Abstract:

In this experiment we first built a comparator by using resistors and an op amp, we then built a low pass filter using an op amp, resistors, and a capacitor. We were able to use a variable power supply, cut off frequencies, gain, BODE plots, and Vout's to analyze how the circuits were affected by the different components and the changes to the components. This experiment allowed us to get a better understanding of comparators and low pass filters, especially by comparing this to real world applications/

Introduction:

Operational amplifiers, commonly known as op amps, are components of circuits that allow for the signal to be boosted, inverted, or both boosted and inverted. An op amp consists of a negative pin, which is the inverting input, and a positive pin, which is the non-inverting input, which can be seen below in figure 1. Op amps also have two power supplies, +Vs and -Vs. It is important to always assume the circuit has an ideal op amp; when we have an ideal op amp the input impedance is infinite, meaning the input resistance is infinity and current is zero, so the voltage drop between the inverting and non-inverting pins are zero, meaning V+ and V- are assumed to be equal.

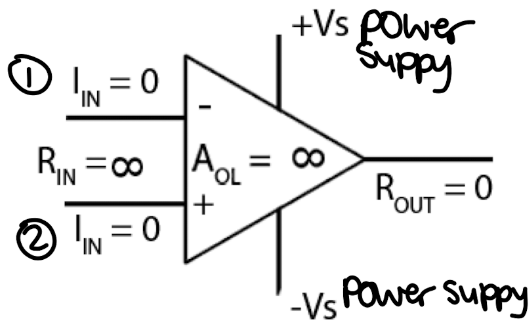

Figure 1

A comparator compares two different input voltages and outputs whichever voltage is higher, which can also be seen in Figure 1. Comparators also can flip between the different saturation limits. A circuit like Figure 2 gives us hysteresis, which means its time-dependent on the output, but it helps provide a stable signal despite Vin being a little noisy.

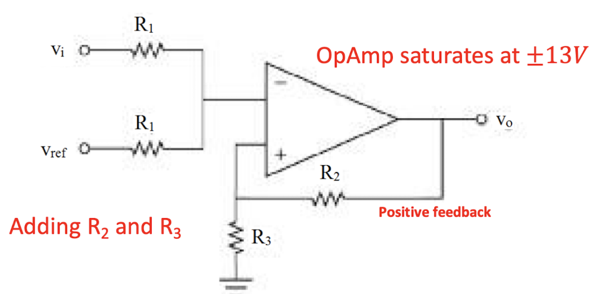

Figure 2

A capacitor stores electrical energy and resists changes in voltage drop. When the voltage of a circuit changes, current is produced. A capacitor used in a bread board circuit can be seen below in Figure 3.

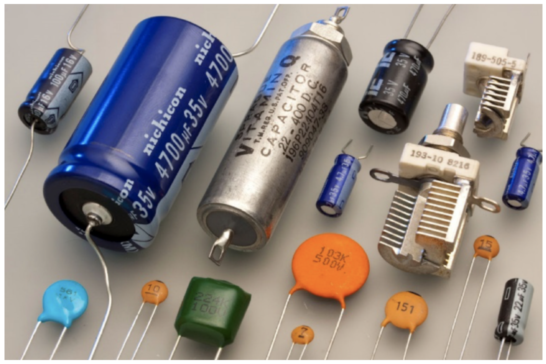
Figure 3

A low pass filter is a filter that removes high frequencies from the circuit, only allowing low frequency signals to pass through.

In this experiment, we use op amps, comparators, and capacitors to build both a comparator and a low pass filter. We then are able to measure the voltages, resistances, gain, and frequency of circuits. More specifically, the resistors and capacitors allow us to measure the gain of the system, while the op amps allow us to build a capacitor and a properly functioning circuit, as well as a low pass filter.

