Lab: Electroencephalogram

An Electroencephalogram (EEG) is a method used to record the brain's electrical activity through electrodes placed on the scalp. These electrodes detect voltage changes resulting from the synchronous firing of neurons in the brain's cortex. In our setup, EEG sensors captured these voltage fluctuations in microvolts, allowing us to measure the brain's electrical signals during both resting and task-based (mental arithmetic) conditions.

Circuit Diagram

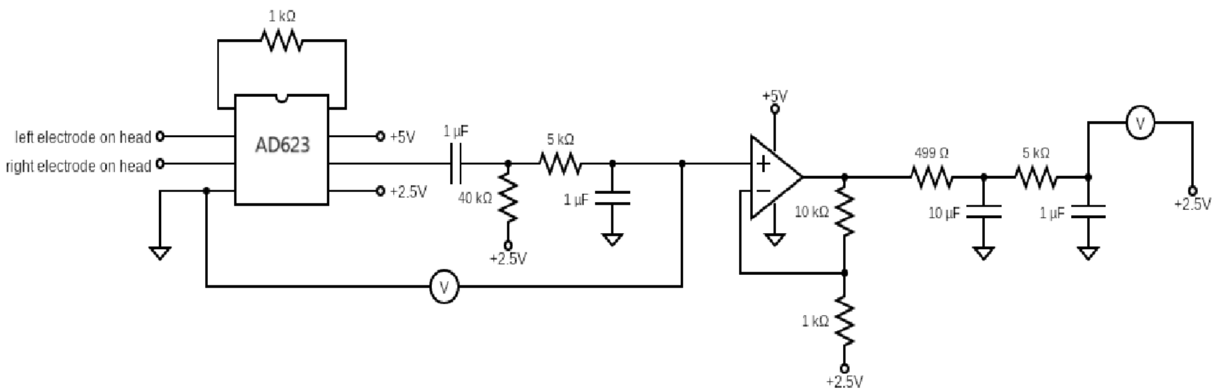
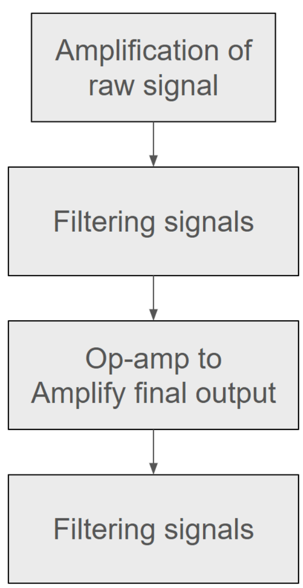


Figure 1: circuit diagram of the circuit to be built

Function of the circuit

Our instrumentation performs the main task of amplifying the raw brainwave signals generated via the electrodes. For simplification it can be broken down into these main functions:



(a) Procuring the raw data

To generate the waveform input for the oscilloscope, we used a CSV dataset containing time-stamped voltage values. This dataset, sourced from Kaggle, features EEG recordings collected from participants both before and during mental arithmetic tasks. The recordings were sampled at 500 Hz, with voltages measured in microvolts. We provided this data as an input waveform with the help of the O-scope. More detail on this in the “Final measurements” section.

Although we originally intended to use live EEG data from a subject, our hardware setup (shown below) was not sufficiently sensitive to capture the extremely small voltage variations produced by brain activity.

