Are You Watching? A DIY EEG Exploration

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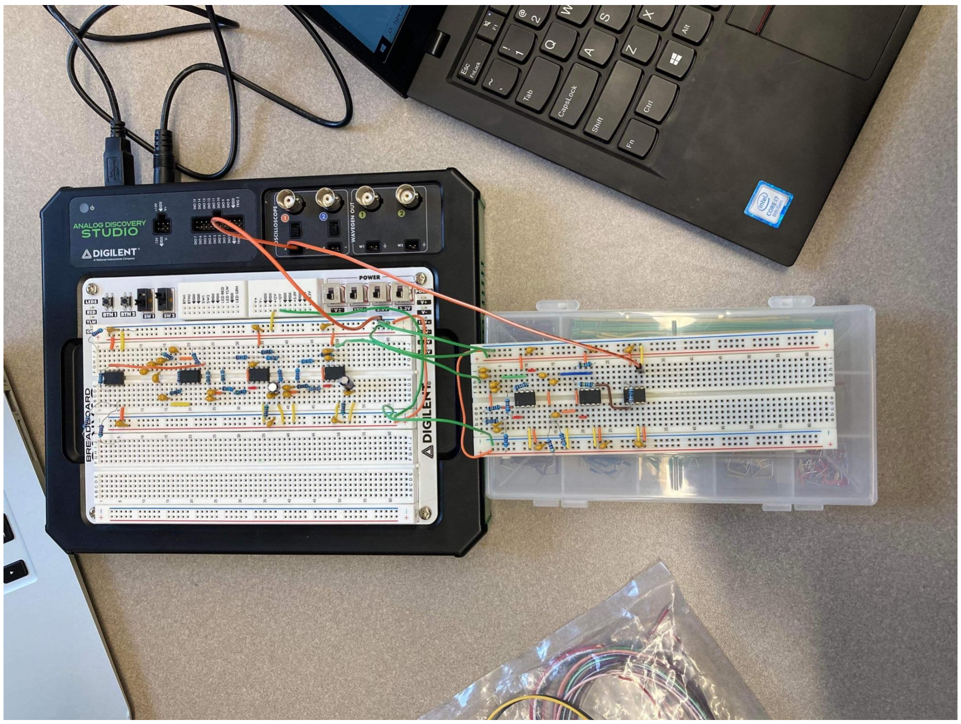
Physics 111A Final Project

