EEG for the Diagnosis of Epilepsy

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***Abstract* - Epilepsy is a neurological disorder in which the brain activity becomes abnormal and causes seizures, or a burst of uncontrollable movements, such as stiffness or twitching, as a result of irregular electrical activity in the brain. In order to accurately detect the occurrence of such seizures, this project focuses on an electroencephalogram design that is able to diagnose and monitor epileptic seizures. Utilizing an EEG, frequency and brain signals from electrogram graphs can be interpreted to detect certain disorders, in this case seizures due to epilepsy. The EEG design implemented consists of three main components: the instrumental amplifier, band pass filter, and non-inverting amplifier. These components work together to input signals to the brain, amplify them, and filter them to isolate the brain waves, ultimately disclosing an epileptic seizure.**

I. Introduction

Epilepsy is one of the most common neurological conditions, affecting about 5.1 million people in the United States [5]. Seizures due to epilepsy are bursts of uncontrollable movements, such as stiffness or twitching, that are a result of abnormal electrical activity in the brain. This electrical activity can be measured noninvasively using electroencephalography, or EEG. Diagnosing epilepsy can help improve a health outcome for a patient because if properly diagnosed and treated, up to 70% of people with epilepsy could become seizure-free [8].

In an EEG, 9 traditional ring-shaped Ag/AgCl electrodes are placed all around the head of the patient. These electrodes, consisting of 8 input electrodes and 1 reference electrode, measure brain waves, then input the signal frequency into their individual circuit. The circuit uses bandpass filters to read only one type of brain wave (determined by the electrodes location), and then amplifiers to allow the signal to be read by the computer. A typical EEG measures 4 types of brain waves, Beta (β), Alpha (α), Theta (θ), and Delta (δ) waves. Beta waves occur at a frequency of 12–30 Hz, Alpha waves are 8-12 Hz, Theta waves are 4-8 Hz, and Delta waves are 0-4 Hz. The computer will plot the voltage of the wave signals from the electrode location on an electrogram graph. The amplitude and oscillation of the signal on the electrogram graph will allow visualization of what is happening in the brain, which can help a doctor determine if an epileptic seizure is occurring based on the amplitude of the wave.

A epileptic seizure is characterized in an electrogram graph by two phases: the tonic phase, where an individual loses consciousness and their body stiffens, followed by a clonic phase that consists of the body rhythmically jerking [8]. On an EEG, the tonic phase is represented by smooth lines with low amplitudes, followed abruptly by rapid, sharp wave signals indicating the clonic phase.

Although clinicians can reasonably diagnose seizures based on accounts of the patient and witnesses, EEGs can help distinguish between a complex partial seizure with focal IED, and an absence type seizure with generalized IED, increasing the precision of the diagnosis, and aid in diagnosis when aid of the patient or witnesses are not available [5].

One example is the misdiagnosis of PNES as Epilepsy. PNES or a psychogenic non-epileptic seizure triggered by PTSD or abnormally high levels of stress, *which is very distinct from Epilepsy*. PNES seizures can look and feel the same as epileptic seizures, causing their misdiagnosis, but people with PNES are not experiencing the same electrical overload in their brains as would one with Epilepsy.

The process of diagnosing PNES with the current EEG can be lengthy. Patients are referred to a seizure specialist who obtains an EEG that measures the electrical activity of the patient's brain during multiple seizures over a span of a couple of days (in a clinical environment). Patients who have epilepsy will often show characteristic spikes in electrical activity on the EEG, while patients who have PNES will show normal brain activity [3]. PNES still remains unfamiliar, making one wonder that if one can measure different waves through one electrode, could one discover more about the brain activity of someone who appears to have Epilepsy.

The goal of this EEG device is to specifically measure the brain activity of a person suffering from seizures to determine if they have epilepsy, which can allow proper preventative measures to be taken and lead to potentially life saving results. Additionally, it hopes to make the device more versatile by making the EEG read any brain wave frequency from an electrode at any location, allowing the observer to get a fuller picture of the brain's activity during a seizure or anytime else.

