Report Results

Daniel Rodríguez Gómez, Galahad Sáenz Sellman,
Rodrigo Rivas González, Eduardo Adrián Domínguez Soria
Tecnologico de monterrey
México
A01754690@tec.mx
a01749134@tec.mx
A01028540@tec.mx
A01750049@tec.mx

Abstract— This project presents the development of a biofeedback system using surface electromyography (sEMG) to capture muscle signals. A circuit based on operational amplifiers was designed to accurately read the electrical activity of muscles during stimulation. The study details the design process, components, and results, demonstrating the circuit's effectiveness in muscle signal analysis. Conclusions highlight the system's performance and key insights gained.

I. INTRODUCCIÓN

In recent years, biofeedback has gained significant attention as a method to enable individuals to control physiological processes that are typically automatic. Among the various biofeedback techniques, surface electromyography (sEMG) stands out as a non-invasive method to record and analyze the electrical activity generated by muscles. sEMG signals are essential in numerous fields, including rehabilitation, ergonomics, biomechanics, and sports science, due to their ability to provide insights into muscle function, motor control, and fatigue.

Our team developed a circuit based on operational amplifiers designed to read and interpret the signals generated by muscles when stimulated. This innovative approach allows for a precise and efficient method of capturing and analyzing muscle activity, which can be used in various biofeedback applications.

II. Content Development

Biofeedback is a technique that allows individuals to control involuntary bodily functions such as heart rate, muscle tension, and breathing patterns. This is achieved using devices that monitor these functions and provide real-time feedback. Specifically, muscle activity is monitored using an electromyograph, which employs sensors to measure muscle tension. This information is crucial in developing strategies for individuals to control their muscle responses, especially in situations of pain or stress. As stated, “A machine called an electromyograph uses sensors to measure muscle tension. This helps you become aware of muscle tension so you can take steps to control it”(Mayo clinic, 2023) .

In our project, we have designed a circuit based on operational amplifiers capable of reading and processing sEMG signals produced by muscles during contraction. This prototype focuses on capturing the electrical activity of muscles, providing a precise tool for analysis and use in biofeedback applications. Like traditional biofeedback machines that measure muscle tension, our circuit is designed to provide information that can be used to improve the health and well-being of the user.

This development includes the selection and configuration of appropriate components such as operational amplifiers, filters, and analog converters, which are essential for the accurate processing of sEMG signals. Additionally, detailed calculations were performed, and schematics were designed to ensure the functionality and efficiency of the prototype in capturing and analyzing muscle signals.

III. Components

	materials
component	**specs**
Op amp	Lm741 (8 pins) , Tl084 (14 pins)
resistor	10kΩ, 13.5kΩ, 100Ω, 37kΩ, 1kΩ,
diode	silicon(.7 Volts)
Capacitor	10nF
Electrolytic capacitor	1μF
Arduino 1	microcontroller
Battery	9 Volta
Electrodes	read the muscle/electric signals

Description, datasheets and circuits used in the assembly of the electromyograph:

Component LM741CN: This component contains an Op Amp and was used in the filter stage.

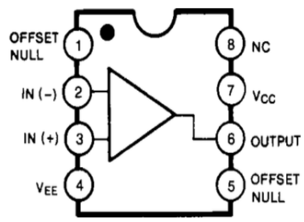


Figure 1. Connections pins of the LM741CN.

Component TL084C: The component contains 4 Op Amps inside, so it’s very useful when you need to connect a more complex circuit. In this circuit it was used to wire the first stage of our complete circuit. Using the datasheet and this diagram of the pins connections we were able to design and complete the part of the instrumental amplifier.

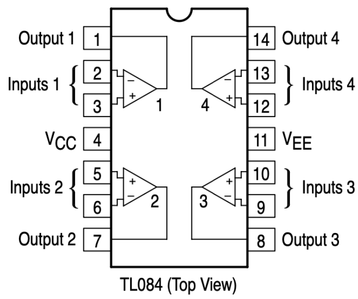


Figure 2. Connection pins of the TL084A

These two components were essential in order to complete the circuit, and also to make the analysis and get the values we were expecting to have as a result of the gain and also to the visual result on the display.