Methods:

In the laboratory we performed two experiments, the first experiment utilized resistors and an op amp to create a comparator, and the second experiment utilized resistors, an op amp, and a capacitor to build a low pass filter.
We start by gathering all of the needed materials: a breadboard, four resistors, Elvis Board, wires, an op amp, and a laptop with the Elvis software.

Experiment 1:
In this experiment we built a comparator using R1=9.87K Ohms, R1=9.89K Ohms, R2=98.38K Ohms, R3=32.63K Ohms, an op amp, Vref, and Vi. We connected Vout to op amp port 1, V- to the second port, V+ to the third port, Vcc- to the fourth port, and Vcc+ to the eighth port, allowing us to build a comparator and low pass filter. Vi flowed into R1 and Vref flowed into the other R1, which both flowed into the V- component of the op amp. R3 was grounded and split into V+ and R2, which both R2 and V+ flowed into Vout. We used a variable power supply for the input voltage and to ground the circuit, and we then measured the Vout of the circuit by connecting our red and black alligator wires to the ground and op amp, which can be seen below in Figure 4.

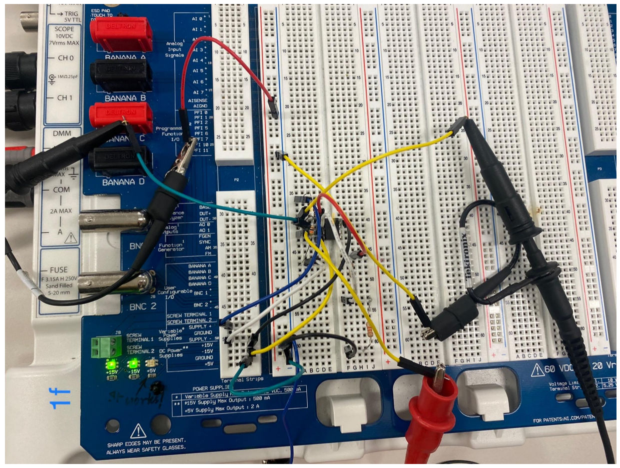

Figure 4

After measuring the Vout with a variable input, we switched the input value and re-measured the Vout, which allowed us to see how the circuit was affected by the variable power supply.

Experiment 2:

In experiment two we set up a low pass filter by using Vi as our power source, Ri= 9.963K Ohms, Rf= 98.9K Ohms, Cf=0.047, with an unknown Vout. We connected Vout to op amp port 1, V- to the second port, V+ to the third port, Vcc- to the fourth port, and Vcc+ to the eighth port, allowing us to build a comparator and low pass filter. Vi flowed into Ri, which split and part flowed into V- and also flowed into Cf and Rf, which then in turn flowed into Vo, meanwhile V+ was grounded. We then connected our red and black alligator wires to the ground and op amp, which can be seen below in Figure 5.

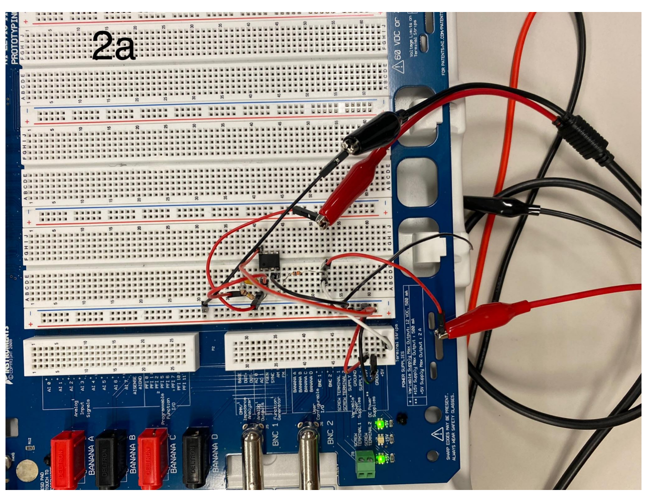

Figure 5

After setting up the wiring for the circuit, we applied a DC input of +15V, which allowed us to verify what the gain was and determine the value of Vout. We then used the function generator to apply an input with an amplitude similar to the one used in TinkerCad, and eventually we tested the filter at three different frequencies on either side of the cutoff frequency. Bode plots were taken for each frequency above and below the cutoff frequency, allowing us to record the amplitude of the input and output signals.

