Surface Electromyography Sensor

Abstract

The aim of this project is to design a low cost accurate wireless surface electromyography sensor with post-processing to identify the muscle strength and the continuous performance in real-time, the total cost is expected to be less than fifty dollars. Electromyography (EMG) is utilized during the performance assessment to prevent muscle injuries and assess player performance. The sensor should be capable to detect muscle activity and the extensions should be capable to correlate the activity detected with performance, impulse, contraction, and fatigue. With this coaches and physiologists can come up with suitable training for athletes to achieve higher performance.

1 Introduction

1.1 Problem Statement

- An Electromyography Sensor is used to detect the electromechanical gradient of voltage produced when there is muscle activity. There are quite a lot of models of the sensor currently on the market. Usually, athletes, coaches, and physiologists use this to analyse muscle activity. It provides a mathematical interpretation of Human Movement. This data helps in understanding how the muscle contractions are during a perfect run and we can compare that with the data when an athlete's performance is low. This helps in making his performance better. It can also help in the detection of diseases. It can also be used in prosthetic arms. It can help in the conversion of action to voice that can help the disabled. So In totes, It has a wide variety of applications. It comes in various types, needle EMGs, Surface EMGs etc.,
- Currently, EMG sensors are a very niche product in the field of sports science. This is mainly due to the high cost and lack of awareness of the possible use cases. EMG sensors are being used extensively in biophysical research but haven't had widespread commercial use. Hence, sports teams prefer collaborating with universities and research labs to get their data. This problem can be mitigated by reducing the cost of the EMG sensors and making data collection and interpretation accurate and easily available. This is exactly what we aim to do through this project.
- This report focuses on the circuitry part of the EMG sensor starting from V_{in} from sensors to V_{out} at the end of the circuit, which can be sent as analog input to the micro-controller for post-processing.

1.2 Idea behind it

When the brain sends a signal to motor nerves to move a muscle, calcium ions are released in the muscle which then depolarises causing the electrical energy to convert into mechanical energy (Electromechanical gradient), this is exactly what is measured by the sensor. When a muscle is contracted and we measure the potential difference between two points we can see that there is a very small emf that's generated there. A component of that can be detected at the skin. If you start contracting the muscle more, you can see a train of signals being generated that are so random and higher than previous values, which almost whites out the entire oscilloscope screen.

1.3 Vulnerabilities

Since we are going with wireless surface electrodes, it's vulnerable to noise, data from neighbouring muscles, sweat and data loss. We have to make the sensor surface sweat proof and instead of alternatives, we can make signal processing better and take away the noise to collect the data just from the required muscle.

2 Design

2.1 Electrodes

We have to start with choosing the electrodes. We will need three electrodes-two for measuring the voltage signal and one as a reference electrode. We have to place the two measuring electrodes at the mid muscle and end muscle parts respectively, placed 1-2 cm away and the reference electrode needs to be placed far away from them at the bony part so that the target muscle activity doesn't disturb the reference voltage. We plan to use 3 Disc surface- 10mm (0.4") diameter that comes in black or red lead wires. Lead wire lengths are 61cm (24") or 122cm (48").

Figure 1: Disc Surface Electrodes

2.2 Circuitry

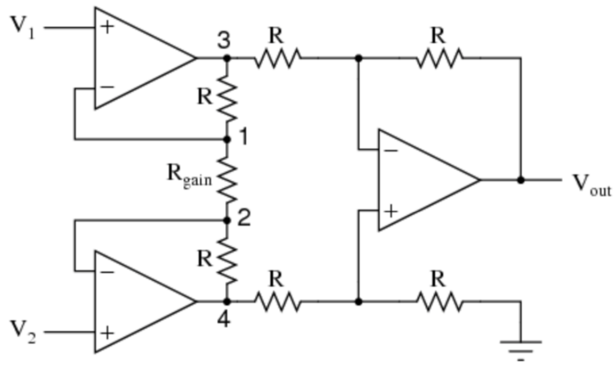
Objectives of circuitry of an EMG Sensor are

- Signal measured at the skin is very small and very tough to analyse. So we need to amplify the signal
- Signal measured is also noisy because of multiple reasons. The circuit should be able to filter out the noise and give us a filtered signal. Usually, EMG Signals range from 5-450 Hz(This varies a lot based on different articles). This signal can be later amplified to get a much cleaner and readable signal.