IV. Circuit development

A. Instrumentation

The first part of the circuit is designed to amplify the muscle signals and achieve the required gain. In this case, we use an instrumentation amplifier due to its high input impedance, low output impedance, and excellent common-mode rejection ratio (CMRR). These characteristics are essential for accurately amplifying the small differential sEMG signals while minimizing noise. The gain of the amplifier can be adjusted by selecting the appropriate resistor value, for instance, using a 50Ω resistor can provide a specific gain depending on the amplifier configuration.

$$K = \left(1 + \frac{R_1}{R_g}\right) \text{ when } R_3 = R_2$$

$$K = \left(1 + \frac{2R_1}{R_g}\right)\frac{R_3}{R_2} \text{ when } R_3 \neq R_2$$

$$V_{out} = (V_2 - V_1)\left(1 + \frac{2R_1}{R_g}\right)\frac{R_3}{R_2}$$

For this stage the components used were 6 resistors with a value approx. of 10KΩ, another resistor with a value approx. 50Ω, the instrument amplifier TL084A.

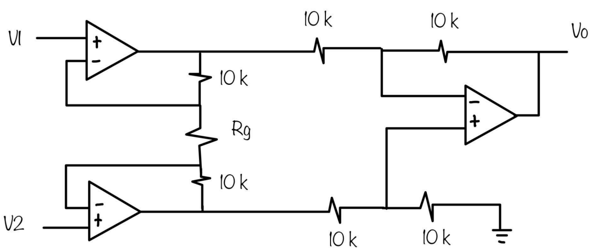


Figure 3. Diagram of the instrumental stage.

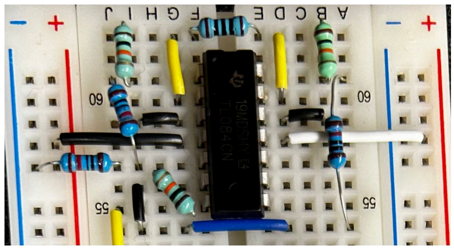
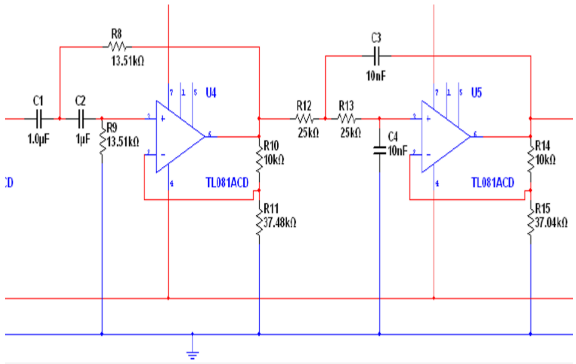


Figure 4. Assembly on protoboard.



B. Pass band filter

The filter used is a band pass filter, which consists of a combination of a low pass filter and a high pass filter. The purpose of this configuration is to allow only the relevant frequencies associated with muscle activity (typically between 20 Hz and 500 Hz) to pass through while filtering out noise and other unwanted signals. This step is crucial for ensuring that the circuit processes only the meaningful sEMG signals, improving the accuracy of the readings.

$$K = 1 + \frac{Rb}{Ra} \; for\ those$$

For the stage of the pass band filter we use two LM741CN Op Amps, that in this case were convenient for the many wire connections that the filter requires. The circuit contains 2 resistors with values of approx. 13.51KΩ, 2 resistors of approx. 10kΩ, 2 resistors of approx. 25kΩ, 2 resistors of approx. 37kΩ, 2 capacitors of 1µF, and 2 capacitors of 10nF.

Figure 5. Diagram of the pass band filter.

