Final Report for EN2019
EMG Based Muscle Strain Detector

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1 Introduction

Our EEG-based Muscle Signal Detector is an innovative device designed to capture and analyze EMG signals to monitor muscle activity effectively. By accurately detecting electrical signals generated by muscle contractions, the system amplifies and filters the signals to ensure precision. The processed data is then used to determine the user's muscle strain level, which is displayed as high, medium, or low thresholds. This device provides an efficient and reliable solution for muscle strain monitoring, making it ideal for applications in rehabilitation, sports science, and biomedical research.

2 Functionality Description

The device captures muscle signals using **three electrodes** placed on the skin. The weak EMG signals are amplified through an **instrumentation amplifier** for precision and noise reduction. The amplified signals are then filtered using **two Sallen-Key low-pass filters** to remove unwanted noise and isolate the relevant frequency range.

The filtered signal is fed into a **comparator**, which determines the muscle strain level by comparing the signal to predefined thresholds. The output strain levels—**low, medium, or high**—are displayed through **LED indicators** connected to the comparator, providing a clear and immediate visual representation of muscle activity. This streamlined process ensures accurate and real-time monitoring of muscle strain.

3 System Model

3.1 Block Diagram

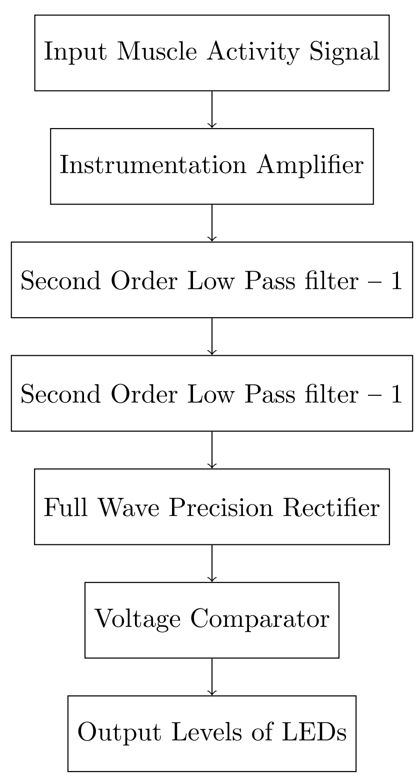


Figure 1: Block Diagram of the Device

3.2 Detailed Description of Each Block

3.2.1 Instrumentation Amplifier

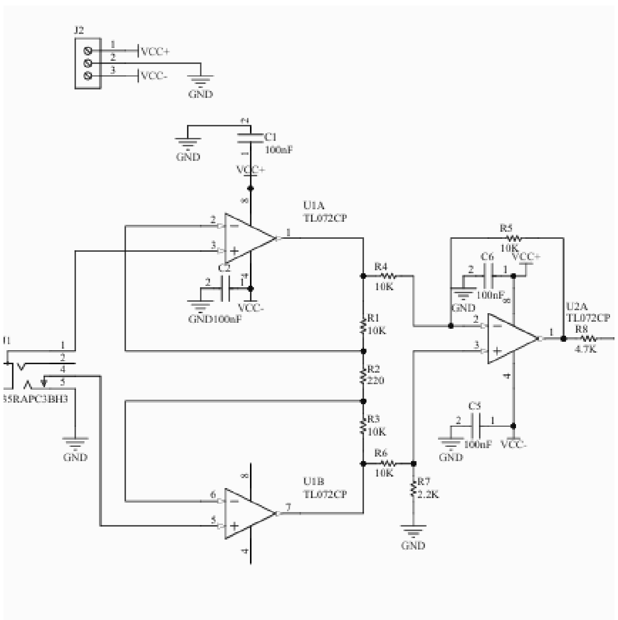


Figure: Instrumentation Amplifier Circuit Diagram. The instrumentation amplifier is a crucial component in EMG signal acquisition because it amplifies the small electrical signals generated by muscle activity while rejecting noise, especially common-mode noise from the environment. Its key features include high input impedance, low offset, and high Common-Mode Rejection Ratio (CMRR), which are essential for capturing weak EMG signals without distortion.