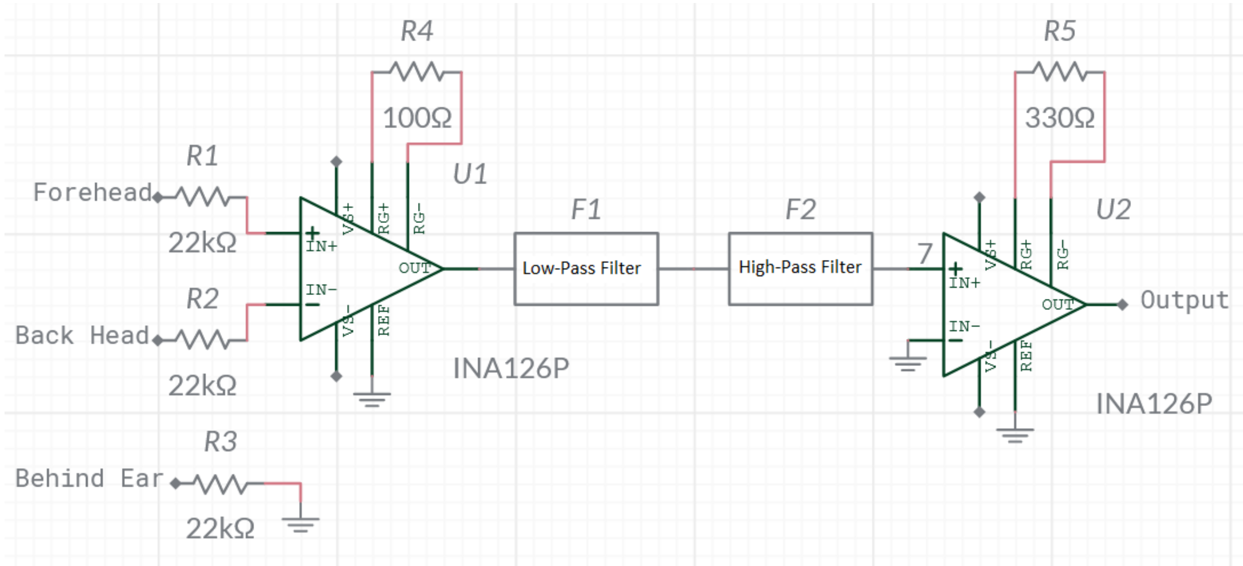
Fall 2021



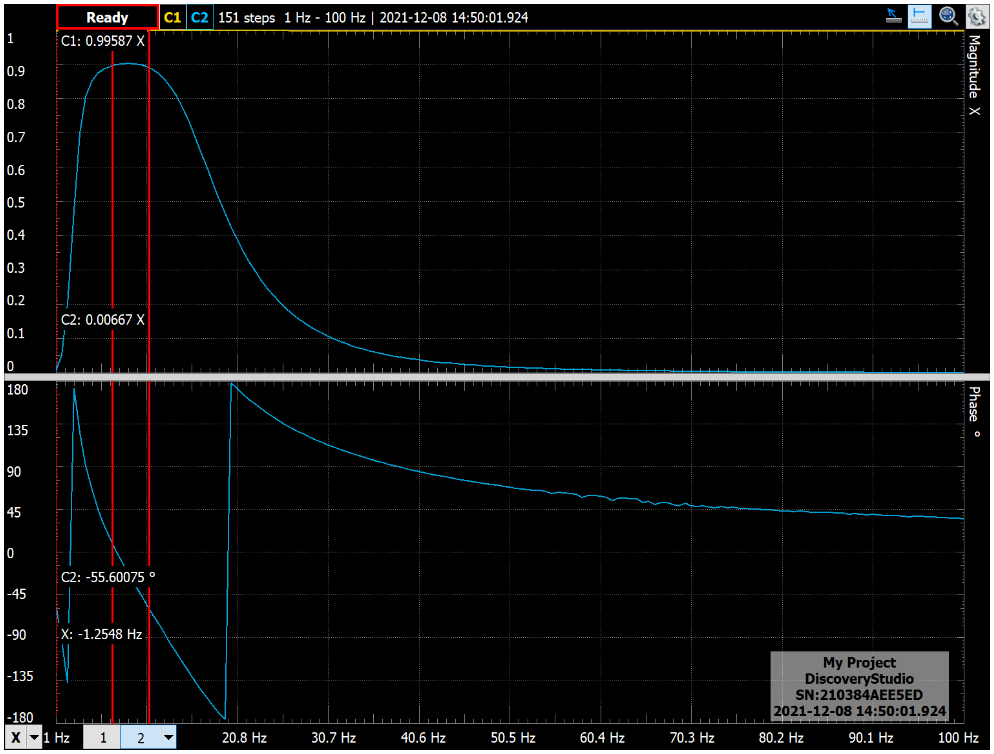
Introduction

Our project seeks to identify alpha waves, a very prominent indicator of brain activity. An easy way to do so is by reading the forehead's differential electrical signal using a basic electroencephalogram (EEG). Our final circuit turns an LED on when the subject's eyes are closed. The process consists of initial amplification and differential reading, filters (60Hz, 1/f noise, power supply), final amplification, and Labview signal processing. The primary obstacles during circuit development were the extremely small signal amplitude and a poor choice of electrodes. Consequently, most of our time was spent designing and testing multiple filters.

Circuitry



The circuit contains four stages: initial amplification and differential reading, 60Hz filter, 1/f filter, and final amplification. We chose physical filtering (instead of LabVIEW implementation) because the initial signal was very small and digitization would have caused significant loss of detail. Note that the entire circuit's ground is set to the baseline body reading of the subject. This allows for accurate relative readings and proper filtering. Each stage is described in detail below, with both filters being designed in Analog Filter Wizard. The network analysis of both filters together is included below.

