E84 Final Project Report

EMG Circuit Tutorial

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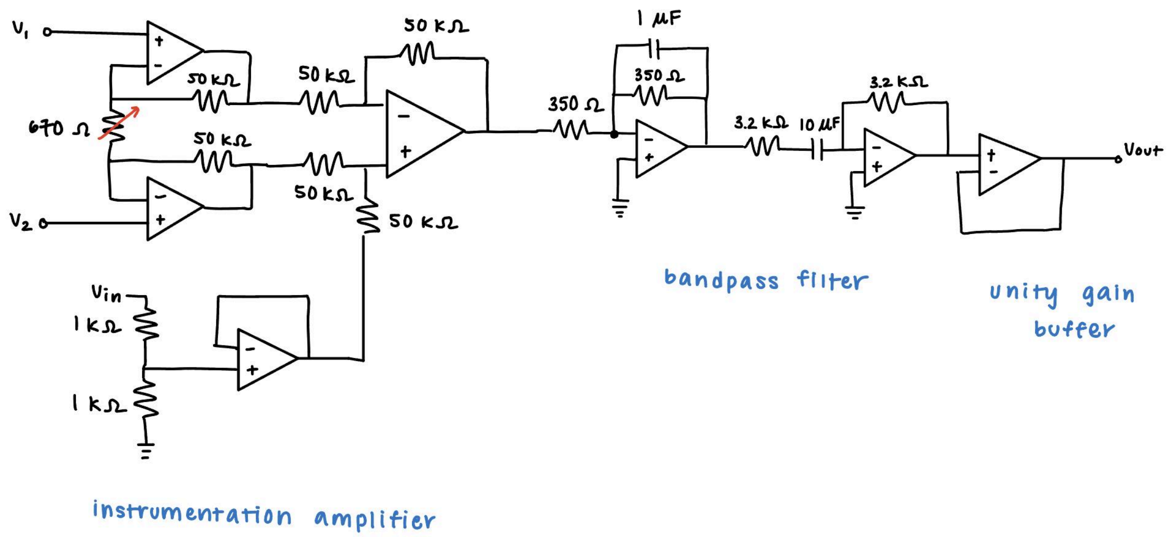
Introduction & System Description

An EMG, or electromyogram, measures the electrical activity produced by movement in skeletal muscles. In this tutorial, we'll be going over how to design, build, and test an EMG circuit to measure the electrical activity of the bicep at different contraction ranges. The voltages produced by the muscles are picked up by electrodes, which act as the input voltage to this circuit. Then, a combination of filters and amplifiers are used in order to clearly read this EMG signal.

The first step in the process is to find the difference between the incoming voltages from the contracted bicep. An instrumentation amplifier, the Analog Devices AD623, will be used to compute this millivolt difference between the sources and amplify the difference. The resistive gain of the AD623 (which is chosen and explained below using circuit analysis) sets the gain of the circuit. The AD623's single rail configuration will be utilized in order to be safe. So, a 2.5V offset, using a non-inverting MicroChip MCP601 Op-Amp, is required to set the voltage at mid-rail. This will allow the difference in voltages to equally reach either side of the mid-rail before railing out at 0V or 5V. The next major contributing part to the EMG circuit is the bandpass filter. This filter includes an active low pass and high pass filter (MicroChip MCP601 op-amps) used to capture most EMG signals (5Hz - 450 Hz). We made each filter gain 1 to avoid deviating from the current-voltage value. Values for the resistors and capacitors in the filters were calculated, as shown below, to accept the previously stated frequency range. The third part of the circuit takes in the bandpass filter's output voltage and inputs it into the oscilloscope. A unity gain buffer (MicroChip MCP601 op-amp) was applied to the end of the circuit to avoid instrument loading.

