Quadriplegic assist device using EOG signals

Analog circuit design to acquire and seggregate the EOG signal

Aniketh Atmakuri and Mallika Garg

1. ECD, International Institute Of Information Technology, Hyderabad, India
2. ECE, International Institute Of Information Technology, Hyderabad, India

***Abstract*— Disabled people, especially the quadriplegic, deal with a great number of barriers to accomplish their day-to-day activities. The quadriplegic, with all their four limbs immobilized, require external assistance to accomplish their tasks. The purpose of this study is to develop a device for their self-sustenance. The basis for developing such a device is the utilization of the signals obtained based on the movement of their eyes.**

Presentation video link

Report.pdf - Personal - Microsoft Edge 2023-05-04 15-28-48.mp4

Keywords—Quadriplegic, EOG signals (electrooculogram signal), instrumentation amplifier, gain, active-bandpass filter, Q- factor, rectifier, buffer, notch filter, bode-plot, parasitic capacitance.

I. Introduction

Disabilities, whether congenital or acquired, can greatly limit an individual's ability to perform daily activities. Quadriplegia, a condition in which all four limbs are immobilized, poses significant challenges for individuals in performing their day-to-day tasks independently. This lack of autonomy can have a profound impact on an individual's quality of life. Assistive technologies have been developed to help individuals with disabilities overcome these challenges. This paper focusses on using the EOG signals, to assist the individual perform rudimentary activities such as movement in a wheelchair. EOG signals are obtained by measuring the cornea-retinal potential. These are used to determine the eye movements and position based on the potential difference received from the two electrodes placed on the skin on either side of the eye. These signals have a differential potential between 0.5mV and 3.5mV. Their frequency range is 0.05Hz – 30Hz. This feeble signal is extremely difficult to interpret. In order to utilize this signal, it has to first be processed by a system. The design of such a system is described below.

II. System Design

The circuit developed utilizes the potential difference created across the eye muscles in response to their movement in a predetermined direction. This is accomplished with the assistance of electrodes. Although, the electrodes capture the signal, the signal strength is very weak and this demands for the design of circuit that makes the signal dominant. The approach to make the signal dominant is by the use of three stages :-

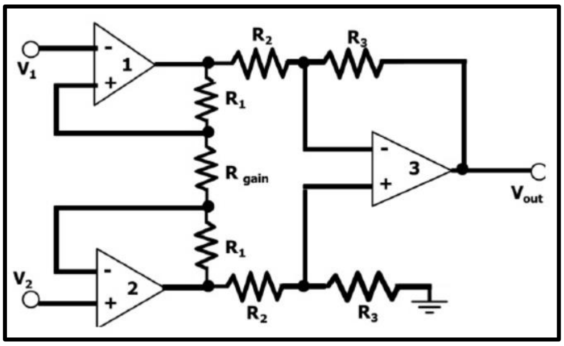
- We first pass the primitive signal through an “instrumentation amplifier”. This helps capture the potential difference and provide a gain.
- The existence of noise in nature is troublesome. In order to irradicate this noise, we make use of an “active bandpass filter”.
- After this stage, the signal is noise-free and has a high amplitude.
- However, we pass this noise-free signal through a gain stage to strengthen the signal.
- Once we are able to detect the eye-movement clearly, we segregate the obtained signal to implement two functionalities.
- For segregation of the signal, we implement a standard rectifier

III. Hardware Implementation

The above-mentioned parts in the system are realised and designed as follows:

1. Instrumentation Amplifier

   An instrumentation amplifier is a differential amplifier equipped with input buffer amplifiers, which eliminate the requirement for input impedance matching, thereby making the amplifier ideally suited for use in measurement and test equipment. This amplifier exhibits several desirable characteristics, including ultra-low DC offset, minimal drift, negligible noise, exceptional open-loop gain, high common-mode rejection ratio, and elevated input impedances. As the EOG signals are very feeble, the instrumentation amplifier becomes the ideal choice for hardware implementation as the first stage. The following is the circuit diagram for the instrumentation amplifier designed.