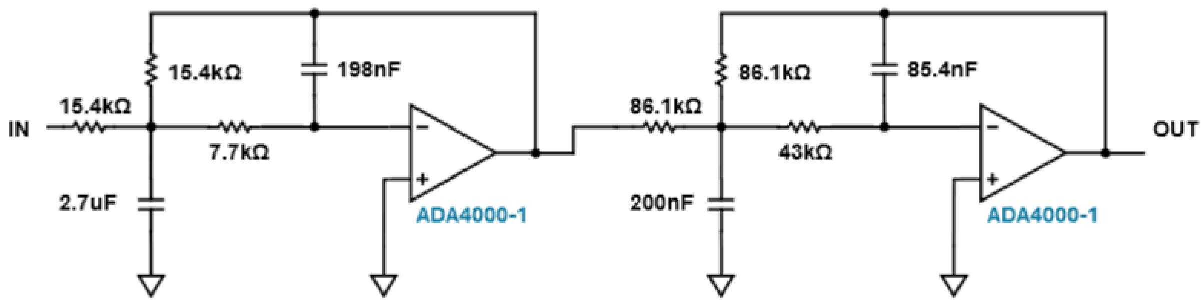


60 Hz LPF + 1/f HPF: Network Analysis

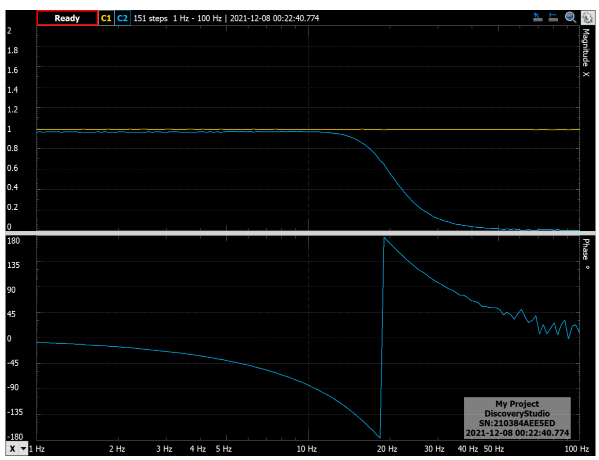
Signal Expectation

We expect an input signal of amplitude roughly 15-50µV. The INA126P instrumentation amplifier from Texas Instruments has a gain of $5 + \frac{80{,}000}{R}$. Two of these in-amps are used, one in the initial stage and one in the final. The resistances are set to $R_1 = 100,\ R_2 = 326$, with an expected total amplification of $805 \times 250 \approx 201,250$. However, to prevent accidental current flow into the subject, we choose to add 22kΩ resistors on the initial human-circuit connection. These reduced the initial gain to 350 (experimentally determined), for a total amplification of $350 \times 250 \approx 87,500$. Thus, we expect the output signal to be roughly 1.3125-4.375V. Any filter attenuations will change these values.

Stage 2: 60Hz Filter

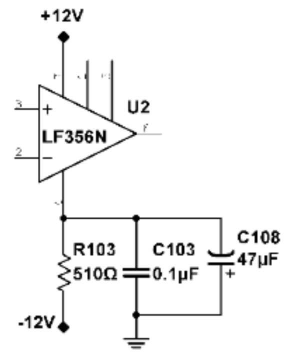


This low pass filter (LPF) is a two-stage, fourth order Butterworth optimized for low noise using multiple feedback. The primary objective is to eliminate 60Hz noise, which is introduced to the circuit through the power supply and environment. Below is the network analysis for the total filter.

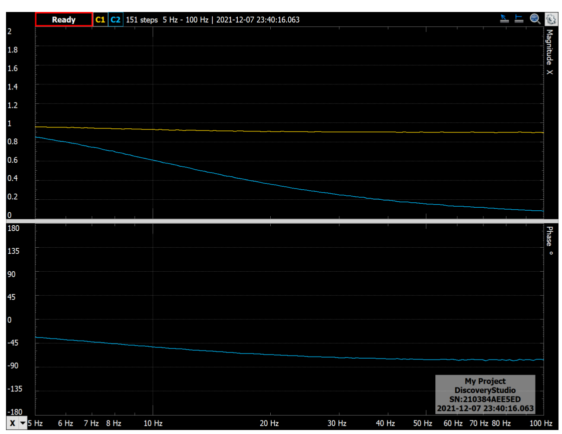


60Hz LPF (no PSFs): Network Analysis

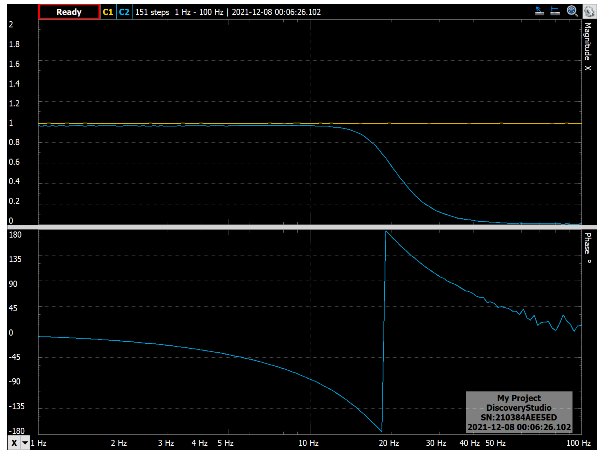
Stage 2: Power Supply Filters



During circuit development, we were concerned that the ground was becoming contaminated and shifted away from its original value. To see whether this was the case, we implemented power supply filters (PSF) on the two op amps in this stage. The design is taken from the Boltzmann's Constant Lab, and serves to stabilize the -12V power supply against fluctuations due to finite impedance and op amp feedback demands (see network analysis below). Network analysis did not indicate any change in performance, however the change is at most 15mV and may not be visible through this analysis. Since the power supply filters were not harming filter performance, we chose to keep them in this stage. Since they did not noticeably improve performance, we chose to exclude them in the next stage.