Figure 2: Skin prep gel (on the left) along with electrodes to record measurement

(b) Amplification of the raw signal

The amplitude of brainwaves is usually in microvolts. 1000000 microvolts is a volt. So, the gain of this circuit would have to be 100,000. We do this using an AD623 IC. The first one has a gain of 101

$$G = 1 + \frac{100k\Omega}{R_g}$$

$$G = 1 + \frac{100k\Omega}{1k\Omega} = 101$$

Below is a closer look at our band pass filter

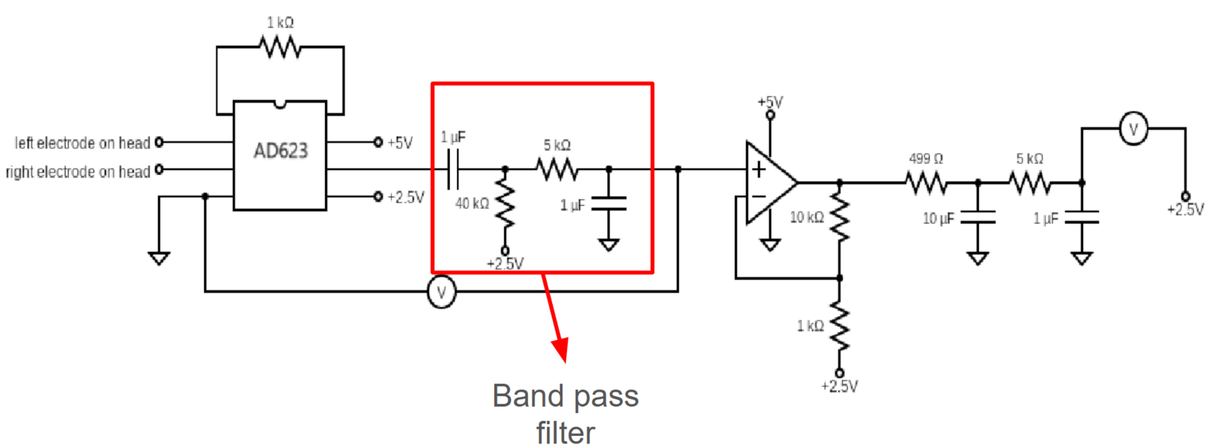


Figure 3: Shows the circuit diagram with emphasis on our band pass filter.

We amplify the raw brainwave signals collected from electrodes placed on the frontal lobe. The system measures the voltage difference between these two electrodes, using a ground electrode positioned on the neck as a reference. Initial amplification is carried out using the AD623 instrumentation amplifier. Since brainwave signals are extremely low in voltage and the subsequent filtering process further reduces their amplitude, early-stage amplification is essential to maintain signal integrity. Additionally, this amplification helps mitigate any signal loss caused by resistive components in the later stages of the circuit.

(c) Filtering the signals

Our circuit incorporates two filters: a high-pass filter with a cutoff frequency of 4 Hz and a low-pass filter with a cutoff frequency of 30 Hz. The reasoning behind these specific values is discussed in detail below. Filtering at this stage is crucial for removing high-frequency noise that may have been introduced and subsequently amplified along with the brainwave signals. Since the amplifier enhances both the desired brainwave signals and any unwanted noise present in the measured data, filtering helps isolate the relevant frequency range associated with brain activity. This improves the clarity and accuracy of the signals obtained from the frontal lobe.

- **Lower cutoff frequency: 4Hz**

$$f = \frac{1}{2\pi RC}$$

$$RC = \frac{1}{8\pi}$$

$$RC = 0.039788$$

$$C = 1\mu F$$

$$R = 39.7k\Omega \text{ (or slightly higher)}$$

We chose to use two $20k\Omega$ resistors in series to make a $40k\Omega$ based on availability in the lab. The capacitor we used was $1\mu F$ to make the high pass filter inside the band pass filters.

- **Higher cutoff frequency: 30Hz**

$$f = \frac{1}{2\pi RC}$$

$$RC = \frac{1}{60\pi}$$

$$RC = 0.005305$$

$$C = 1\mu F$$

$$R = 5.305k\Omega \text{ (or slightly lower)}$$

We chose to use a $4.99k\Omega$ resistor based on availability in the lab. The capacitor we used was $1\mu F$ to make the low pass filter inside the band pass filter.