$$Let\ the\ outputs\ from\ the\ 1^{st} and\ 2^{nd}\ op - amps\ be\ V_{o1}\ and\ V_{o2}\ respectively.$$

$$V_{out} = \left(\frac{R_3}{R_2}\right).(V_{o1} - V_{o2})$$

$$I = \frac{(V_{o1} - V_{o2})}{2R_1 + R_{gain}} \dots\dots\dots.(1)$$

$$I = \frac{V_1 - V_2}{R_{gain}} \dots\dots\dots\dots(2)$$

$$Equating\ (1)\ and\ (2)$$

$$(V_{o1} - V_{o2}) = (2R_1 + R_{gain})\ (\frac{V_1 - V_2}{R_{gain}}) \dots\dots(3)$$

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

In our design, we have chosen $R_1 = R_2 = R_3 = R =$ 25kΩ The resistor values were chosen so as to obtain a gain of 10. The following are the equations that lead to the expression for the gain of the instrumentation amplifier:

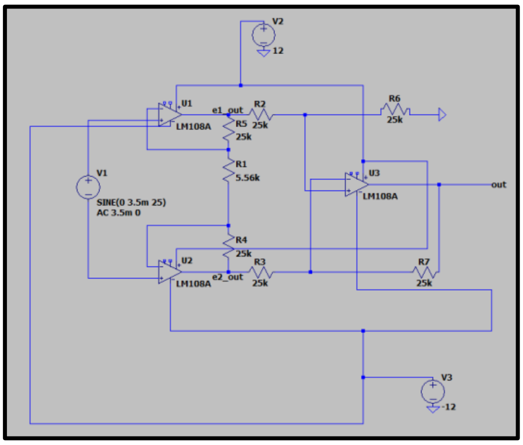
As it can be observed, for the gain to be 10, we want

$$1 + \frac{2R}{R_{gain}} = 10$$

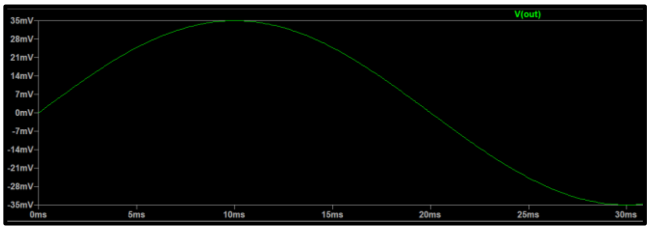
$$1 + \frac{50k}{R_{gain}} = 10$$

$$R_G = 5.56\ k\Omega$$

Therefore, the circuit design followed for simulation and hardware implementation is as follows :



The following is the output obtained from the instrumentation amplifier when simulated with the input as $(3.5 \times 10^{-3})\sin(2\pi(25)t)$:



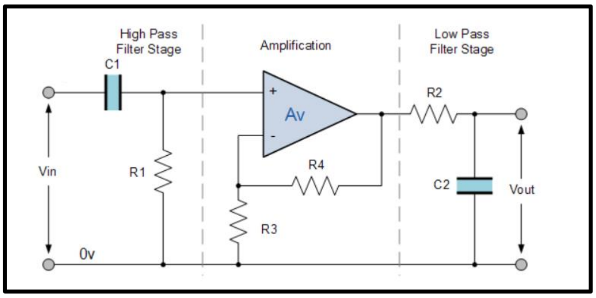
In the above plot, we can observe a gain of 10 as desired.

2. Active Band-pass Filter

The elimination of noise is a critical requirement in many applications, and to address this, an active band-pass filter was selected as the primary solution. Active band-pass filters are preferred over normal bandpass filters because they offer several advantages:

- Firstly, active bandpass filters have a higher Q-factor, which enables them to provide greater selectivity and a narrower passband.
- Secondly, active filters have the ability to provide gain, which can compensate for signal loss that may occur in subsequent stages of a circuit.
- Thirdly, they have a low output impedance, which ensures that they can drive loads effectively without introducing distortion.
- Additionally, active filters can be easily designed and adjusted for specific frequency ranges, making them more versatile than passive filters.
- Finally, active filters are more reliable and stable than passive filters, as they are less susceptible to variations in component values and temperature changes.

