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Final Project: Phase B

An ECG is a very crucial tool in the medical field and is used to diagnose many different heart conditions. In Phase A, we dove into the details on the uses of the ECG and the ways that the ECG works including the parts of the ECG waveform. In Phase B, we will research and view different ways to build the circuit, consider the pros and cons of the different circuits, and choose a circuit. With the circuit that we choose, we will view the different parts of the circuit and reverse engineer it to choose what parts of the circuit we would like to use in our own circuit. We will then design the circuit that we will build and simulate it to verify that we get the desired results. After that, we will build the circuit and try to read our own heartbeat in the laboratory.

The first step was to research different types of circuits that all theoretically work and decide on the pros and cons of each one. In class, we found a total of 11 circuits to choose from. There were some similarities between them all. All the circuits used some sort of instrumentation amplifier that is connected to the leads. Then, the signal usually went from the INA (instrumentational amplifier) into a series of filters to filter out different noise to clean up the reading from the leads. Another commonality between the circuits is a lot of them use buffers between the filters to isolate them from each other. Each circuit had its own pros and cons that we carefully considered before choosing one. Some circuits were complicated and used a lot of operational amplifiers. After analyzing all of the circuits, we created a block diagram to assist in coming up with a circuit that would work in our situation. The block diagram can be found in Figure 1. The block diagram is a simple way to view the requirements of the circuit.

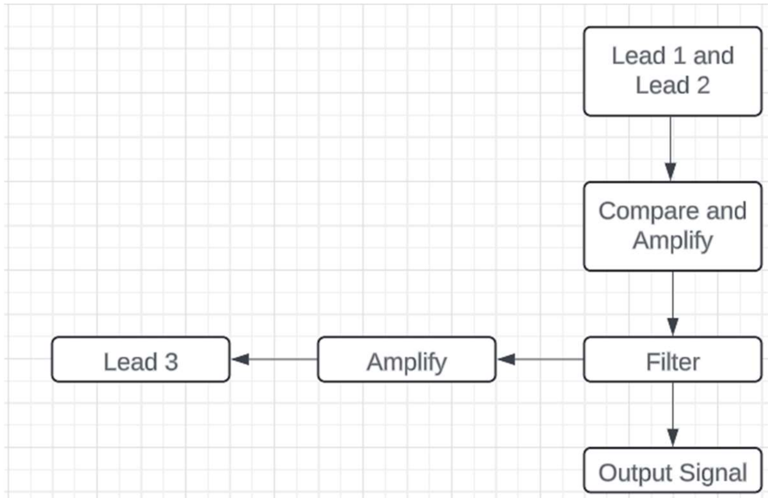

Figure 1: Block Diagram of Circuit

We decided that the circuit needed to include an INA, and we needed to filter out all the noise in the signal to make it more readable to analyze. The circuit we decided to replicate includes the INA, a notch filter to filter out the 60 Hz from the wall socket, and a low pass filter to filter out the EMG noise. The schematic of the circuit that we used for our circuit can be found in Figure 2.