Circuit diagram (component value choices are explained later):



<u>Parts List</u>

1. Adhesive EMG electrodes
2. MicroChip MCP601 op-amps
3. Analog Devices AD623 Instrumentation Amplifier
4. Common electrical components like resistors, capacitors, wires, breadboard(s)
5. Power Supply
6. Oscilloscope

<u>Building Full Circuit System</u>

The first step in building this circuit is performing circuit analysis to determine the values of all the components. For the instrumentation amplifier circuit, equations from the datasheet were used to calculate the resistive gain. For the bandpass filter, which is a low pass active filter in series with a high pass active filter, known equations about their cutoff frequency were used to determine the resistor values. Details on the circuit analysis and calculations are below:

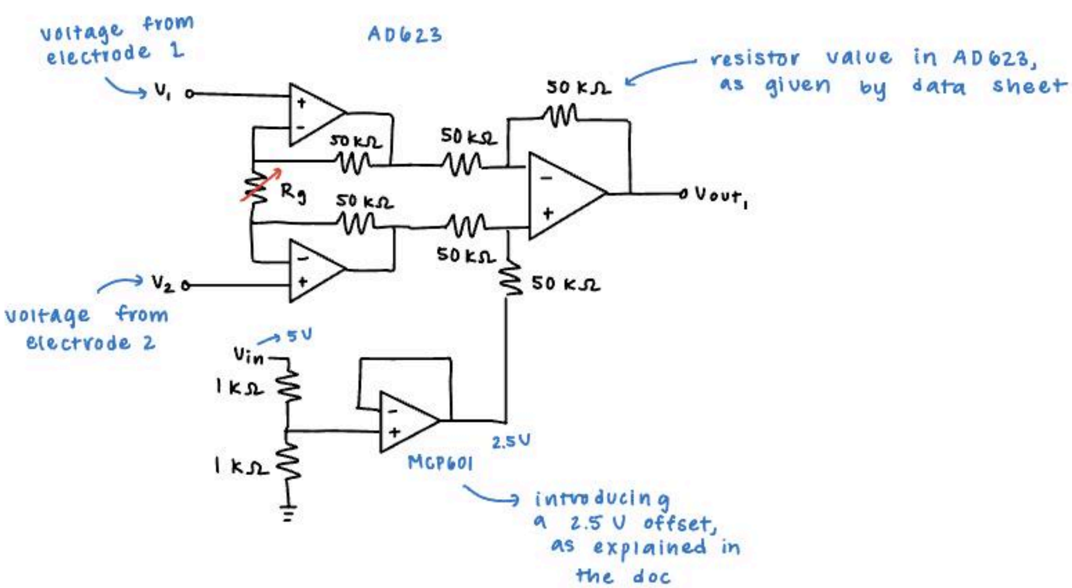
Three different step/stages:

instrumentation amplifier → band pass filter → non-inverting op-amp

① INSTRUMENTATION AMPLIFIER

→ chose the AD623, which has a subtracting amplifier built into it, and this is important b/c the EMG signal is the difference of voltage signals at the end of muscle

schematic from textbook:



differential output equation from AD623 datasheet : $V_{out} = \left(1 + \frac{100\,k\Omega}{R_g}\right)(V_2 - V_1) + V_{offset}$ → $= 2.5\,V$

General electrode range is 1 mV to 5 mV, so assuming maximum difference, $V_2 = 5\,mV$ and $V_1 = 1\,mV$. Maximum Vout before railing out is 5 V. Calculating R_g using this information:

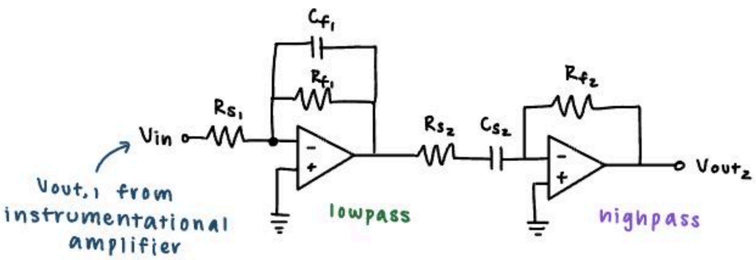
$$5 = \left(1 + \frac{100\,k\Omega}{R_g}\right)(20\,mV) + 2.5$$

$$R_g = 806\,\Omega$$

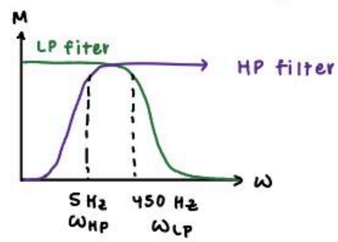
Due to limitation of resources, we chose a 680 Ω resistor for our circuit.

② BAND PASS FILTER

Using an active low pass filter in series with a high pass filter to create a bandpass filter:



From research, we know the majority of the EMG signal is between 5-450 Hz. Therefore, this is the goal for the cutoff frequencies:



Therefore, we want the LP filter to have a cutoff frequency of 450 Hz and the HP filter to have a cutoff frequency of 5 Hz.