Electrode Types: Surface electrodes are commonly used for non-invasive EMG. They are silver/silver chloride (Ag/AgCl) electrodes for better conductivity and signal quality.

Placement: Active Electrodes: Placed over the muscle being monitored.

Reference Electrode: Positioned on a bony or electrically neutral area (e.g., elbow or wrist).

Connection: Electrodes connect to the input terminals of the instrumentation amplifier via shielded cables to minimize electromagnetic interference. Proper skin preparation (cleaning and shaving) ensures good electrode contact and reduces impedance.

The overall gain of the instrumentation amplifier in our final product was 201 (Little bit deviated from the schematic). Which gave a final gain of overall 800 to the device. The instrumentation amplifier gives the signals a very high input impedence and is having a high common mode rejection ratio.

3.2.2 Second Order Low Pass Filter

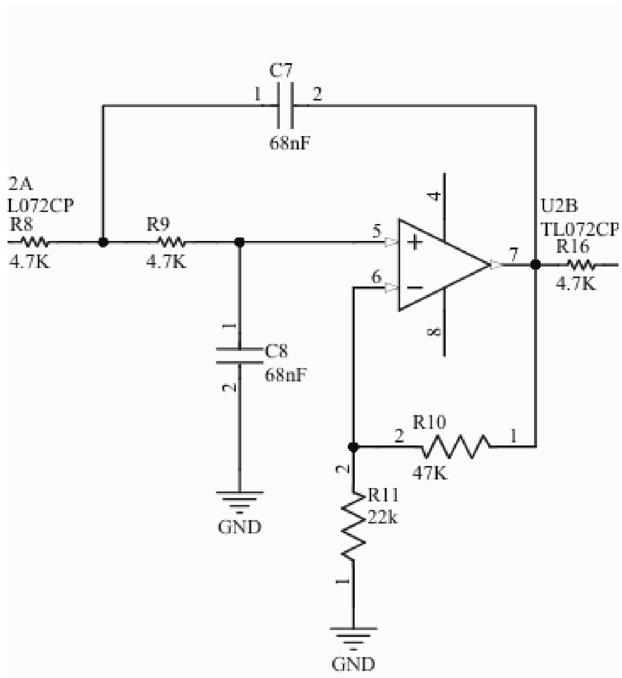


Figure: Second Order Low Pass Filter. An active second-order low-pass filter is commonly used in EMG (Electromyography) signal processing to attenuate high-frequency noise while preserving the relevant low-frequency muscle signals. With a cutoff frequency of 482 Hz, this filter is designed to pass signals with frequencies below 482 Hz and attenuate frequencies above this threshold.This is the frequency at which the filter starts to attenuate the signal. Below 482 Hz, the signal passes through with minimal loss, while above 482 Hz, the signal is increasingly attenuated. This is important for EMG because muscle signals are typically in the range of 10-500 Hz, and higher frequencies (due to noise or electrical interference) need to be filtered out to get a cleaner signal. In our design will be using 2 such filters to obtain a net order of 4. In this configuration, the overall gain of the filter is often set to 2, meaning that the filter not only attenuates high-frequency noise but also amplifies the signal by a factor of 2 within the passband. This gain is determined by the ratio of resistances in the filter circuit, and it ensures that the desired low-frequency components of the EMG signal are preserved and amplified while high-frequency noise is attenuated. The gain of 2 is particularly useful in applications where the EMG signal may be weak or require additional amplification for further processing or display, without causing distortion or excessive amplification that could affect signal accuracy. This combination of signal preservation and amplification makes the second-order low-pass filter ideal for ensuring a clean, usable EMG signal in medical and diagnostic applications.