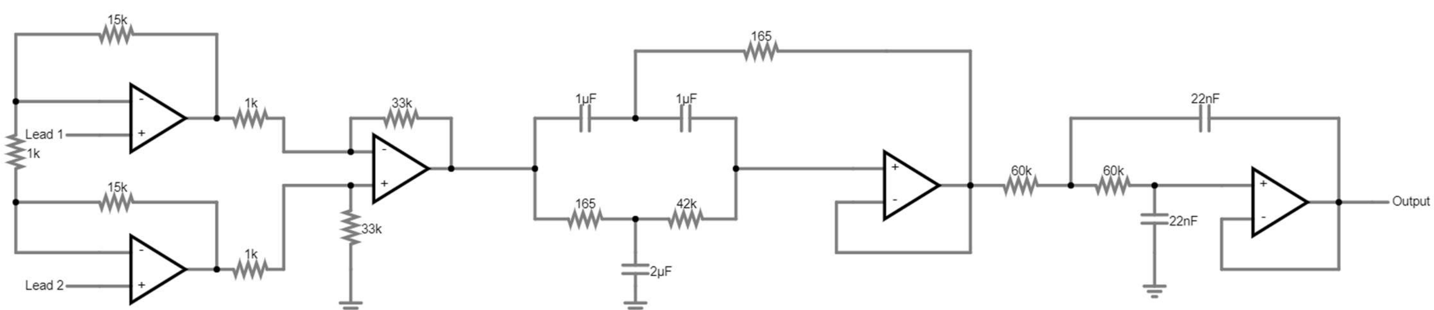

Figure 2: Schematic of Reference Circuit

This circuit can be broken up into three parts. An INA, a notch filter, and a low pass filter. Next, we will analyze the INA to attempt to obtain an equation for the output that goes into the notch filter. To do this, we isolate the INA and remove the resistor values and give each resistor a name. This can be seen in Figure 3. Then KCL is done at each side of the 1k resistor on the left side of the circuit. This can be seen in Equation 1 and Equation 2.

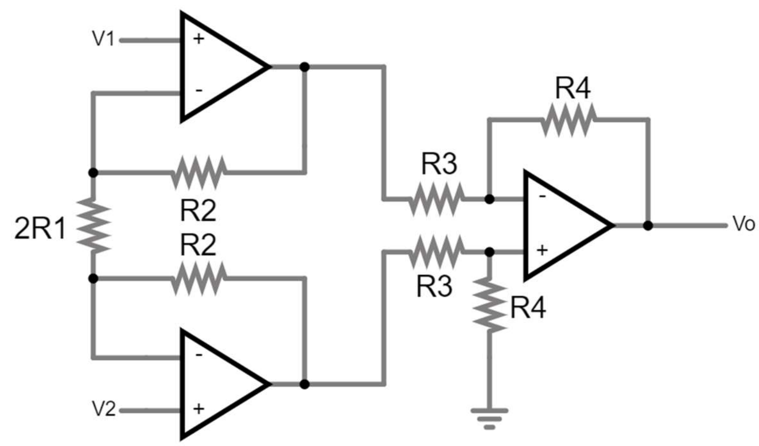

Figure 3: Schematic of Instrumentation Amplifier

$$i_1 + i_2 = 0$$

$$\frac{V_1 - V_2}{2R_1} + \frac{V_1 - V_{O1}}{R_2} = 0$$

$$V_{O1} = \left(\frac{R_2}{2R_1} + 1\right) - \frac{R_2}{2R_1}V_2$$

Equation 1: KCL at Top Node

$$i_1 = i_3$$

$$\frac{V_1 - V_2}{2R_1} = \frac{V_2 - V_{O2}}{R_2}$$

$$V_{O2} = \left(1 - \frac{R_2}{R_1}\right)V_1 + \frac{R_2}{R_1}V_2$$

Equation 2: KCL at Bottom Node

Using the two equations from Equation 1 and Equation 2, we can use the known equation for a differential amplifier to find the equation of the instrumentation amplifier. This can be seen in Equation 3.

$$V_{Out} = \frac{R_4}{R_3}(V_{O2} - V_{O1})$$

$$V_{Out} = \frac{R_4}{R_3}\left(\left(1 - \frac{R_2}{2R_1}\right)V_1 + \frac{R_2}{2R_1}V_2 - \left(\frac{R_2}{2R_1} + 1\right)V_1 + \frac{R_2}{2R_1}V_2\right)$$

$$V_{Out} = \frac{R_4}{R_3}\left(\left(1 - \frac{R_2}{2R_1} - \frac{R_2}{2R_1} - 1\right)V_1 + \frac{R_2}{R_1}V_2\right)$$

$$V_{Out} = \frac{R_4 R_2}{R_3 R_1}(V_2 - V_1)$$

Equation 3: Computation for the Output of the Instrumentation Amplifier

Next, we moved the instrumentation amplifier into Falstad to check the outcome so we can compare it to the circuit that will be built in the lab. The simulation can be found in Figure 4. To test the INA, we used 15mV at Lead 1, and 7mV at Lead 2. We got an output of 8.179 V in Falstad.