LP filter transfer function:

$$G(s) = \frac{-R_{f_1}}{R_{s_1}}\left(\frac{1}{R_{f_1}C_{f_1}s + 1}\right)$$

$$G(j\omega) = \frac{-R_{f_1}}{R_{s_1}}\left(\frac{1}{R_{f_1}C_{f_1}j\omega + 1}\right)$$

$$= \frac{-R_{f_1}}{R_{s_1}}\left(\frac{1}{j\omega/\omega_{LP} + 1}\right)$$

$$\omega_{LP} = \frac{1}{R_{f_1}C_{f_1}} = 450(2\pi)$$

$$R_{f_1}C_{f_1} = 3.537 \times 10^{-4}$$

HP filter transfer function:

$$G(s) = \frac{-R_f}{R_{s_2} + \frac{1}{C_{s_2}s}} = \frac{-R_f C_{s_2} s}{R_{s_2}C_{s_2}s + 1}$$

$$G(j\omega) = \frac{-R_f C_{s_2} j\omega}{R_{s_2}C_{s_2}j\omega + 1}$$

$$= \frac{-R_f C_{s_2} j\omega}{j\omega/\omega_{HP} + 1}$$

$$\omega_{HP} = \frac{1}{R_{s_2}C_{s_2}} = 5(2\pi)$$

$$R_{s_2}C_{s_2} = 0.0318$$

Choosing R_{f_1}, C_{f_1}, R_{s_2}, C_{s_2} based on availability in lab:

$R_{f_1} = 350\ \Omega$
$C_{f_1} = 1\ \mu F$

check: $(350)(1\times10^{-6}) = 3.5\times10^{-4}$ ✓

$R_{s_2} = 3.2\ k\Omega$
$C_{s_2} = 10\ \mu F$

check: $(3200)(10\times10^{-6}) = 0.032$ ✓

Since we're already amplifying the voltage with the differential circuit, we've decided to have a gain of -1 for both the low pass and high pass filters.

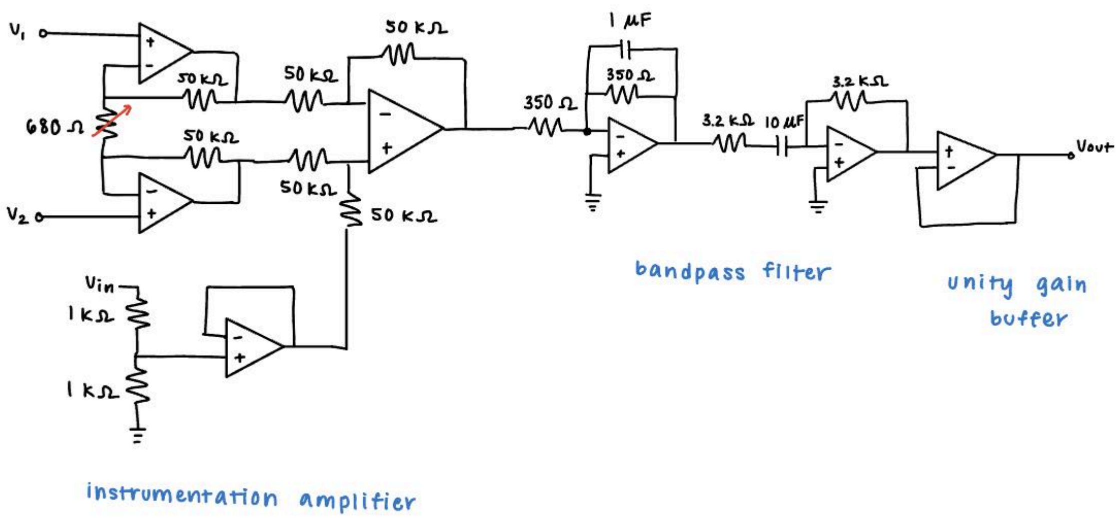
$$G_{LP} = \frac{-R_{f_1}}{R_{s_1}} = -1 \qquad G_{HP} = -\frac{R_{f_2}}{R_{s_2}} = -1$$

