Audio Equalizer Final Project

William Wong
12/14/2022

Abstract

This report will document and analyze the process of making a simple audio equalizer that will be able to output stable sound through a speaker. The equalizer testing process will be divided into four steps: filters, operational amplifiers(op amps), summing amplifier, and finally an audio amplifier. To test the filters, I will use the Frequency Response Analysis(FRA) tool on the oscilloscope to see if the -3dB values match the deliverables. To test the rest, which mainly consists of op amps, I can measure the VRMS values when the wipers are maxed out or lowered all the way down and compare those values with the deliverables. Additionally, from the VRMS values we can calculate how much power is flowing into our speaker. Finally, we will use the FRA tool to see if our frequency response is a straight line, meaning our output doesn't have a lot of noise when different frequencies are going through the circuit. This experiment is relevant because in the real world because speakers are built using almost the same way as our experiment: filters and op amps.

1. Objectives

1.1 Low Pass, High Pass, and Band Pass Filters

The objective of the first part of the audio equalizer is to first see if our filters work as expected. We can do this test be outputting a $1V_{p-p}$ sinusoidal wave from our oscilloscope to each respective filter. We can measure the input from the wave and the output after the filter. For the low pass filter we want a -3dB cutoff frequency of around 320hz, for the high pass filter we want a cutoff of 3200hz, and finally for the bandpass we want both 320hz and 3200hz.

1.2 Op Amps After Each Filters

The objective of this subsection is to see if our operational amplifier, or more specifically, an inverting circuit, works as intended. The LM324 is a quad op amp I will be using for the op amps. I will be using three out of the four op amps in the LM324 for the filters. For example, If our $1V_{p-p}$ sinusoidal wave is inputted into our inverting circuit, we should be able to control the output voltage being in a range from around 0_{p-p} to $1V_{p-p}$ by using a potentiometer. When our potentiometer is set at its maximum resistance at 10kΩ, we should have an output peak to peak voltage of 1V.

1.3 Summing Op Amp

The objective of this subsection is to see if our summing amplifier works as intended. I will be using the last of the four op amps in the LM324 for the summing amp. We will have three resistors in parallel with the input for each of them being each filter respectively and the output all going into another inverting amplifier with another 10kΩ controlling the output voltage. $100mV_{RMS}$ is the output voltage we want when all of the wipers for the potentiometers are maxed out and less than $15mV_{RMS}$ is what we want when all of the wipers are turned to the opposite side.

1.4 Low Voltage Audio Amplifier

The objective of this subsection is to see if our low voltage audio amplifier is working as intended. I will be using the LM386N-4 for the low voltage audio amplifier. We are checking if the power going into the speaker(8Ω resistor) is going to be 400mW. Another way to check our output is to make sure our audio amplifier circuit has a gain of 20. So if we have a $100mV_{p-p}$ after the summing amp we can expect to have a $2V_{p-p}$ after the audio amplifier.

2. Theory

2.1 Filters

To first make the filters we must know the cutoff frequency equation that is able to help us decide what capacitor and resistor values we need for our filters. In the deliverables we are given certain cutoff frequencies for each of our 3 filters. Equation 1 shown below is the general equation to get cutoff frequency(CF).

$$CF = \frac{1}{2RC\pi} \tag{1}$$

When given the cutoff frequency, all I had to do was replace the capacitor value with 0.1μF because 10 of those capacitors were provided with our lab kit. As a result, we only have the resistor to solve for. Figure 1 is an example circuit diagram of a low pass filter. We can think of this circuit

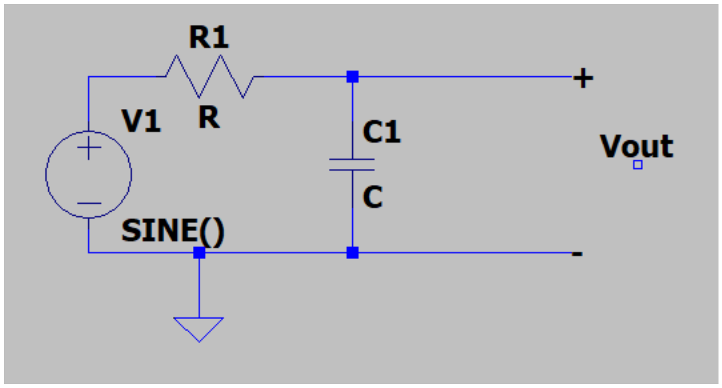

Figure 1: Example Low Pass Filter Circuit

as a voltage divider. If our frequency is low, we can think of our voltage going through the resistor and rejecting the capacitor and going straight to V_{out} because it will not be able to charge it in time. For the high pass filter, however, it's basically the opposite. To make a high pass filter, we

