Utilizing Passive Filters in an Audio Equalizer

Matthew Van Ausdal

Section 020 Adam Kures

12/8/2021

Abstract:

One of the simplest usages of passive signal filters is audio control and equalization. An audio equalizer containing three channels will be designed and built to show off the utilization of passive filters and operational amplifiers. The filters will effectively split the input signal into three channels, one for highs, mids, and lows. The highs are defined in this case as frequencies greater than 3.2 kHz, the mids as frequencies from 320 Hz to 3.2 kHz, and the lows as frequencies from 0 to 320 Hz. Each channel will have its own adjustable amplifier that will control the gain for each frequency range, allowing the user to "equalize" the input signal to their liking. The circuit will be designed to meet certain specifications regarding channel gain, low-pass and high-pass frequencies filtering, and amplifier output power. Each component of the circuit will be designed to meet these specifications, then tested and assembled as a working audio equalizer.

Objectives:

The purpose of this report is to build and demonstrate the usage of passive filters and operational amplifiers in a practical circuit, in this case an audio equalizer. The audio equalizer will take an input signal, filter the signal into three different channels based on frequency, and then allow each channels volume to be adjusted individually. The three channels will then be recombined, and the volume of the output as a whole can be adjusted as well.

The audio equalizer circuit will contain four main components – an adjustable equalizer sub-system, a volume control module, a power amplifier, and a crossover filter. The equalizer sub-system will contain three filters, one for the bass frequencies, mid frequencies, and treble frequencies. Each of these filters will be connected to an adjustable amplifier that will control the loudness of each set of frequencies. The volume control module is simply a summing, adjustable amplifier that combines all three channels. The power amplifier will amplify the final signal to an audible power, and then transfer the signal to the crossover filter which will split the signal between a tweeter speaker and a woofer speaker. These components will be built to the specifications detailed in *Table 1.1*.

Table 1.1 Audio Equalizer Specifications (Electrical Engineering Fundamentals Laboratory I, 2019)

Specification	Requirement
Speaker Resistance	8Ω
Bass filter -3 dB cutoff	320 Hz ±10%
Mid filter -3 dB bandwidth	0.32 kHz to 3.200 kHz ±10%
Treble filter -3 dB cutoff	3.200 kHz ±10%
v_{amp} with all equalizer knobs turned to minimum settings	<15 mV_{RMS} ±10% @ 200 Hz, 2 kHz, and 10 kHz
v_{amp} with all equalizer knobs turned to maximum settings	100 mV_{RMS} ±10% @ 200 Hz, 2 kHz, and 10 kHz
$v_{amp,max}$ - $v_{amp,min}$ max ripple with equalizer at max	15 mV_{RMS} from 200 Hz to 10 kHz
Amplifier output power	>400 mW from 200 Hz to 10 kHz

The satisfied specifications will be displayed in the form of oscilloscope graph outputs and graphs created with Python Matplotlib.

Theory:

A highly relevant equation is that for calculating V_{RMS} for a given sine wave. The calculation is shown in *Equation 2.1*, with V_{pp} being the peak-to-peak voltage of the sine wave.

Equation 2.1 V_{RMS} Calculation

$$V_{RMS} = \frac{V_{pp}}{2\sqrt{2}}$$

Passive filters are combinations of capacitors, inductors, and resistors whose values are chosen to resonate at a specific frequency (Allred, 2015). The simplest of passive filters is the first-order RC filter. The RC filter can be arranged as either a high-pass filter, that only passes frequencies higher than its resonant frequency, or a low-pass filter, which only allows frequencies lower than its resonant frequency to pass. In the case of a high-pass filter, for frequencies which are beneath the resonant frequency, the circuit exhibits a very high impedance which greatly decreases the amplitude of the input signal. This effectively "filters" out signals beneath a certain frequency by reducing the signal until it is irrelevant to the operation of the circuit. For a first-order RC filter, the resonant frequency can be calculated using the formula in *Equation 2.2*.

Equation 2.2 Component Values for Filters

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

The circuit will also make use of the LM324N operational amplifier, a chip that applies a set gain to a signal. According to the datasheet (Texas Instruments, 2000), the output gain of the LM324N is set by the ratio of the resistor between the input and output pins and the resistance of the input. Additionally, the LM324N will act as an inverter since the input will go through the negative input pin on the chip. To maintain adjustability of the gain, a 10 kΩ potentiometer will be used as a variable resistor between the input and output pins. The pinout of the LM324N is shown in *Figure 2.1*.

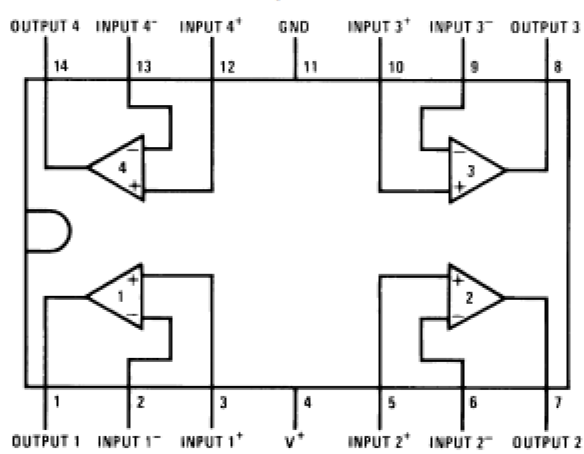

Figure 2.1 LM324N Pinout (Texas Instruments, 2000)

A combination of a passive RC filter, a LM324N, and a potentiometer as a variable resistor creates an amplifier that can adjust the gain on a specific range of frequencies. In the circuit schematic in *Figure 2.2*, resistor R1 and capacitor C1 make up the low-pass filter, while resistor R2 and the potentiometer connecting the input and output control the gain of the op-amp, labeled as U1. Because the RC filter removes all frequencies higher than its resonant frequency, the amplifier will only increase the amplitude of the intended lower frequencies.

