PURDUE
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Audio Equalizer Lab Formal Writeup

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Abstract:

The goal of this lab is to design and test an audio amplifier. This amplifier must combine the various techniques learned throughout the semester with the multitude of components utilized in ECE 20007. This audio amplifier will be designed building three filters: a high pass (to pass in the treble), a band pass (to pass the mid), and a low pass (to pass the bass). The filters will each be connected to a potentiometer-controlled op-amp to allow direct control of the amount of each frequency passed. The three op-amps will meet at a node, feeding into a summing amplifier. The summing amplifier, which will consist of an op-amp controlled by a potentiometer. This summing amplifier will allow for direct volume control. When put together, we will have an audio amplifier which, when combined with a breadboard jack for an audio source, will allow for complete control of the input audio with direct volume control. This project will not only add to our understanding of circuitry but will help us gain an appreciation for the complexity of something so fundamental to modern electronics.

1. Objectives:

1.1 Design Filters with Expected Frequencies:

We are to create three filters; low-pass, mid-pass, and high-pass, with cut off frequencies at the -3dB point. The low-pass filter needs a cutoff point in the range of 288Hz to 353Hz. The mid-pass filter will need a lower cutoff point in the range of 288Hz to 353Hz and a higher cutoff point of 2880Hz to 3520Hz. Finally, the high-pass filter will require a cutoff point in the range of 2880Hz to 3520Hz. In order to verify these filters, a frequency analysis plot of phase and magnitude of each filter, with a cursor marker on the -3dB point must be shown for each filter.

1.2 Verify Amplifier Voltage and Gain:

We are tasked with verifying the V_{amp} with the equalizer knobs fine tuned at specific settings. It is required that the equalizer has as minimal leakage as possible when on low, mid, and high pass frequencies, when the potentiometers are turned to the minimum setting. Leakage is minimal if the V_{amp} is less than $15mV_{rms}$ at 200Hz, 2kHz, and 10kHz. In order to prove this, we will have to provide screenshots of each setting which includes the value of V_{in} and V_{amp} at each frequency.

Additionally, we also must show that V_{amp} is equal to $100mV_{rms}$ at 200Hz, 2kHz, and 10kHz, with all the potentiometers turned all the way up. This would demonstrate the equalizer’s gain for low, mid, and high frequencies is correct. In order to prove this, we will provide screenshots of V_{pp} V_{in} and V_{amp} at each frequency.

1.3 Verify the Ripple At Max, Min, and Mid:

We are tasked with ensuring that the V_{amp} maximum and minimum ripple is $15mV_{rms}$ from 200Hz to 10kHz. While testing, the equalizer must be at maximum while testing. When testing, it must be shown that the equalizer frequency response is a straight line when all the knobs are turned all the way up. Additionally, we must create a plot of the phase and magnitude of the equalizer with a cursor on the maximum magnitude. We need a plot of the phase and magnitude with a cursor at the minimum magnitude. Finally, we must calculate the difference in voltage of maximum and minimum, it must be less than $15mV_{rms}$.

1.4 Verify Amplifier Power Output:

We must show that the amplifier's power is greater than 400mW from 200Hz to 10kHz. It will also prove that the amplifier is amplifying at all frequencies correctly. For the power calculations, the potentiometers must be turned all the way to their highest position. We must also provide a plot of phase and magnitude of our equalizer with a cursor on the minimum magnitude. We must also supply an image which shows the amount of current the amplifier is drawing from the power supply when the equalizer has an audio source connected to it. Finally, we must provide a handwritten calculation which shows that at the minimum magnitude the power is above 400mW.

2. Theory:

2.1 RC Circuit:

One important component of this lab is the RC Circuit. In circuitry, it is important to understand how to connect an oscilloscope to an RC Circuit in order to test the gain, as well as the frequency response. This circuit shown in figure 1 will show how an RC circuit is wired.