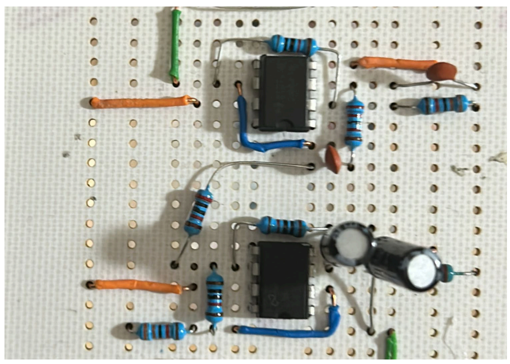


Figure 6. Assembly on protoboard.

C. *Rectifier*

The next stage in the circuit is the rectifier. Since the sEMG signal is an alternating current (AC) signal that varies in polarity, a rectifier is used to convert this signal into a unidirectional (DC) signal. This process is essential because it makes the signal easier to analyze by providing a consistent positive signal that corresponds to the muscle activity, which is particularly important for further processing in the biofeedback system.
We use the inverter equation since the configuration is the same except for the diodes

$$Vo = -\frac{R_2}{R_1} Vi$$

For the stage of the rectifier the components used were two diodes, and two resistors of approx. 10KΩ, and the operational amplifier TM741CN. This part of the circuit is for the signal to only show us the positive side, for later added the integrator and have a clean view of the muscle when it contracts.

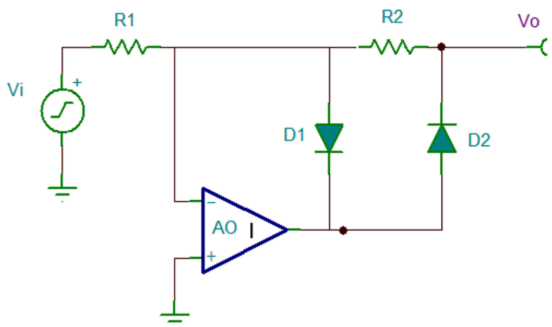


Figure 7. Diagram of the rectifier stage.

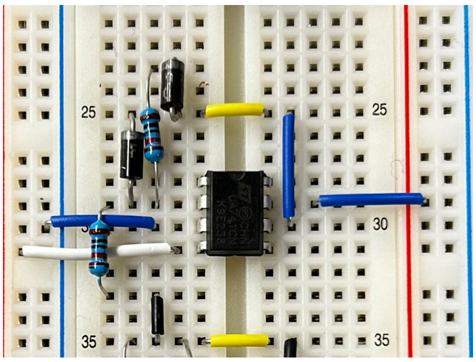


Figure 8. Assembly on protoboard.

D. *Integrator*

The final stage of the circuit is the integrator. After the signal has been rectified, the integrator is used to smooth out the rectified signal over time, effectively averaging the signal. This creates a more stable output that reflects the overall level of muscle activity, rather than the rapid fluctuations that occur naturally in the raw sEMG signal. The integrator helps in providing a clear and interpretable signal for analysis or feedback purposes.

$$-\frac{1}{RC}\int Vin(t)dt = Vo(t)$$

For this part the components used were, one Op Amp LM741CN, two resistors, one with a value of 1kΩ, the other with a value of 2.2KΩ, and one capacitor of 1μF.

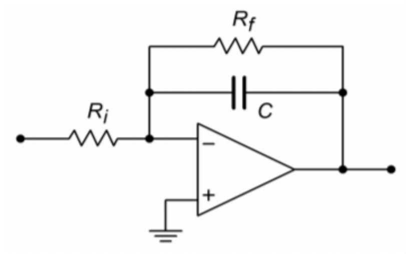


Figure 9. Diagram of an integrator Op Amp.

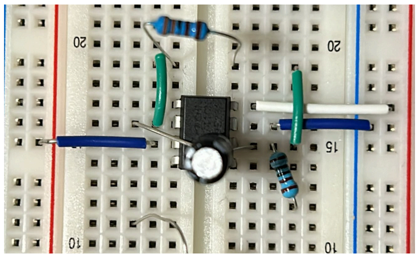


Figure 10. Assembly on protoboard.