(d) Op-amp to amplify the final output

We aim to keep the signal within a higher voltage range to ensure that significant changes in brainwave activity are easily visible and distinguishable. For this we use an Op-amp with a gain of 10 to further amplify the signal and make it more readable. This gain is dictated by a $1k\Omega$ and $10k\Omega$

(e) Filtering the signals (post op-amp)

Filtering is performed at this stage to reduce high-frequency noise. This section uses two low-pass filters, each with a cutoff frequency of 30 Hz.

- **Higher cutoff frequency for Low pass filter 1: 30Hz**

$$f = \frac{1}{2\pi RC}$$

$$RC = \frac{1}{60\pi}$$

$$RC = 0.005305$$

$$C = 1\mu F$$

$$R = 5.305k\Omega \text{ (or slightly lower)}$$

We chose to use a $4.99k\Omega$ resistor based on availability in the lab. The capacitor we used was $1\mu F$ to make the low pass filter inside the band pass filter.

- **Higher cutoff frequency for Low pass filter 2: 30Hz**

$$f = \frac{1}{2\pi RC}$$

$$RC = \frac{1}{60\pi}$$

$$RC = 0.005305$$

$$C = 10\mu F$$

$$R = 530.5\Omega \text{ (or slightly lower)}$$

We chose to use a 499Ω resistor based on availability in the lab. The capacitor we used was $10\mu F$ to make the low pass filter inside the band pass filter.

Below is a closer look at our low pass filters:

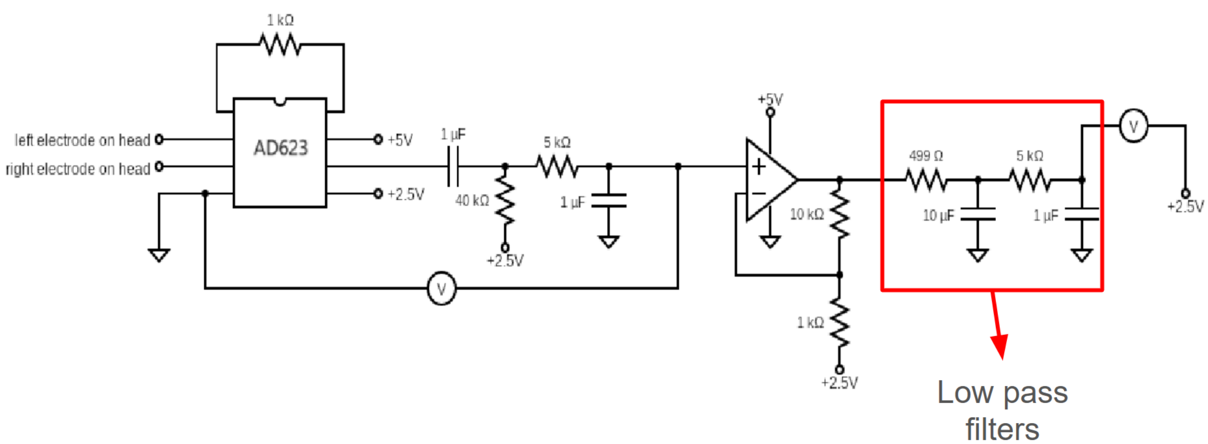


Figure 4: Shows the circuit diagram with emphasis on our second order low pass filter.

Conversion Description

EEG signals are direct measurements of electrical voltage fluctuations in the brain, typically recorded in microvolts. Since the raw EEG data we used was already in voltage form, no conversion to a different data type was necessary. Instead, the transformation carried out by our instrumentation involved amplifying these raw signals. Because EEG signals are extremely small and often obscured by noise, amplification is essential to make these voltage differences more detectable and suitable for further processing. Our circuit enhances the signal strength, allowing analysis tools like a patient monitor to interpret the brainwave data more effectively.

