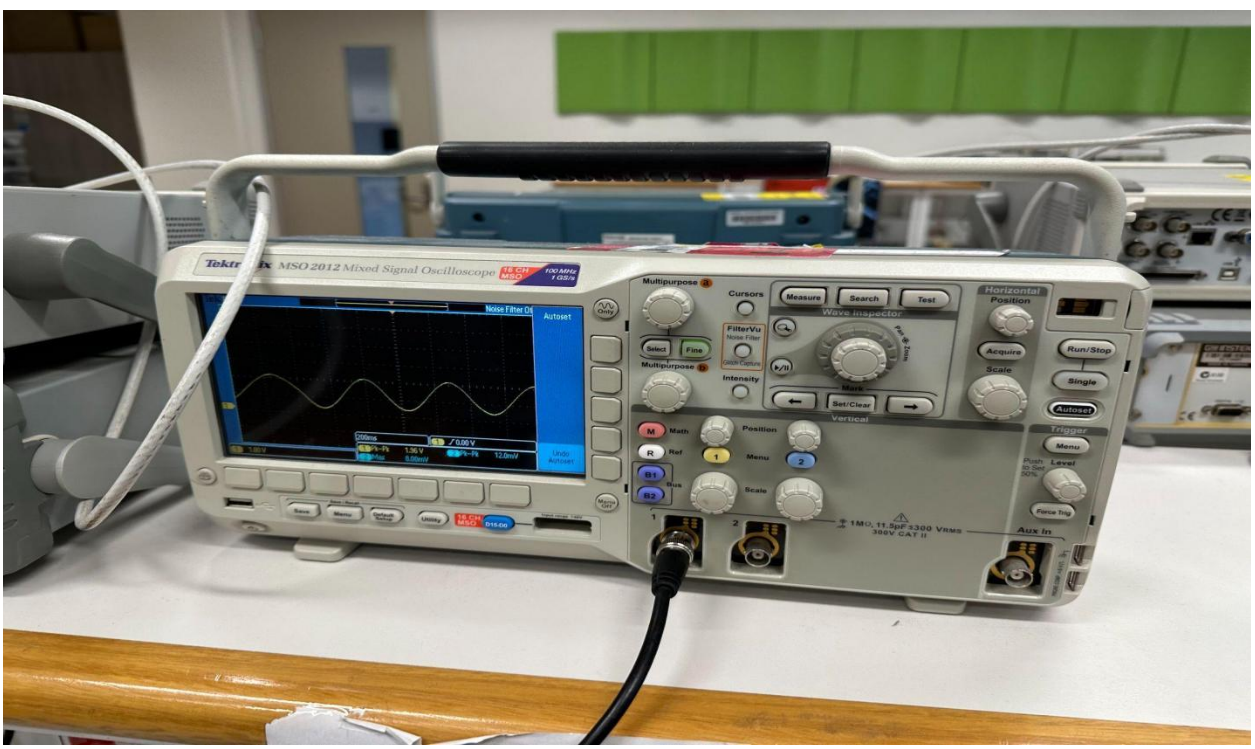
(Figure 4a: Vout when frequency=0.5Hz for the first stage of RC and op-amp circuit)