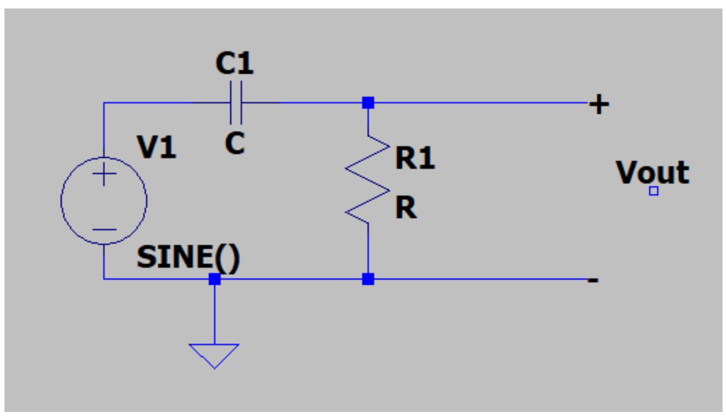

Figure 2: Example High Pass Filter Circuit

can switch the capacitor and resistor, as shown in Figure 2, but an important detail to keep in mind is the high pass filter will have a higher cutoff frequency. If we use the same idea from the low pass filter here, we see that in lower frequencies the voltage wouldn't get pass the capacitor, however when the voltage is at higher frequencies it is able to get to V_{out}.

Making a band pass filter is more complicated. As shown in figure 3 below, we need an op amp in order to stop the two first order filters(low pass and high pass) from interacting with each other causing a second order filter, which is a lot more complicated to calculate the values for. Another reason we need an op amp in between is to prevent loading, which is random voltage or noise to be shown when we are measuring the circuit. having the op amp, or in this case a buffer, will mitigate loading and gives us smooth results.

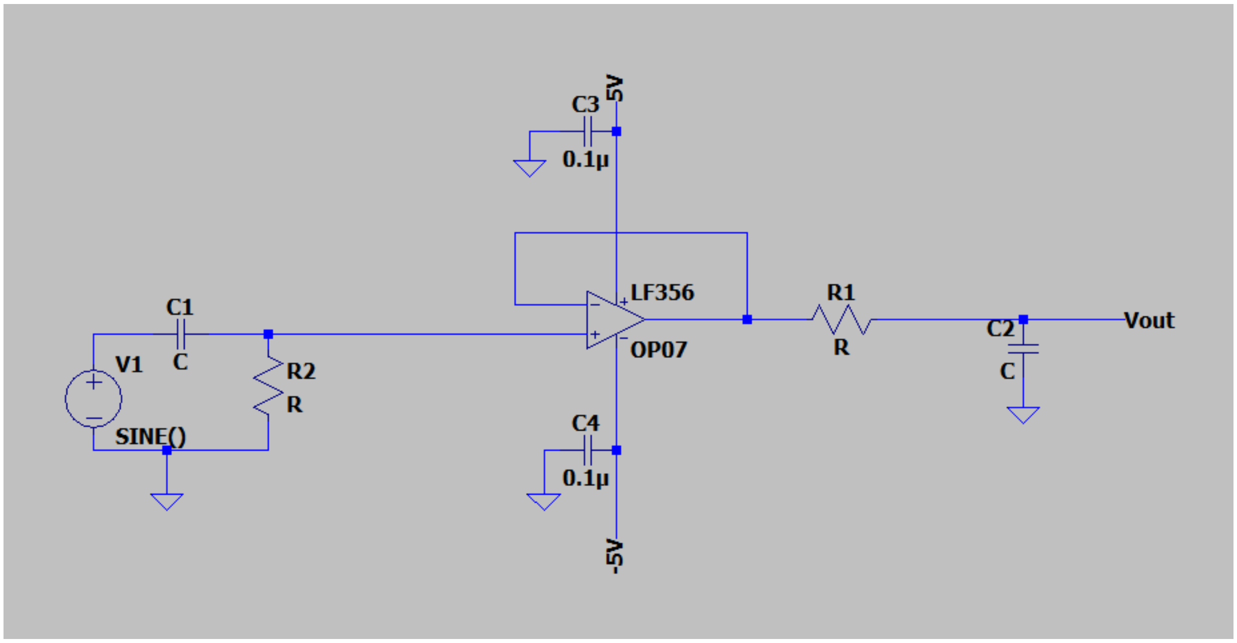

Figure 3: Example Band Pass Filter Circuit

After setting up these circuits we want to get the frequency responses from each of these circuits. To test out if the values we calculated matches with the results shown on the oscilloscope, we measure from the -3dB point because that is half of the input power, which is our cutoff frequency.