II. *Instrumental Design*

A. Overall Design

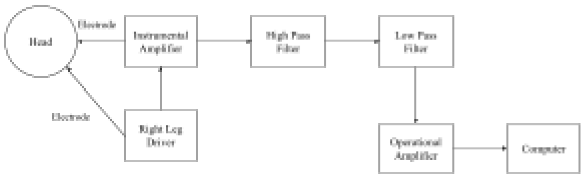

Figure 1: Overall Design Flow Map

The signal first comes from the head to the instrumental amplifier. The instrumental amplifier is used in order to amplify the imputed voltage by amplifying the voltage difference across the inputs. The instrumental amplifier is connected to the right leg driver which grounds the circuit and reduces any electromagnetic interference

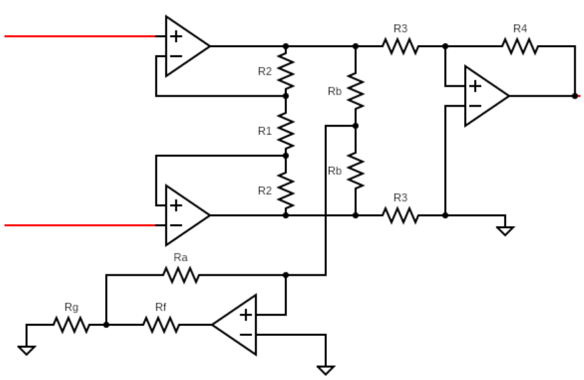

Figure 2: Instrumental Amplifier with Right Leg Driver

Following the instrumental amplifier is the band pass filter. This consists of both the high pass and low pass filters. As the signal passes through the band pass filter it isolates and identifies specific waves of the signal.

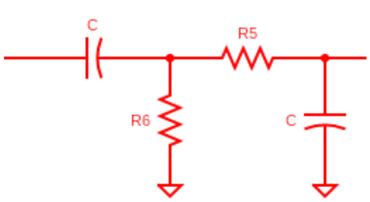

Figure 3: Band Pass Filter

After the band pass the signal then feeds into a non-inverting operational amplifier. This op-amp produces an amplified output signal in with the input signal

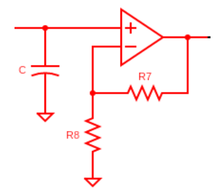

Figure 4: Non-inverting Operational Amplifier

It was determined that for this circuit a total gain of 10100 would be enough to send the signal taken from the brain to the computer. This is as the electrode should be within the range of about 10uV-100uV and the input range for ADC is around 0 - 3.3V.

In order to analyze all the different types of waves in the brain we must set each band pass filter for each sub section of the circuit to the specific signals required to identify each wave.

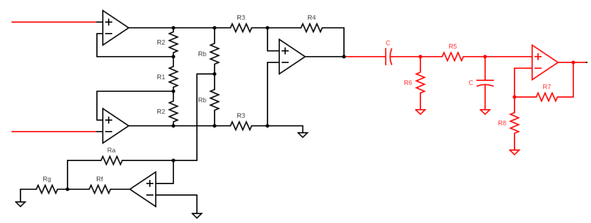

Figure 5: One Section of Overall Circuit

B. Electrodes

Ag/AgCl electrodes provide the circuit with stable, low-noise recordings of the electrical activity of the brain. The EEG design utilizes a total of 9 Ag/AgCl electrodes. One of the electrodes is the reference electrode which calibrates the level of zero voltage. The other eight electrodes work in reference to the reference electrode and can be placed on each lobe of the brain and measure the signal brain waves in that area.

In principle, the electrode converts the ion current at the surface of human tissues to an electron current to be delivered through an electrical wire to the measurement instrument [4]. The Ag/AgCl electrode consists of a silver (Ag) disc coated with silver chloride (AgCl). The silver chloride coating ensures that electrical contact is stable overtime and can withstand sweat or other skin oils. The electrode itself is filled with a conductive gel, which allows for electrical contact with the skin. The conductive gel contains chloride ions which allows ion currents to flow through the electrolyte gel, resulting in the same conductivity as human tissues [4]. The Ag atoms of the electrode oxidize as the ion current develops, so Ag+ cations enter the solution while the electrons flow through the electrical wire carrying the electrical charge [4]. At the same time Cl- anions in the electrolyte gel react with Ag + on the Ag(s) electrode surface, and form AgCl, enabling the ion current to pass from the electrolyte gel to the electrode as the electron current flows through the wire to the measuring device [4]. The Ag/AgCl electrode also has a low impedance, which minimizes noise and interference in the recorded signal. Thus, the Ag/AgCl is deemed a reliable choice for measuring electric signals for an EEG or any other physiological electrical activity.