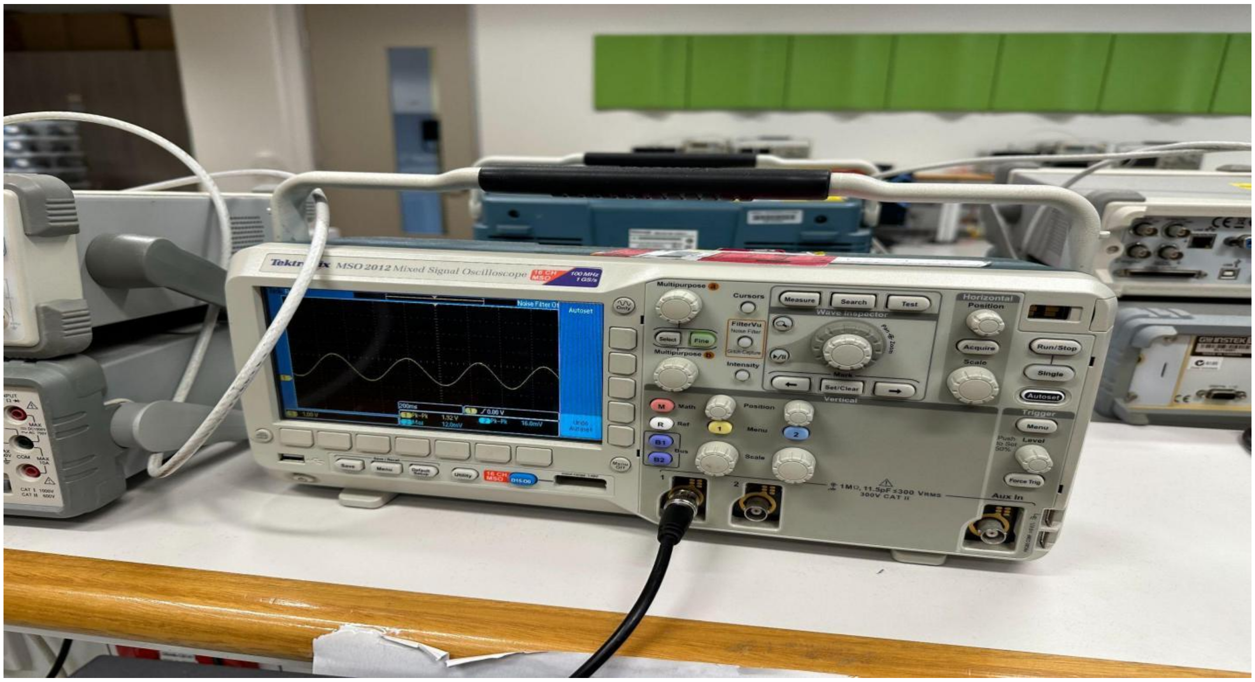
(Figure 4b: Vout when frequency=1Hz for the first stage of RC and op-amp circuit)



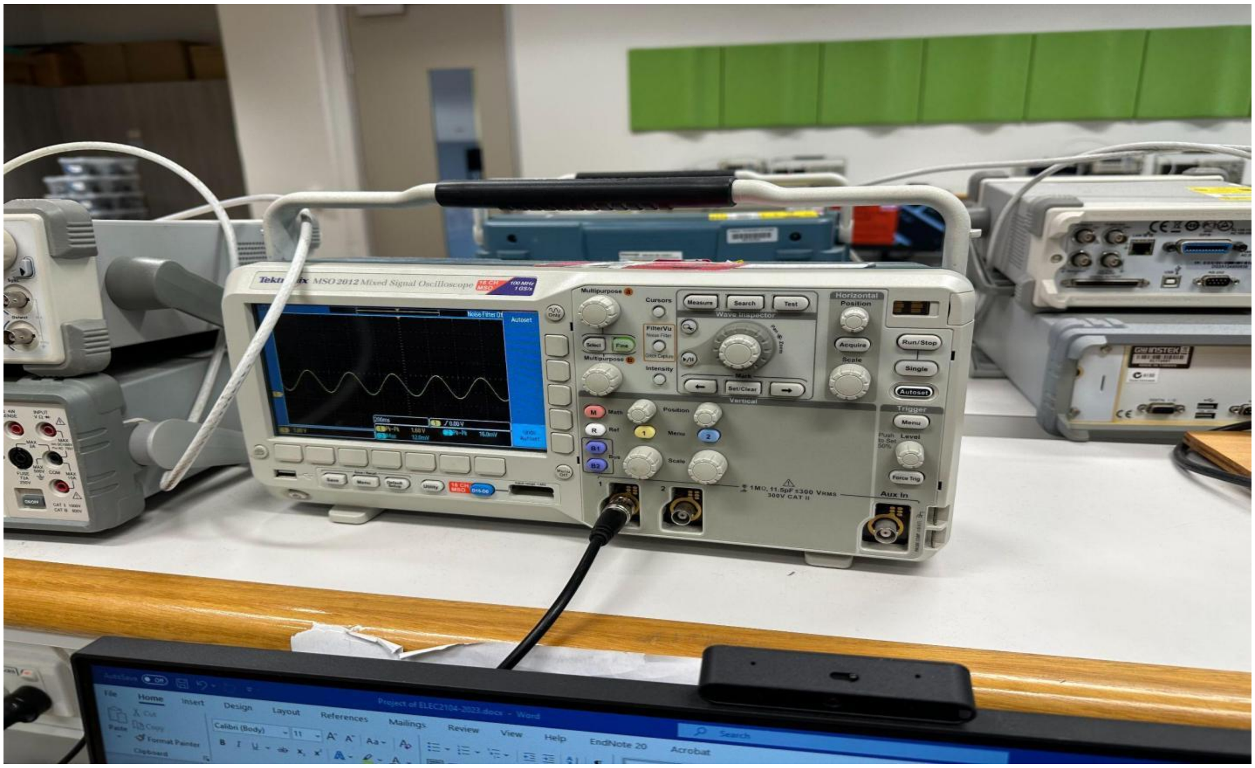
(Figure 4c: Vout when frequency=1.5Hz for the first stage of RC and op-amp circuit)