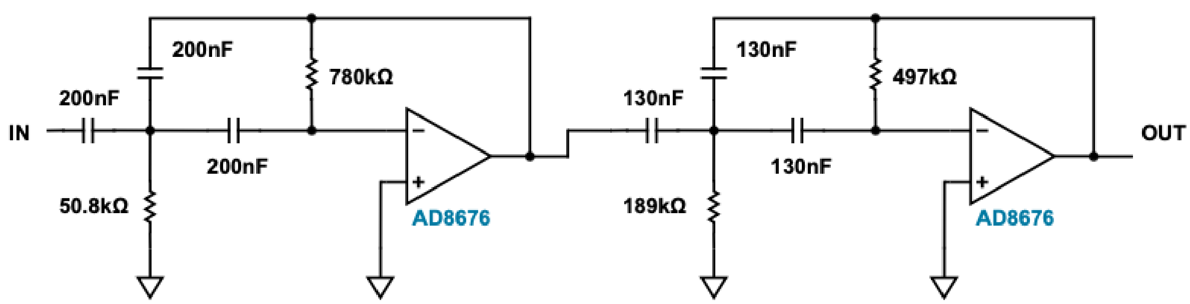


Power Supply Filter: Network Analysis

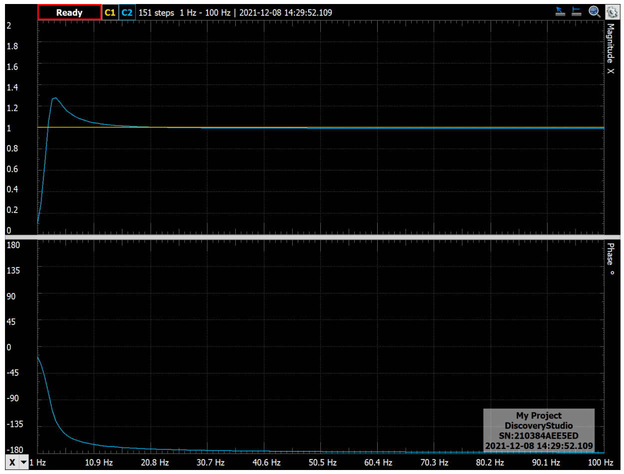


60Hz LPF + PSFs: Network Analysis

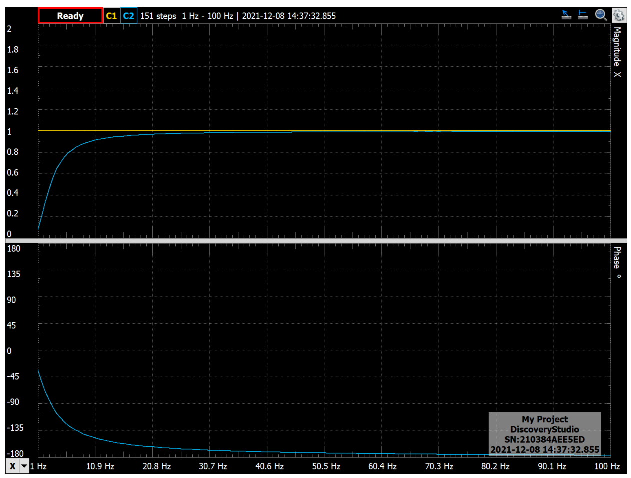
Stage 3: 1/f Filter



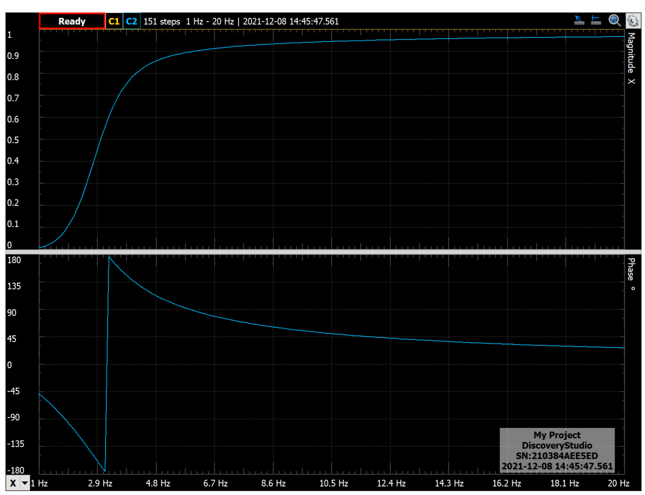
This high pass filter (HPF) is a two-stage, fourth order Butterworth optimized for low noise using multiple feedback. The primary objective is to eliminate 1/f noise and remove the signal's DC offset. Below are the network analysis for the first section, second section, and total filter.