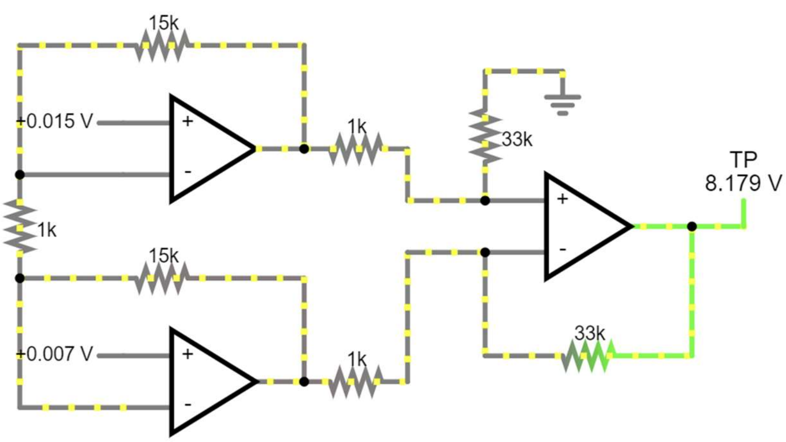

Figure 4: Falstad Simulation of the INA

The next step was to simulate and test the filters to ensure that we get the desired outcome before the circuit is to be built. For the notch filter, we want a rejection frequency of 60 Hz and for the low pass filter, we want a cutoff frequency of 100 Hz. A buffer was placed in between the notch filter and the active low pass filter to isolate them. The simulation of the filters can be found in Figure 5, Figure 6, and Figure 7.