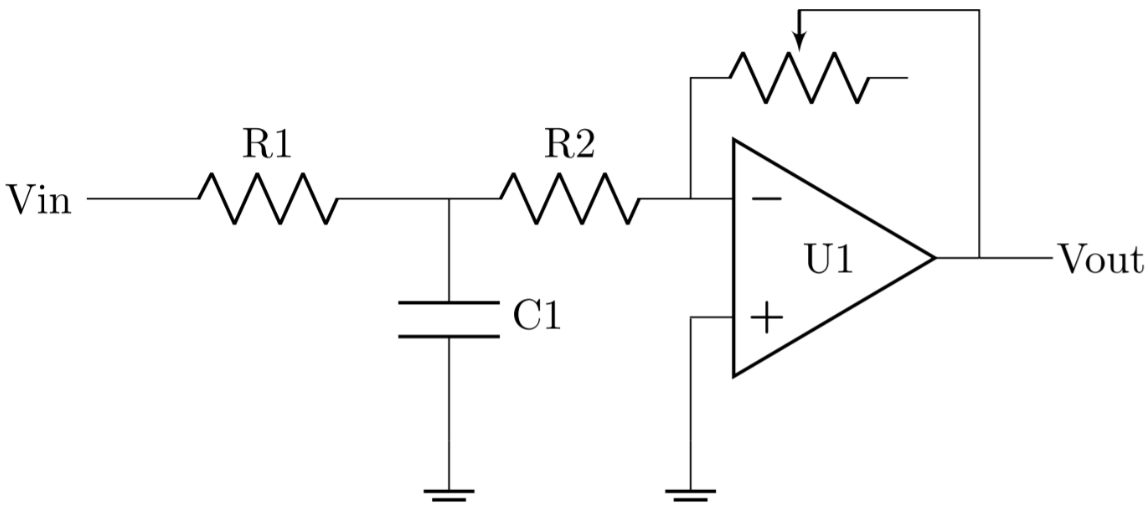

Figure 2.2 RC Filter and Op-Amp Schematic

An additional usage of operation amplifiers is as a buffer. By shorting the positive input and the output of the op-amp the gain is set to one. This seems useless at first, but due to the impedance characteristics of the amplifier it can actually be used to separate difference circuit components that might unintentionally interact with each other otherwise. In *Figure 2.3*, op-amp U1 is being used as a buffer between the low-pass filter made up of resistor R1 and capacitor C1, and the high-pass filter made up of resistor R2 and capacitor C2. This prevents the second filter from impacting the cutoff frequency of the first filter.

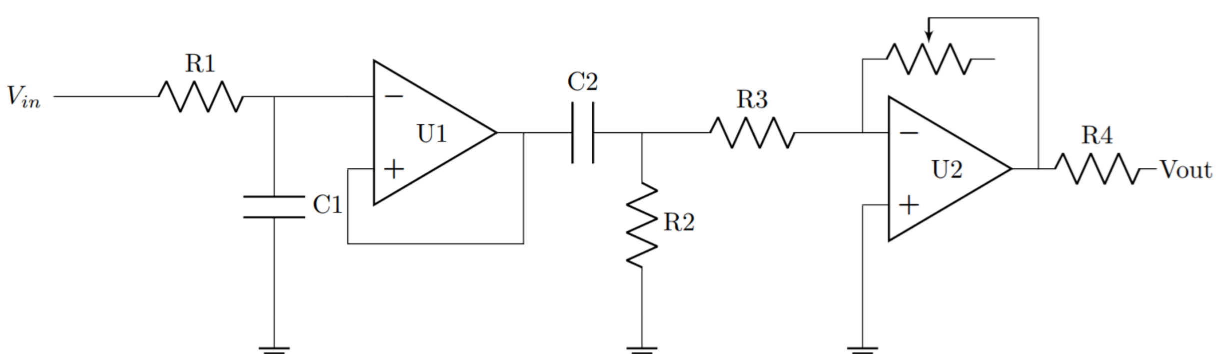

Figure 2.3 Band-Pass Filter Using Op-Amp as Buffer

Procedure:

The circuit topology, as shown in *Figure 3.1*, was chosen. It contains three filters, one for each frequency range shown in the specifications in *Table 1.1*, as well as an adjustable operational amplifier for each frequency range, shown as U1, U3, and U4. Additionally, it contains a buffer (U2), a master volume control (U5), a power amplifier (U6), and a pair of crossover filters to split the output among two speakers.