Results:

Experiment 1:
We first drew and analyzed the simple comparator circuit, which can be seen below in Figure 6.

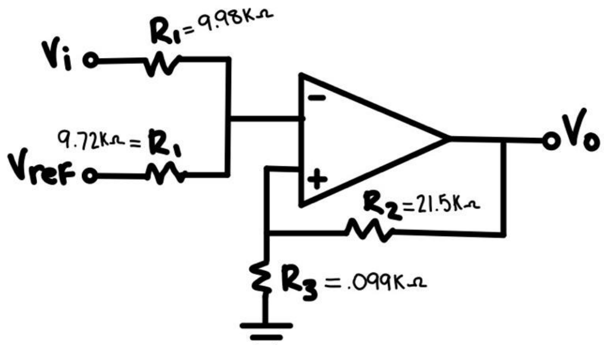

Figure 6

We also created the circuit on TinkerCad, which can be seen below in Figure 7.

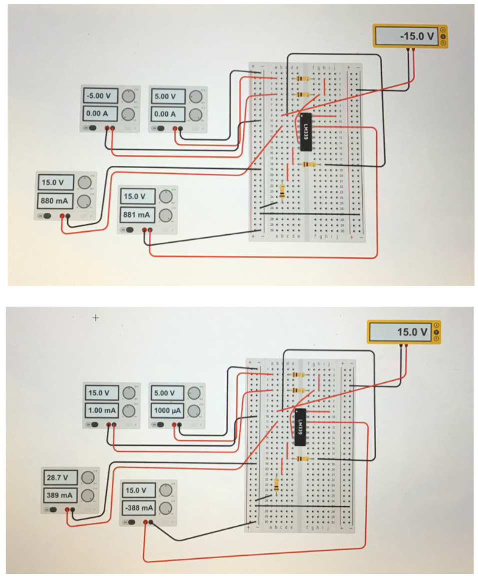

Figure 7

The bread board set up for the first part of the experiment can be seen below in Figure 8.

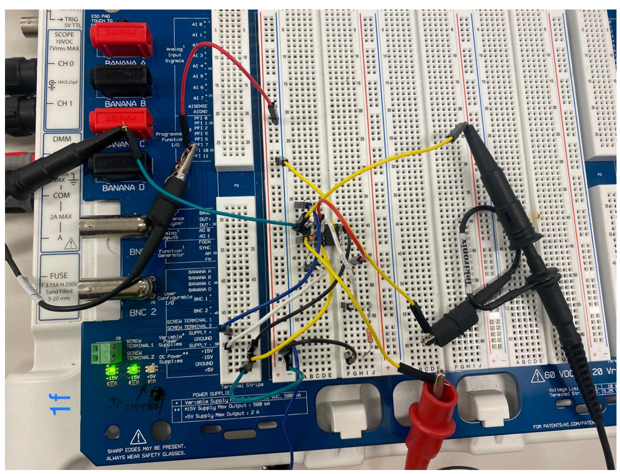

Figure 8

We used a variable power supply of + and -, as our Vin, and the node voltages change as the output saturation switches, which can be seen on the multimeter. The expected behavior was demonstrated in this experiment, which can be seen in oscilloscope results for each of the two possible comparator outputs in Figure 9 and Figure 10. In Figure 9 and Figure 10, we can see that the voltage switched from -12V to +12V. The yellow/green line represents the voltage at V- and the blue line represents Vout. V- doesn't change much in the original oscilloscope compared to the switched, but Vout changes/flips. As - Vin is equal to zero, the +Vin is larger than the voltage switch V+.