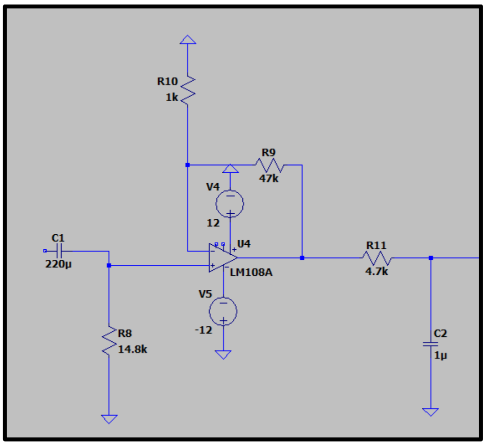
The following is the circuit-diagram for the design of an active- bandpass filter:



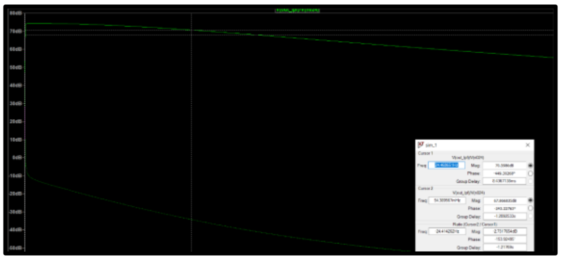
The values of R_1, C_1 , R_2 , C_2 are determined by the cut-off requirements. Since the range for the EOG signal is 0.05Hz – 30Hz, the cutoff for low-pass filter has to 30Hz and that for the high-pass filter is 0.05Hz. The cut-off frequency for either the low-pass or the high-pass is given by $f_C = \frac{1}{2\pi RC}$. Upon, considering the cut-off frequencies, we obtain the following values:

- R_1 = 14.8kΩ and C_1 = 220μF
- R_2 = 4.7 kΩ and C_2 = 1 μF

A gain of 48 is provided from the amplification segment of the active band-pass filter. This is achieved by choosing R_4 as 47 kΩ and R_3 as 1 kΩ. We can observe that the amplification segment is just a non-inverting amplifier. The gain for such an amplifier is given by $(1 + \frac{R_4}{R_3})$. Therefore, the circuit design followed for simulation and hardware implementation is as follows:



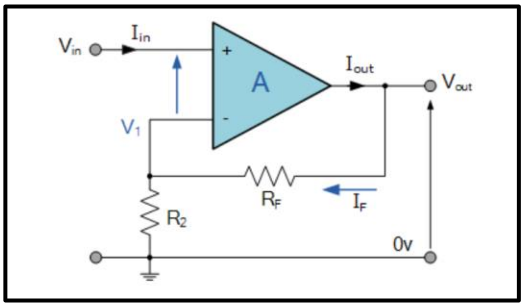
The bode plot obtained from this filter is as follows:



With the aid of cursors in the simulation, we can observe the frequencies at which -3dB occurs and hence verifying our cut-offs.

3. Gain Stage

A non-inverting operational amplifier was used for the gain stage. A non-inverting operational amplifier (op-amp) is a type of electronic amplifier circuit that amplifies an input signal without inverting its polarity. It has a high input impedance and low output impedance, making it useful in a wide range of applications such as audio amplification, filtering, and signal conditioning. The basic circuit consists of an op-amp with a feedback loop that connects the output back to the non-inverting input, effectively amplifying the input signal by a factor determined by the feedback resistor values. Non-inverting op-amps are commonly used in applications where a high gain is required, and the input signal must be preserved in its original form.