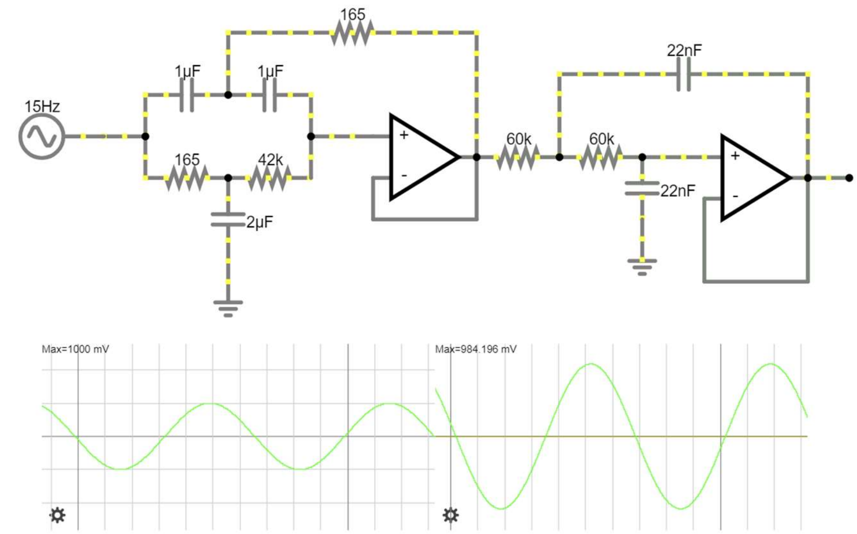

Figure 5: Simulation of Filters at 15 Hz

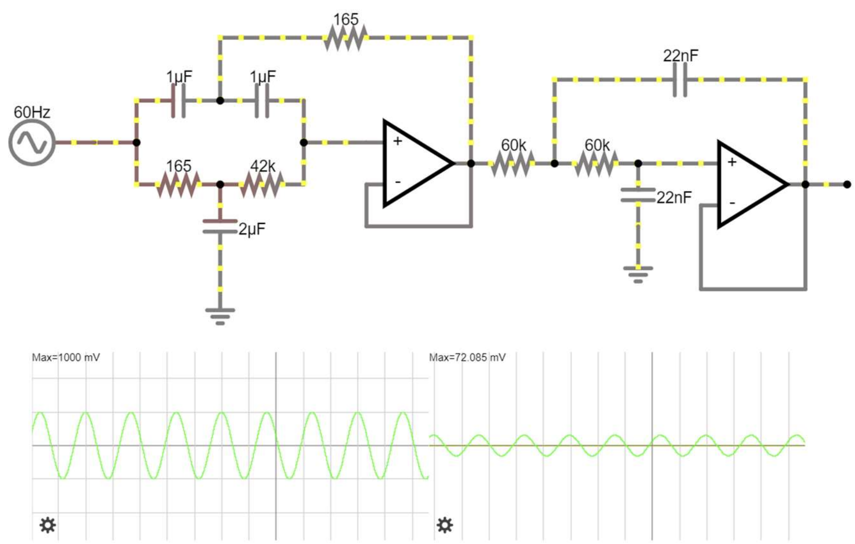

Figure 6: Simulation of Filters at 60 Hz

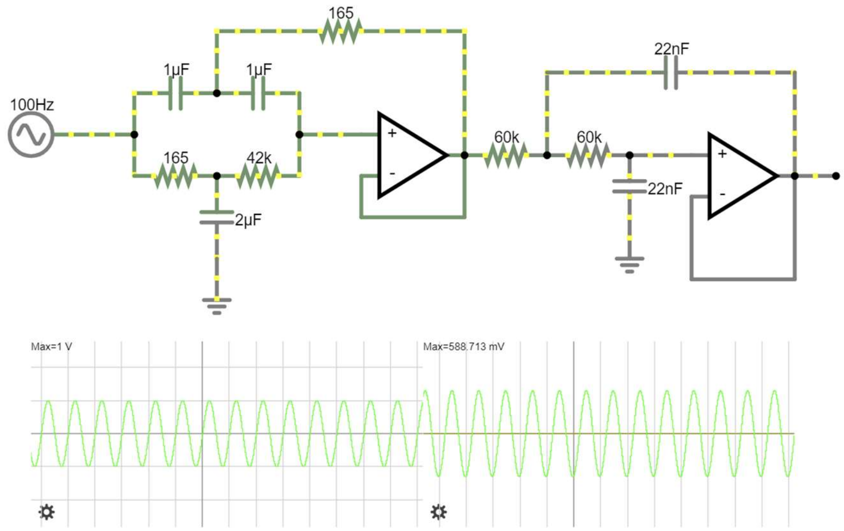

Figure 7: Simulation of Filters at 100 Hz

As seen in Figure 5, when a waveform of 15 Hz is input into the signal, no change occurs to the amplitude, but in Figure 6, at 60 Hz almost all the amplitude of the waveform is removed. This is the notch filter filtering out our desired out 60 Hz. Finally, in Figure 7. At 100 Hz, we are around a -3 dB of decrease in the waveform. As you increase the frequency, the amplitude also decreases to nothing past the 100 Hz frequency. This shows that our filters are working as designed.

The next step was to build the circuit in the lab. The first thing that was done was we built just the INA to ensure that it was working as we wanted. The reading of the oscilloscope can be found in Figure 8. 15mV and 7mV were inputted into the two lead points same as was done in the simulation above.

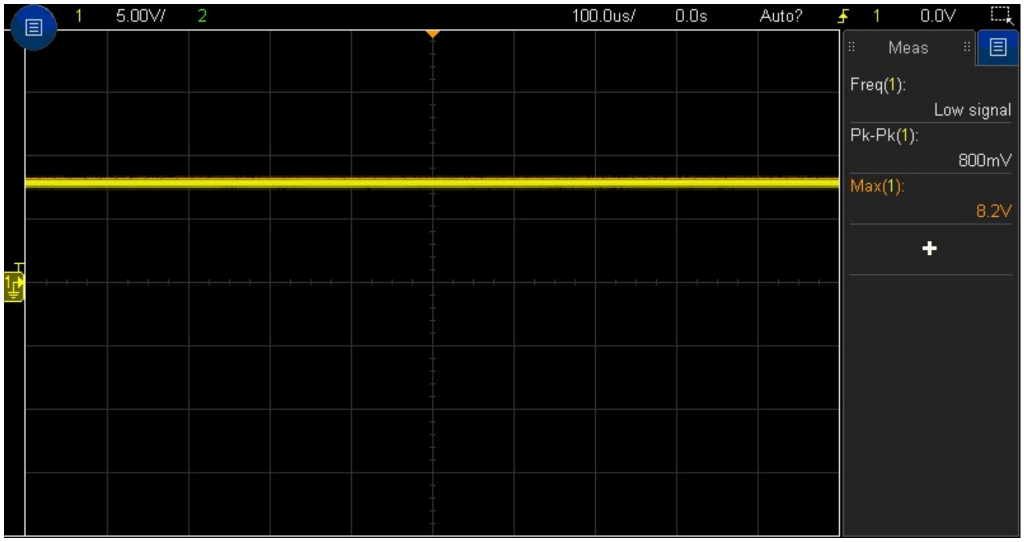

Figure 8: Oscilloscope Reading of the INA

As seen in Figure 8, the output of the INA that was built in the lab has very similar results as in the simulation done in Falstad in Figure 4. The slight error could have been caused by the tolerance of the resistors.