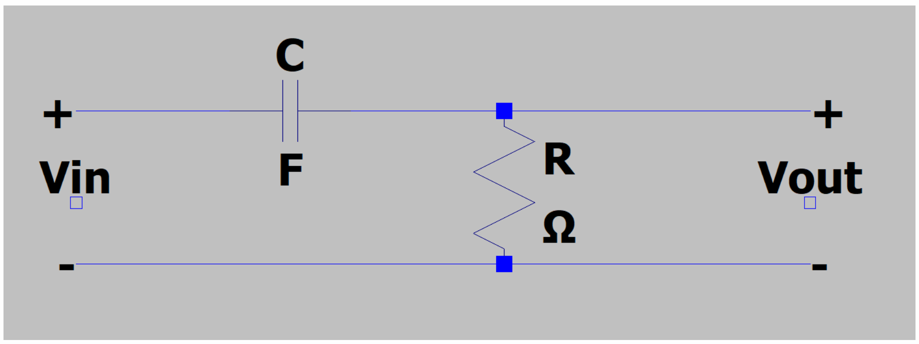

Figure 1: Example of an RC Circuit

2.2 Resonance Frequency:

In order to select the right values of the capacitors and resistors for all the filters, understanding of resonance frequency is fundamental. Resonance frequency is the maximum or minimum of the transfer function in RLC circuits. This occurs when the imaginary part of the impedance is canceled out and goes to either infinity or zero. The RC circuit resonance frequency is:

$$f_r = \frac{1}{2\pi RC}$$

Equation 1: Resonance Frequency of an RC Circuit

2.3 Op-Amp Based Voltage Buffer:

Arguably the most important component of the lab, the Op-Amp based voltage buffer will use the LF356N and the LM324 Integrated Circuit. The purpose of the Op-Amp Voltage Buffer produces a stable output voltage. We can manipulate this output from a varying signal to a stable on/off output. Adding a potentiometer to the Op-Amp allows direct control over the gain between the input and output voltage from 0 to 1. There will be three types:

Inverting: Negative feedback is present from V_{out} to the input. Virtual short-circuit analysis can be applied. This causes V- to go down to zero.

$$V_{out} = -\frac{R_2}{R_1}V_{in}$$

Equation 2: V_{out} for an Inverting Amplifier

Non-Inverting: Input is applied to V+. Virtual short circuit drives the node to V- = V_{in}.

$$V_{out} = (1 + \frac{R_2}{R_1})V_{in}$$

Equation 3: V_{out} for a Non-Inverting Amplifier

Summing: This amplifier can be used to combine and amplify multiple unique signals. It also amplifies each signal individually before combining. This analysis is done with superposition.