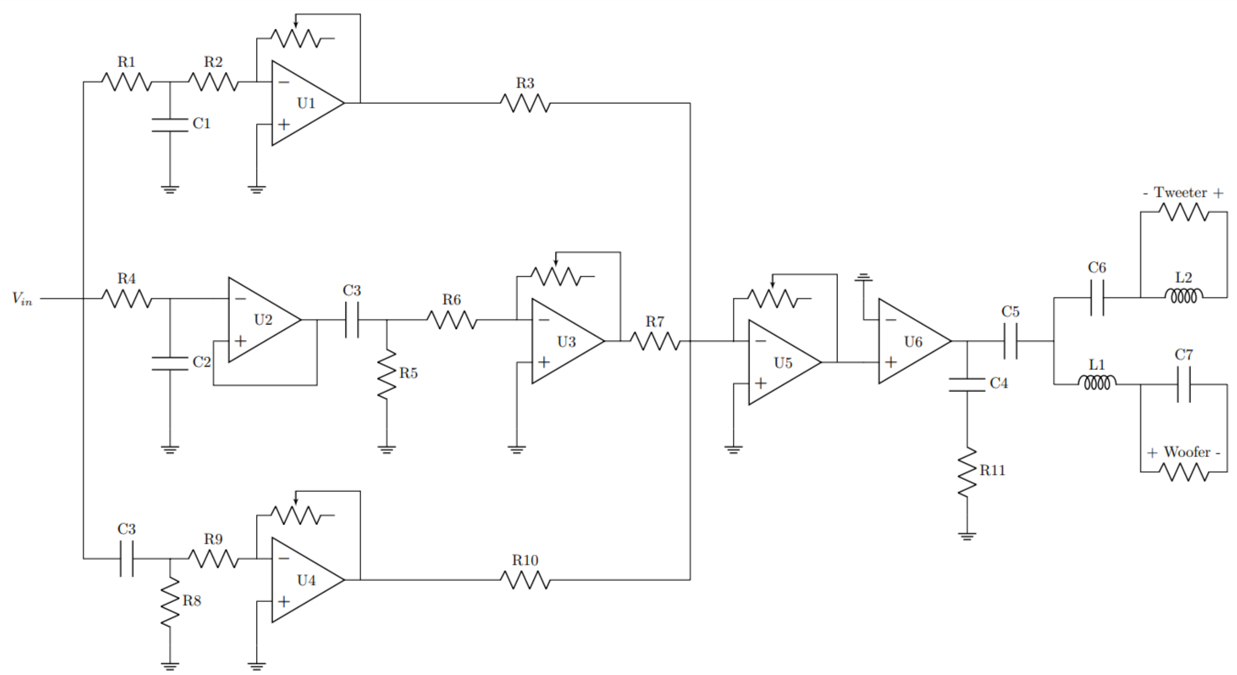

Figure 3.1 Audio Equalizer Circuit Topology

The chosen ICs for the amplifiers are shown in *Table 3.1*. The LM324N was chosen for op-amps U1 through U5 because the output amplitude is easily adjusted through the ratio between the input resistance and the resistance between the input and output. Additionally, the LM324N contains four op-amps within one package, meaning the circuit can be more compact and less chips need to be used. The chosen power supply for the LM324N was ±15 V to account for potential input signals of greater than 2.5 V peak-to-peak. The LM386N was chosen as the power amplifier (U6) due to its default internal gain of 20.

Table 3.1 Audio Equalizer ICs

Component	IC
U1-5	LM324N
U6	LM386N

The values for the remaining components are shown in *Table 3.2*. The values for the resistors that make up the low-pass, band-pass, and high-pass filters were calculated using the frequencies given in the specifications in *Table 1.1* and the formula shown in *Equation 3.1*. For simplicity, all capacitors used in the filters were chosen to be 0.1 μF, as that is the most common capacitor in the kits being used and allows for the easy calculation of reasonable resistances. The resistors R2, R6, and R4 were chosen to be 100kΩ to produce a maximum amplitude of 10% when the 10k potentiometer used to connect the input and output of the LM324Ns was set to max. Additionally, resistors R3, R7, and R10 were chosen to be 10kΩ so that the maximum amplification of the summing amplifier and volume control, U5, was 1.

Table 3.2 Audio Equalizer Component Values

Component	Value		Component	Value	
R1	4920	Ω	C1	0.1	μF
R2	100k	Ω	C2	0.1	μF
R3	10k	Ω	C3	0.1	μF
R4	492	Ω	C4	0.05	μF
R5	4920	Ω	C5	100	μF
R6	100k	Ω	C6	10	μF
R7	10k	Ω	C7	10	μF
R8	492	Ω	L1	1	mH
R9	100k	Ω	L2	1	mH
R10	10k	Ω	Tweeter	8	Ω
R11	15	Ω	Woofer	8	Ω

Equation 3.1 Component Values for Filters

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

The design of the crossover filters at the output of the circuit, as well as the component values for the crossover filters, was taken from page 150 of *Electrical Engineering Fundamentals Laboratory I (2019)*.

Results:

The designed circuit met all specifications. The frequency response graphs for the low-pass filter, the band-pass filter, and the high-pass filter are shown in *Figure 4.1, Figure 4.2,* and *Figure 4.3* respectively. All filters were within ±10% of the specified frequencies.