When +Vin equals -Vin, the value is larger than V+ but it is negated. The variable power supply needs to be adjusted either above or below the V+, this allows us to see a voltage switch. There is hysteresis in the circuit that allows for a more stable switching of voltage. When there is noise on the Vin it causes Vout to vary, which gives us hysteresis, meaning the time dependence of the output. The circuit is not susceptible to noise due to the output being VCC+ and VCC-, meaning noise cannot pass through the op amp in the circuit. Since noise cant pass through the op amp, this causes our comparator to not be susceptible to noise.

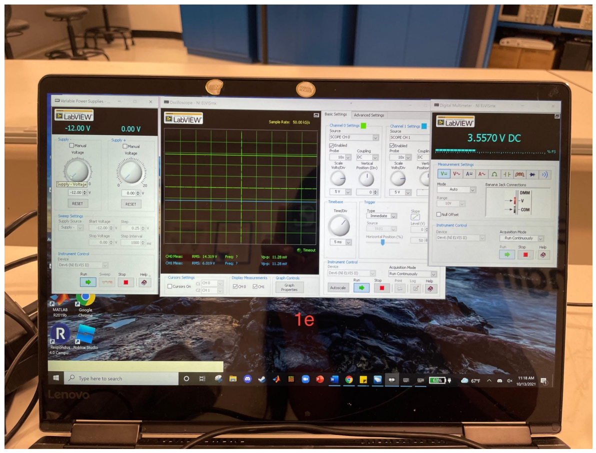

Figure 9

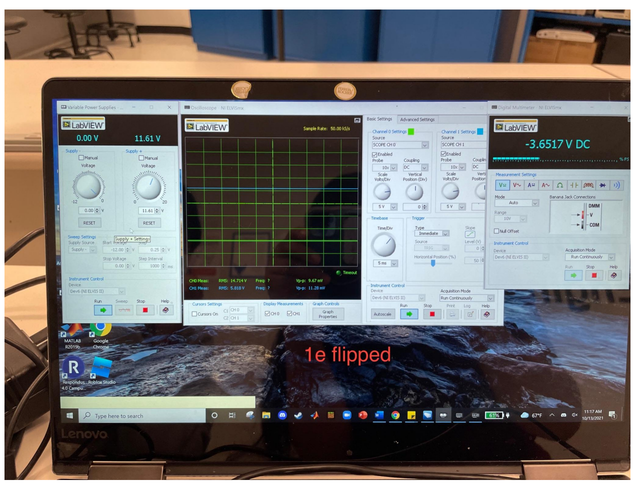

Figure 10

Experiment 2:

We used resistor and capacitor values of: Ri=9.963K Ohms, Rf=98.9K Ohms, and Cf=0.47 mu F. We first calculated our transfer function of the system, which is otherwise known as the system gain. The equation for system gain is $gain = -Rf/Ri$, plugging in our values we get $gain = -98.8K\ Ohms/9.963K\ Ohms$, giving us a gain value of

-9.92K Ohms. We also built the circuit on TinkerCad, which can be seen below in Figure 11.