1/f HPF: Section 1 Network Analysis



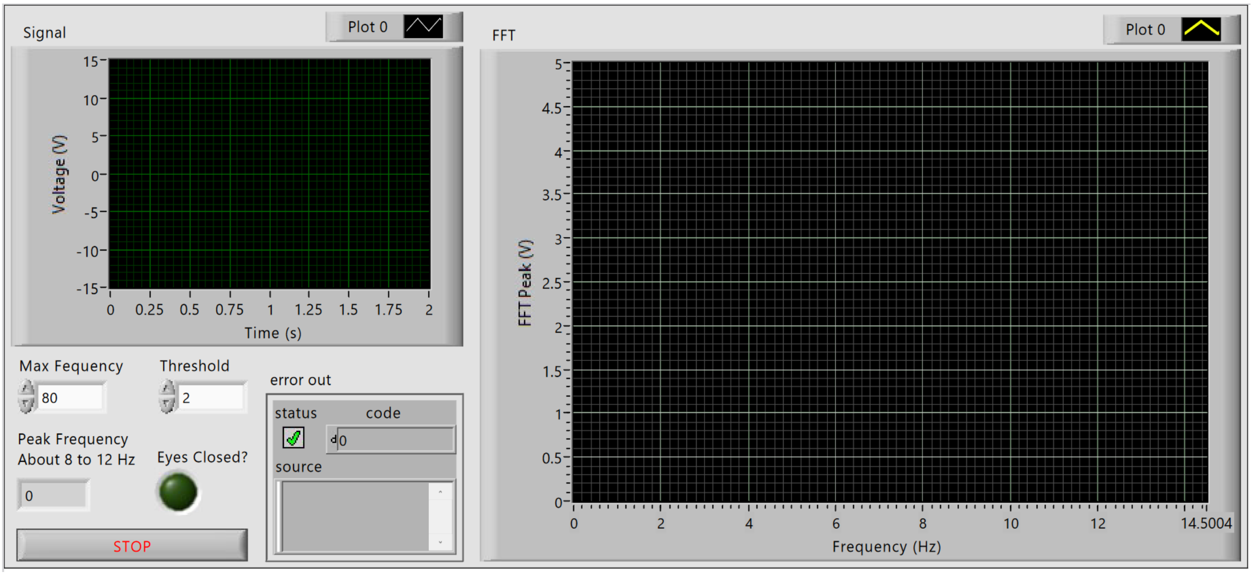
1/f HPF: Section 2 Network Analysis



1/f HPF: Total Network Analysis

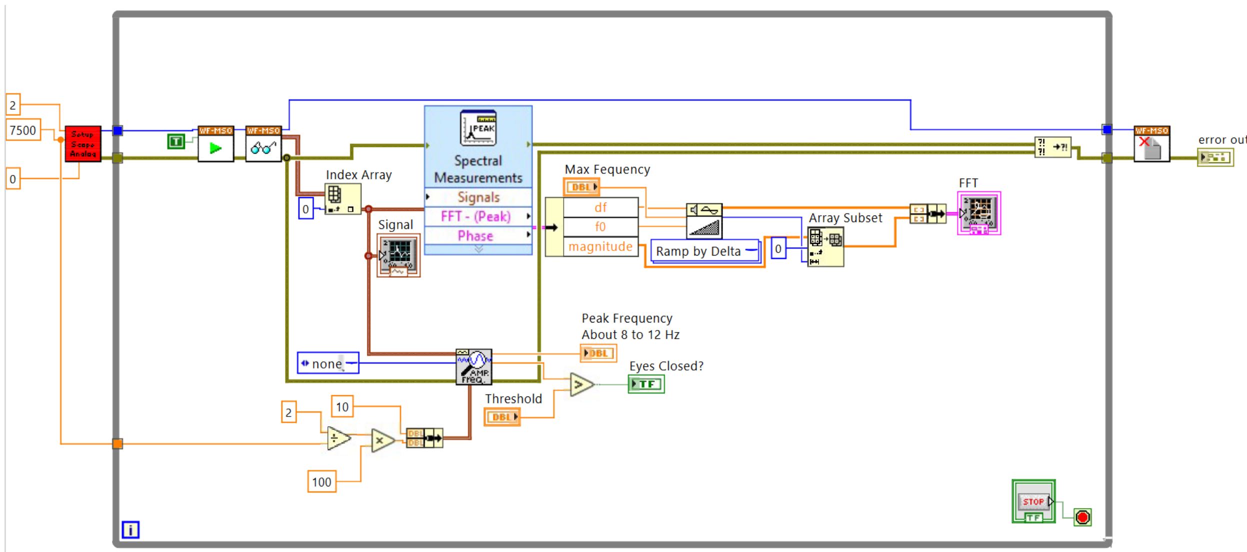
LabVIEW

Front Panel:

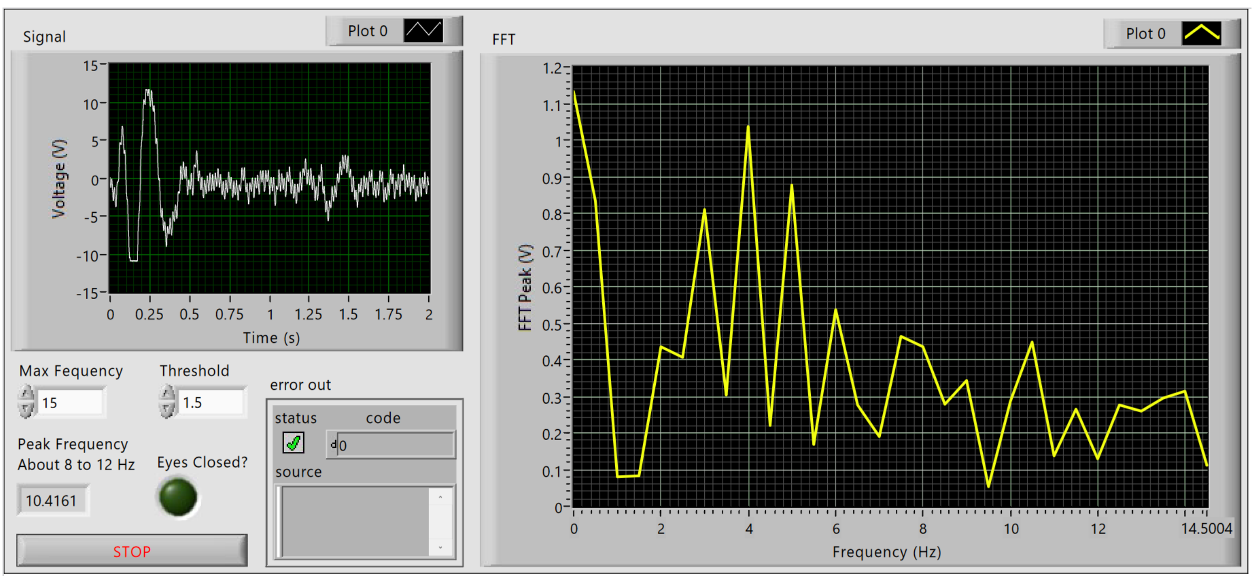


The program reads off the ADS scope with a sample time of 2 seconds and the roughly maximum sample rate (for this sample time) of 75000 samples/s. The reason we sample for 2 seconds is to have good enough frequency resolution to easily differentiate frequency peaks. Specifically, when our eyes are open the brainwaves peak below 7.5 Hz, and when they are closed they peak above 8 Hz, so we need to differentiate between these frequencies. We aim for the maximum number of samples to minimize the effect of white-noise. The program graphs both the measured signal and the single-sided FFT peak voltage, where the Max Frequency control sets the maximum frequency to graph in the FFT. The program searches for the peak frequency from about 8 Hz to 12 Hz, since this is the range of alpha waves which appear when our eyes are closed. If the peak amplitude it finds is less than the Threshold control, our eyes are open. If the peak amplitude is above the threshold, our eyes are closed and the corresponding light in the front panel turns on.