C. Individual Components

The Resistor and Capacitor values of the circuit are

$$R_1 = 1\ k\Omega,\ R_2 = 50\ k\Omega,\ R_3 = 500\ \Omega,\ R_4 = 50\ k\Omega,$$

$$R_5 = 2.5\ k\Omega,\ R_6 = 1\ k\Omega,\ R_7 = 99\ k\Omega,\ R_8 = 1\ k\Omega,$$

$$R_g = 1\ k\Omega,\ R_f = 1\ M\Omega,\ R_a = 400\ k\Omega,\ R_b = 2\ k\Omega,$$

$$C = 5\ \mu F$$

The gain of the Instrumentation Amplifier was calculated using the following equation

$$A_i = (1 + 2\frac{R_2}{R_1})\frac{R_4}{R_3} \qquad (1)$$

Used the chosen values of the resistors listed above, The gain of the Instrumentation Amplifier is 10100.

The gain of the Right Leg Driver using the equation

$$A_R = -\frac{R_a}{R_b} \qquad (2)$$

and the listed resistor values is calculated to be -500.

The Band Pass Filter utilized a high pass filter and a low pass filter to allow the wave within the desired cutoff range through each circuit. The high pass filter sets the upper bound and the low pass filter sets the lower bound of the allowed frequency. The equation used for the cutoff frequencies is

$$f_c = \frac{1}{2\pi RC} \qquad (3)$$

The following table shows the frequency cutoff and ranges for each brain wave measured by the electrode.

Wave	Low pass cutoff frequency (Hz)	High pass filter cutoff frequency (Hz)
Delta	0	4
Theta	4	8
Alpha	8	12
Beta	12	30

Table 1. The cutoff frequency for each wave that is measured by electrodes

Lastly, the gain of the non-inverting amplifier is calculated using the equation

$$A_n = 1 + \frac{R_7}{R_8} \qquad (4)$$

The gain of the non-inverting amplifier is 100.

III. Results

Using a circuit simulation tool, the operation and behavior of the device was tested.

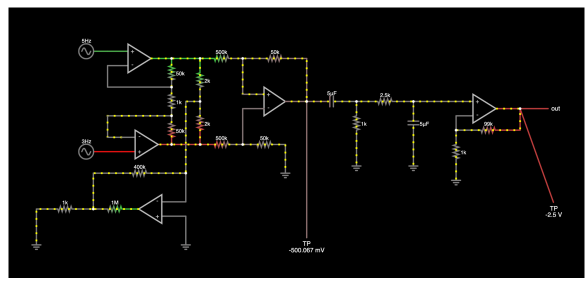

Figure 6: Circuit simulation of the Beta wave section of the circuit

At the first Testing Point (TP in Figure 1), the output voltage measurement of the instrumental amplifier and op amp is 500.067 mV. This voltage needs to be sufficiently high enough in order for the signal to still be available after going through the band pass filter.

At the second Testing Point, the output voltage measurement is 2.5 V. This output voltage leads to the computer, so it will need to be high in order for the computer to be able to read the signal and plot it, but it should also not be too high. If the output voltage is greater than the input power supply to the amplifier, saturation would occur. For our circuit, an output voltage of 2.5V is ideal, and it will allow the computer to plot proper wave signals without over saturation.

IV. Discussion

There are many advantages to implementing an EEG seeking to diagnose and detect cases of epilepsy. The versatility that this EEG design creates offers many more opportunities for research due to the additions implemented in the circuit design. The design additionally allows for receival of all types of brain wave signals from every region of the brain, giving the advantage of higher obtainability of acquiring results. Not only does it receive all wave signal types, but it is also able to accurately identify which wave is from which area. Furthermore, the EEG design offers more precise diagnoses from the EEG graphs that helps to better distinguish certain features. A relevant example includes the easily visible diagnosis of PNES compared to epilepsy.

The EEG is not without limitations, however. A major drawback for EEGs in general is the lack of accessibility for EEG usage in terms of cost and time. In terms of the EEG's performance in detecting epileptic seizures, the detection of IEDs occurs unpredictably, which can lead to false EEG results. In addition, considerably large areas of cortex that are in the order of a few square centimeters for electrode placement on the scalp must be activated synchronously in order to generate enough potential for the electrodes [3]. Spatial and temporal samplings are major limitations of EEGs that also constrain its performance, especially with IED detections as mentioned previously.

In conclusion, the objective of this report is to introduce a device that is able to diagnose and monitor epilepsy through an electroencephalogram. This was accomplished through a circuit design, the main components including an instrumental amplifier, bandpass filter, and operational amplifier.

These components work together to receive signals from the brain that can then be amplified and filtered so that brain waves can be distinguished thereafter. An EEG device to diagnose epilepsy has great significance in terms of Bioengineering applications as it is a step toward the detection of many other neurological conditions through an EEG. It is also innovative in distinguishing between epilepsy and PNES, further improving the diagnosis of seizure-related conditions.

V. References

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