E. *Inverter*

Inverting Amplifier with Variable Gain. Since the output signal from the integrator stage is negative, we introduced an inverting amplifier with a variable gain to invert the signal and allow for fine-tuning of the gain. This stage uses a potentiometer to adjust the gain, providing flexibility in signal amplification and ensuring that the final output is positive and optimized for further analysis or display.

The output voltage of the inverting amplifier is given by:

$$Vo = -\frac{R_1}{R_{in}} \cdot Vin$$

Where Rf is the feedback resistor, and Rin is the input resistor. In our configuration, Rf is replaced with a potentiometer, allowing for the gain to be adjusted dynamically.

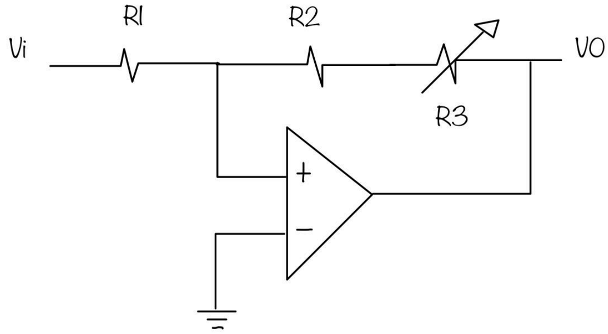


Figure 11. Diagram of the inverter stage.

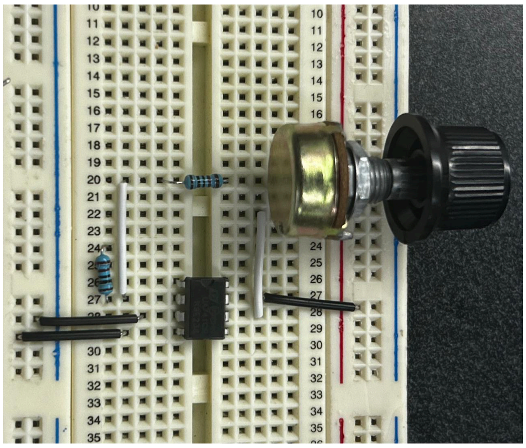


Figure 12. Assembly on protoboard.

V. Results

The results that the team obtained shows that in every part of the experiment the assembly and wire of the circuit because in each of them the results obtained were the ones that we were expecting.

A. Instrumentation.

The result expected on this stage of the circuit was to see an amplified signal, to compare the voltage entering and voltage amplifier going out.

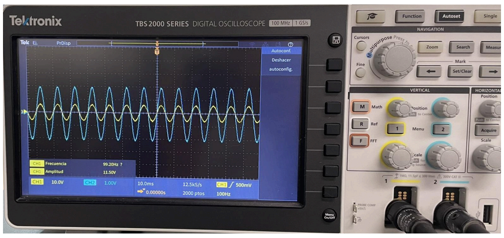


Figure 13. Result on the oscilloscope.

B. Pass band filter.

In this stage the result in the oscilloscope was a sign in which depending on the frequency it will not pass ar the filter will let the frequency as we can see on the image.

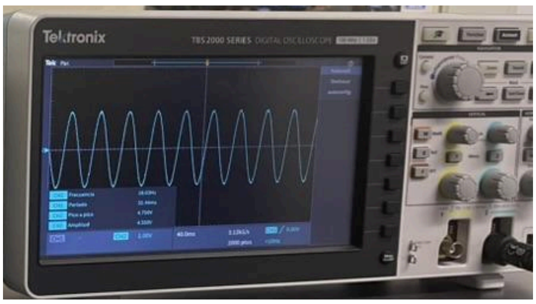


Figure 14. Result on the oscilloscope.

C. Rectifier.

In the rectifier stage, as we can see in the image, the signal on blue is only on the positive side. That is the rectifier circuit correcting the signal.