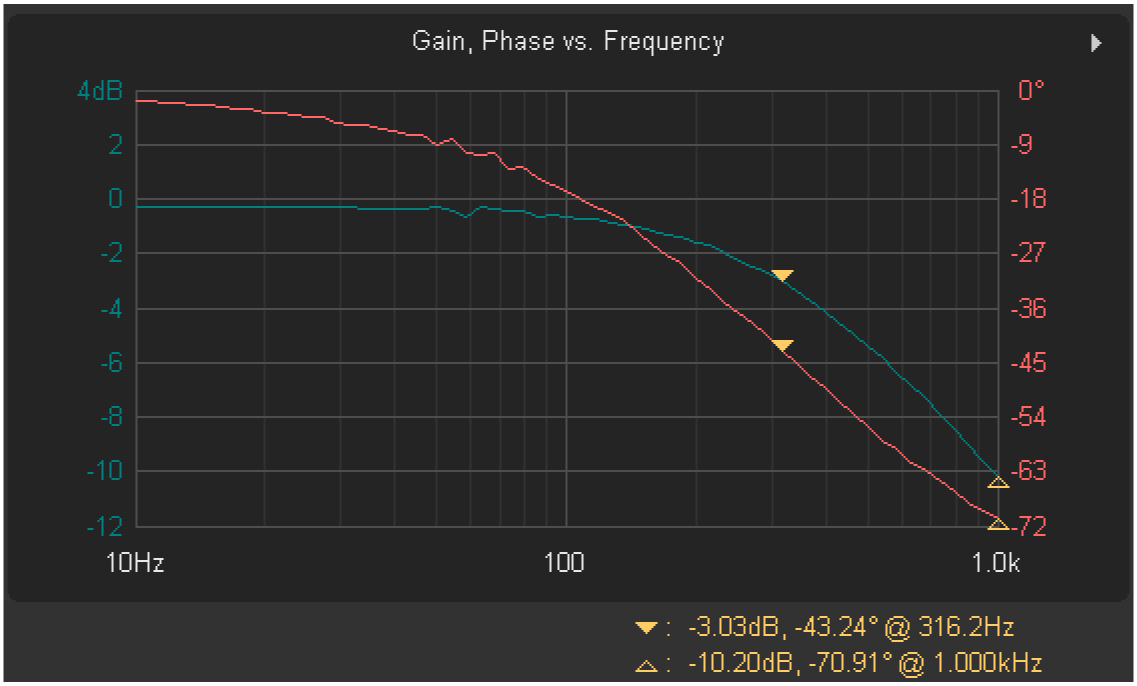

Figure 4.1 Low-Pass Filter Gain, Phase vs. Frequency

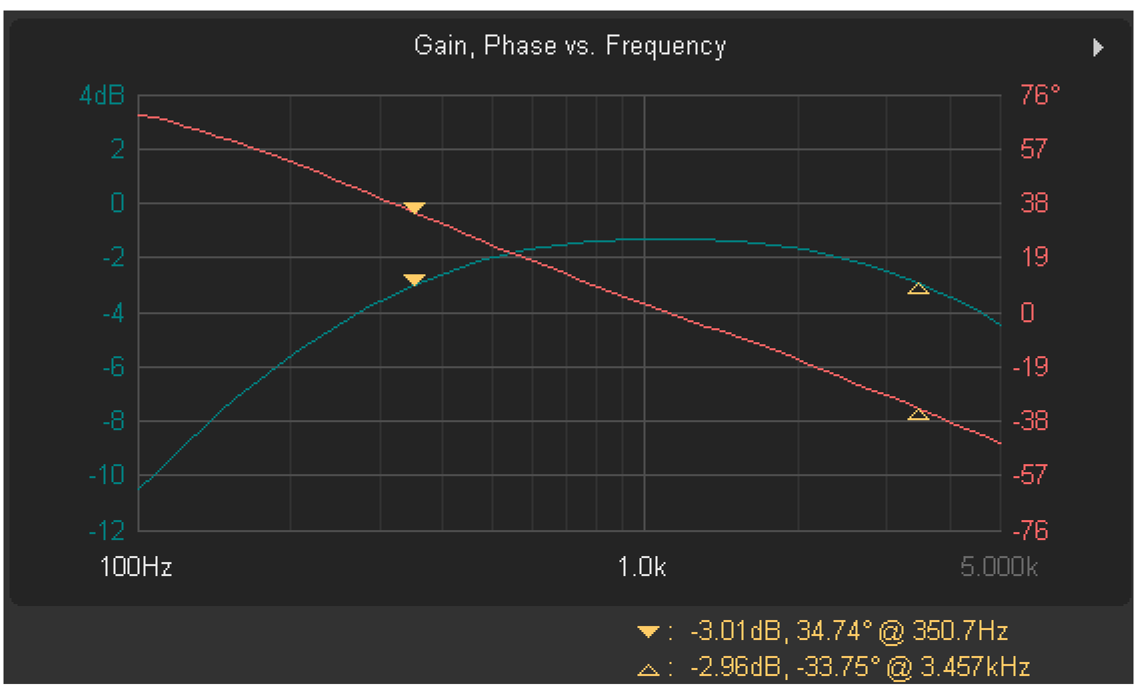

Figure 4.2 Band-Pass Filter Gain, Phase vs. Frequency

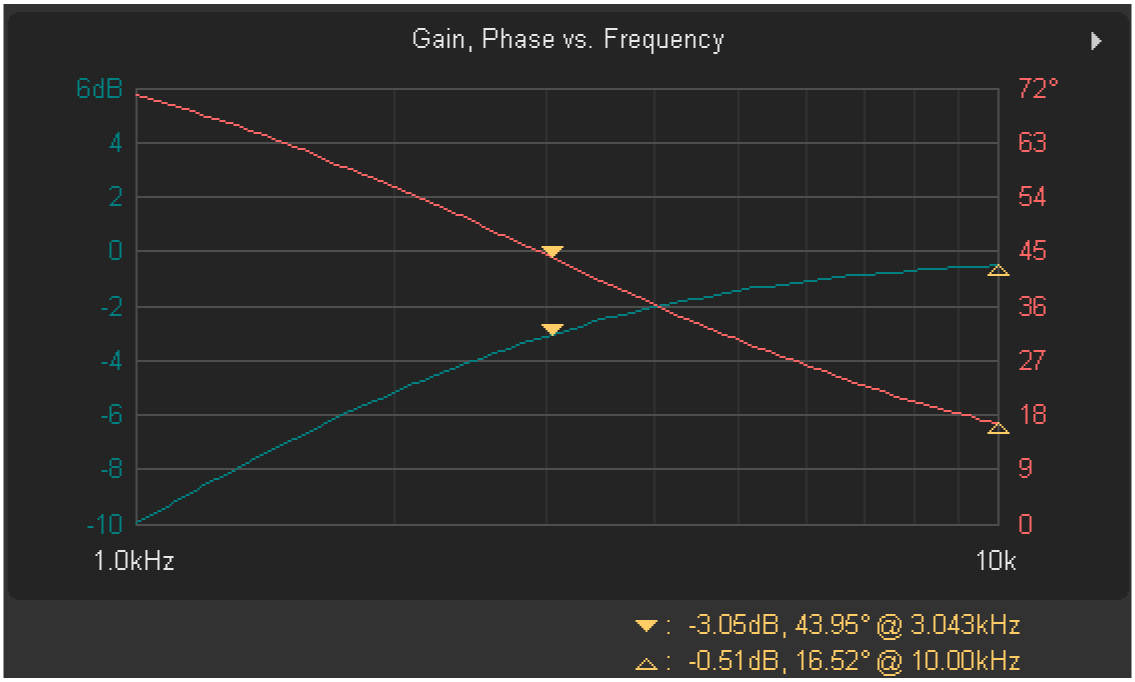

Figure 4.3 High-Pass Filter Gain, Phase vs. Frequency

The output of the amplifiers at various frequencies were also within ±10% of the given specifications with the equalizer knobs turned to their minimum value, as shown in *Figure 4.4*, *Figure 4.5*, and *Figure 4.6*, and their maximum value, as shown in *Figure 4.7*, *Figure 4.8*, and *Figure 4.9*.