2.2 Op Amps and Volume Control

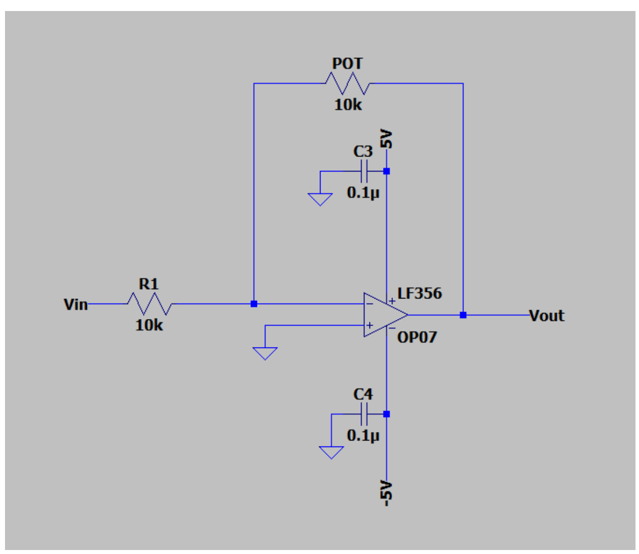

Figure 4: Generic 1 Gain Op Amp Circuit

To make a volume controller, we need to use an op amp with a gain of 1 with a variable resistor, or in this case a potentiometer. We can utilize the fact that the potentiometer has a range of 0 to 10kΩ to control how much voltage gets out of our op amp. By utilizing the gain equation for an inverting amplifier we can do this as shown in Equation 2 because our circuits for all of our op amps are going to be inverting. Equation 2 is finding gain with R_{POT} being the potentiometer resistance and R_1 being the resistor being the 10kΩ resistor because when the potentiometer is maxed out at 10kΩ we want a gain of 1.

$$Gain = -\frac{R_{POT}}{R_1} \tag{2}$$

From Equation 2 we can see that our gain is in a range from 0 - 1, which we wanted. The negative sign in the gain equation would become obsolete because were are passing in a wave voltage, meaning that even if there is a negative sign the output would still be a wave voltage and we're using those V_{p-p} measurements. We would see if our V_{out} matches our V_{in} on the oscilloscope to see if we truly have a gain of 1.

2.3 Summing Amplifier

The summing amp is the same as the op amps that come after the filters, however, the only difference is the inverting amplifier has three input resistors instead of just one.

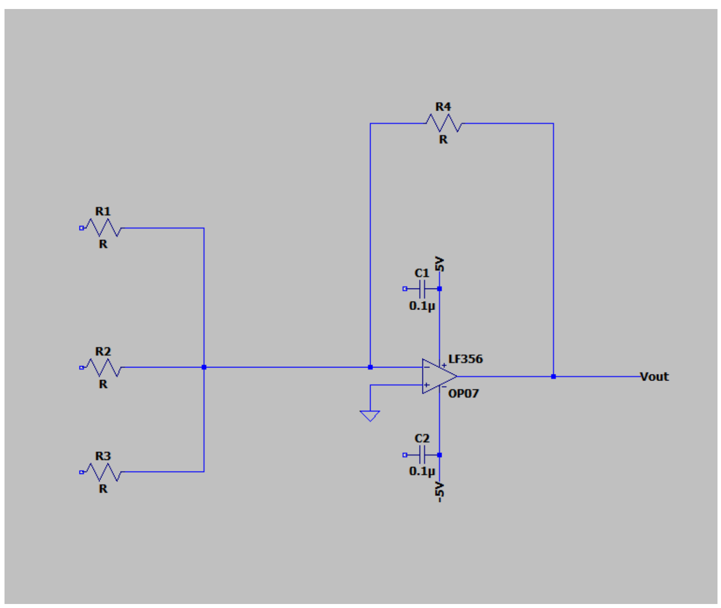

Figure 5: Summing Amplifier Circuit

In the deliverables we are tasked with getting a V_{RMS} value of around 100mV. If we think about this problem by solving for one circuit at a time, meaning solving for one filter, the other two filters will have the same values. If we have the input and output voltages, then we are able to solve for gain as shown in Equation 3.

$$V_{in} * Gain = V_{out} \tag{3}$$

After we solve for gain, we now know 2 unknowns out of the three: potentiometer resistance and the gain. All we need now is the input resistor. To get this resistor value, all we need to do is use equation 2. After that we know that the other two resistor values are going to be the same since the V_{RMS} output after each filter op amp are also going to be the same.

Now that we have the filters, op amps, and summing amp done we see our circuit's ripple by using the FRA tool on the oscilloscope. We want our frequency response to be a straight line because we want our voltage to stay consistent as the frequency increases to make sure our filters are working correctly and equally. Using the equation shown in Equation 4(the dB to V_{RMS} formula) below we can calculate V_{RMS} from the dB values we get from the FRA.

$$V_{RMS} = \frac{10^{dB/20} * V_{in}}{2\sqrt{2}} \tag{4}$$

After finding the max and min dB values from our FRA and finding their respective V_{RMS} values, we can use Equation 5 shown below to take the difference between the two and see if our difference is less than 15mV meaning our voltage isn't noisy.