$$V_{out} = -R_F \sum_{i=1}^{n} \frac{V_{IN,i}}{R_i}$$

Equation 4: V_{out} for a Summing Amplifier

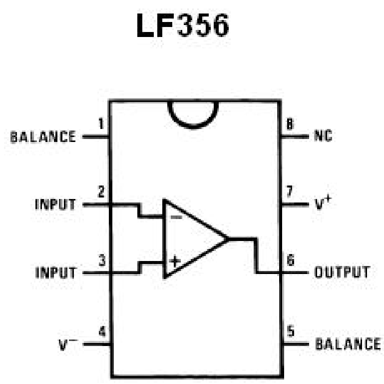

Figure 2: LF356N Pinout

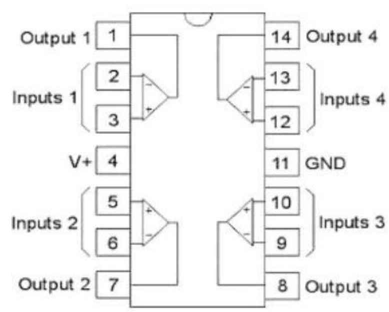

Figure 3: LM324 Pinout

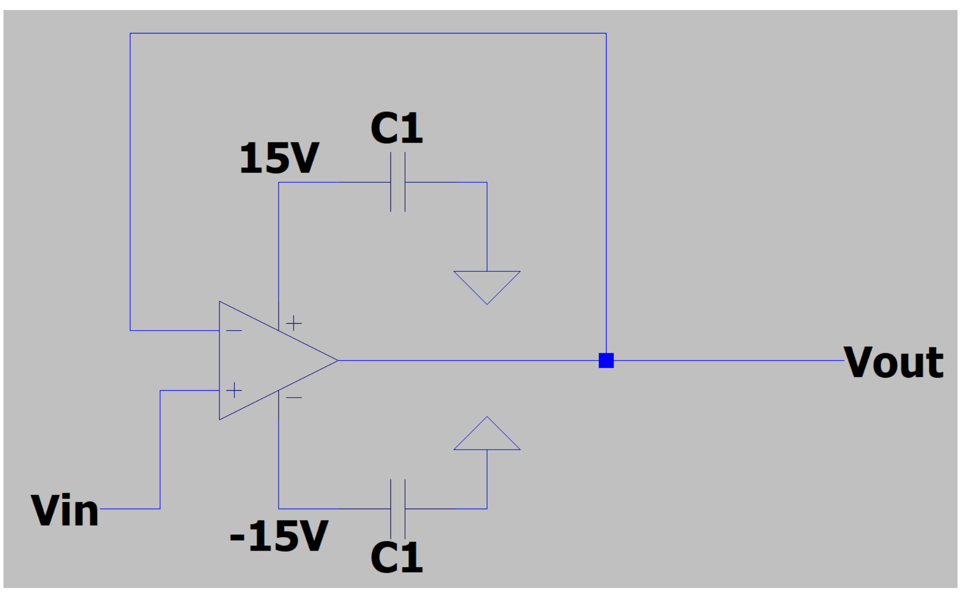

Figure 4: OP Amp based Voltage Buffer Schematic

2.4 Voltage Gain:

For this lab, it is paramount to ensure that we have a voltage gain that ranges from 0 to 1. Voltage gain is just the ratio of output voltage to the input voltage. Having a gain that ranges from 0 to 1 means the output can go from being completely canceled out to being identical to the input wave. By controlling the gain, we are able to control the volume along with the levels of bass, mid, and treble.

$$G = \frac{V_{out}}{V_{in}}$$

Equation 5: Voltage Gain with V_{out} and V_{in}

2.5 Frequency Response:

Magnitude scale and phase shift of a system over the frequency, frequency response can be estimated by applying a sinusoidal input of a mixed frequency, and then measuring the output's magnitude and relative phase. We will display a magnitude and phase compared to frequency plot to represent this data.

$$H(w) = \frac{V_{out}(w)}{V_{in}(w)}$$

Equation 6: Frequency Response with V_{out} and V_{in}

2.6 Equivalent Resistance in Parallel:

For this lab, it is important to understand how resistors are combined in parallel to make an equivalent resistance. In order to combine multiple resistors in parallel, follow this equation:

$$R_{eq} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n}$$

Equation 7: R_{eq} For Parallel Resistors

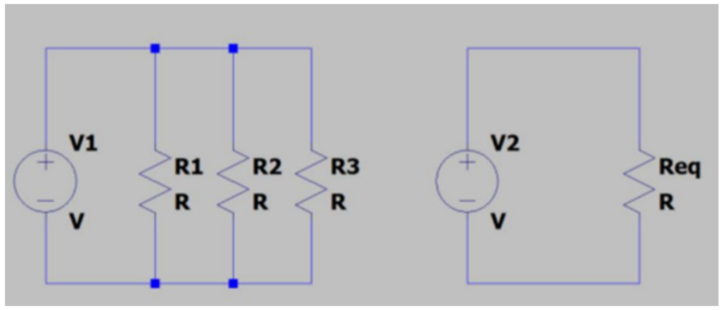

Figure 5: Simplification of Parallel Resistors

2.7 Power:

In order to verify the output of the amplifier, it is important to understand the relationship power has to current and voltage.

$$P = \frac{V^2}{R}$$

Equation 6: Power Related to Voltage and Resistance

3. Procedure:

3.1 Find R and C Values:

Before any of the circuit is actually built, we have to calculate the values for the resistors, and capacitors for the given frequency values of each filter. For example, the frequency of the high pass filter is 3.5kHz. Repeat the process for the other two filters. When calculating the mid pass filters, it is imperative to remember that the frequencies for the low and high pass filters are reversed. To find values for the resistors in the summing amplifier, we must use equation 7 to find a resistor equal to a value close to 10kΩ.