3.2.3 Full Wave Precision Rectifier

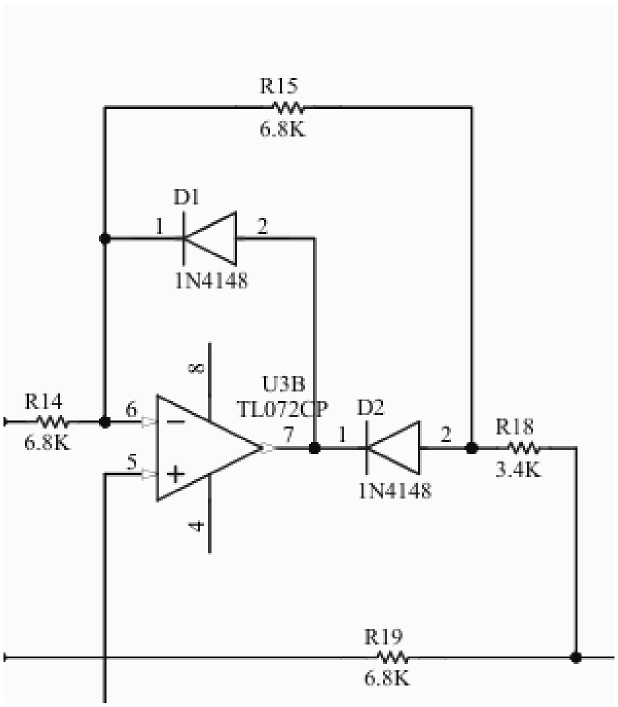


Figure: Second Order Low Pass Filter. essential component in EMG (Electromyography) signal processing because it helps convert both the positive and negative portions of the signal into a unidirectional waveform. This is particularly useful in extracting the envelope of the EMG signal, which is crucial for muscle activity analysis. Accurate Signal Rectification: Unlike a simple diode rectifier, a full-wave precision rectifier uses operational amplifiers (op-amps) to rectify the signal without significant distortion. It allows both the positive and negative portions of the EMG signal to be converted into a positive voltage, preserving the integrity of the waveform.

Improved Signal Quality: The precision rectifier minimizes the voltage drop and the non-linearity typically introduced by regular diodes, ensuring the rectified signal is as faithful as possible to the original EMG signal. This is critical for accurate muscle activity measurement.

Envelope Detection: In EMG applications, the rectified signal often needs to be further processed to extract the envelope, which is used to analyze muscle contraction levels. The full-wave rectifier provides a smooth, continuous waveform, which can then be easily passed through a low-pass filter to obtain the envelope.

Increased Sensitivity and Precision: The use of a precision rectifier allows for better detection of small amplitude signals and fine details in the EMG, especially when detecting subtle muscle activity that might otherwise be obscured by noise or low signal levels.

Enhanced Performance at Low Voltages: Since precision rectifiers operate without large voltage drops (as compared to traditional diodes), they perform effectively even at low signal levels, which is common in EMG applications where the signals are often weak.