EEG (electroencephalogram) signals reflect the electrical activity generated by neurons firing in the brain. Different patterns and frequencies in these signals correspond to various cognitive states and activities. In our dataset, these signals were captured while participants performed mental arithmetic tasks, enabling us to observe brain responses associated with focused cognitive effort.

Bode plot

Title : Bode plot for EEG amplification instrumentation

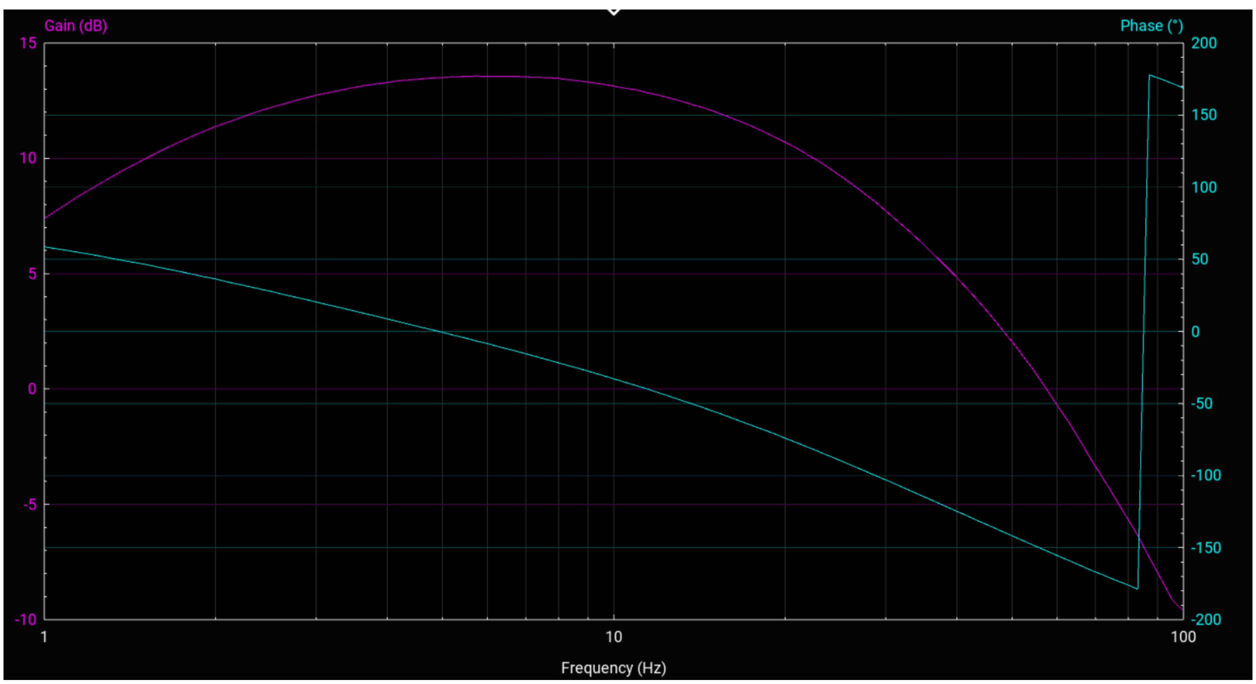


Figure 5: The bode plot (Gain in dB vs. Frequency in Hz) above represents the cut off frequencies of the circuit dictated by three low pass filters with a cut-off frequency of 30 Hz and one High pass filter with a cutoff frequency of 4 Hz. This can be seen above. It should be noted that the initial AD623 amplifier gain was changed to 1 to visualize the bode plot better.

Final measurements

To record the final measurements, we used a dataset of raw eeg scan data as shown in the below figure. We loaded this into the O-scope and ran the waveform generator. It should be noted that the gain of the amplifiers for the op-amp was changed to 10 and the overall gain was changed to 1000 as the initial signal was scaled up by 1000 to ensure no data loss when uploaded to the O-scope. However if eeg electrodes were to be used the circuit gain should be reverted to the original.