$$R_{s_1} = R_{f_1} \qquad R_{f_2} = R_{s_2}$$

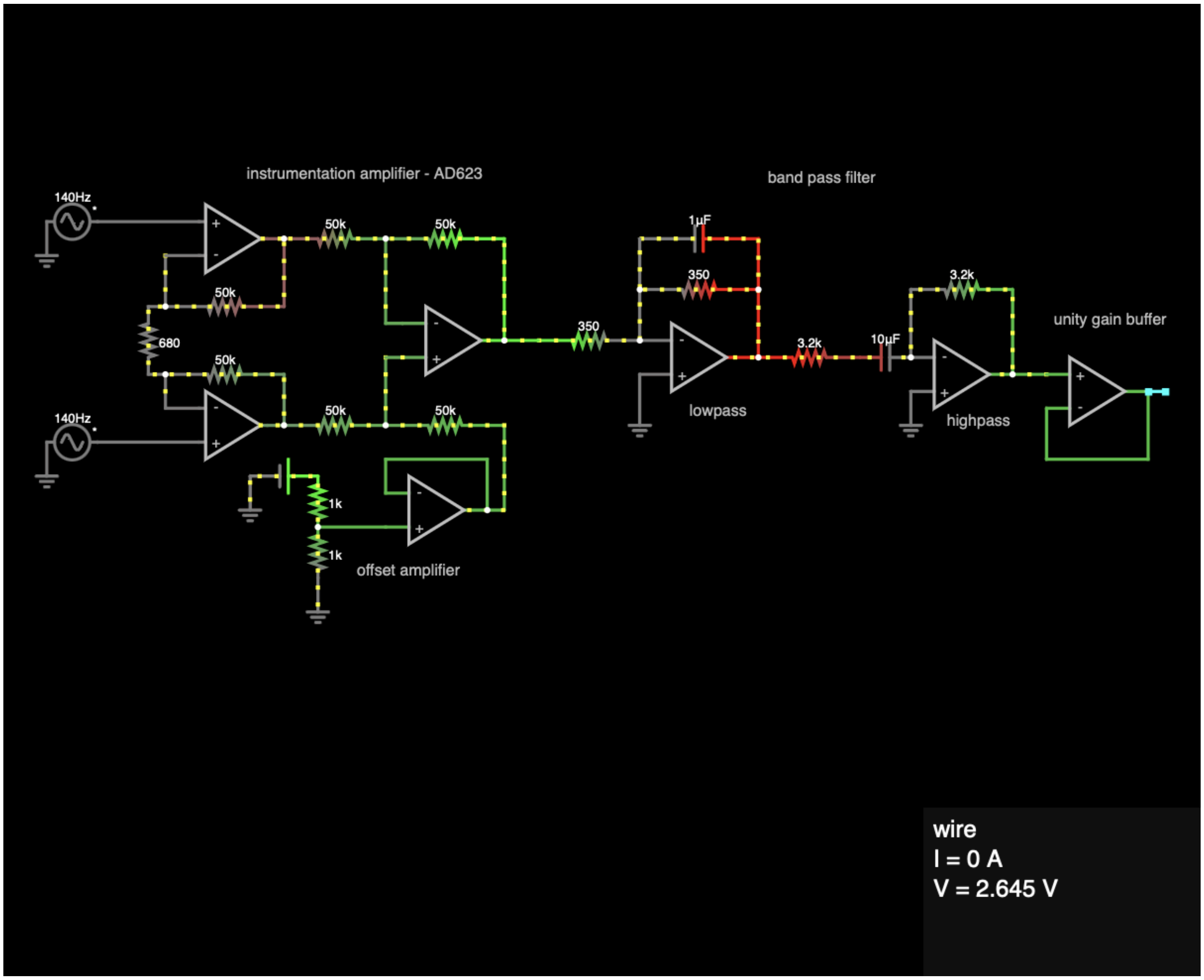
$$R_{s_1} = 350\ \Omega \qquad R_{f_2} = 3.2\ k\Omega$$

In the end, adding a unity gain buffer to prevent loading the circuit.