Specification	Low Pass	Mid-Pass	High Pass	Sum
Resistance	4.7kΩ	470Ω, 4.7kΩ	470Ω	33Ω,33Ω, 33Ω
Capacitance	0.1μF	0.1μF, 0.1μF	0.1μF	N/A

Table 1: Calculated Values for R and C for Various Filters

3.2 Build Circuit With Given Values:

Once we have established the values for the components, we now need to build the circuit. In order to prevent loading we recommend utilizing buffers between the filters and the Op-Amp. The schematic for the circuit will be added below.

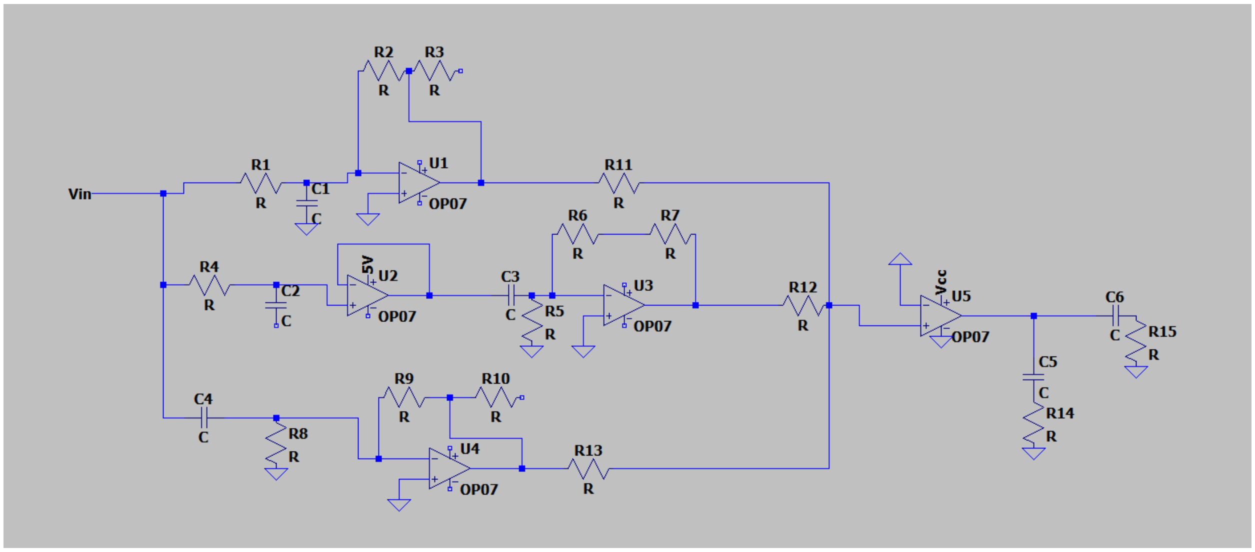

Figure 6: Audio Equalizer Circuit Schematic

3.3 Test and Plot Frequency Response of Filter:

Once the circuit is built, it is then time to test it and observe the frequency response of each filter. To test, we must use two channels from the oscilloscope, as well as the power supply. After attaching a signal to the start of the filters and adding the V_{in} and the V_{out} to the proper pins, as shown in figure 1, we then must plot the gain and frequency response for each of the three filters. For a more accurate result, we will plot 100 points of data. After the plot has been made from the oscilloscope, we will use the cursors to find the -3dB point. We will then compare our results to make sure they correspond with the expected results.

3.4 Test and Plot Gain of Each Op-Amp:

Once the filters have been tested and plotted, we will then be required to measure the gain of the op-amp with the oscilloscope and the function generator. In order to do this, we must connect the input signal to the op-amp and the two channels of the oscilloscope to V_{in} and V_{out} respectively. We will observe the ratio between the two voltage's peak to peak values. Using equation 5, we will analyze the gain. It is imperative to observe how the potentiometer affects the gain. It is only working if the gain ranges from 0 to 1. Continue this for each op-amp.