Raw waveform of EEG signal uploaded to O-scope

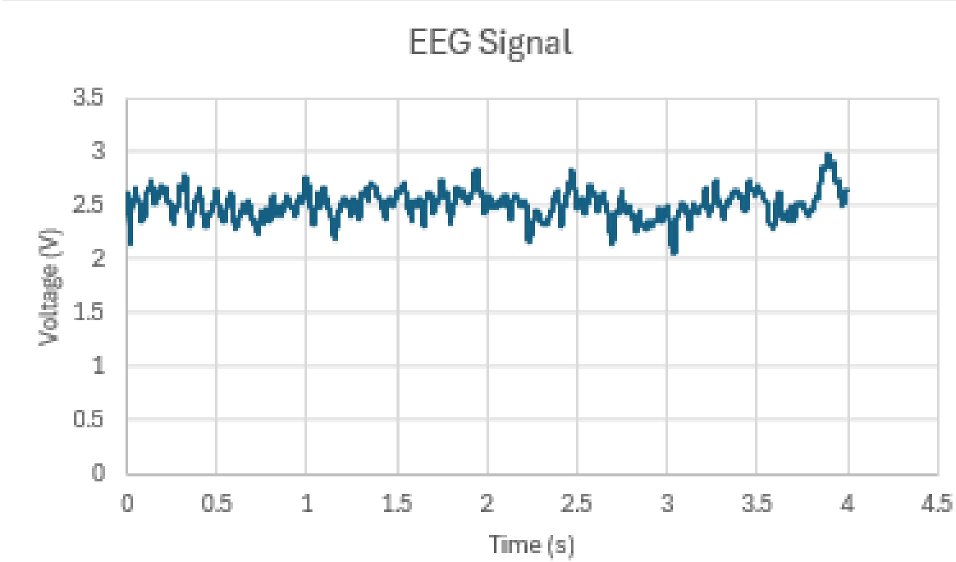


Figure 6: shows the raw EEG signal as imported into the O-scope by from the dataset. Since the AD623 amplifier compares the signal with a reference of 2.5V the waveform is offsetted by 2.5V and since the O-scope only takes in values with 6 significant figures we had to scale up the waveform by 1000.