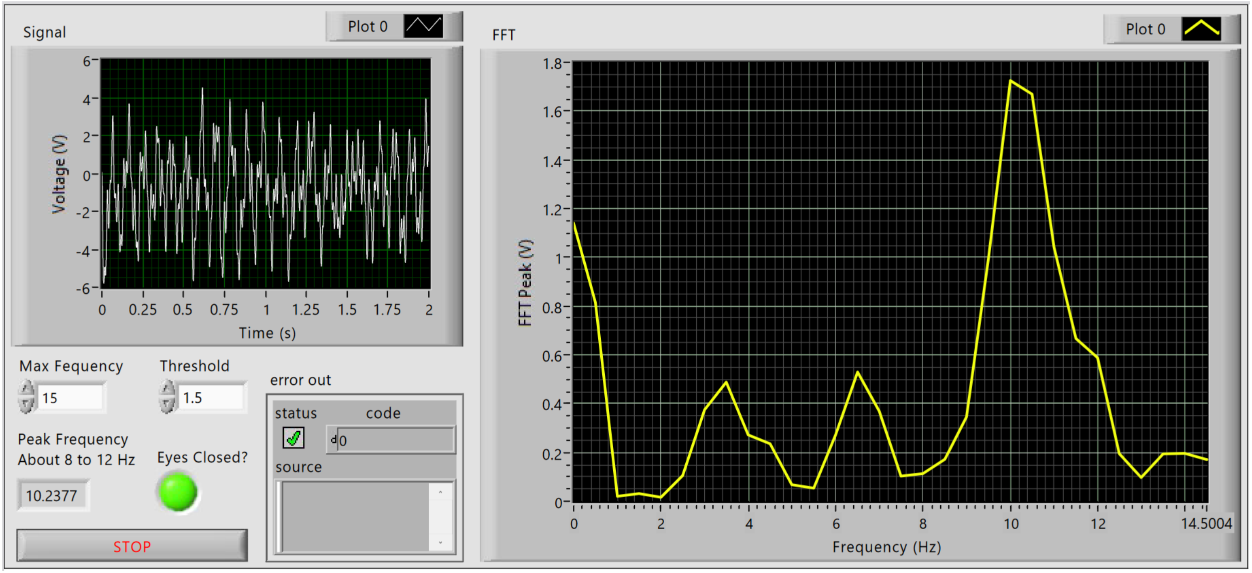
Block Diagrams:



Example Data:



Eyes Open

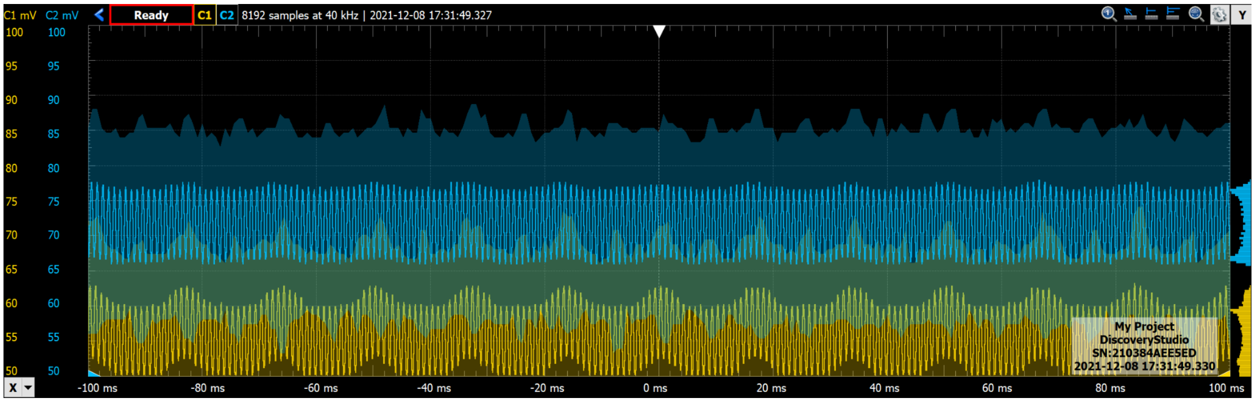


Eyes Closed

Extra Information

The Electrode Pads:

Unfortunately, the electrode pads we ordered were not ideal for EEG measurements. The given connections did not interface with our wires, so we had to strip the wire of the pads and use alligator clips. We were unable to consistently get a signal out of them for most of the project. We eventually realized that the pads dried out quickly, and even when coated with extra electrode gel, failed to provide a good signal after only a couple uses. Additionally, the BNC cables were adding noise that drowned out our signal and were extremely sensitive to motion. We got around these problems by shielding the BNC cables with tinfoil and using new pads with plenty of electrode gel to get a satisfactory signal. To test whether there is a measurable difference between old and new pads, we passed 10mV sine waves into the pads and measured the wire output. The results are below and do not appear to indicate any difference.