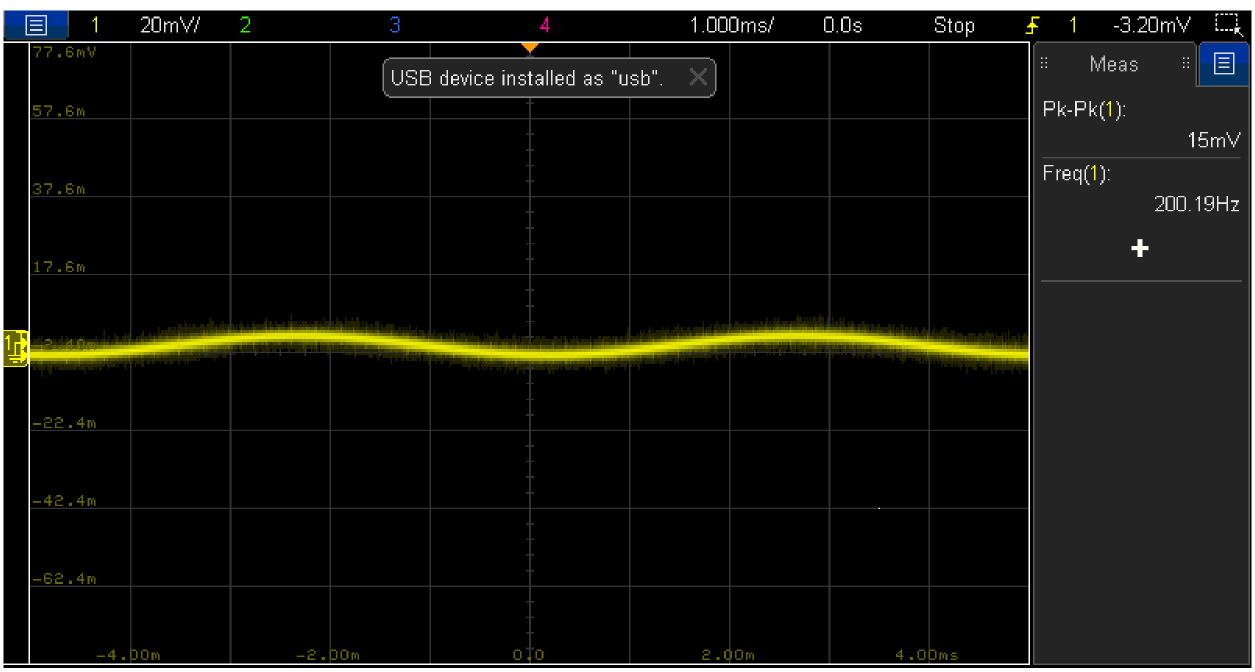

Figure 4.4 Equalizer Knobs at Min Value @ 200 Hz

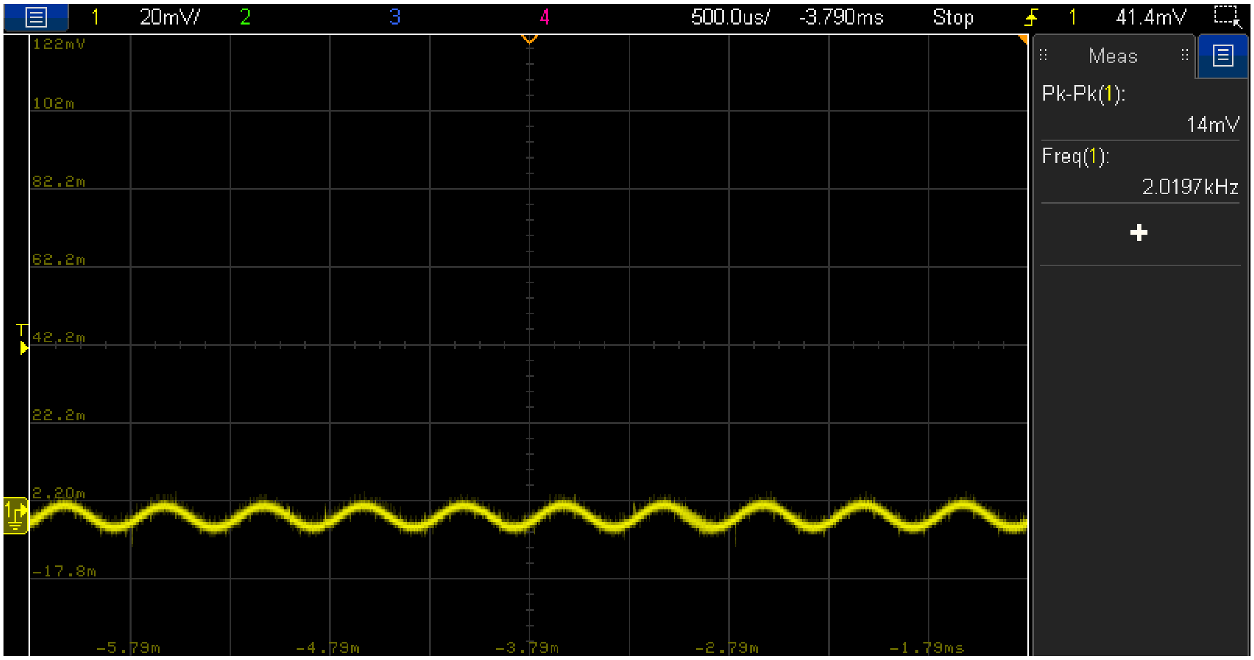

Figure 4.5 Equalizer Knobs at Min Value @ 2 kHz

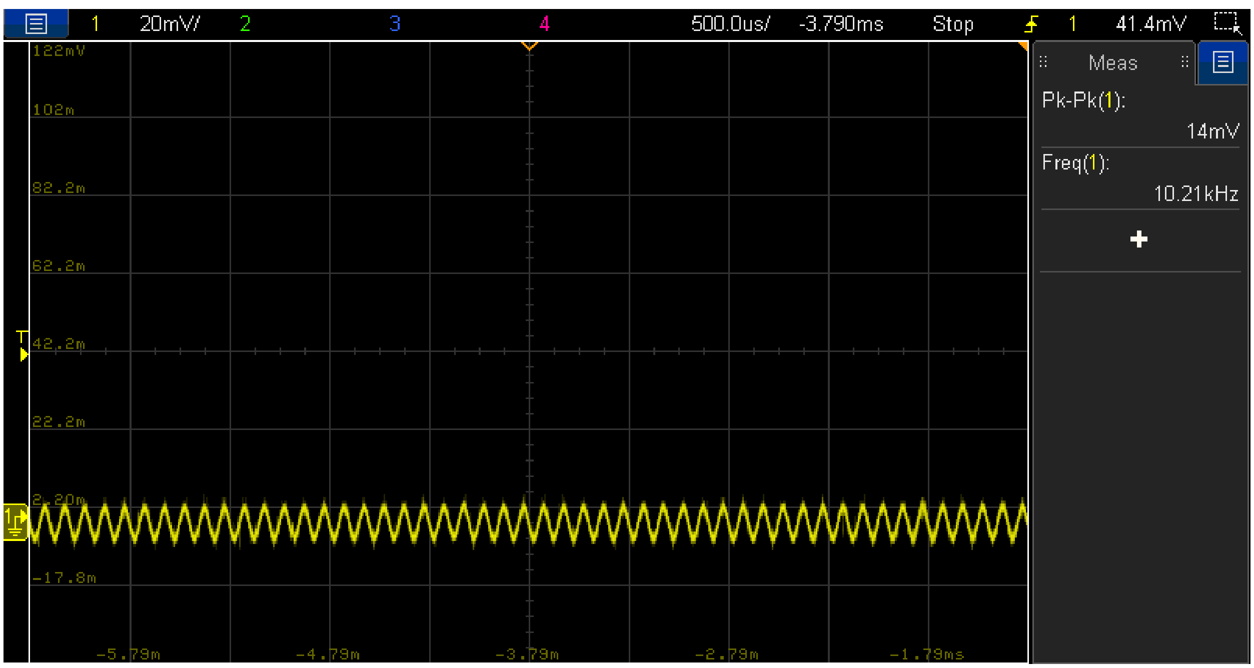