It consists of an

- Instrumentation Amplifier
- A Band Pass Filter
- A Non-Inverting Amplifier

2.2.1 Instrumentation Amplifier

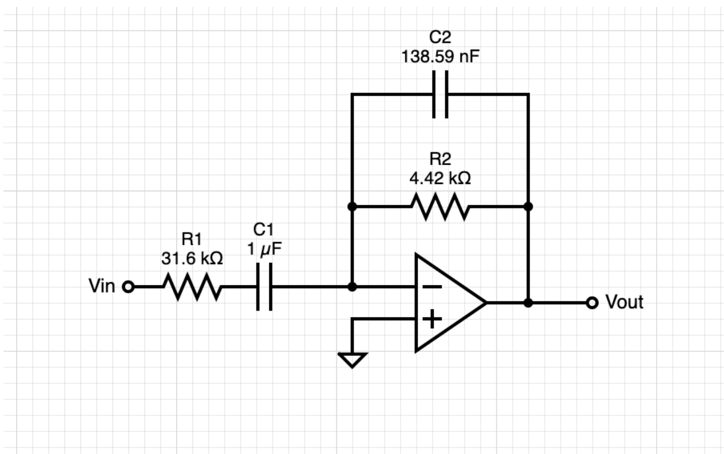


The two inputs from the electrodes are given to the amplifier directly or, we can use a unity gain differential amplifier to obtain the $V_1 - V_2$ and ground the bottom amplifier to make the circuit simpler. This circuit amplifies the input as well as differentiates the output from the input. We can adjust the gain by only changing one resistor R_{gain}. On calculating the relation between V_{in} and V_{out}, we get something like this. In the circuit I simulated below, Since amplification needs to be done here at a lesser magnitude since we do not want the noise in the signal to amp up high, I wish to get a gain of 10x, So I used 200Ω and 909Ω resistors as R_{gain} and R respectively.

$$V_{out} = V_{in}(1 + \frac{2R}{R_{gain}})$$

2.2.2 Band pass Filter

EMG signal usually lies in the band of 5-450 Hz, Every other frequency mostly comprises noise. I have tried out various filters to achieve this band. I do not wish to use Inductors in the filter as they occupy a lot of space. So I finally was satisfied with this design of Bandpass filter.



The transfer function of this filter is

$$H(s) = \frac{sC_1R_2}{(1 + sC_1R_1)(1 + sC_2R_2)}$$

So the poles are $1/R_1C_1$ and $1/R_2C_2$. I have assumed some things here before calculating the values.

- $1/R_1C_1 << 1/R_2C_2$.

- The lower cut-off frequency is close to zero.
- The higher cut-off frequency is the higher ω_{3db} of the transfer function, which on calculating you will get it around $\frac{\sqrt{3}}{R_2 C_2}$.
- Maximum magnitude response in bode plot is less than zero, so that noise gets cancelled out better.

So with this I can calculate the values of R_1, R_2, C_1, C_2 we are going to use, After calculations, I found them as