2.4 Audio Amplifier

We are provided with the schematic of the LM386N-4, which is going to be our circuit's audio amplifier as shown below in Figure 6. We know that the amplifier will have a gain of 20.

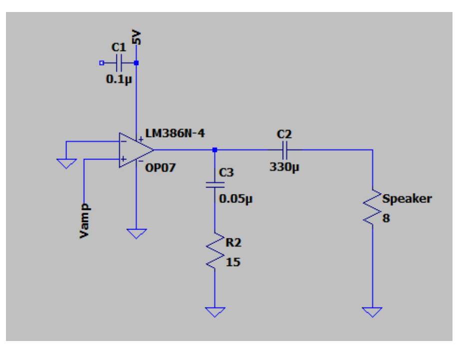

Figure 6: Audio Amplifier Circuit

If we know the load resistance(speaker) and the input voltage(V_{amp}), then we are able to find power, which is our last deliverable. Using the power equation, shown in Equation 5 below, we are able to see how much power is going into our speaker.

$$Power = \frac{{V_{amp}}^2}{R_{Load}} \tag{5}$$

An important idea to note is that we need decoupling capacitors for every voltage source we use to power an amplifier to reduce jumping in voltages or noise.

3. Procedure

3.1 Filters

Figure 1, 2, and 3 shows the schematics of the low pass filter, high pass filter, and band pass filter respectively. As we can see, the low pass filter and high pass filter just needs a resistor and capacitor. Figure 3 is the band pass filter, however, it starts out with a low pass filter, has a buffer in between, and ends with a high pass filter. The following table shows the values of the components needed for the low pass filter with respect to Figure 1.

Components	**Low Pass Filter**
V_1	Sine Wave $1V_{p-p}$
R_1	5000Ω
C_1	0.1μF

Table 1: Components for circuit in Figure 1

To make the circuit, we need to connect the resistor in series with the sinusoidal output from the oscilloscope. Then we can connect one end of the capacitor in series with the resistor and the other end to ground. To measure the FRA of this circuit we connect the oscilloscope probes right before R_1 and ground(This will be our V_{in} and the next set of probes on V_{out} as shown in Figure 1. The following table shows the values of the components needed for the high pass filter with respect to Figure 2.

Components	**High Pass Filter**
V_1	Sine Wave $1V_{p-p}$
R_1	500Ω
C_1	0.1μF

Table 2: Components for circuit in Figure 2

To make the circuit, we need to connect the capacitor in series with the sinusoidal output from the oscilloscope. Then we can connect one end of the resistor in series with the capacitor and the other end to ground. To measure the FRA of this circuit we connect the probes the same way as the low pass filter.

Making the band pass filter needs a low pass filter, a buffer, and a band pass filter. The following table shows the values of the components needed for the high pass filter with respect to Figure 3.

To make the circuit, we need to connect C_1 in series with the sinusoidal output from the oscilloscope. Then we can connect one end of R_2 in series with C_1 and the other end to ground. We then need a buffer(LF356) to separate the low pass filter and the high pass filter. Connect a wire going in series from the output of the low pass filter into the non-inverting port(+) on the buffer. The

Components	Band Pass Filter
V_1	Sine Wave $1V_{p-p}$
R_2	500Ω
C_1	0.1μF
R_1	5000Ω
C_2	0.1μF

Table 3: Components for circuit in Figure 3

inverting port(-) can just be wired to the output. Make sure to have a voltage source to power your amplifier, in my case I used 5V and -5V because the amplifier has a supply voltage range of 4.5V to 48V. You must add decoupling capacitors to your voltage sources to prevent noisy data. Finally, you can attach your high pass filter with the values described in Table 3 and the steps described in the high pass filter section. Attaching the oscilloscope probes are the same as the previous two filters, with a set at the input and another set at the output.

When using the FRA tool on the oscilloscope make sure to set the number of points to be graphed at 100 and set your output sinusoidal voltage to high-z mode to get smoother data for a better plot. Then you can compare your values with the deliverables.

