EEG Monitor for Detecting Neurological Disorders

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***Abstract* - An EEG records the electrical activity of the brain and converts the signals to various waveform patterns, of different frequencies, that play a vital role in diagnosing, monitoring, and understanding neurological diseases. An EEG can detect abnormal patterns of brain activity that indicate several neurological disorders such as epilepsy, Alzheimer's disease, ADHD, anxiety disorders, and Parkinson's disease. Our EEG design utilized an instrumentation amplifier to amplify the weak signal captured. Furthermore, a notch, high pass, and low pass filters were used to remove any motion artifacts or unwanted noise. Analyzing the spikes, sharp waves, and slow wave activity differentiated several neurological disorders aiding in early diagnosis, treatment planning, and evaluating the efficacy of therapeutic interventions.**

I. INTRODUCTION

Neurological disorders are a type of medical condition that affects the brain and nerves throughout the human body as well as the spinal cord. These disorders may stem from structural, biochemical, and electrical abnormalities in the brain. Neurological disorders can also arise from genetic disorders, brain or spinal cord injuries, malnutrition, and psychiatric illnesses. Some of the symptoms include paralysis, abnormal movement, seizures, difficulty swallowing, and more.[7]

The types of neurological disorders that we are attempting to identify using the EEG model are the following: epilepsy, Alzheimer's disease, ADHD, anxiety disorders, and Parkinson's disease. Epilepsy is a disorder in which nerve cell activity in the brain is hindered resulting in seizures. Alzheimer's disease is a progressive disease that destroys memory and important mental functions as the brain cells and their respective connections are degenerating. Attention deficit hyperactivity disorder (ADHD) is a chronic condition that contributes to attention difficulty, hyperactivity, and impulsiveness. Anxiety disorder is considered a mental health disorder in which a person experiences heightened feelings of worry, anxiety, or fear that impact their daily routine. Lastly, Parkinson's disease is a disorder stemming from nerve cell damage that results in slow movement, stiffness, and loss of balance.

An EEG (electroencephalogram) is a non-invasive method that measures and records the spontaneous electrical activity in the brain using electrodes attached to the scalp, specifically the cerebral cortex, via a headband. Since brain cells communicate via electrical impulses, their activity can be recorded as EEG waveforms. The categorization of this biofeedback and analysis of abnormal patterns will help clinicians diagnose various neurological conditions and assess brain functions.

II. METHODS

A. Assumptions

We assume that during EEG recording sessions, the user's state remains relatively stable, with distinguishable variations occurring between different neural states. Our circuit incorporates high pass, low pass, and notch filters specifically designed to effectively remove unwanted frequency components e.g. outside the alpha wave range (8-12 Hz), ensuring accurate measurement of brain activity. It is assumed that there is minimal interference from external electrical sources that could potentially introduce noise into the EEG signal, allowing for clear and reliable data collection. Our circuit assumes an ideal amplification response of the instrumental amplifiers, with linearity maintained within the desired frequency range of the alpha waves. Additionally, the gain of the amplifiers remains constant across varying input voltages. Consistent and stable contact between the EEG electrodes and the user's scalp is crucial for reliable signal transmission. We ensure this contact is maintained throughout the recording session to minimize signal loss or distortion.

B. Procedure

For our design we can utilize a headband with embedded electrodes that are placed on respective locations of the scalp. One electrode must be placed on the mastoid which is the bone behind the ear. Another electrode is placed about an inch above and towards the right of the nasion which refers to the ridge between your nose and forehead (slightly above the eyebrows). Another electrode is placed an inch above the inion, which is the point where the skull ends at the back of the head. Hence, these electrodes lay on the occipital lobe of the brain which is responsible for visual processing.

When neurons fire to communicate with other neurons, a small electric current is generated due to the movement of ions across the cell membrane. The flow of ions creates an electric field around each neuron which is amplified when a collection of neurons fire simultaneously. The EEG will measure the electrical activity in the brain by recording the fluctuations of voltage due to ionic current flow.