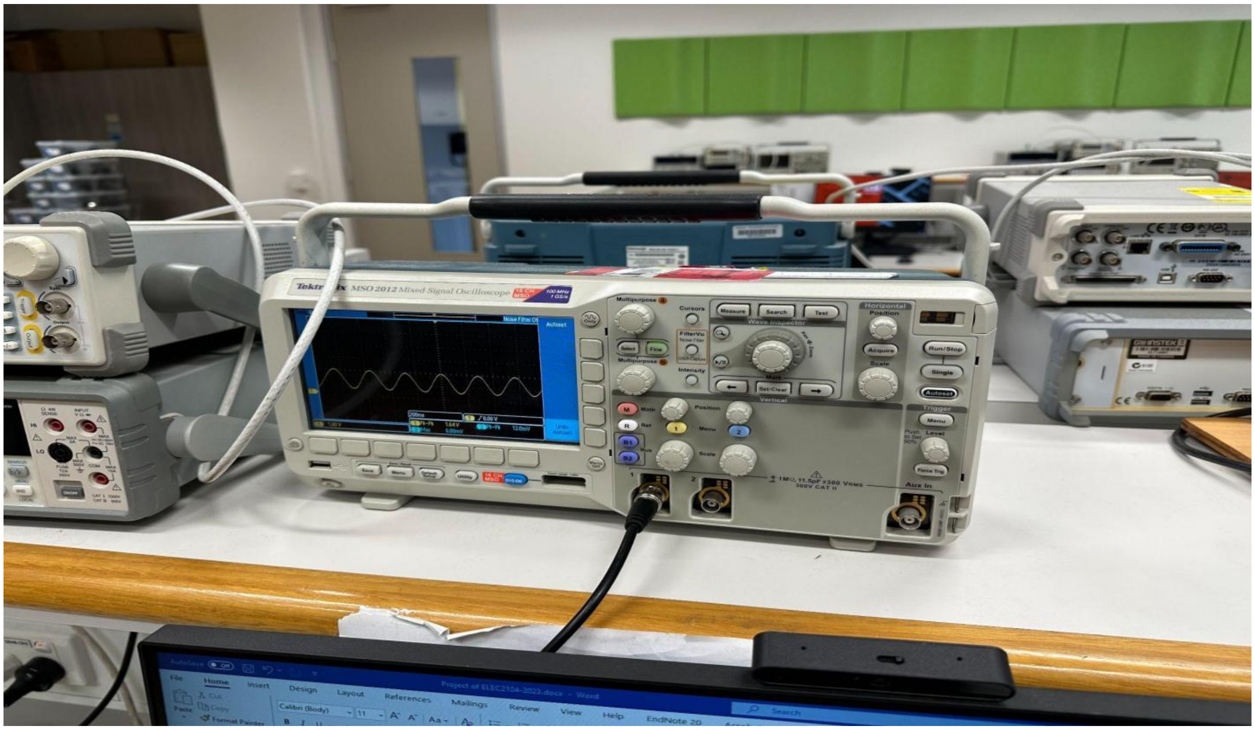
(Figure 4d: Vout when frequency=2Hz for the first stage of RC and op-amp circuit)