3.2 All Op Amps

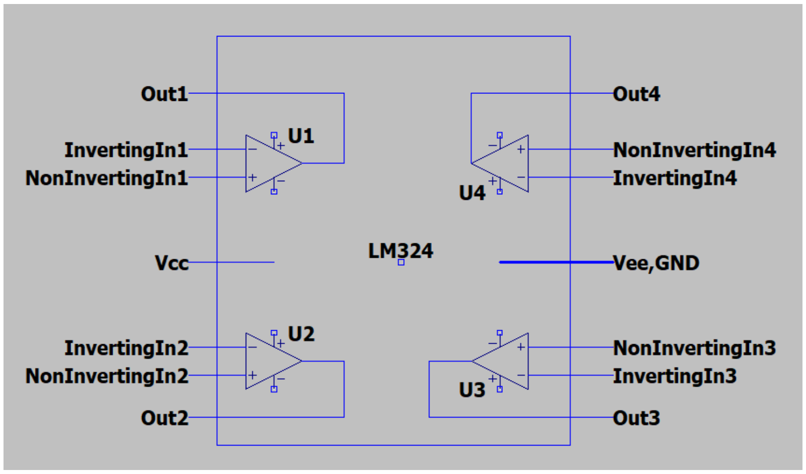

Figure 7: Summing Amplifier Circuit

Shown in Figure 7 above is the schematic for the LM324 quad amp, which I will be using for my 3 op amps after the filters and the summing amplifier. Figure 4 already has the necessary values for a generic op amp with a gain of 1. While we are using the LM324 quad amp, the only difference is shown in table 4 below. Here is another situation where the power sources powering this amplifier needs decoupling capacitors.

We can see that the LM324 has four amps, hence the description "quad amp." We can set aside

Components	LM324 Quad Amp
V_{cc}	5V
V_{ee}	-5V

Table 4: Components for circuit in Figure 7

amps 1-3 to be used as our amplifiers after each filter and save amp 4 to be used as our summing amplifier.

After connecting the output of our filters to the amplifier by connecting the output in series with V_{in} shown in Figure 4, we can move on to making the summing amplifier. The following table shows the resistor values for the summing amplifier circuit in Figure 5.

Components	Summing Amplifier
R_1	35kΩ
R_2	35kΩ
R_3	35kΩ
R_4	10kΩ(potentiometer)

Table 5: Components for circuit in Figure 5

In all four of the op amps in the LM324 there is a potentiometer to be used as a volume control. To attach the potentiometer, we need to set a wire from the output voltage of an input resistor to one end of the potentiometer. Next, we set a short circuit wire between the other end of the potentiometer and the middle pin. Then, we can set a wire from the middle pin to our output node from where ever our output is from the LM324. The reason why we need that short circuit wire is to make the potentiometer a variable resistor, with one end pin representing the changing resistance of a potentiometer and the other end pin staying at a static 10kΩ.

To test if our op amps are working we will put a set of oscilloscope probes at the sinusoidal input and another set at the output of the summing amplifier. Then as we change our sinusoidal frequency from low to high and turn our wipers either at its minimum or its maximum rotation, we can see our Voltage values and check if we have close values compared to the deliverables. Additionally, we can do a FRA using the oscilloscope to see if we can see a straight line, meaning our data wasn't noisy.

3.3 Audio Amplifier

The values and components for the audio amplifier were provided for us in our lab manual. To connect the summing amplifier to our audio amplifier we just put a wire in series from the output of the summing amplifier to the input of our audio amplifier in the non-inverting port of the LM386N-4 audio amplifier. This is another situation where the amplifier is getting a voltage supply and needs a decoupling capacitor.

By replacing the speaker with an 8Ω resistor and placing a set of oscilloscope probes across that resistor we can see the voltage and compare it to V_{amp} which we can find by placing another set of probes right at the output of the summing amplifier. We know that our gain is 20 and if we use Equation 3 and get a gain of 20, then we have built our circuit correctly. Next, if we verified that our amplifier works as intended, by using the power equation in Equation 5, we can check if our power is greater than the power needed in the deliverables.

To test if audio works and can be played we need to attach a speaker and breadboard jack to our circuit. We can already see how to attach a speaker from Figure 6. We need to connect the output of the audio amp in series with our speaker and our speaker has to go to ground. Attaching a breadboard jack is the same thing as replacing our sinusoidal voltage source with the breadboard jack. To attach the breadboard jack, we need to wire one of the end pins to where ever the positive terminal column our sinusoidal voltage source was attached to and the other end pin to where ever the negative terminal column is. We can then plug in the audio cable provided in the lab kit from the breadboard jack into the headphone jack of your computer of choice. Now we can play any Youtube video we want and see the results of turning our wipers to its minimum or maximum positions.