3.5 Test Ripple of V_{amp} at Maximum and Minimum:

After all the tests have concluded and it works, it is then time to ensure that V_{amp} at various frequencies are under $15mV_{rms}$. In order to do this, a frequency response will be run from V_{in} to V_{amp}. From there, we will use the data traces to find where the maximum and minimum gain occur. After we have found the frequencies at these points, we input those frequencies into the equalizer using the wave function generator on the oscilloscope. At the various frequencies, we measure the RMS at the output. We then subtract the RMS_{max} from RMS_{min} to make sure the difference is less than $15mV_{rms}$.

3.6 Test Amplifier Output Power:

In order to test the amplifier output power, we will run a frequency response like the test explained above. After we have plotted the graph, we will find the frequency with the lowest gain. We will use this frequency as the input to V_{in} and measure the voltage across the speaker. We then use equation 8 with the 8Ω speaker’s resistance. If this value is greater than or equal to 0.4W, then any other frequency will exceed the specification.

4. Results:

4.1 Frequency Response of Filters:

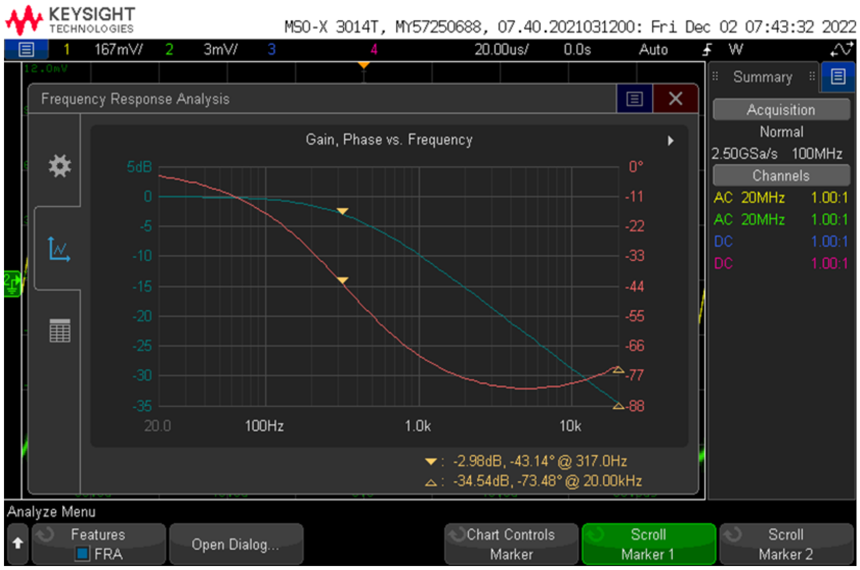

Figure 7: Frequency Response of Base Filter

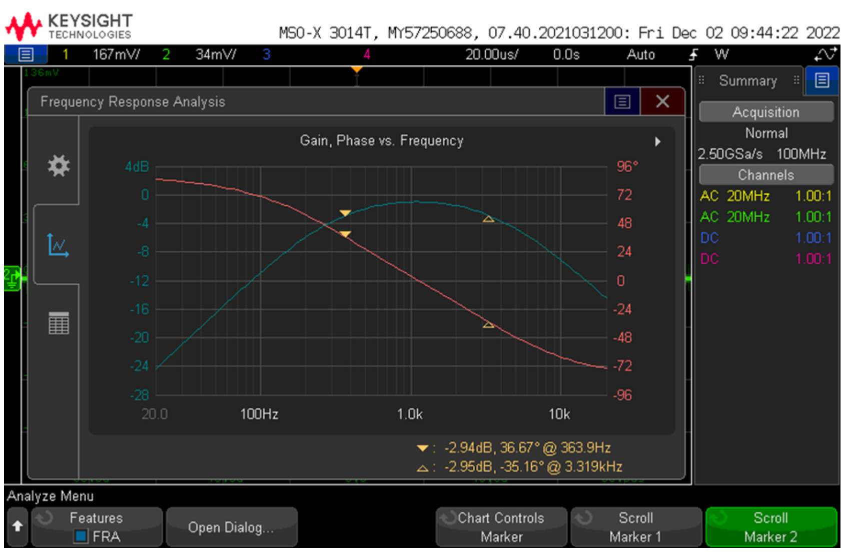

Figure 8: Frequency Response of Mid Filter

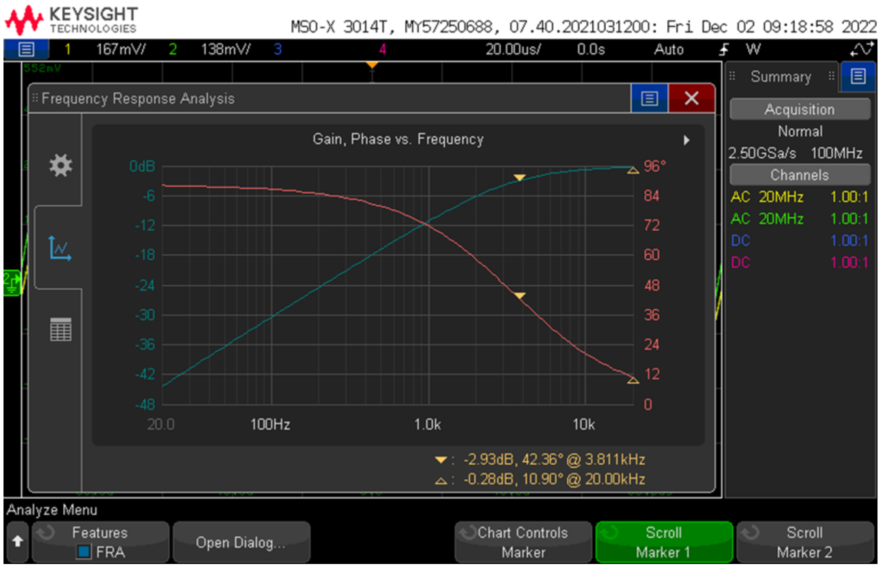

Figure 9: Frequency Response of Treble Filter

4.2 Op-Amp Gain:

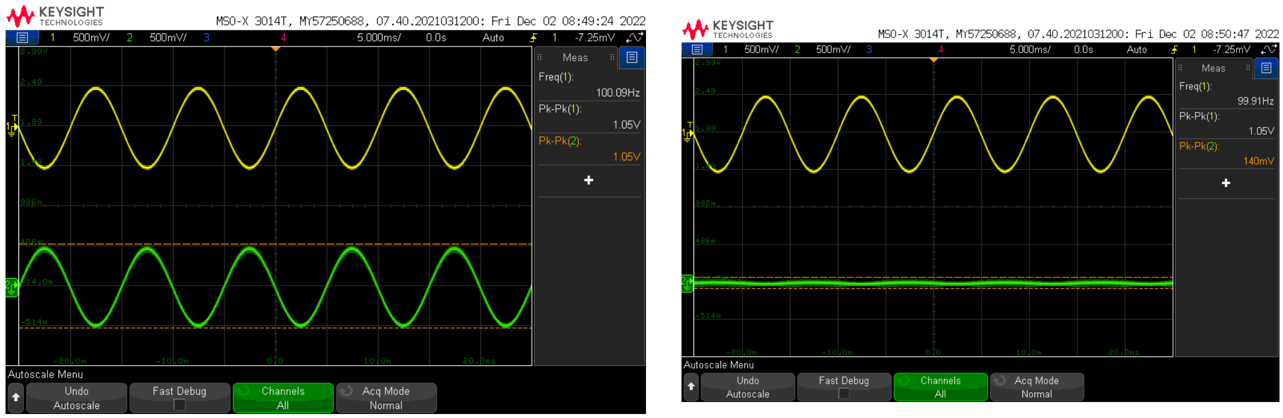

Figure 10: Gain of Low Filter Op-Amp