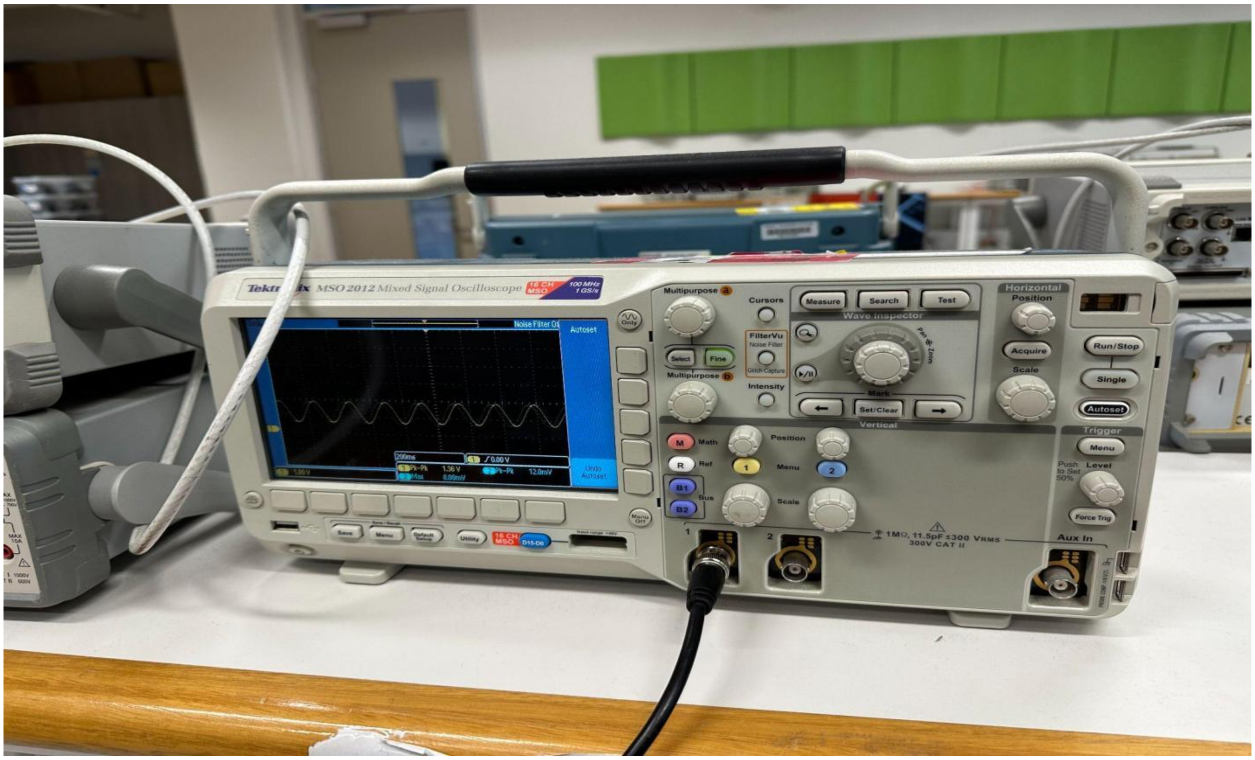
(Figure 4e: Vout when frequency=2.5Hz for the first stage of RC and op-amp circuit)