Applying all this to create a circuit schematic:



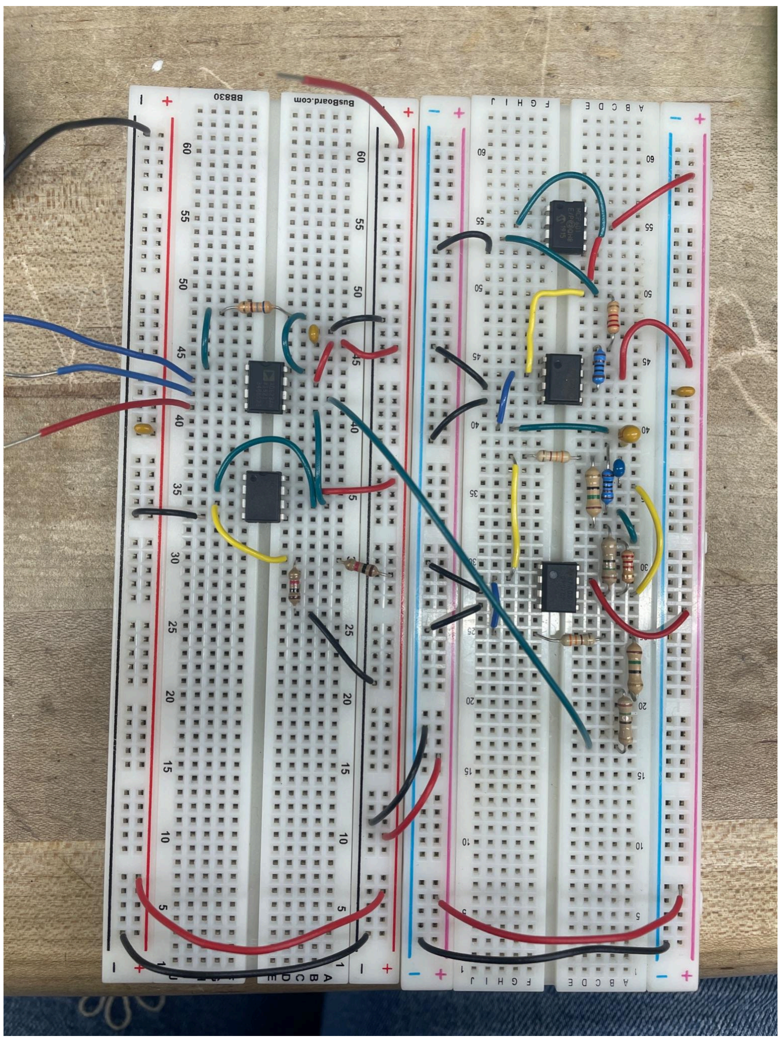
Once the circuit analysis is complete and all the component values are chosen, the next step in building the circuit is simulating it. We chose to simulate our circuit on Falstad, so we replicated the circuit in the schematic above. This allowed us to verify that our chosen circuit design was functional and outputted an appropriate result. Our circuit simulation is shown below:



This is the simulated circuit. The input voltage sources to the circuit represent the input voltages from the muscle. Upon research, we concluded that the input voltages are in the mV range. Therefore, we chose the top input voltage to be a 40 mV AC signal, and the bottom input voltage to be a 20 mV AC signal. With research, we also concluded that the frequency of the muscle contractions is between 5 and 400 Hz. Therefore, we chose a frequency of 140 Hz for both of the input signals. The output from the simulation is as expected. We used equation 1, which is the equation to determine the output voltage of the instrumentation amplifier, to calculate the output voltage of the whole EMG circuit. Because the bandpass filter has a gain of 1, we did not take its gain into account. We used Rg being 680 Ohms like we determined and calculated the output voltage to have an amplitude of 5.44 V. Because this is an AC signal centered at 0 V, in the simulation, we saw the output voltage oscillating between around positive and negative 2.8 V. This matches up to an amplitude of around 5.44 V, so we concluded that the simulation works as intended.

$$V_{out} = (1 + \frac{100\ k\Omega}{R_G})(20\ mV) + 2.5 (1)$$

Now that our simulation was working as intended, the next step was to physically build the EMG circuit on a breadboard. We initially breadboarded the whole circuit on one breadboard, but upon testing the circuit, we determined that part of that breadboard was not functional. Therefore, we moved the 2.5 V offset amplifier and instrumentation amplifier to another breadboard, and connected the output of the instrumentation amplifier to the input of the bandpass filter on the other breadboard. We first gathered all the necessary resistor and capacitor values. Then, we used the datasheets for the MCP601 and AD623 (found online) to determine the pin numbers of the op-amps. Using these and the circuit schematic above, we built the circuit on the breadboard. An image of the final breadboarded circuit is shown below, with the breadboard on the left housing the 2.5 offset MCP601 and AD623 instrumentation amplifier, and the breadboard on the right housing the low pass active filter, high pass active filter, and unity gain buffer at the end. Power is provided to the circuit via a 5 V power supply to the red wires, and the actual signals from the body are supplied to the two blue wires on the instrumentation amplifier.