Since the electrical signals captured by the electrodes are relatively weak, the signal requires amplification and filtering with the utilization of an instrumentation amplifier and a notch, high pass, and low pass filter. This also removes any motion artifacts or unwanted noise which improves the signal to noise ratio. The amplified electrical signals are recorded and displayed as a series of wave patterns that depict voltage fluctuations with respect to time.

The first method to identify waveforms is to visually identify the variations in frequency, amplitude, and the general EEG waveform. A more accurate method to categorize the waveforms would be to determine the frequency and amplitudes using mathematical algorithms. The frequency ranges allow each waveform to be categorized into either alpha, beta, theta, or delta waves to be further analyzed.[8] The variability will provide information regarding the neurological disorders associated with each frequency range.

The alpha waves, depicted with a frequency of 8-12 Hz, are observed when a person is awake but relaxed. Reduced alpha wave activity or abnormalities detect conditions such as epilepsy, Alzheimer's disease, dementia, and ADHD. If the amplitude of the alpha wave falls outside of the ideal range of 20-200 microvolts, neurological disorders can be observed. There are multiple abnormalities that can depict epileptic activity. For example, sharp spikes or peaks, meaning higher amplitudes, that occur for 20 to 70 milliseconds followed by a wave component are clear indications of a seizure. The beta waves, depicted with a frequency of 12-30 Hz, are observed when a person is fully awake, specifically mentally concentrated. Beta wave abnormalities are categorized by amplitudes that are lower than the ideal 5-10 microvolt range. If both alpha and beta waves increase linearly with time, the individual is experiencing dementia.[5]

The high pass filter removes theta and delta waves, as they pertain to an individual's unconscious state, which is not relevant for analyzing neurological disorders. Theta waves, occurring at a frequency of 4-8 Hz, are observed when a person is experiencing light sleep, drowsiness, or even deep meditation. Delta waves, occurring at a frequency below 4 Hz, are observed when a person is in deep sleep. Any abnormalities in the theta and delta waves provide data regarding sleep disorders.

III. EEG CIRCUIT DESIGN

A. Overview

The EEG design's purpose is to capture alpha waves. Neurons within the brain communicate through electrical signals. The ongoing neural activity manifests as distinct wave patterns that can be analyzed via recordings obtained through an EEG. Electrodes placed on the scalp allow the capturing of these electrical signals. It incorporates a comprehensive order of components adapted to enhance signal fidelity and isolate the desired brainwave acidity. First, the inclusion of an instrumentation operational amplifier (op-amp) allows optimal signal amplification with minimal noise interference. A notch filter is integrated to eliminate unwanted frequencies to enhance the clarity of alpha wave signals. Subsequently, a high-pass filter is employed to reduce low-frequencies, while a low-pass filter refines the signal by removing high-frequencies noise components. The addition of a second instrumentation op-amp amplifies the filtered signal again. Lastly, a second notch filter is implemented to provide a great deal of attenuation over a narrow band of frequencies.

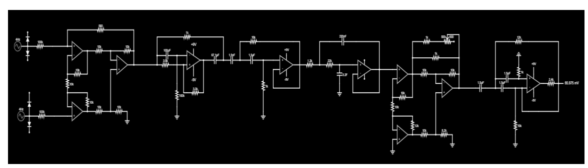

Figure 1: EEG Schematic with (left to right) Instrumentation op-amp, 1st notch filter, high-pass filter, low-pass filter, instrumentation op-amp with variable gain, and 2nd notch filter.