Once we had the INA working and verified, we could build the rest of the circuit and attempt to read our heartbeat. In the lab, we were instructed to use a passive low passive filter with a cutoff frequency of 40 Hz in place of the notch filter and the active low pass filter. To achieve this, we used a 0.1 µF capacitor and a 510 Ω resistor in series with a 3.3 kΩ resistor. This gave us a cut off frequency of 417 Hz. The slight error in cut off frequency was due to the availability of components that were in the lab. This slight error did not have an adverse effect on our outcome. Once the filter was added to the already built INA, we connected the leads to my body. The red lead went on my left wrist, the blue lead went on my right wrist and the black lead went on my right ankle. A photo of the finalized circuit can be found in Figure 9.

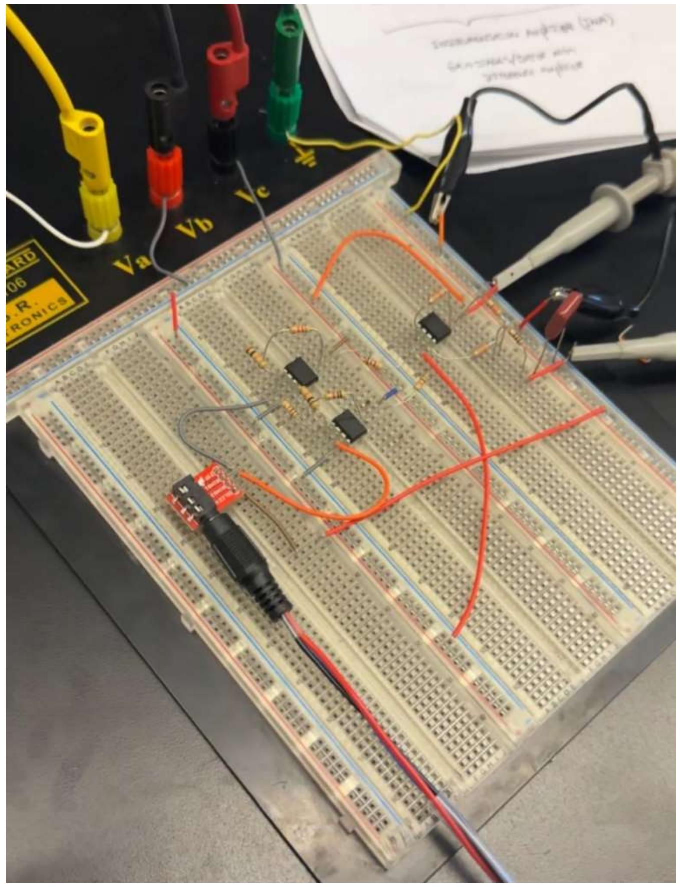

Figure 9: Photo of Completed ECG Circuit

The circuit began reading my heartbeat and outputting it onto the oscilloscope. This reading can be found in Figure 10. In the oscilloscope reading, there are two waveforms. The yellow waveform is the circuit output before the filter, and the green waveform is the output of the circuit after the filter. There is a clear difference between the two waveforms. With the filter, we get a much cleaner and more readable waveform to analyze.