Figure 4.6 Equalizer Knobs at Min Value @ 10 kHz

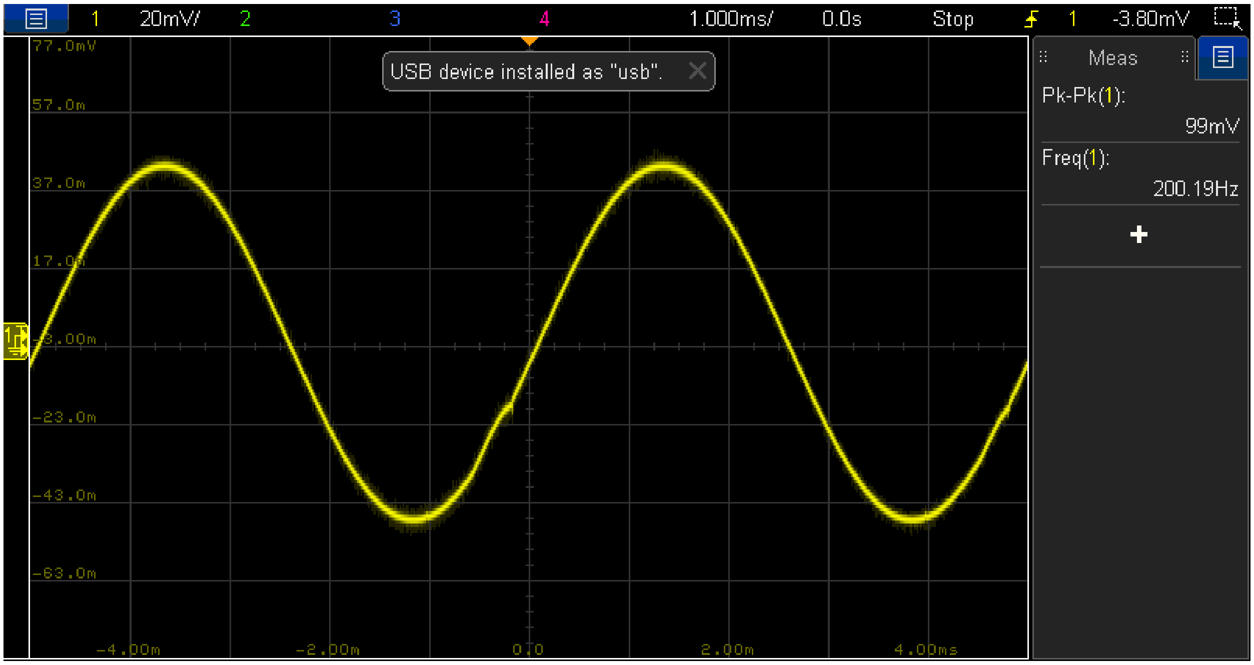

Figure 4.7 Equalizer Knobs at Max Value @ 200 Hz

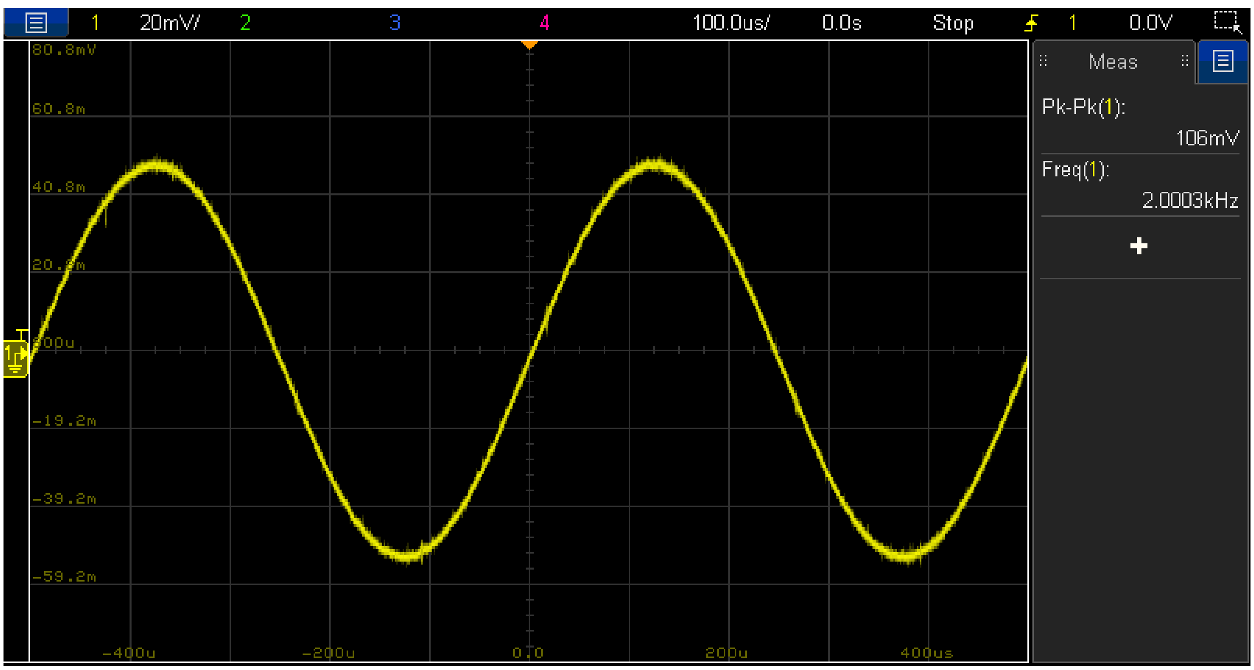

Figure 4.8 Equalizer Knobs at Max Value @ 2 kHz