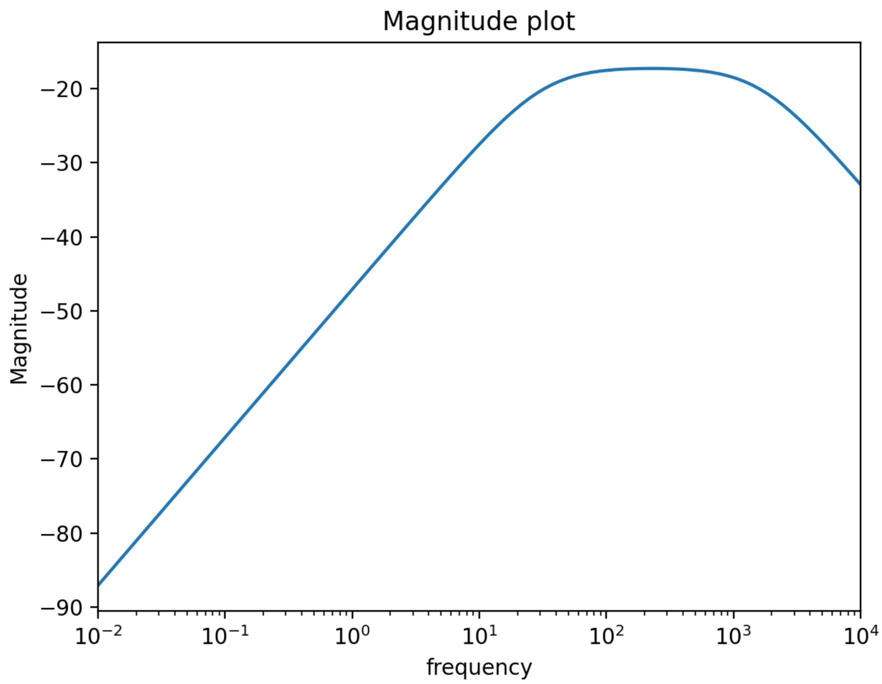
$$R_1 = 31600\Omega$$

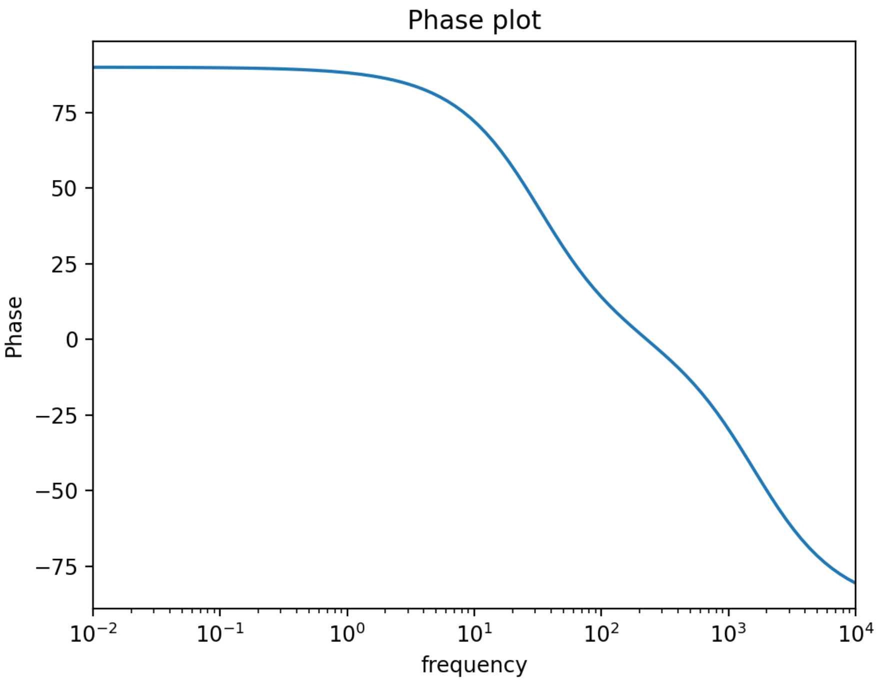
$$R_2 = 4420\Omega$$

$$C_1 = 1\mu F$$

$$C_2 = 138.59nF$$

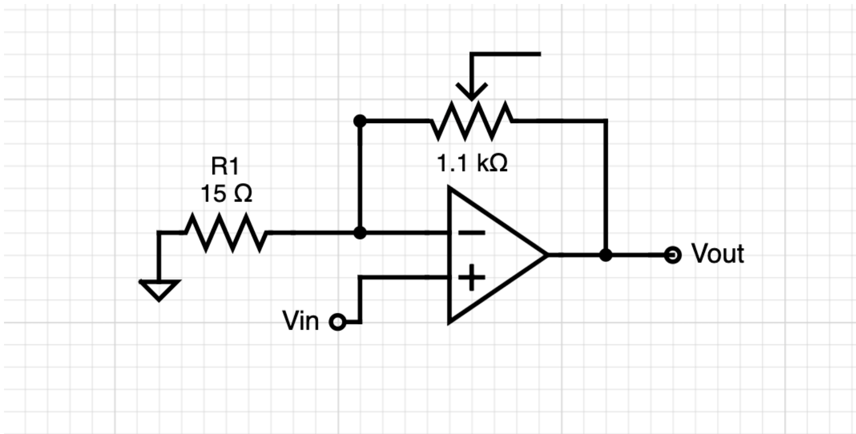
Below are the Bode plots of the above transfer function. We can see that the cutoff frequencies are almost $31.6455 - 2827.5610676$ rad/s or $5 - 450$ Hz





2.2.3 Non-Inverting Amplifier

A simple non-inverting amplifier with a very large gain is implemented so that we can get back the amplitudes for the necessary frequencies that were decreased during the filter action. This can be a variable gain. Optimum gain values range between 100 - 1000. The gain is adjusted using a potentiometer. Below are the circuit and the values I have considered for the simulation.