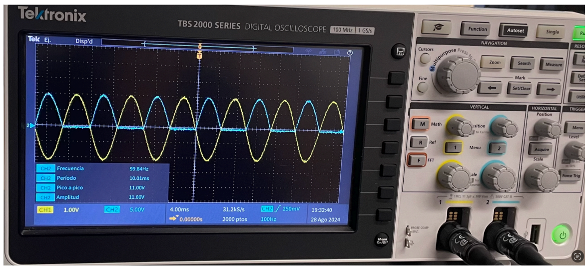


Figure 15. Result on the oscilloscope.

D. Integrator.

For this stage, we expected to see the amplified signal of the muscles with the electrodes, and see how the signal is going up as the contraction of the muscle is going on.

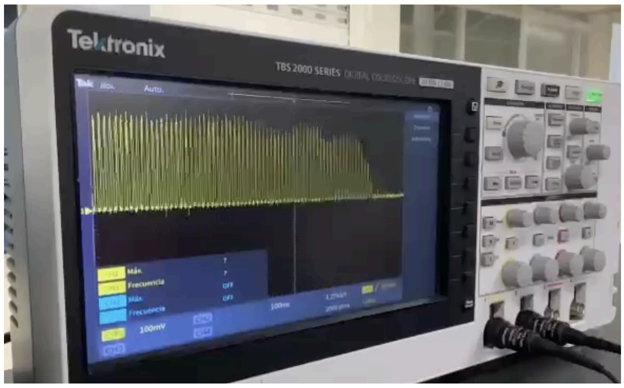


Figure 16. Result on the oscilloscope.

E. Inverter

In this final stage the inverter moves the sign from the negative part of the oscilloscope to the positive side. This stage is for us, so easily put the digital part of the led to turn on with a positive voltage.

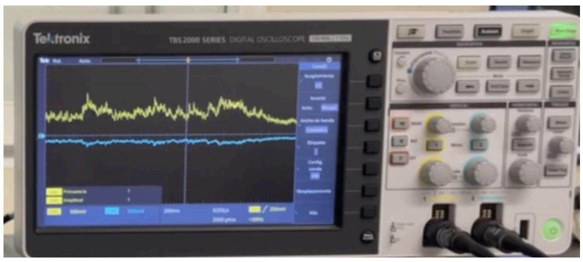


Figure 17. Result on the oscilloscope.

VII. .Conclusion

In conclusion, the results obtained in this project demonstrate the successful assembly of an electromyograph, consisting of four distinct stages, each designed and assembled with specific components to fulfill well defined objectives. Throughout the development of this project, we not only managed to capture and accurately analyze electromyographic (sEMG) signals produced by muscles, but also gained deep insight into the challenges and technical considerations involved in designing circuits for biomedical applications.

During the development process, we learned the importance of selecting appropriate components, such as operational amplifiers, filters, rectifiers, and integrators, to ensure the circuit functions optimally and provides reliable results. The amplification stage, utilizing an instrumentation amplifier, was crucial in achieving a clear and noise-free output signal, which is essential for the accurate interpretation of muscle signals. The use of band-pass filters allowed us to isolate relevant frequencies, ensuring that only significant signals associated with muscle activity were processed. Additionally, the rectification stage and subsequent signal integration provided a stable and easy-to-analyze output, offering a clear view of muscle activity in real-time.

This project also allowed us to practically understand the theory behind operational amplifiers and their application in biofeedback systems, which is critical for designing non-invasive medical devices. The hands-on experience gained in assembling and wiring circuits on a protoboard, as well as interpreting results on an oscilloscope, has been invaluable and has significantly contributed to our development as mechatronics engineers.

VIII. Links of the Datasheets used in this work.

[1]https://www.alldatasheet.com/datasheet-pdf/view/53590/FAIRCHILD/LM741CN.html

[2]https://www.alldatasheet.com/datasheet-pdf/view/28779/TI/TL084A.html

IX. Sources.

- Biorretroalimentación - Mayo Clinic. (2023, 12 mayo).n https://www.mayoclinic.org/es/tests-procedures/biofeedback/about/pac-20384664#:~:text=La%20biorretroalimentaci%C3%B3n%20es%20un%20tipo,respiraci%C3%B3n%20y%20las%20respuestas%20musculares.
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