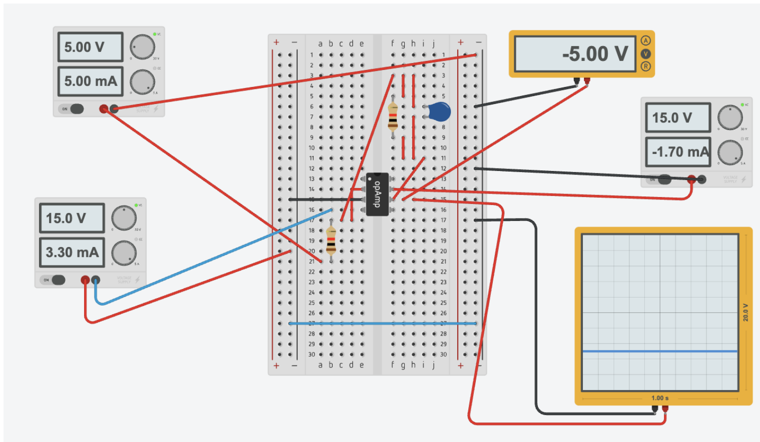

Figure 11

After applying a DC input to the circuit, we were able to verify that the gain is approximately what we calculated on paper, seeing our input was +10.564V and the output was -10.554V. The output can be seen by using two different colors on the oscilloscope reading, below in Figure 12.

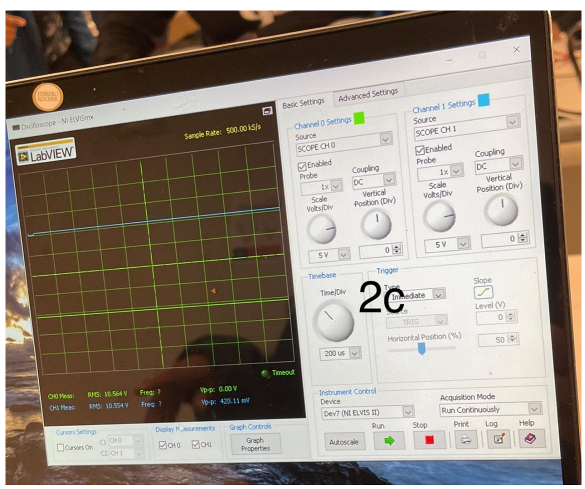

Figure 12

We then used the function generator to apply an input with an amplitude similar to the one used in TinkerCad, which can be seen below in Figure 13.

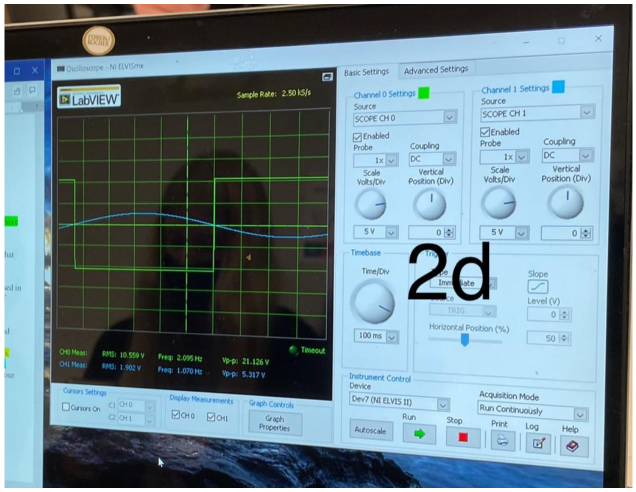

Figure 13

We then determined the cutoff frequency of our filter by changing the input frequency from the function generator, which can be seen below in Figure 14.

$$f_c = \frac{1}{2\pi C R_F}$$

$$f_c = \frac{1}{(2\pi)(.47\mu F)(98.9k\Omega)} = 3424$$

3KHz

1K 931.3mHz   1KHz
1.5KHz   1.5KHz
2KHz   2KHz

Figure 14

Since we had a gain value of -9.92K Ohms, we would expect the signal to be not amplified. In Figure 13 we can see that that signal was not amplified in comparison to the signal in Figure 12, and the frequency was slightly below the cutoff frequency we calculated prior. We can also see that the input signal was reduced by about the same value as the gain we calculated prior, which was expected.
We then tested the filter at three different frequencies on either side of the cutoff frequency, which can be seen in Figures 15 - 20.