EEG signal after Being processed by our Circuit

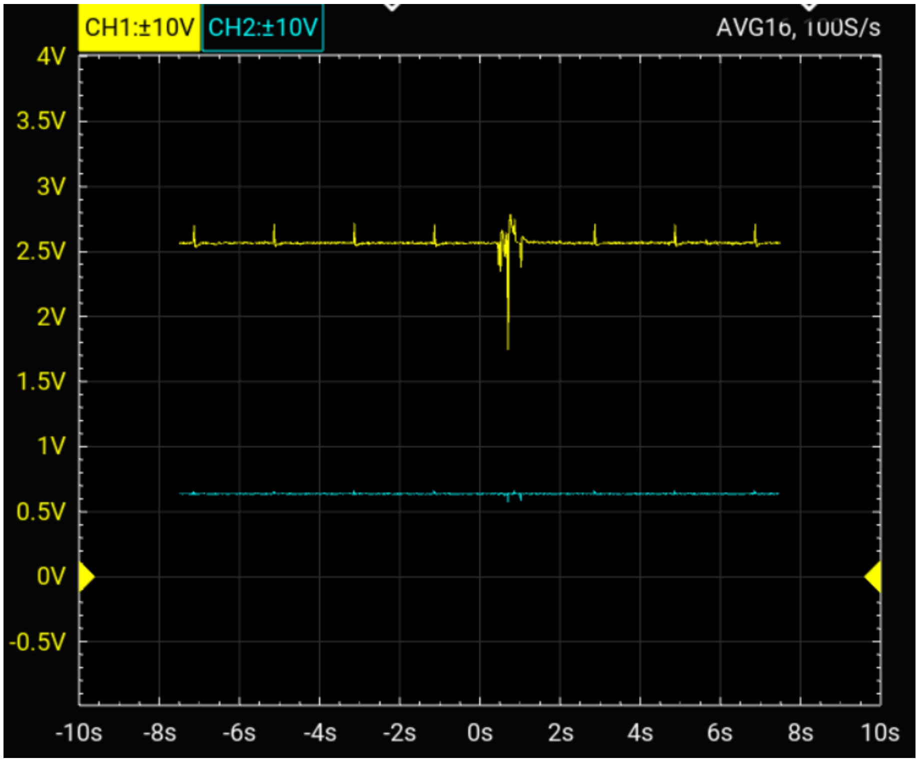


Figure 7: Shows the processed EEG signal showing the spikes in brain activity as measured by 2 electrodes on the head by a laboratory and passed through our circuit through the O-scope

This signal is reasonable as it mimics the trends of other processed eeg signals. As shown in the below figure out circuit makes repeated spike waves and shared and slow waves more prominent and noticeable. Due to the clarity of this plot and how it matches scientific data, it is likely a similar circuit configuration can be used to measure EEG signals.

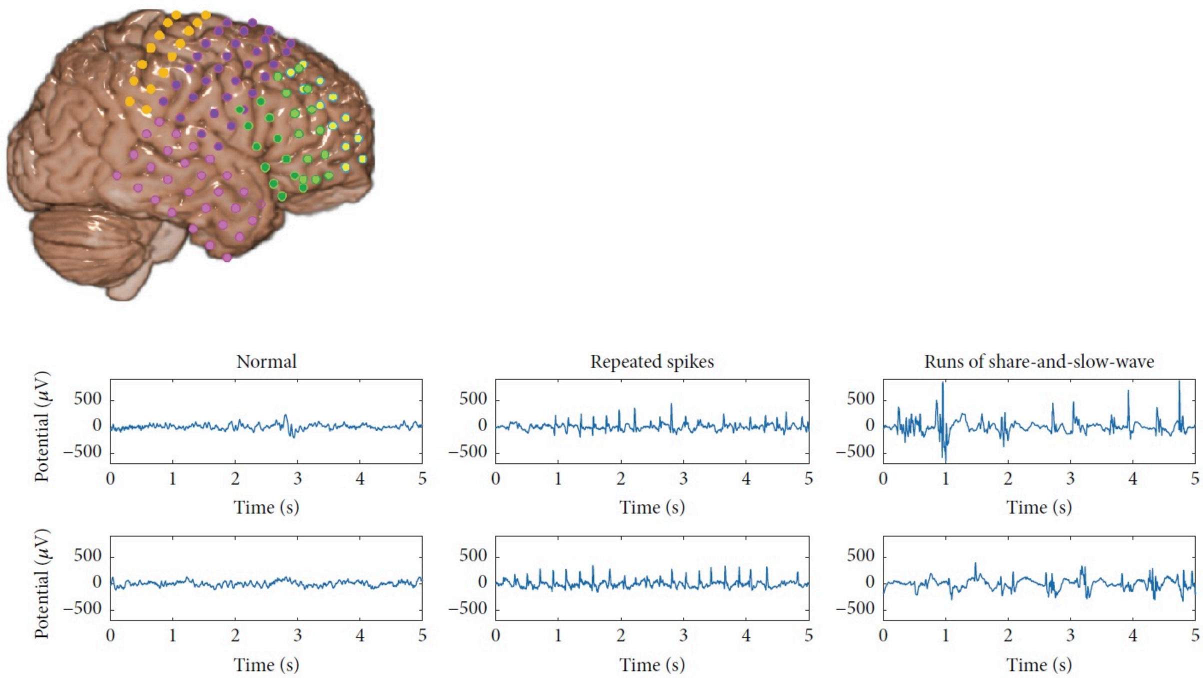


Figure 8: shows the different types of EEG signals that can be measured using electrodes.