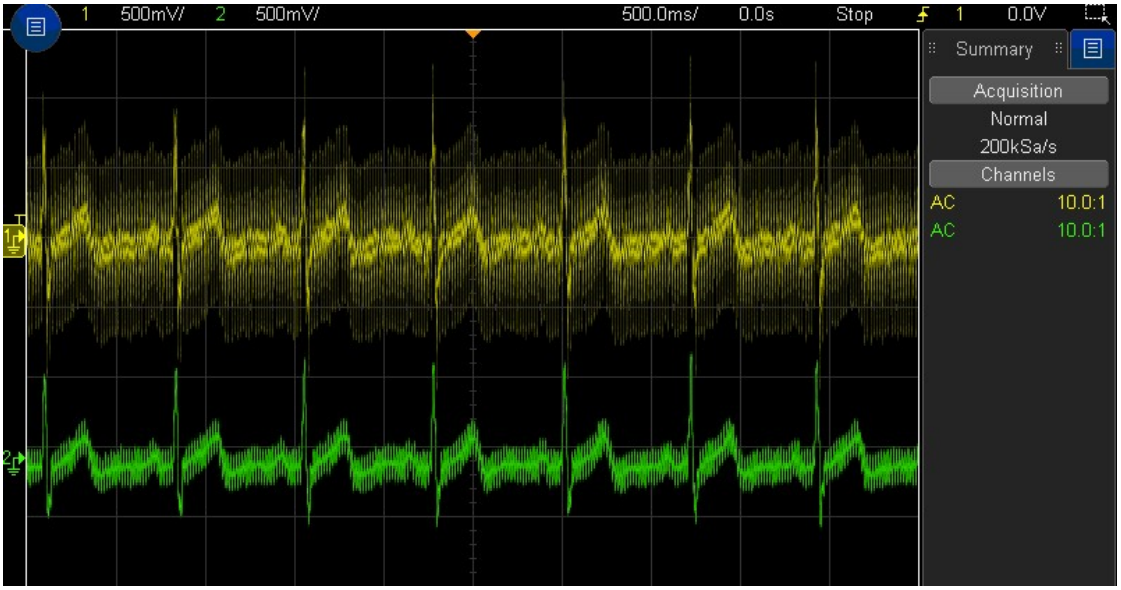

Figure 10: Heartbeat Reading of the ECG Circuit

We also noticed that when I would more, or open and close my hands, the output of the circuit would become very noisy and unreadable. This can be seen in Figure 11. This noise is called muscle contraction noise. This is why when a medical professional is trying to get your heartbeat, they ask you to stay as still as possible, because if not, it makes reading your heartbeat harder to read and analyze.

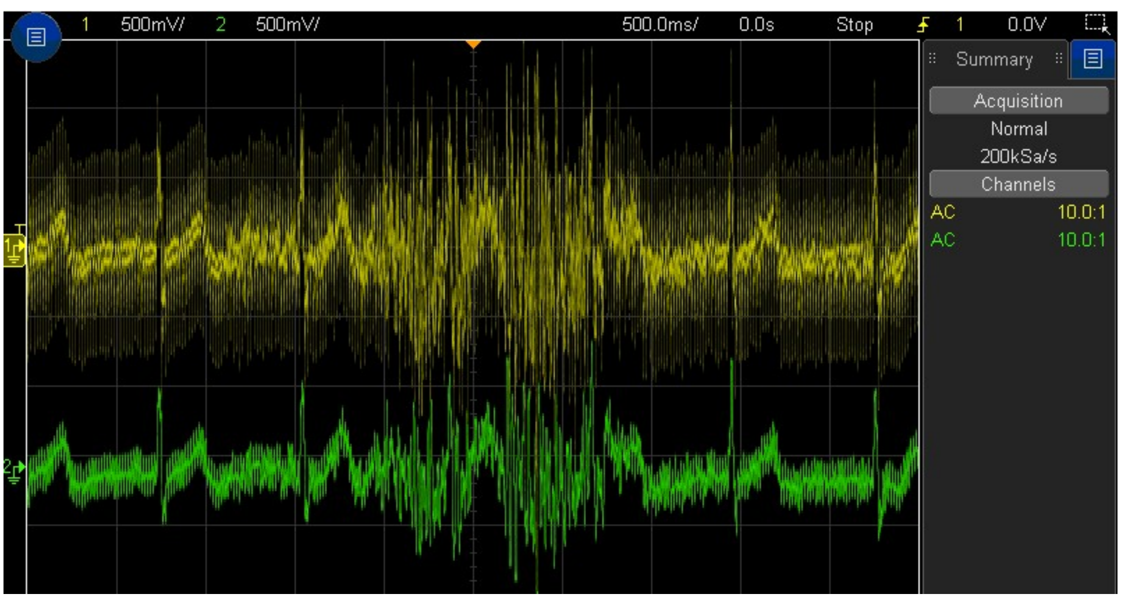

Figure 11: Heartbeat Reading of the ECG Circuit with Hand Movements

Overall, this Final Project was an amazing way to tie everything we have learned together and make a circuit that functions and is used in many health industries. This lab was a success and also showed that even though a circuit can look daunting at first, if you just break it apart into its different parts that we already know, it makes the circuit more digestible. We can further this project more by filtering out our signal even more to attempt to get a much cleaner output.