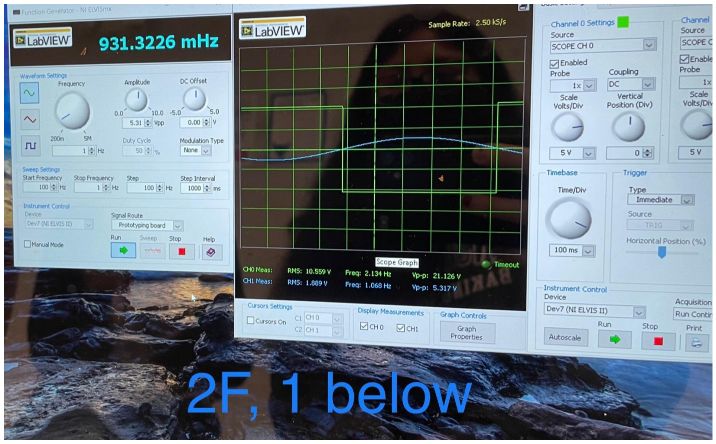

Figure 15

Figure 16

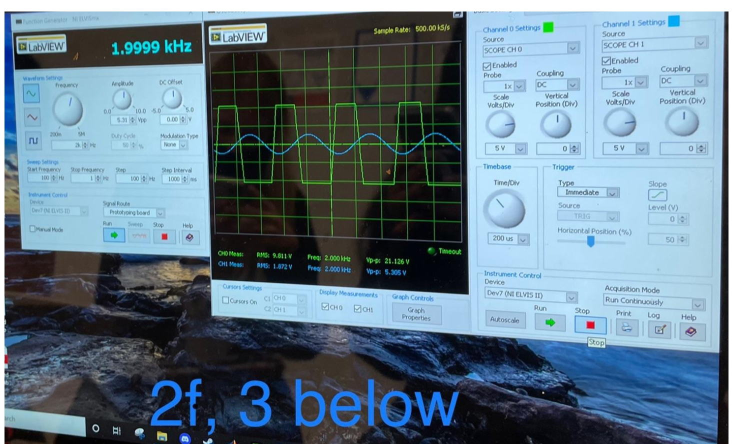

Figure 17

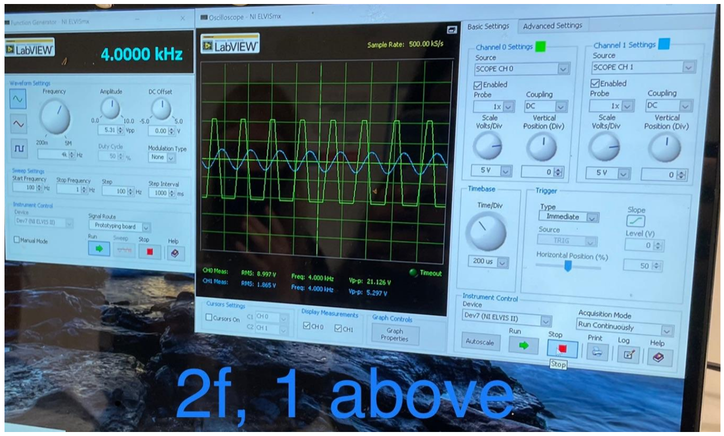

Figure 18

Figure 19

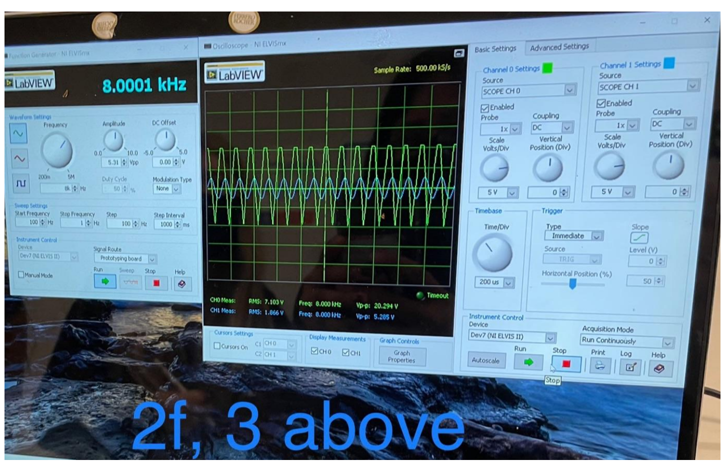

Figure 20

For each frequency we recorded the input and output amplitude, which can be seen below in Table 1.