B. Instrumentation Amplifier

In EEG setups, amplifiers play a crucial role in boosting small voltage signals, such as the low-amplitude alpha waves that range from 15-50 μV. Generally, instrumentation amplifiers take their two input voltages and output the difference multiplied by a specific gain factor, G. For our device, we choose to reference the AD620 instrumentation amplifier chip which offers high accuracy and requires only one external resistor to set gains ranging from 1 to 10,000.[2] Using this amplifier chip specifically, allows us to alter the gain by changing the value of the resistor, R_G, between pin 1 and 8. The gain factor is represented by the following formula:

$$G = 1 + \frac{49.9k\,\Omega}{R_G}$$

From this formula, we equated a gain of about 91 with a 560 Ω resistor for adequate signal detection in stage 1 of our design. However, as we can infer, offsets, which encompass noise and interference, are typically present on both input terminals of the amplifier. Implementing the instrumental amplifier as our first component provides ample amplification when dealing with high levels of noise in data. Since brain waves like alpha, beta, gamma, and delta occur at very low voltages (around 20-100 uV), substantial amplification becomes necessary throughout the course of our circuit design. Further, we can note that the Common-Mode Rejection Ratio (CMRR) indicates how effectively the amplifier disregards common offsets between input voltages, with higher ratio values suggesting better performance.[10]

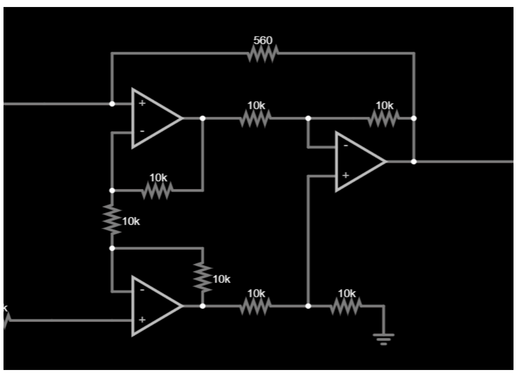

Figure 2: Instrumentation Amplifier (Gain ~ 91).

C. 1st Notch Filter

A notch filter was utilized to filter out power line interference that could be affecting our data. Power line interference includes interference that comes from the other electrical components in the circuit as well as the wiring. Most power line interference occurs at an interference level of around 60 Hz.[4] To remove this interference so that more gain can be applied to the circuit, a notch filter was used before the other components. A notch filter was also utilized at the end of our circuit to remove any power line interference that may have been generated after the first notch filter was used.

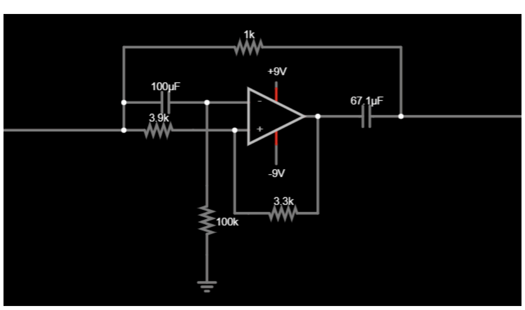

Figure 3: 1st Notch Filter

D. High Pass Filter

High pass filters to filter out specific frequencies, and one is used in the EEG to filter out the frequencies that occur from the galvanic skin response. Since the EEG obtains data through electrodes that have direct contact with the human scalp, a voltage is produced through this contact. This voltage is known as the galvanic skin response and usually has a very low frequency. This interference is filtered out using the high pass filter that has a frequency of 7.2 Hz.[4] Since this filter removes interference occurring at a low frequency it also removes most of the theta and delta wave data, since they both occur at low frequencies with theta waves occurring from 4-8 Hz and theta waves occurring below 4 Hz.

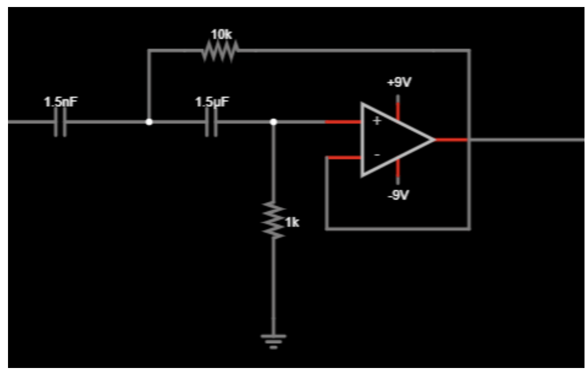

Figure 4: High Pass Filter.