3.2.4 Level Detector - Voltage Comparator

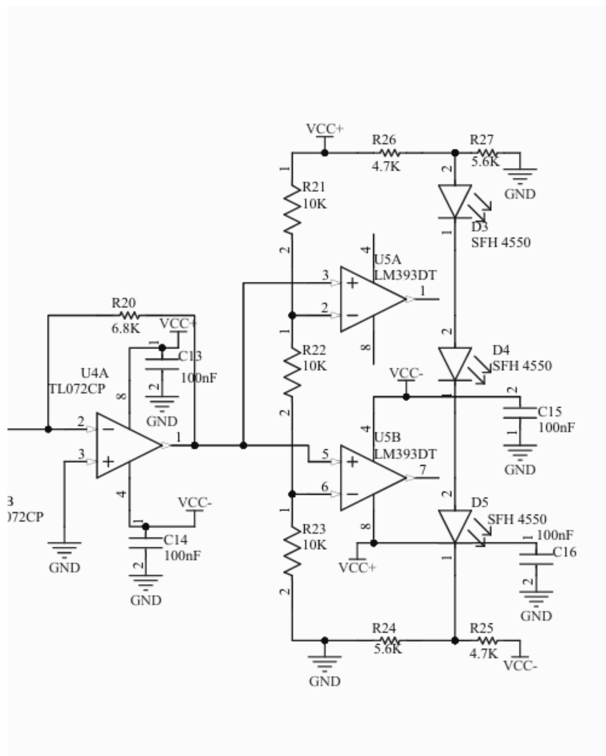


Figure: Level Detector

A three-level voltage comparator circuit compares an input signal to three reference voltages and outputs one of three distinct states based on which reference level the input signal falls into. The circuit typically uses operational amplifiers (op-amps) configured as comparators. In this setup, the op-amps are connected to the input signal and the three reference voltages, with each reference voltage corresponding to a different output state. When the input signal is compared to these levels, the output will change depending on whether the input is higher or lower than the reference voltages. The comparator will provide one of three output voltages: low, medium, or high. This output can be used for further processing, such as triggering actions in a control system or providing feedback based on the input signal's level. The key advantage of this circuit is its ability to classify a continuous input signal into discrete levels, which is especially useful for systems that need to differentiate between multiple input conditions, such as monitoring muscle activity in EMG systems.

3.3 Mathematical Model

3.3.1 Instrumentation Amplifier Gain

The gain of an instrumentation amplifier is given by the formula:

$$G = 1 + \frac{2R}{R_g}$$

Where:

- $R = 10\,\mathrm{k\Omega}$ is the resistor value,
- $R_g = 100\,\Omega$ is the gain-setting resistor.

Substituting the values into the formula:

$$G = 1 + \frac{2(10,000)}{100} = 1 + 200 = 201$$

Therefore, the overall gain of the instrumentation amplifier is:

$$\boxed{G = 201}$$

3.3.2 Low-Pass Filter Cutoff Frequency

The cutoff frequency f_c of a low-pass filter is calculated using the formula:

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

Where:

- $R = 4.7\,\mathrm{k\Omega}$,
- $C = 68\,\mathrm{nF}$.

Substituting the values into the formula:

$$f_c = \frac{1}{2\pi(4.7)(68 \times 10^{-9})}$$

$$f_c = \frac{1}{2\pi(0.3196)} \approx \frac{1}{2.003} \approx 498\,\mathrm{Hz}$$

Thus, the cutoff frequency for the low-pass filter is approximately:

$$\boxed{f_c \approx 498\,\mathrm{Hz}}$$

3.3.3 Low-Pass Filter Gain

The gain of a low-pass filter is determined by the ratio of the resistors:

$$G_{\text{LPF}} = 1 + \frac{R_f}{R}$$

Where:

- $R_f = 220\,\Omega$,
- $R = 220\,\Omega$.

Substituting the values:

$$G_{\text{LPF}} = 1 + \frac{220}{220} = 1 + 1 = 2$$

Thus, the gain of the first low-pass filter is:

$$\boxed{G_{\text{LPF}} = 2}$$

Since there are two such filters, the total gain will be multiplied. Therefore, the total gain of the filters is:

$$G_{\text{total}} = G_{\text{LPF1}} \times G_{\text{LPF2}} = 2 \times 2 = 4$$

Thus, the overall gain of the device is:

$$\text{Overall Gain} = 201 \times 4 = 804$$

3.3.4 LED Voltage Calculation

The voltage required to light the LEDs is 3V each. Given that the total gain of the filters is 4, the total voltage output required to light all three LEDs is:

$$V_{\text{output}} = 3V \times 3 = 9V$$

Thus, the output voltage required to turn on the LEDs is:

$$\boxed{V_{\text{output}} = 9V}$$

4 Schematic Design

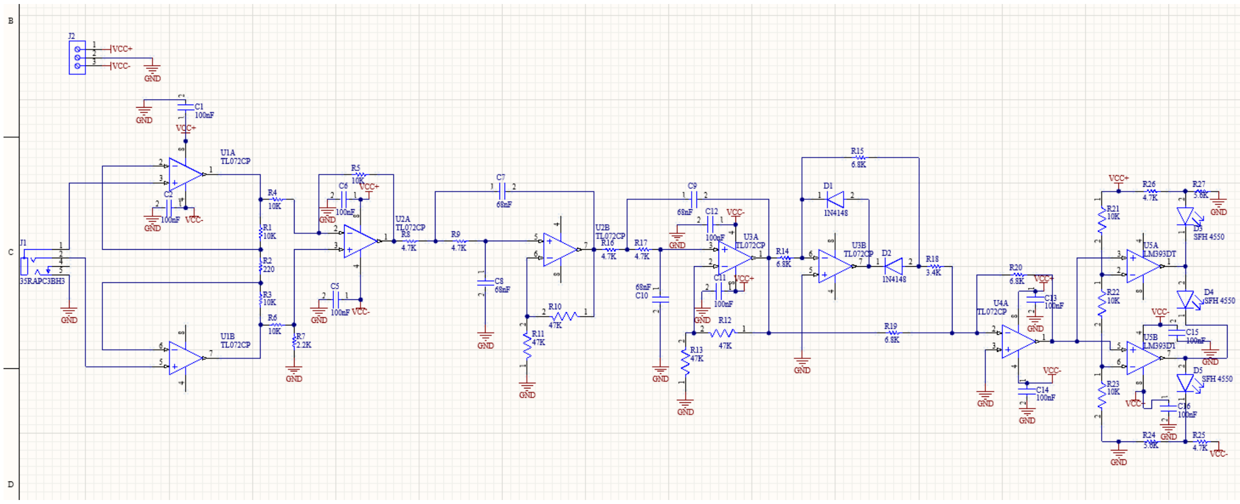


Figure 2: Schematic designed using Altium Designer

5 Component Selection

5.1 Power Supplying Unit

9V Batteries

- **Sufficient Voltage Swing:** A 9V supply provides a sufficient voltage swing for op-amps used in EMG applications. This ensures that the op-amps can amplify the small EMG signals effectively.
- **Isolation from Ground Noise:** Using separate batteries for the positive and negative supplies can help isolate the circuit from ground noise. This is important because ground noise can interfere with the weak EMG signals and lead to inaccurate measurements.
- **Availability and Cost:** 9V batteries are readily available and relatively inexpensive, making them a convenient choice for many applications.

Figure 3: 9V Batteries.

5.2 Main Circuit

TL 072CP - Dual Operational Amplifier

- **Low Noise:** EMG signals are inherently weak, so low-noise op-amps are essential. The TL072CP is known for its low input noise voltage and current, minimizing the introduction of additional noise into the system.
- **High Input Impedance:** High input impedance is crucial to minimize the loading effect on the EMG electrodes. This prevents the op-amp from significantly affecting the recorded EMG signals. The TL072CP has a very high input impedance, making it suitable for this purpose.
- **Wide Bandwidth:** The TL072CP has a wide bandwidth, allowing it to amplify the frequency range of EMG signals accurately. This is important for capturing the dynamic information contained within the muscle activity signals.
- **Availability and Cost:** TL072CP op-amps are readily available and relatively inexpensive.

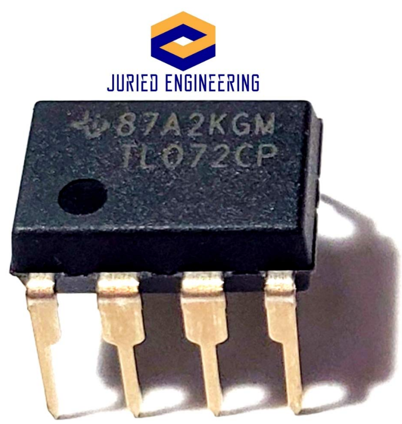


Figure 4: TL072CP

SMD Capacitors and Resistors

- **Improved Performance:** SMD components can lead to improved high-frequency performance. This is particularly important in applications like EMG where high-frequency signals are involved.
- **Reduced Parasitic Effects:** The shorter leads of SMD components can reduce parasitic inductance and capacitance, leading to improved signal integrity and reduced noise.