Figure	Input Amplitude (V)	Output Amplitude (V)
15	1.889	10.559
16	1.876	10.004
17	1.872	9.811
18	1.865	8.997
19	1.866	8.095
20	1.866	7.103

Table 1

We can see that as the input frequency gets larger on either side of the cutoff frequency, that the output amplitude is slowly decreasing.

In Figure 21, we can see the BODE plots, with a frequency value of 3.91Hz, phase of -48.82, a gain of .65, and another gain of -3.77dB.

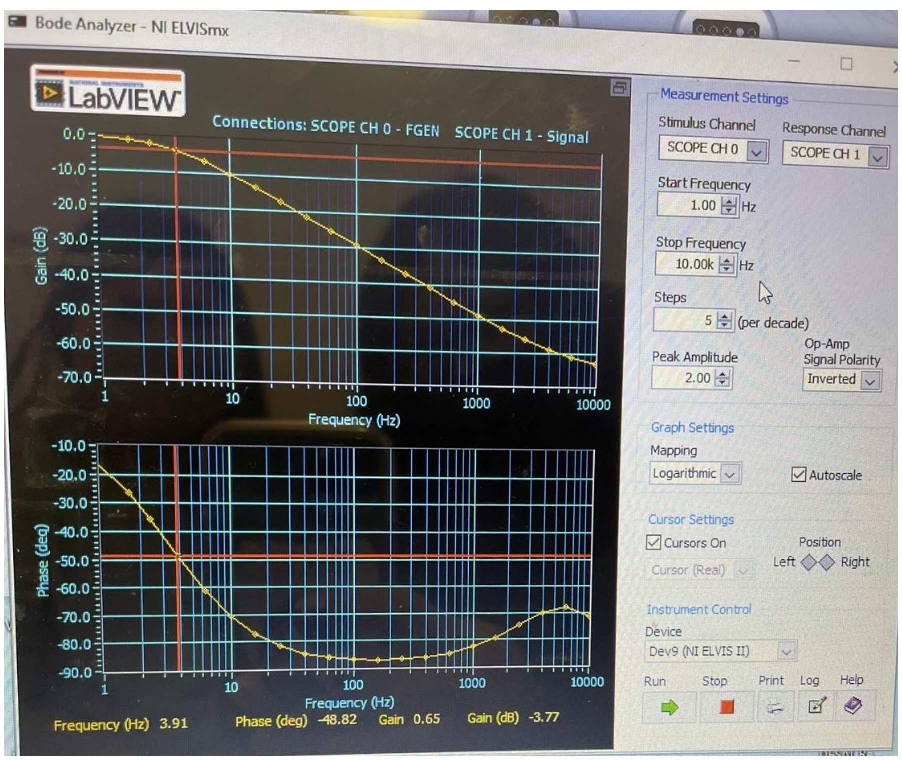

Figure 21

We would use a low pass filter when we want the lower frequencies to get through, but not the higher frequencies. One real life engineering application of a low pass filter is a bass speaker. We want the lower bass frequencies to pass through, but not the higher frequencies. A second real life application of a low pass filter is EMGs, which remove the higher frequencies but allow the lower frequencies to pass through.

Conclusion:

This experiment allowed us to use op amps, comparators, and capacitors to build a comparator and a low pass filter. By using gain, variable power sources, cutoff frequencies, and Vout’s, we were able to see how these circuits were affected by saturation and different frequencies, which allowed us to get a better understanding of how these circuits function. We were also able to compare how these systems are used in everyday engineering.