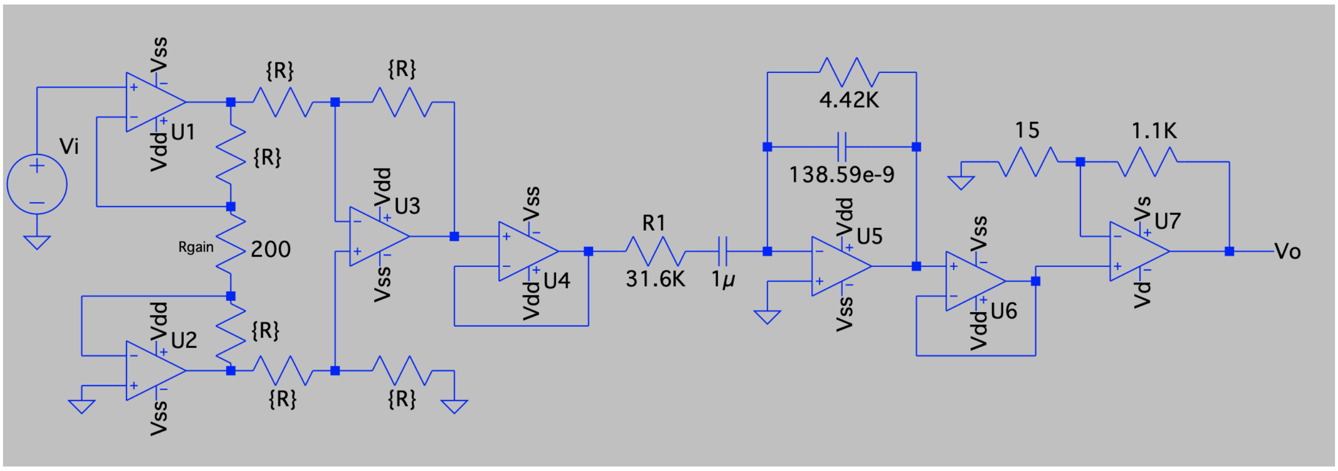
The gain here is around

$$1 + \frac{R_2}{R_1} = 74.33$$

3 LTspice Simulation

I have made this entire circuit in LTspice and simulated it with various inputs to test the output. It seemed to be working well with all the above constraints and satisfying the above constraints. Attaching certain outputs here.

3.1 Circuit Schematic



3.2 AC Analysis

This depicts both the filter and amplification action of the circuit. Magnitude and Phase response from LTspice below shows that this circuit meets the objectives of the problem.

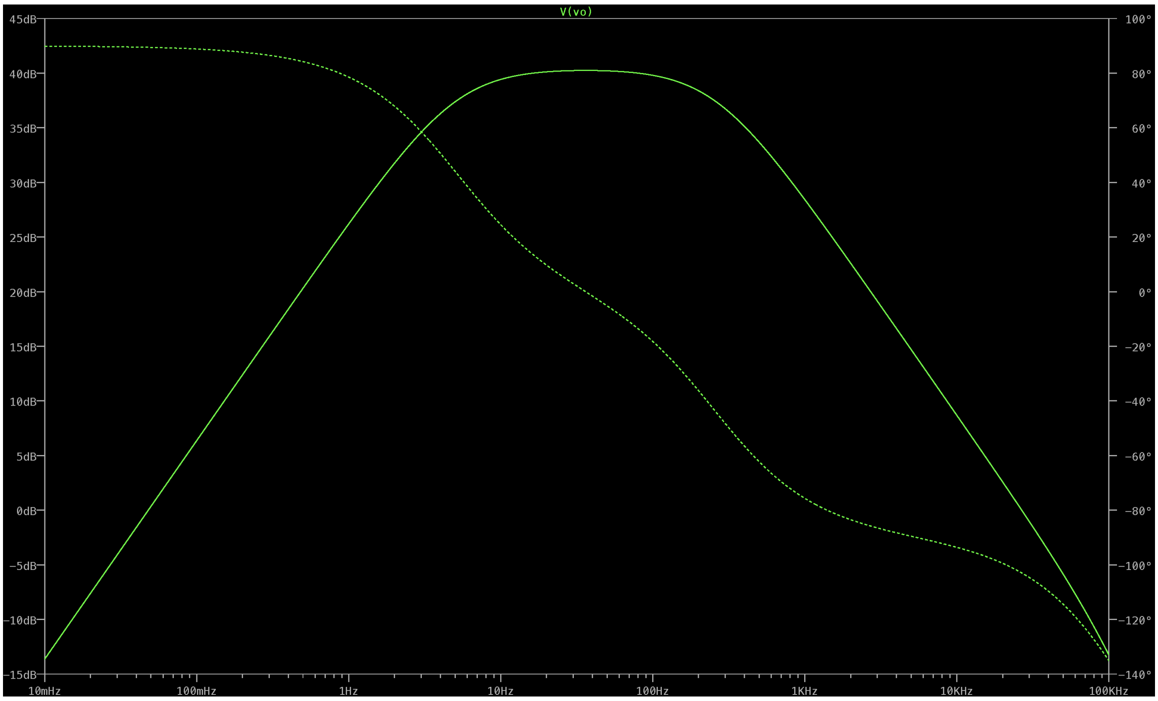


Figure 2: AC Analysis of Output(Dotted line represents phase response.)