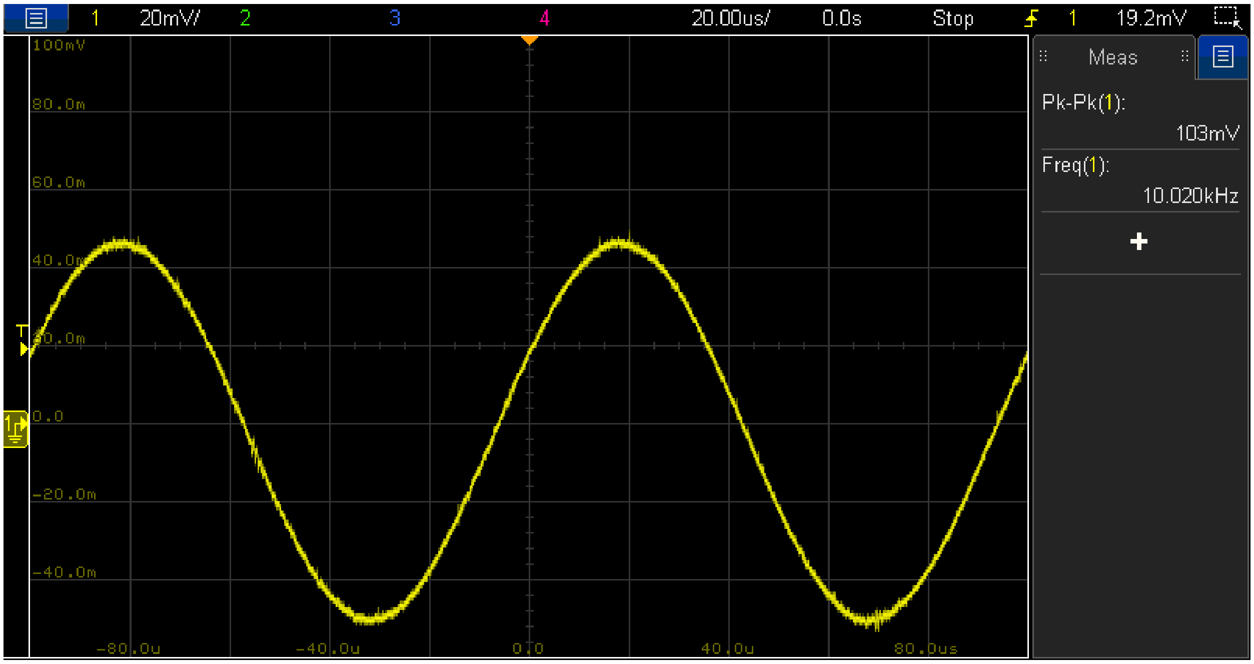

Figure 4.9 Equalizer Knobs at Max Value @ 10 kHz

Additionally, the equalizer was able to output within the specified ranges with the volume knob at its minimum, its