<u>Conclusion on full system + reflection</u>

During the process of building and testing the circuit, there were many things that didn't function as intended, causing us to change our initial build and test plan. We bought electrodes to paste on the bicep muscle to help draw the input voltages from the muscle contraction. One of these electrodes was supposed to go on the top of the bicep, another at the bottom of the bicep, and the third at the elbow to act as ground. However, the electrodes we bought didn't end up working, as we saw no signal produced when using them. We also tried holding alligator clips to our bicep, but this method was not sustainable and did not work as well. After talking to Prof. Shia, we resorted to using the Wave Generator function on the oscilloscope to produce these input voltages. We used the known fact that our muscles produce voltages in the mV range, and decided to use two oscilloscopes (because there are two input voltages) to simulate the voltages from our muscles. However, when we tried using two oscilloscopes to do this, we were getting an odd signal that was difficult to read and interpret. Upon talking to a grutor (Diego), we concluded that this was because the oscilloscopes could be out of phase, we could cause destruction and not the correct signal to be outputted. Therefore, we resorted to only using one oscilloscope. In order to simulate the 20 mV difference, we set one of the inputs to the instrumentation amplifier to be 20 mV and the other to ground.

Another thing we learned during this process was how to account for AC vs. DC signals. Originally, we were using the instrumentation amplifier as a single rail op amp, which was causing our signal to rail out. In order to fix this issue, we resorted to using the dual rail function of the instrumentation amplifier, providing +5V to the positive input and -5V to the negative input (instead of ground). This allowed us to get a signal that didn't rail out. We learned that because we were inputting an AC signal that has negative voltage, we needed to utilize the dual rail capability of the instrumentation amplifier.

After these changes, the 2.5 V MCP601 offset amplifier and the AD623 instrumentation amplifier were both working as intended. The output from the instrumentation amplifier, as produced on the oscilloscope, is shown below in Figure 1. We expected a peak to peak voltage of around 5.44 V (as previously mentioned), but we were not getting that. We tried troubleshooting, but were not able to figure out why we were getting a peak to peak voltage of 3.14 V. However, we decided to move forward with the circuit, because we were observing the general patterns we were expecting.

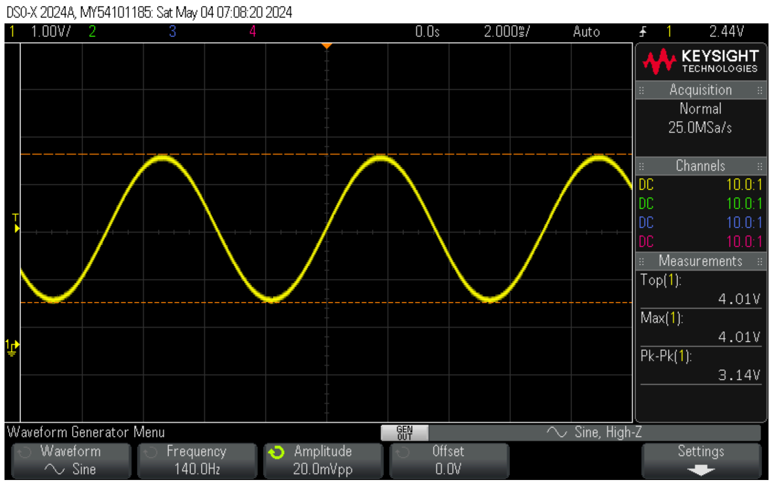


Figure 1. Output from AD623 instrumentation amplifier

When we tried testing the output of the bandpass filter, we were getting a signal that was railing out. Upon further troubleshooting, we realized that this was because the bandpass filter circuit was loading the instrumentation amplifier circuit. We tested this by connecting the output of the instrumentation amplifier to the input of the bandpass filter, and then testing the output from the instrumentation amplifier just as below. The result we got is shown below in figure 2, with the railing out implying the loading. In the future, to prevent this from happening, we could use a unity gain buffer between the instrumentation amplifier and the bandpass filter. We did not have enough time to implement this on our circuit.