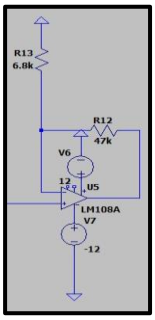
The gain of the non-inverting operational amplifier is given by $(1 + \frac{R_F}{R_2})$. The considered values in our design are as follows :

Rf = 47k

R2 = 6.8k

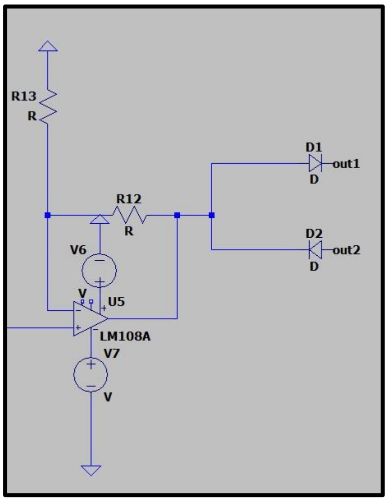
This resulted in a gain around 8.

The circuit design followed for simulation and hardware implementation is as follows:

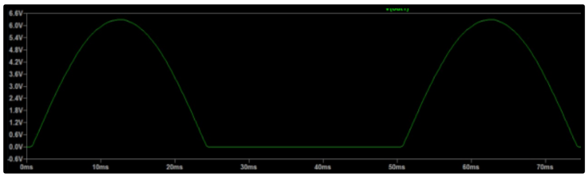


4. Distinguishing Eye Movement from EOG signals

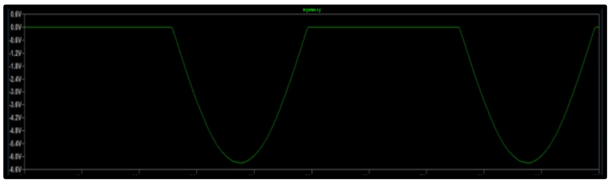
Upon obtaining the EOG (electrooculogram) signal, we observe a positive pulse and a negative pulse with the movement of eye to the right and left respectively. To extract these two signals for multiple functionalities, a rectifier circuit is implemented. This is done by using diodes in forward and reverse bias. The diode in forward bias detects only the positive pulses and the one in reverse bias detects only the negative pulses. To summarize, we are using this technique to isolate and extract the specific signals we need from the overall EOG signal. The design of this part of circuit is as follows:



Upon passing a sinusoidal input of amplitude 7V and frequency 20Hz to this part of the circuit, we observe the following plots at ‘out1’ and ‘out2’ respectively.



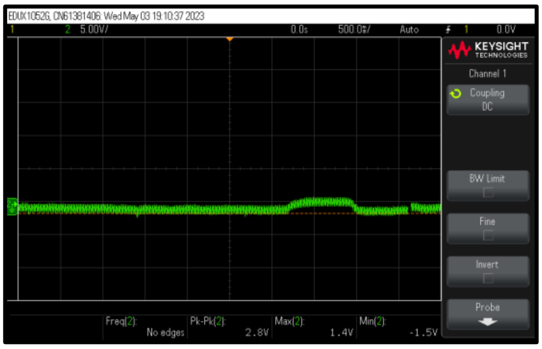
‘out1’



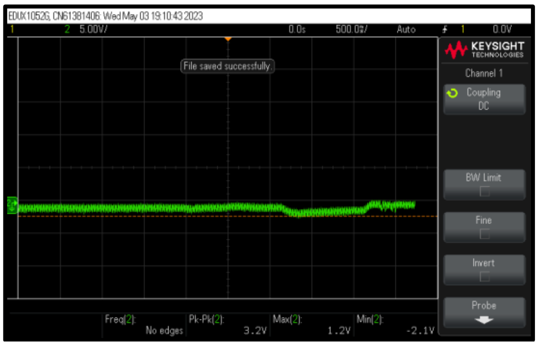
‘out2’

We can observe rectification taking place. This design was chosen due to its simplicity and effectiveness. There was an alternative to detect the eye-movement using the level-shifter. In comparison to the level-shifter circuit, this is much simpler and more efficient in terms of power.