3.3 Noise Analysis

Noise Analysis is used to calculate the noise power spectral density generated by a circuit internally. The output noise, at a specified output node, is the root mean square sum of the noise generated by all the resistors and semiconductors in the circuit. This includes thermal, shot and flicker noise. You can use this simulation to change components to check results and see which components suit the best. We can see that the noise rolls off for higher frequencies but stays persistent for lower frequencies.

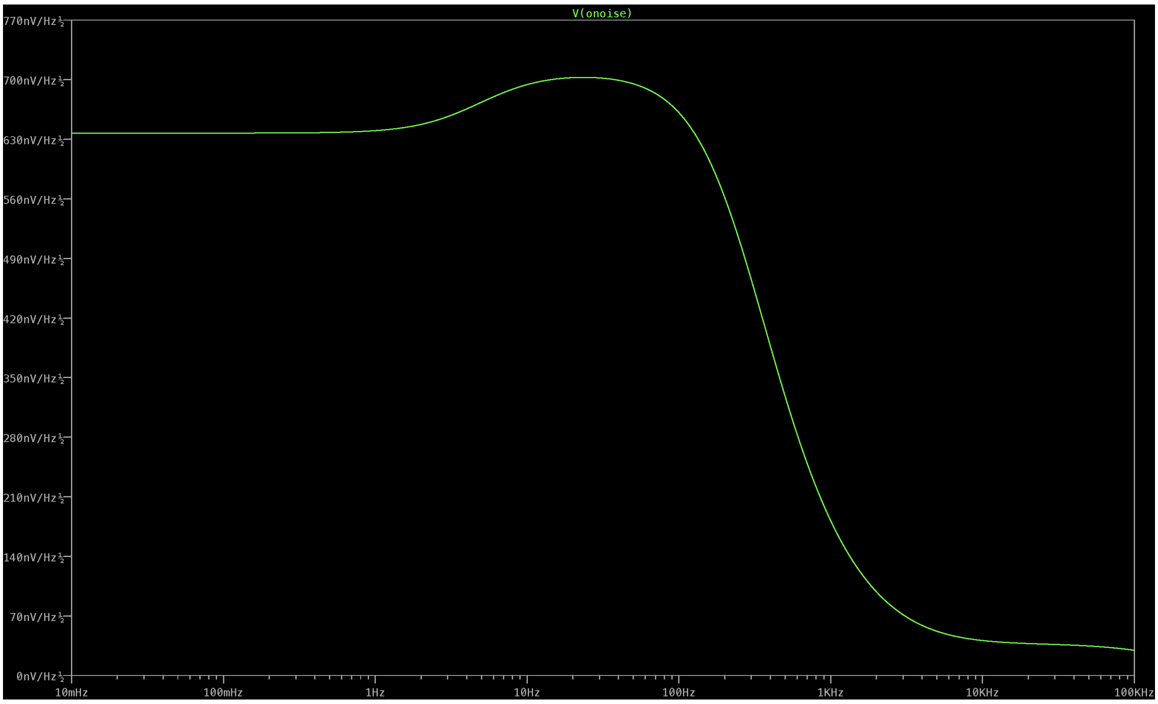


Figure 3: Noise Analysis of Output

4 Scope of Improvement

- This has its limitations. Amplifiers are almost ideal, and a Rectifier isn't yet implemented in the circuit. We can explore designs where you can implement rectifiers along with the Instrumentation amplifier, These articles below might make things more clear. We can't come to a conclusion about its accuracy and TYP details unless we realise this. Despite all this, these are the necessary things to be implemented in the final circuit. But these are not sufficient.
  - Wireless Sensor Devices In Sports Performance, Róisín Howard
  - Data Sheet of Three-lead Differential Muscle/Electromyography Sensor
- Post processing should still be taken care of. After receiving the data from the sensor, we can transfer it from a microcontroller attached to the device using a wireless communication protocol to our simulator where filtering and output analysis can happen. We have to take care of readability and usability while doing this. One of the primary aims of this project is to ease the readability so that coaches and athletes can use this without the help of any professionals.