4 Results

4.1 Filter FRA Results

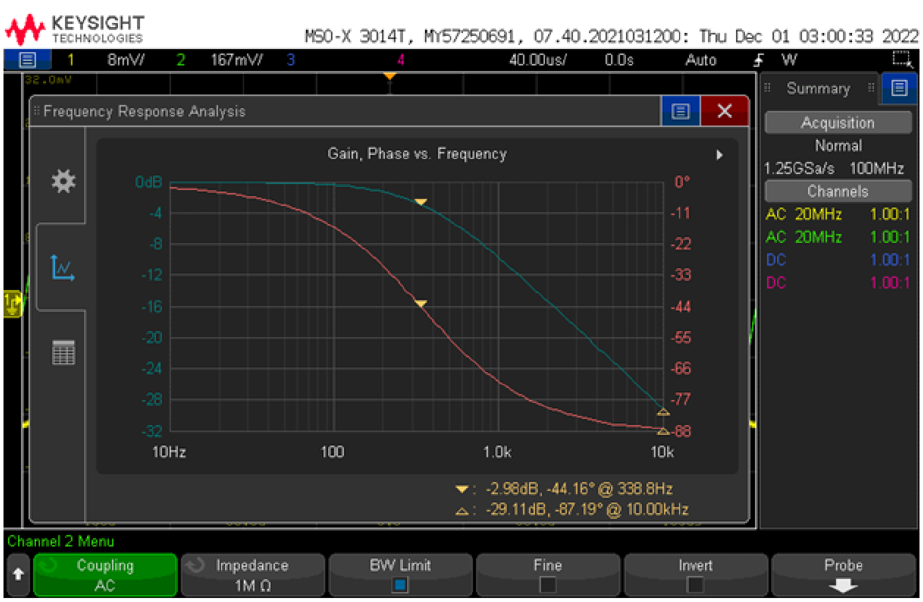

Figure 8: Low Pass Filter FRA

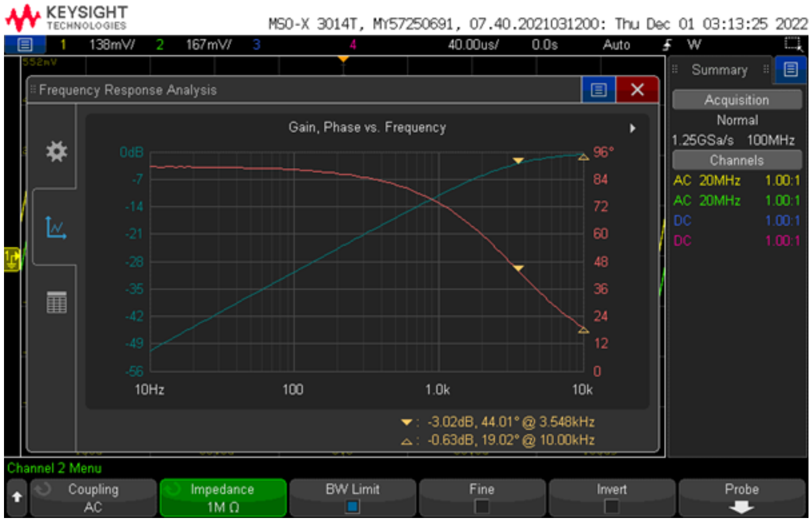

Figure 9: High Pass Filter FRA

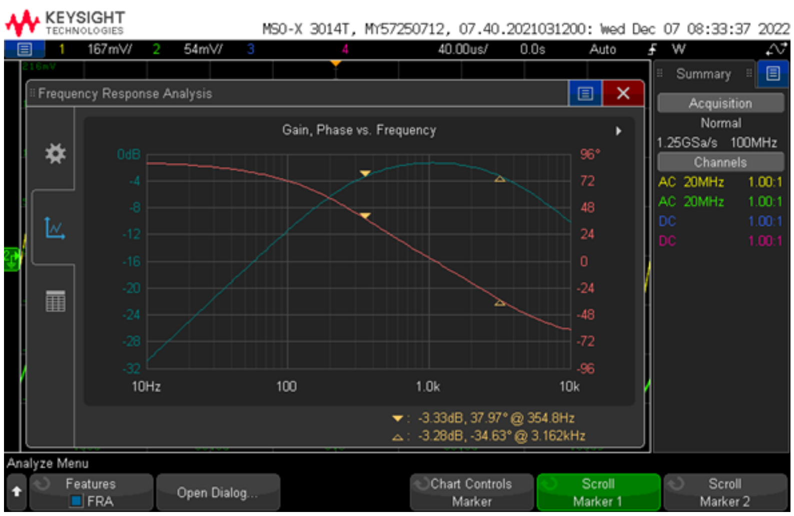

Figure 10: Band Pass Filter FRA

Filters	Cutoff Freq. 1 (hz)	Cutoff Freq. 2 (hz)	Per. Error 1	Per. Error 2
Low Pass	338.8	NA	5.55%	NA
High Pass	3.548k	NA	9.81%	NA
Band Pass	354.8	3.162k	9.81%	1.20%

Table 6: FRA Filters Results

Each of the percent errors of cutoff frequencies for each filter being in the ±10% range from the deliverables, meaning the circuit for the filters are correct.