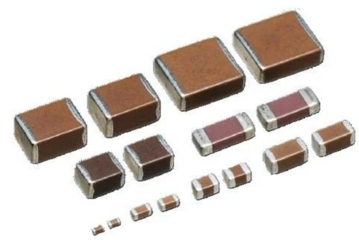


Figure 5: SMD Capacitors and Resistors

5.3 EMG Signal Acquisition Unit

3 Wires Connected to 3.5mm Jack

- **Reliability:** The connection between the EMG wire and the 3.5mm jack is typically reliable, reducing the risk of signal loss or interference.
- **Shielding:** 3.5mm jacks are shielded, which can help to reduce electromagnetic interference (EMI) that may affect the EMG signal.
- **Ease of Use:** 3.5mm jacks are easy to connect and disconnect, making it convenient to set up and use the EMG strain detector.

Figure 6: SMD Capacitors and Resistors

Dry Electrodes

- **Convenience:** Dry electrodes eliminate the need for messy gels or adhesives, making them much easier and quicker to apply and remove. This can significantly improve user comfort and convenience.
- **Improved Hygiene:** Dry electrodes are more hygienic than gel-based electrodes, as they minimize the risk of skin contamination.
- **Portability:** Dry electrodes are generally more compact and portable than gel-based electrodes, making them suitable for a wider range of applications.

- **Reduced Preparation Time:** The elimination of gel application and skin preparation steps can significantly reduce the time required to set up the EMG strain detector.

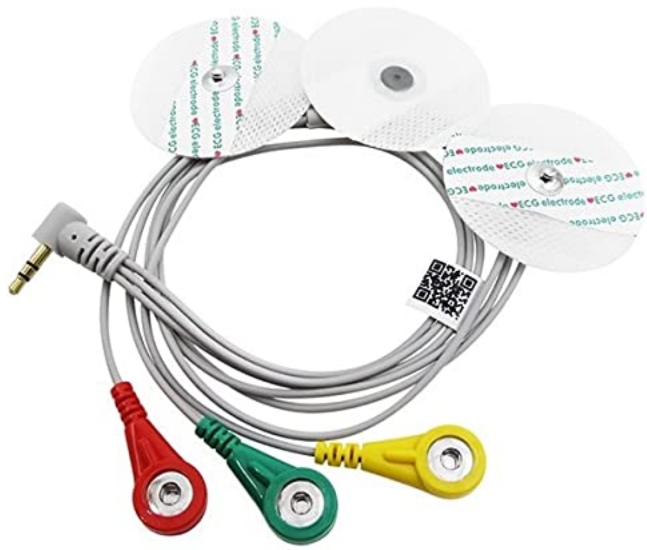


Figure 7: Dry ECG Electrodes.

6 PCB Design

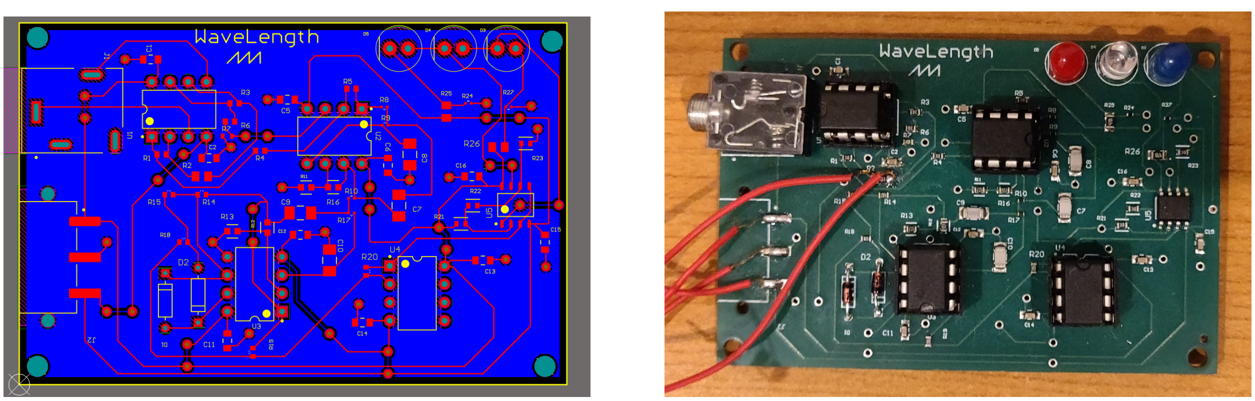


Figure 8: Images of PCB

PCB is one of the main components in our device. By using a PCB we have integrated all electronic components and reduced noise, improving the integrity of the signal.