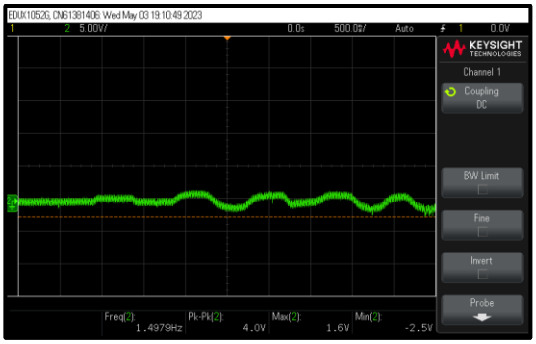
IV. RESULTS



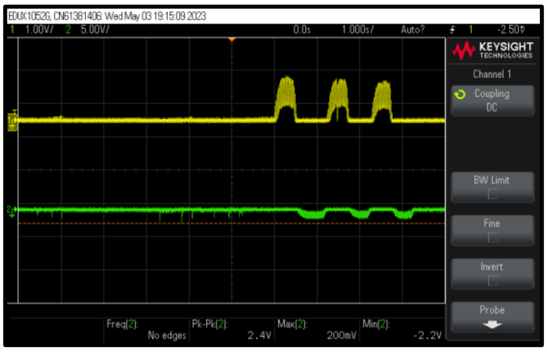
Signal when eyes are moved towards right.



Signal when eyes are moved towards left.

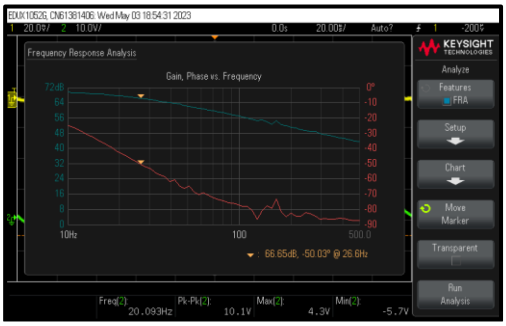


Signal when eyes are moved left and right alternatively.



Segregating the signal obtained by moving eyes left and right alternatively into two output lines.

Bode plot for the circuit output.
Gain observed = 69.7dB



Bode plot for the circuit output.
-3dB observed around 26.6Hz

V. CHALLENGES FACED

1. Re-designing the circuit :
The initial design consisted of an instrumentation amplifier, 3rd order bandpass filter and a rectifier. We included a buffer after each stage and the circuitry got complicated. Although this was done to attenuate noise, the complicated circuitry just accumulated more noise. Due to this, the design had to be altered to something much simpler.

2. Noise:
The noise was significantly active despite there being a low-pass filter with a cut-off frequency of 30Hz. As this was a major issue, we have designed a notch filter to eliminate 50Hz noise. Upon analysis of the bode plot, we observed that the amount of attenuation at 50Hz frequency didn't improve prominently. So this idea was discarded and went ahead with the former design.

3. Parasitic Capacitances:
The values calculated theoretically for the cut-off frequencies gave different results than expected when the Bode-plot was observed. We realized this was due to the existence of parasitic capacitance on the breadboard. In order to overcome this deviation, we had to try and figure out the appropriate capacitance,

4. Wearing out of electrodes:
The aqueous gel on the electrode dries up fast. Therefore, during testing, electrodes had to be changed frequently. At times, we obtained wrong results and a lot of noise due to worn out electrodes and this was a major issue.

VI. CONCLUSION

In conclusion, with the implementation of a basic circuit consisting of an instrumentation amplifier,

an active band-pass filter, a gain stage, and a rectifier, we were able to extract a signal based on eye-movement. This circuit is ideal to assist the quadriplegic as it is reliable, economic, and efficient. The simplicity of the circuit is one of the key features of the design. The motive behind the paper was to assist the quadriplegic and the output signal obtained serves that purpose. For example, the output from this circuit could be used as an input to the motors in a wheelchair. In this scenario, the person can maneuver as they wish simply based on the movement of his eyes. This can be thought of as a step ahead in a world with progressing technology.

VII. REFERENCES

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VIII. ACKNOWLEDGEMENT

We would like to express our sincere gratitude to our advisor, Dr. Anshu Sarje for providing us with the problem statement. We would also like to thank her for her guidance and support throughout the project.