E. Low Pass Filter

The low pass filter is used to remove all data above 30 Hz because alpha and beta waves do not occur over frequencies of 30 Hz. This low pass filter was set at a frequency of 32.9 Hz in order to remove any interference data above 30 Hz.

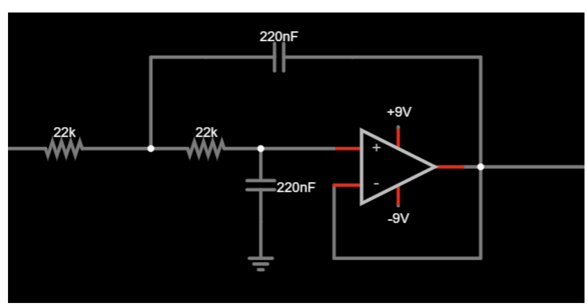

Figure 5: Low Pass Filter.

F. Instrumentation Amplifier with Variable Gain

As we are to encounter weak neural signals captured by scalp electrodes, we incorporated an instrumentation amplifier with variable gain in addition to the first instrumentation amplifier to accommodate the wide range of alpha wave amplitudes observed in different individuals.[10] In terms of the circuit configuration, at the core of the amplifier, is a non-inverting amplifier with its gain controlled by a potentiometer. The gain (G) of this circuit is determined by the resistance values of R_{12}, R_{13}, and R_{14}, set in series and parallel as per the following equation:

$$G = 1 + \frac{R_{16}}{(R_{17}+R_{18})}$$

The potentiometer, acting as a variable resistor, allows for linear adjustment of resistance between 0 to 1000 Ω, thereby modulating the gain of the amplifier to range from approximately 90 to 460.[6] In turn, this variable gain feature enables more precise control over the amplification of neural signals, ensuring optimal signal-to-noise ratios across diverse recording conditions.

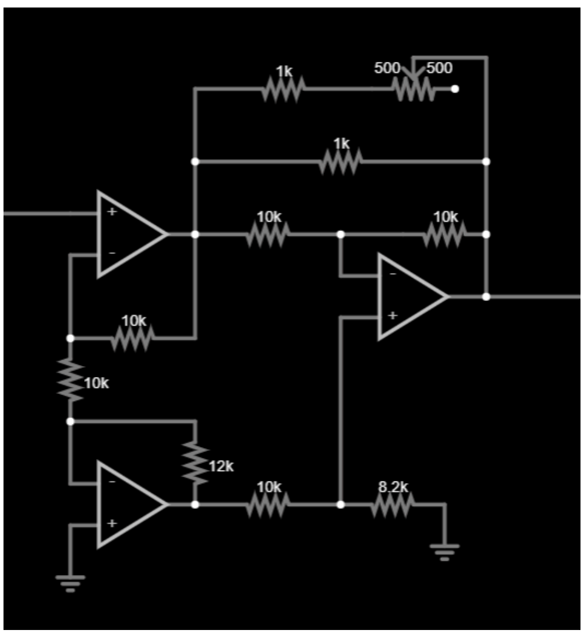

Figure 6: Instrumentation Amplifier with variable gain (Gain ~ 90 - 460).