6.1 Design Objectives

- Make the PCB compact to improve signal integrity

- Easily connect inputs and power supply
- Ensure proper grounding and reduce signal interference
- Use component which are easily accessible to reduce cost

6.2 Design Process

To design the PCB we have used Altium Designer software. To achieve design objectives, the majority of components included in this PCB are Surface-Mount Devices (SMD). By doing so, we have reduced the size of the PCB considerably. Also, to ensure signal stability and to reduce interference, the bottom layer of the PCB has been designed as a ground plane.

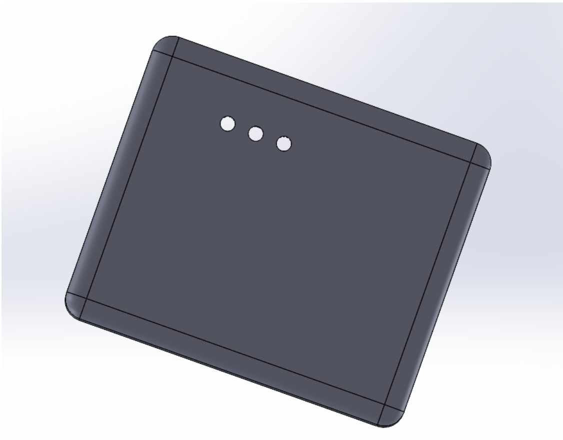
When considering the current going through the PCB it is less than 100mA. This is because the major components used for this PCB are OPAMPS and LEDs. So, the trace width used was 10mil which is more than enough for the above mentioned current. In addition, the OPAMPS have been placed in the center of the circuit to ensure correct routing. Furthermore, all signal traces are in the top plane to reduce interference. A small amount of power traces have been routed through the bottom plane to reduce the PCB size. To ensure a stable power supply to OPAMPS, 100nF decoupling capacitors have been added to the power supply inputs.

6.3 Fabrication Process

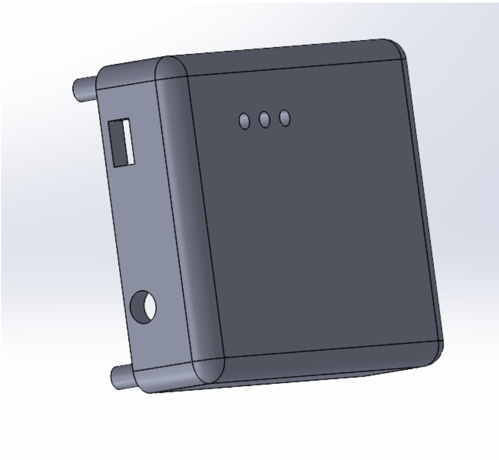
The PCB was fabricated by the renown PCB manufacturer, JLC PCB. The dimensions of the PCB are 76.2 mm*50.3 mm which is quite compact. Also the PCB thickness is 1.6mm with a outer copper weight of 1 oz. The surface finish used is HASL (Hot Air Solder Leveling), which ensures reliable soldering and protects copper traces from oxidation. A white silkscreen was also applied to identify components.

7 Enclosure Design

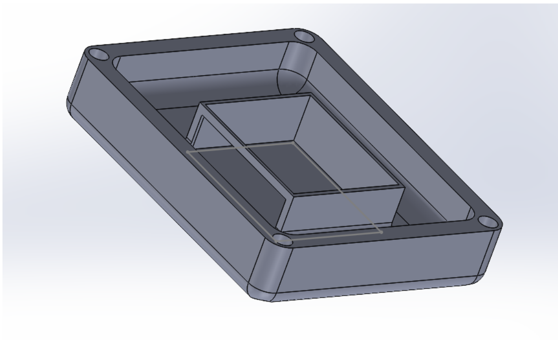
The enclosure is designed with two parts. The top part consist of the part that holds the PCB and the LEDs which acts as the indicators. The bottom part consists of the battery compartment.