4.2 Voltage Amplified Results

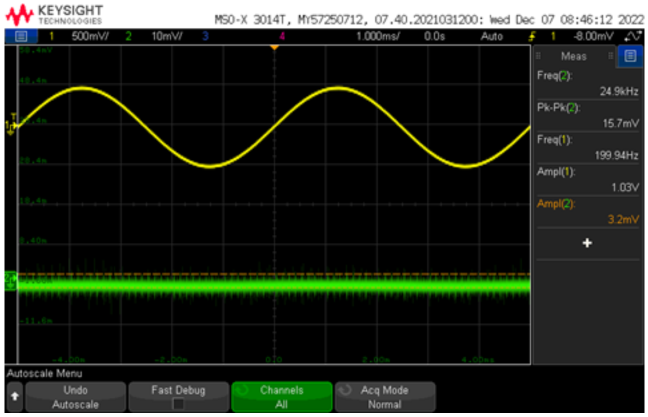

Figure 11: V_{amp} min at 200hz

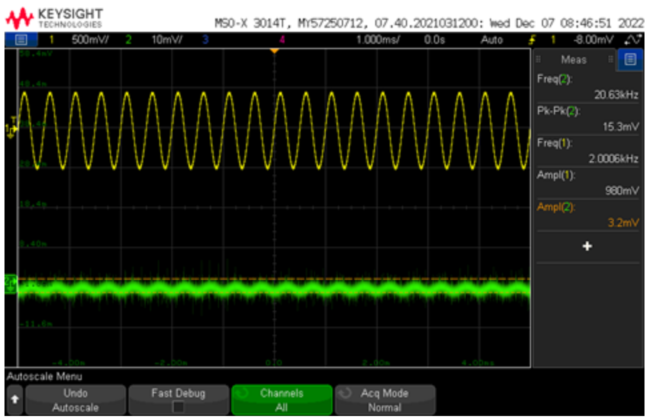

Figure 12: V_{amp} min at 2000hz

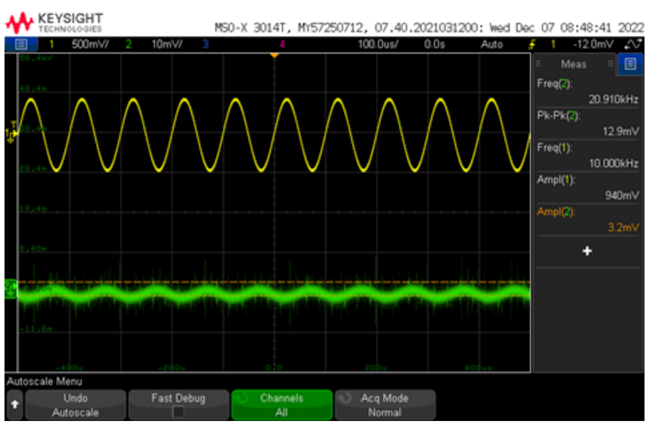

Figure 13: V_{amp} min at 10000hz

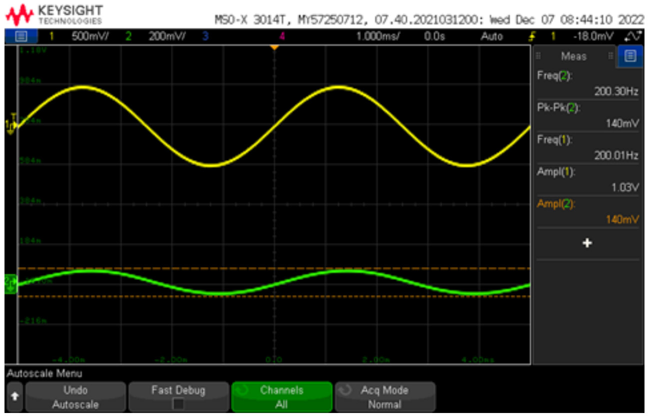

Figure 14: V_{amp} max at 200hz

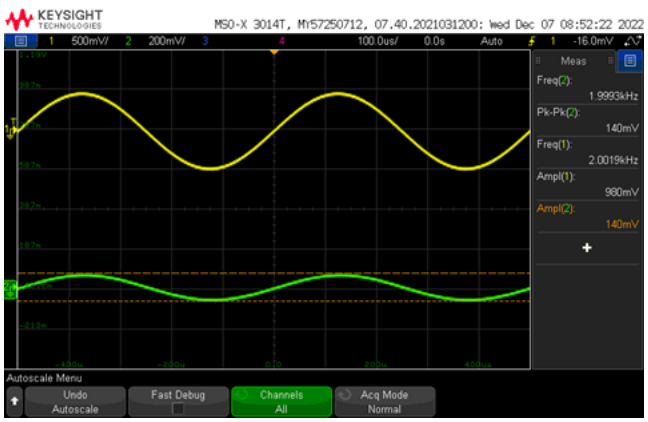

Figure 15: V_{amp} max at 2000hz

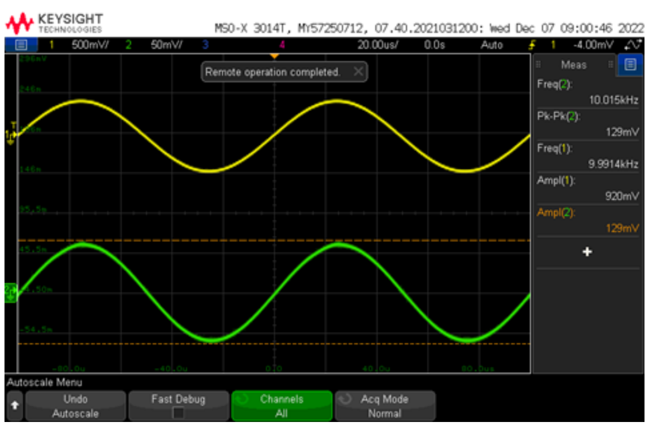

Figure 16: V_{amp} max at 10000hz

The deliverables asked for our V_{amp} values when the wipers are at its minimum to be less than 15mV. As seen on Table 7 shown below, our results are lower than 15mV. When our wipers are at its maximum our V_{amp} had to be $\pm 10\%$ from 100mV, meaning from 90mV to 110mV. Since our results pass what the deliverables asked for, our circuit is correct up to the point of the volume controller.

Setting	Frequencies(hz)	V_{p-p}(mV)	V_{amp}(mV)
Min	200	3.2	2.26
Min	2000	3.2	2.26
Min	10000	3.2	2.26
Max	200	140	98.99
Max	2000	140	98.99
Max	10000	129	91.22

Table 7: V_{amp} Wiper Results

4.3 Audio Amplifier Results

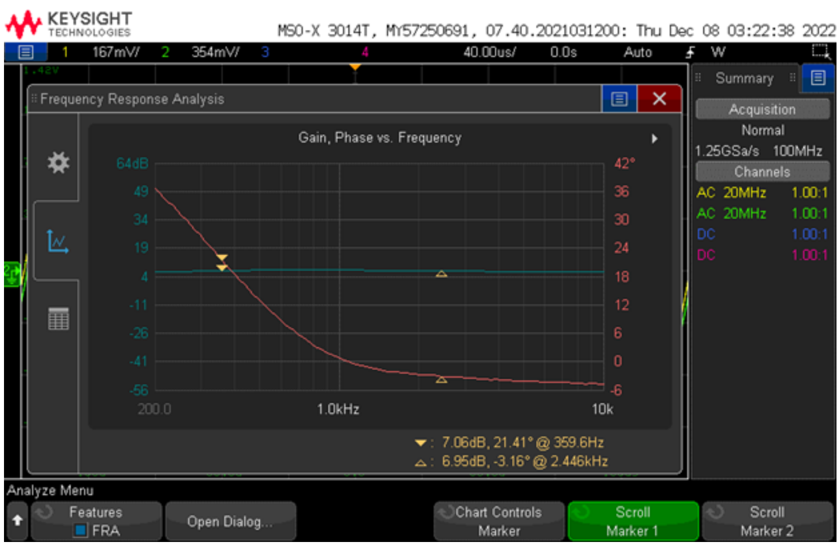

Figure 17: V_{amp} Ripple FRA Test

Type	Decibel(dB)
Min	6.95
Max	7.06

Table 8: V_{amp} Ripple FRA Test Results

In Figure 17 we can see that the line is almost straight and if we convert the values found in Table 8 using Equation 4, we find the difference to be 10.06mV, which is less than 15mV as stated on the deliverables. On the oscilloscope the V_{RMS} across the resistor load was 2.2542V. By using the power equation, Equation 5, we end up getting a power of 508mW, which is greater than 400mW as stated on the deliverables.

5. Conclusion

For the filters, we found out that a filter is just a resistor and capacitor. For the band pass filter we included a buffer in between the low pass and high pass filters to prevent loading and dealing with a 2nd order circuit, which has complicated calculations. It is important to note that when making the low pass and high pass filters on the band pass filters you must swap the resistors, otherwise nothing will be able to pass through the first low pass filter when your frequency is at its specified range. The op amps after the filters were easy to make because all you had to keep in mind were the the gain being 1 and the potentiometer having a max resistance of 10kΩ. However, making the summing was a bit tricky, calculating the new gain and dealing with parallel input resistors. The low voltage audio amplifier circuit was given to us, as a result, that was easy to integrate into our circuit. A good way to test voltage throughout our entire circuit was to have the black cord of the oscilloscope probe in ground and place the other probe after each component to see if we have the correct voltage being passed in between different areas. Through this method we realized that one of our op amps was completely dead and wasn't taking current. We have met all of our objectives because in the Results section I talk about how we met each deliverable needed for the equalizer.