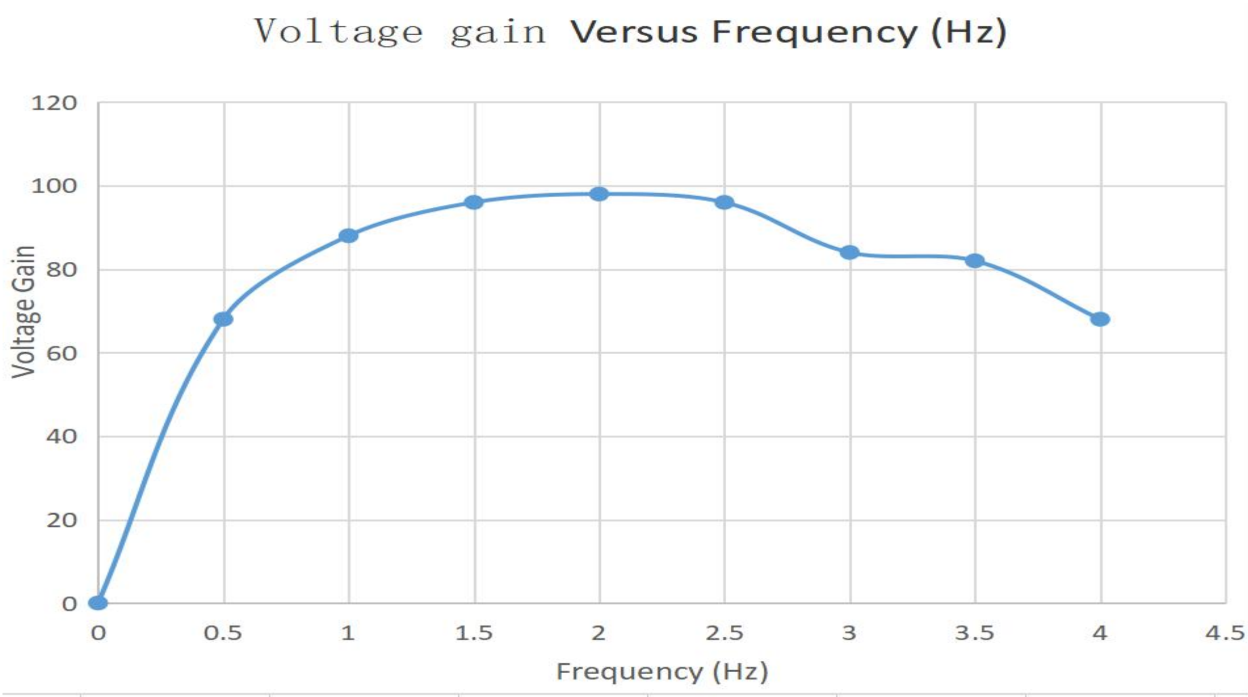
(Figure 4f: Vout when frequency=3Hz for the first stage of RC and op-amp circuit)



(Figure 4g: Vout when frequency=3.5Hz for the first stage of RC and op-amp circuit)



(Figure 4h: Vout when frequency=4Hz for the first stage of RC and op-amp circuit)



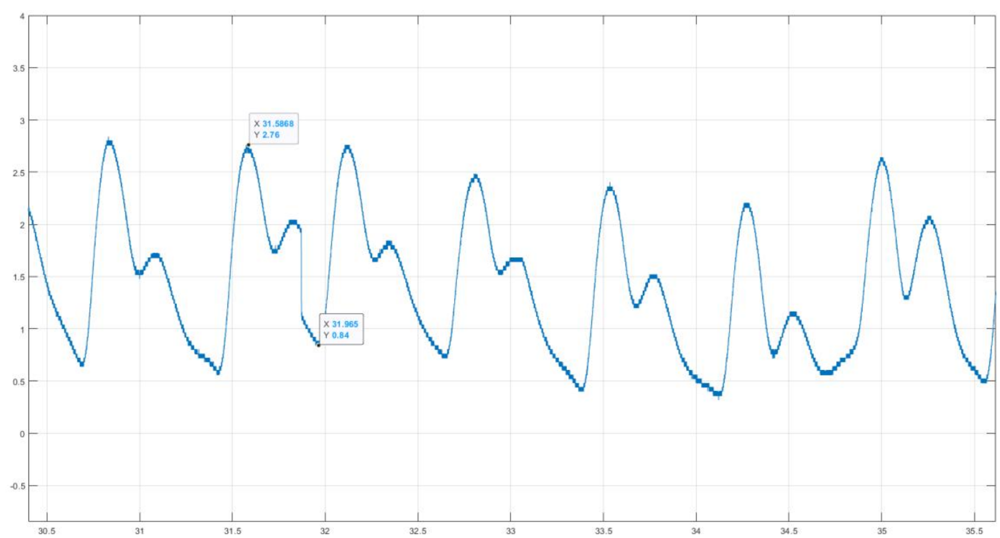
(Figure 4i: Voltage gain versus frequency for the first stage circuit)

As shown in figures above (from figure 4a to figure 4h), we tested the Vout values in different frequencies (from 0.5Hz to 4Hz). In this part, we used the function generator to represent Vin, which is a constant (0.02V). For enhanced clarity and intuitive comprehension, an Excel-generated scatter plot (figure 4i) was employed to visually depict the relationship between voltage gain and frequency in our circuit analysis. At the resonant frequency of 2 Hz, the circuit achieves its maximum voltage gain (Vout/Vin), reaching 98 as determined by the ratio of 1.96V to 0.02V. However, at frequencies of 0.5 Hz and 4 Hz, the voltage drops to 68, constituting a decrease to 70% of the maximum value at 2 Hz. Therefore, the bandwidth in our circuit is from 0.5Hz to 4Hz.