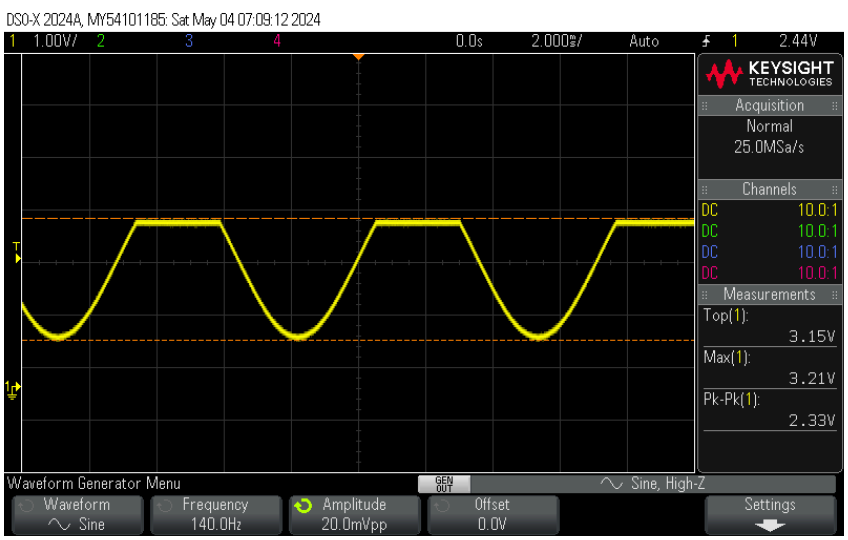


Figure 2. Output from AD623 instrumentation amplifier connected to the bandpass filter, demonstrating the effects of loading.

Even though we were not getting the exact value of output voltage we were expecting from the instrumentation amplifier, we were still observing the general expected behavior. We increased the input voltage from the generated wave from 20 mV to 30 mV to observe the results. As expected, we saw that increasing the difference between the input voltages resulted in a larger output voltage (figure 3). This is expected because it shows that the instrumentation amplifier is working as intended: it's taking the difference between two voltages and amplifying them. This is simulating what will actually happen if we measure muscle contraction.

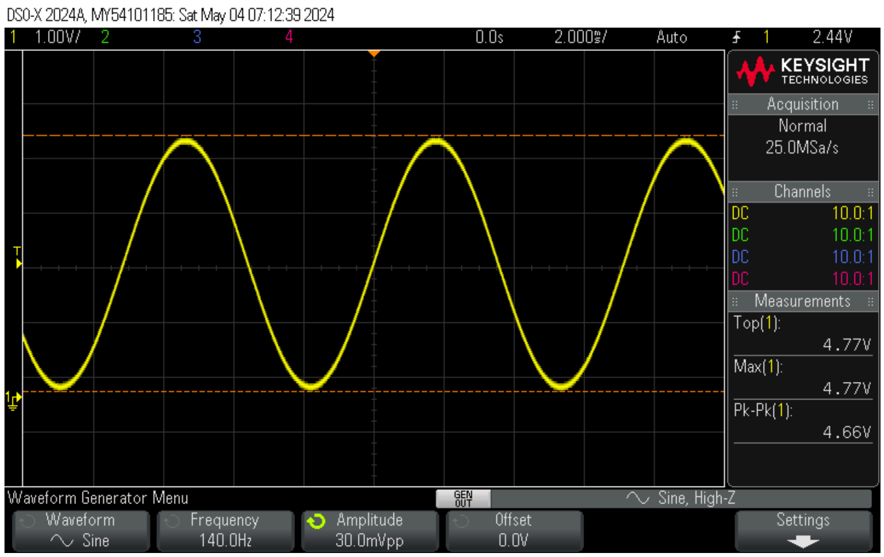


Figure 2. Output from AD623 instrumentation amplifier after increasing the input voltage amplitude to 30 mV.

Overall, although we weren't able to get the exact intended results, this was a valuable learning experience. We learned how to apply the theory of low and high pass filters to design a bandpass filter during the circuit analysis stage. We also learned how to effectively breadboard, especially when we found out our breadboard wasn't working as intended. We learned about the physical effects of loading as well as other troubleshooting techniques as we learned how to work with AC signals. We also learned how to test a circuit's functionality with the intended output in mind.