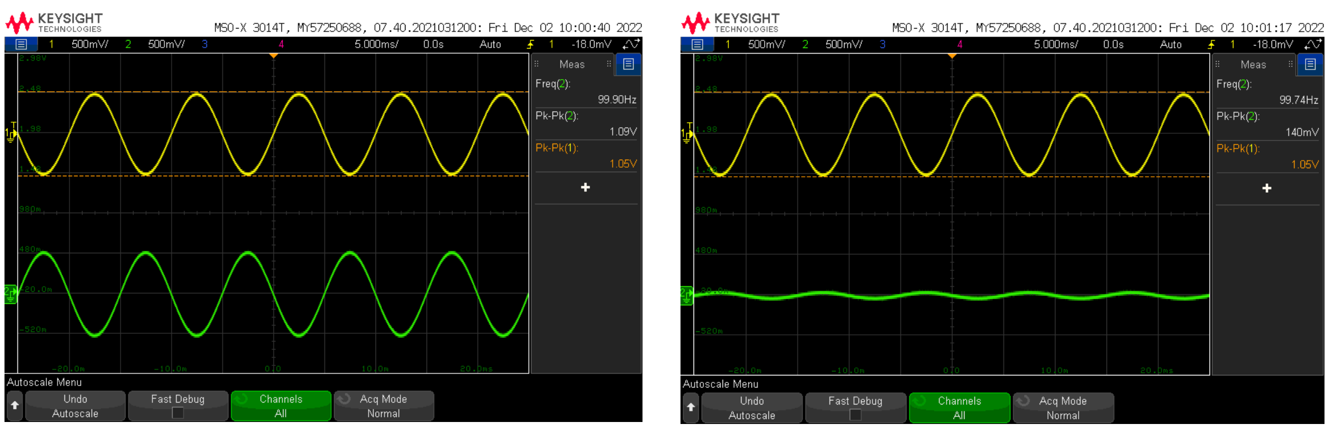

Figure 11: Gain of Mid Filter Op-Amp

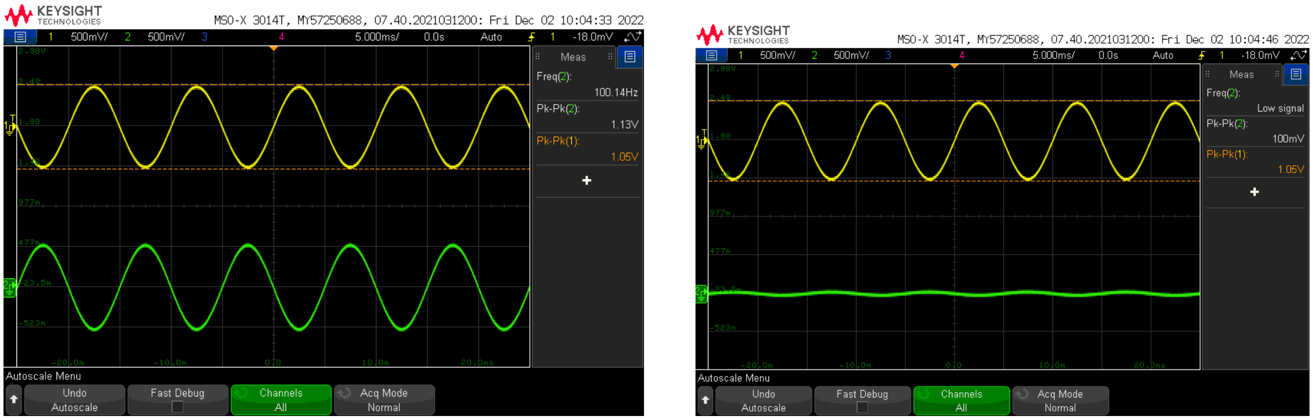

Figure 12: Gain of High Filter Op-Amp

4.3 Ripple of V_{amp}:

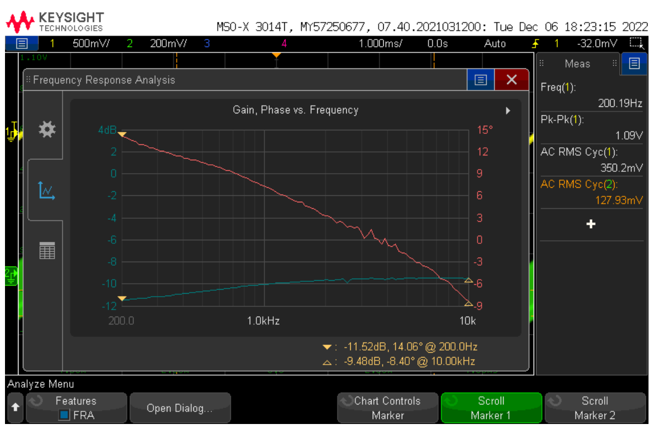

Figure 13: Frequency Response Across Amplifier

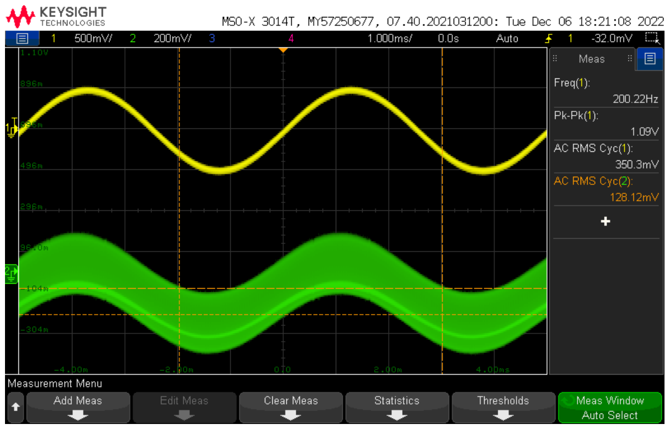

Figure 14: V_{rms} at Minimum Gain

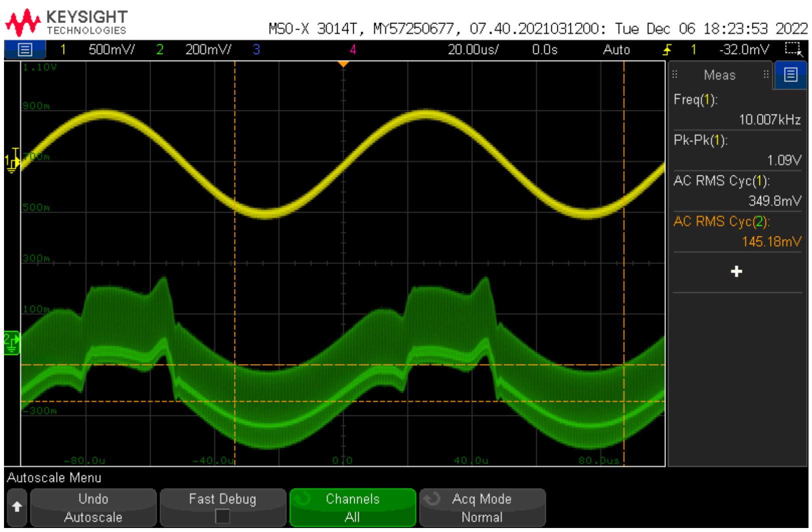

Figure 15: V_{rms} at Maximum Gain

$$V_{rms} = 145.18mV - 126.12mV$$

$$V_{rms} = 19.06mV$$

5. Conclusion:

To conclude, we were able to complete a working audio equalizer. After adding an input audio source, we were able to fine tune and adjust the bass, mid, and treble, as well as the volume of the audio. It was very informative to see how audio channels can be manipulated through all that we had learned throughout the year. As an audiophile, I take sound quality very seriously, so being able to fine tune an input with a circuit that I built allowed me to gain a greater appreciation for what is important in technology. Not to mention, even though it seemed impossible, like in modern smartphones, I was able to include a headphone jack in my circuit. It was fulfilling to see all that I learned about RC circuits being utilized in the filters, all that I learned about integrated circuits being used to make Op-Amps and adders, and all that I learned about wiring to a basic speaker to connect to an output. This final project really sparked a curiosity in me, more so on how could I merge this with a user interface and code to make the circuit smaller and more efficient.