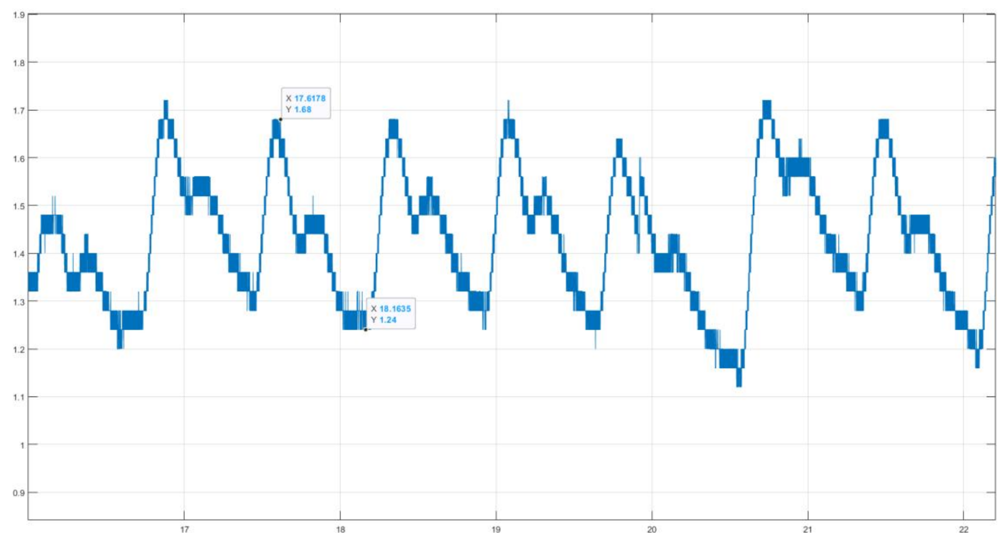
The theoretical voltage gain, calculated as 113, corresponds reasonably with the observed maximum voltage gain of 98 at the resonant frequency of 2 Hz during experimental testing. The bandwidth, calculated from 1Hz to 3Hz theoretically and determined between 0.5Hz and 4Hz experimentally, shows a slight discrepancy. One possible reason is that there was a slight difference between the values of selected resistors and that calculated resistor values.

In conclusion, our circuit demonstrates a frequency response that accommodates a range from 0.5 to 4 Hz. With the highest voltage gain achieved at 2 Hz and a notable decrease to 70% at both 0.5 Hz and 4 Hz, the circuit exhibits its ability to effectively process signals within this specified frequency band. While there are minor variations between the theoretical calculations and experimental results, the overall alignment suggests a successful implementation of the band-pass filter with the chosen resistor values.

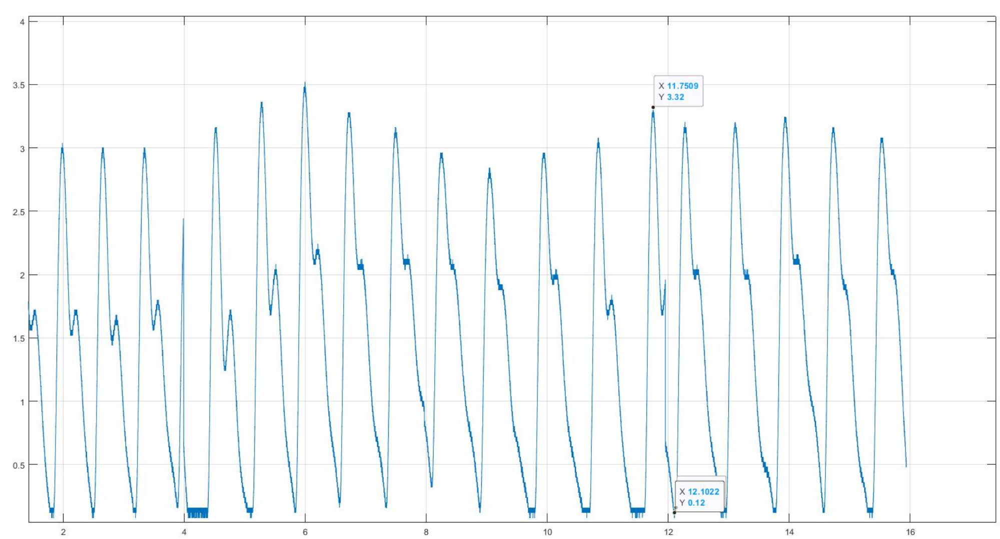
4. Final result and performance analysis