Comparison: Old Pad (yellow) and New Pad (blue)

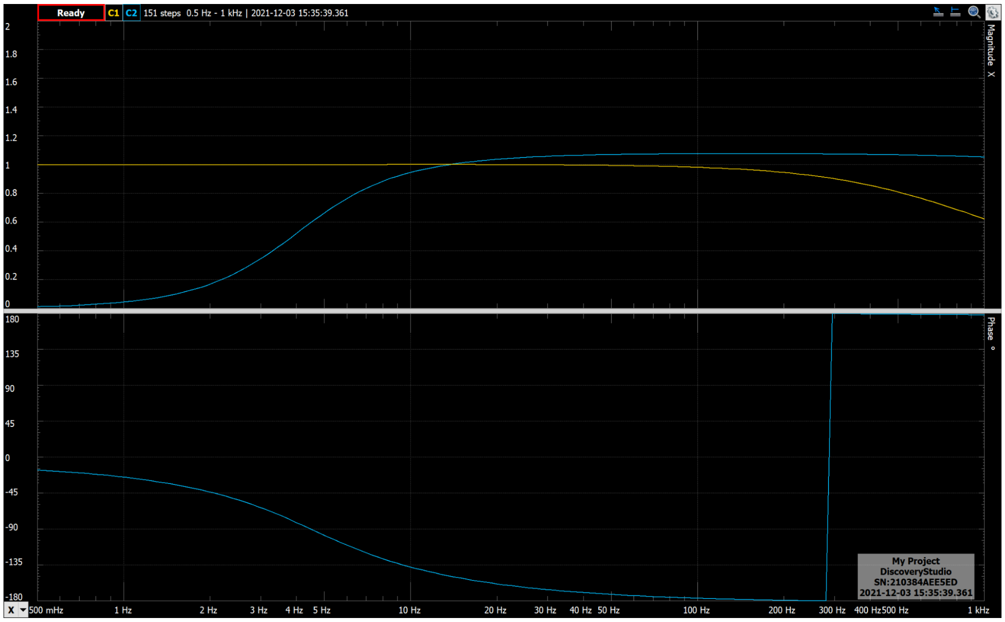
This process inadvertently revealed another issue with these pads: directionality. Designed for delivering electrical signals to the pad from the wire, this product may not be fully two-directional. This was noticed qualitatively when accidentally wiring the above pad comparison in reverse. Through discussion with peers, we determined that other electrodes--specifically the professional, metal, snap-fit electrode cups--work much much better.

Instrumentation Amplifier:

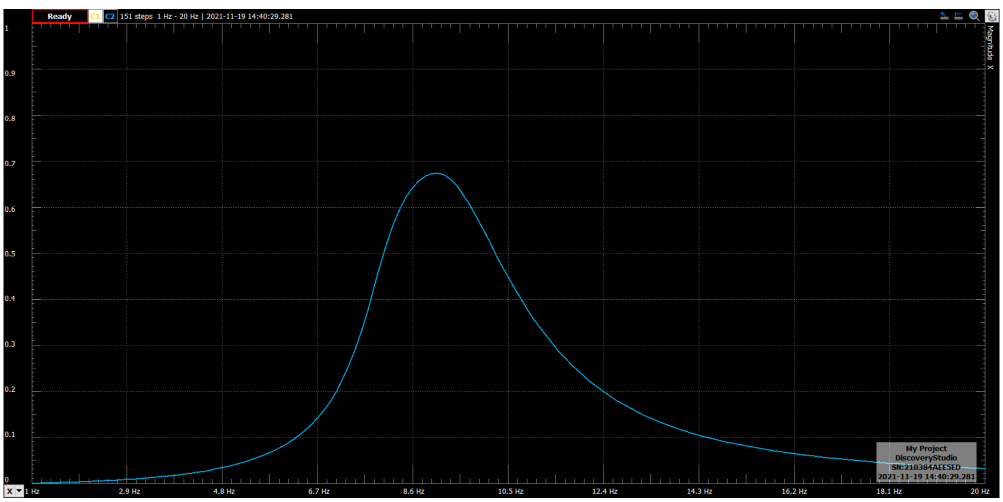
We originally built our own instrumentation amplifier, but were not getting a readable signal, so we replaced them with integrated circuitry. However, it turns out the problem was from our wiring of the ground and not from being unable to build a good InAmp. By the time we realized this, we already had better InAmps, so we just kept using those.

Filters:

Many of the filters we built did not work out well from being unable to properly match components. In particular, an old 2-stage band pass had too small a pass band and dampened our signal too much, and we had a similar experience with a 1-stage high-pass (network analysis below). Furthermore, we attempted to build a 60 Hz notch filter instead of a low-pass, but its design was too sensitive to component values and the result was an extremely wide and not deep stop band (only around -3dB at best, 10s of Hz wide).



Initial 1-Stage HPF: Network Analysis



Initial 2-Stage Band Pass