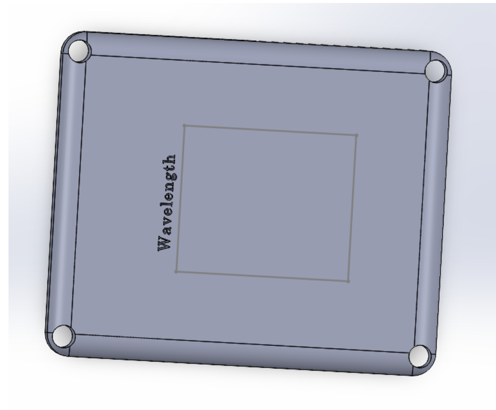
(a) Top Part Front View



(b) Top Part Side View



(a) Bottom Part



(b) Bottom Part front View

8 Simulation and the Test Results

The simulations results that we obtained at the testing and debugging stage of our project is given below.

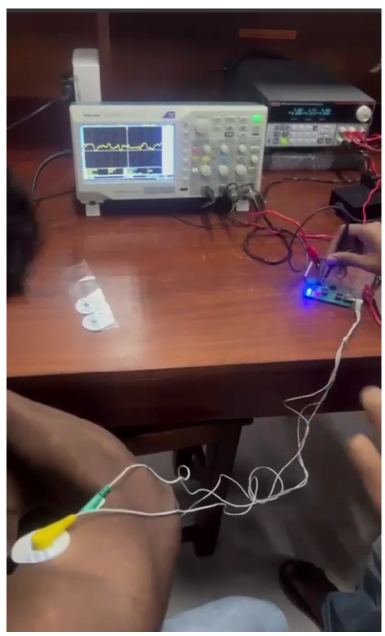


Figure 11: capturing the signal

Figure 12: Signals observed through oscilloscope

9 Individual Contribution

Name	Task
Dulsara G.M.L.	Enclosure Design and Assembling
Fernando S.R.N.	PCB Design and Circuit Debugging
Abeysinghe	Initial Schematic Designs and LT Spice Simulation
Cooray M.S.T.	Documentation, Circuit Debugging and Component Selection

10 Conclusion

he **EMG-based Muscle Strain Detector** effectively captures, processes, and analyzes muscle signals to provide real-time feedback on strain levels. By utilizing three electrodes, an instrumentation amplifier, Sallen-Key low-pass filters, and a comparator, the device ensures precision, noise reduction, and accurate signal interpretation. The visual output through LED indicators allows users to easily monitor muscle strain in **low, medium, or high** levels. This system is reliable, cost-effective, and suitable for applications in rehabilitation, sports science, and biomedical research, offering a practical solution for muscle activity monitoring and analysis.

11 Future work

The current implementation of the **EMG-based Muscle Strain Detector** provides accurate strain level monitoring through a simple and effective system. For future work, the following improvements and extensions can be considered:

- **Wireless Data Transmission:** Integrating wireless communication modules, such as Bluetooth or Wi-Fi, to enable real-time data monitoring on external devices like smartphones or computers.
- **Advanced Signal Processing:** Implementing digital filters and machine learning algorithms to improve accuracy and classify more detailed muscle activity patterns.
- **Compact Design:** Developing a more portable and wearable form factor for ease of use in sports and medical applications.
- **Real-Time Data Visualization:** Designing software or mobile applications to display strain levels and trends over time for better analysis and feedback.
- **Integration with Other Sensors:** Combining EMG with other physiological sensors (e.g., heart rate or motion sensors) for a comprehensive health monitoring system.

These enhancements will improve the device's versatility, accuracy, and usability, expanding its potential applications in various fields such as sports science, rehabilitation, and biomedical research.