IV. RESULTS

A. Limitations

In the pursuit of a better understanding of neurological activity through EEG technology, it's crucial to recognize the inherent limitations. These limitations highlight areas where refinement is essential for maximizing the utility of EEG in clinical and research settings such as our experiment on neurological disease detection. One of the foremost challenges in EEG analysis is the presence of artifact signals that can obscure or distort the brain's electrical activity. These artifacts may stem from various sources, including muscle movements or spasms, eye blinks, or environmental interference. Despite the implementation of signal processing techniques via the integration of high-pass, low-pass, and notch filters, genuine neural signals are still prone to offsets that may be magnified during processing through the instrumental amplifier. In such a case, distinguishing these artifacts from targeted neural signals requires robust signal processing filtering and careful consideration during data interpretation. Secondly, the accuracy and reliability of EEG recordings are heavily impacted by precise electrode placement. However, achieving consistent and optimal placement poses practical challenges due to individual variations in skull anatomy in different adults and electrode-skin interface impedance. Improper electrode positioning can compromise data quality and impede the interpretation of EEG findings and contribute to artifact signals. Likewise, the number and configuration of electrodes in the setup directly influences its ability to capture and isolate neural signals accurately. Lastly, the diverse range of neurological phenomena captured by EEG necessitates tailored experimental setups to extract meaningful information. Each distinct waveform pattern, from alpha to theta waves, requires specific recording parameters and analysis protocols. In our circuit design, we were only able to detect alpha and beta waves. With some tweaks to our circuit design, we should be able to measure delta and theta waves. Managing the variability demands robust standardization of procedures to ensure reproducibility across experiments.

B. Future Improvements

Further developments in the EEG design aim to enhance signal quality and reliability. It is common in signal processing to incorporate independent component analysis (ICA) where multivariable signals are decomposed into independent non-Gaussian signals [11]. The integration of ICA offers advancements in signal processing and quality by eliminating motion artifacts with minimal delays in signal propagation. This would aid in ensuring the extraction of independent component-time courses, which helps in isolating various sources of signal interference, thereby enhancing the accuracy of EEG data analysis. Additionally, optimal electrode placement is crucial as it influences the ability to capture electrical signals originating from specific brain regions in many different individuals, and the overall signal-to-noise ratio of the recorded data. By accounting and customizing for an individual's skull variations while targeting universally recognized areas, more precision results can be obtained. Lastly, the integration of specialized filters and additional electrodes dedicated to filtering out various sources of noise, such as eye/heart movements and muscle contractions will contribute to the accuracy of the electrical neural activity captured through the EEG device. Lastly, for better signal enhancements and resolution, the resistor within the front end (R_1) can be manipulated with the inclusion of a potentiometer. By varying R_1 resistance, the amplification level can be better suited for the EEG signal characteristics and requirements. The potentiometer in the second stage only focuses on further conditioning the signal and adjusting the baseline offset, thus the addition or replacement with the potentiometer in the first stage aids in optimizing signal processing.

V. CONCLUSION

The EEG monitor is designed with four main components, the instrumentation amplifier, notch filter, high pass filter, and low pass filter. The signal was successfully amplified and filtered out unwanted noise to depict accurate results for alpha and beta waves. Electrical activity was simulated using AC voltage sources to mimic the patterns of neural firing in the brain. The incorporations of the instrumental op-amp and filters allowed the EEG design to filter out abnormal readings while amplifying the simulated electrical signals. As a result, our design was able to replicate the characteristic frequencies of alpha waves, accompanied by the voltage differences reflecting human brain dynamics. With the obtained results, we were able to identify abnormal patterns, such as spikes, sharp waves, and slow wave activity, in the brain that may be linked to neurological disorders. With the utilization of this technology, our aim is to identify and implement preventive measures for neurological disorders. Additionally, the EEG monitor will improve diagnostic accuracy, evaluate personalized treatments, and enhance our knowledge of neurobiology. For example, the device can be integrated to capture lower alpha wave power that diagnoses Alzheimer's disease.

ACKNOWLEDGMENTS

We extend our appreciation to Professor Gert Cauwenberghs and the BENG 186B TAs for their guidance and profound expertise this quarter. Their support and extensive knowledge enhanced our comprehension of the class material as well as our project's concepts.

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