(Figure 5a: light intensity collected from IR LED)



(Figure 5b:light intensity collected from red LED)



(Figure 5c: combined both red and IR LED)

As shown in figures (5a, 5b and 5c) above, we collected data from the labview and used the Matlab to visualize them from IR LED, red LED and both of them. The x-axis represents time and the y-axis represents the intensity of light that is either transmitted through the skin. The waveform between two consecutive peaks represents one heartbeat. The light intensity collected from the IR LED ranges from 0.84 to 2.76, for the red LED it varies between 1.24 and 1.68, and when both LEDs are combined, the intensity spans from 0.12 to 3.32. After that, we further calculated the ratio of normalized absorbance (R) and oxygen saturation level (SpO2) as shown below:

$$R = \frac{\ln\left(\frac{I_{red,min}}{I_{red,max}}\right)}{\ln\left(\frac{I_{IR,min}}{I_{IR,max}}\right)} = \frac{\ln\left(\frac{1.24}{1.68}\right)}{\ln\left(\frac{0.84}{2.76}\right)} = 0.255$$

$$S_P O_2 = \frac{0.81 - 0.1R}{0.63 + 0.11R} * 100\% = \frac{0.81 - 0.18(0.255)}{0.63 + 0.11(0.255)} * 100\% = 116\%$$

However, a healthy adult's blood oxygen saturation level is generally 95%-100%. Compared to our measurement, there are minor discrepancies, but they fall within the project's acceptable tolerance range. There are some possible reasons which may cause this situation. Firstly, skin pigmentation plays a significant role. The melanin content in the skin impacts the absorption and reflection of light. Therefore, it's essential to maintain consistency, such as testing using the same finger. However, we didn’t test the data using the same finger during the lab so it may be possible to modify our operations in the future. Additionally, ambient light, particularly in lab settings, can interfere with measurements. Thus, it's crucial to ensure a controlled environment for reliable results. Finally, inherent instrument noise and system limitations, especially within the LabVIEW system, might introduce minor variations to the readings.

In summary, our findings align with the project's specifications. Although the calculated SpO2 value of 116% surpasses the standard range for healthy adults, multiple elements, including skin pigmentation, external light disruptions, and built-in system inaccuracies, can impact these values. Despite these variations, our observations remain within the acceptable thresholds set for our project.

5. Troubleshooting

In this section, we will discuss several challenges we met during labs and possible methods we used to overcome them. Initially, incorrect resistor values were used, leading to inaccurate gains when tested with the oscilloscope. The issue was then identified and the incorrect resistor replaced with the appropriate ones, ensuring accurate calculations and measurements. Additionally, the final waveform generated by the device was providing unreliable data. It was discovered that the cover over the sensor was insufficient to block out external light, causing interference and inconsistent readings. To address this problem, we improved the design of the cover by making the casing thicker, ensuring it effectively blocked ambient light, leading to more reliable and accurate measurements.

Conclusion

In conclusion, the pulse oximeter performed successfully, utilizing optical sensors, filters and amplification to generate waveforms consistent with theory.The final system built through the aforementioned circuit design, sensor testing / filtering, and data acquisition, demonstrated accurate measurements of oxygen saturation levels in the blood, despite minor discrepancies attributable to factors like skin pigmentation and ambient light. Overall, the system is effective at measuring a person's vital signs along with the oxygen levels within a person's blood.

Contribution

Joel: 50 Percent

Yancheng: 50 Percent