maximum, and at some point in the middle. This is shown with a 2 kHz sine wave input in *Figure 4.10*, *Figure 4.11*, and *Figure 4.12*.

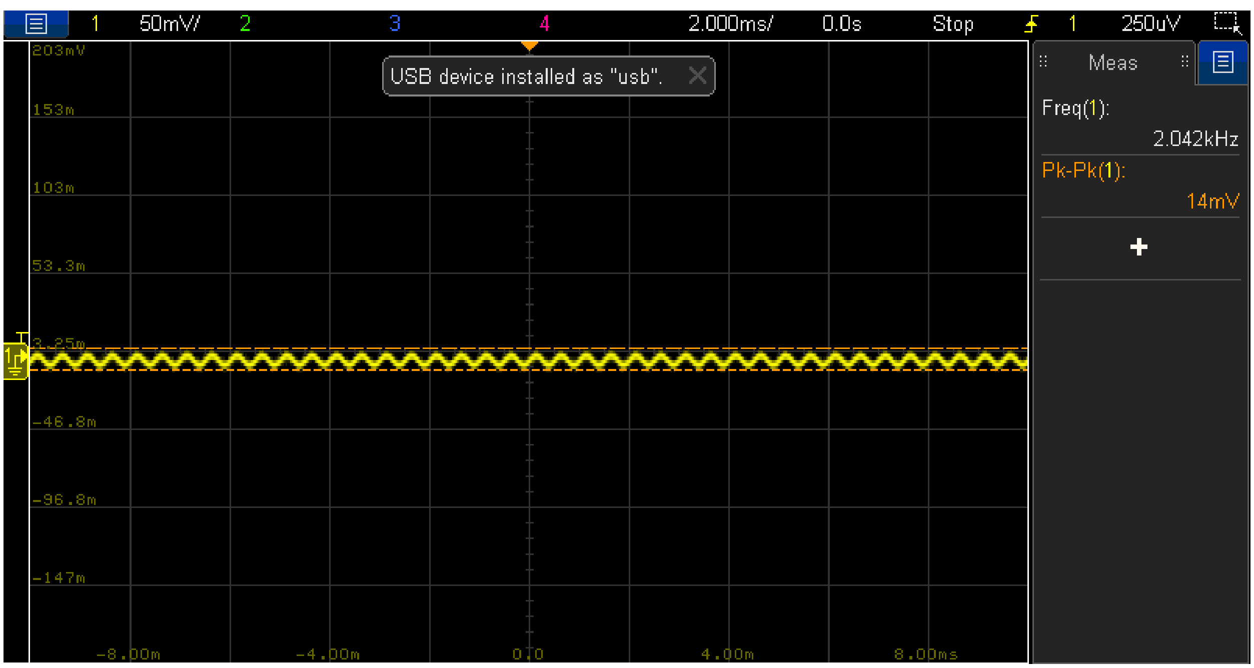

Figure 4.10 Minimum Volume @ 2 kHz

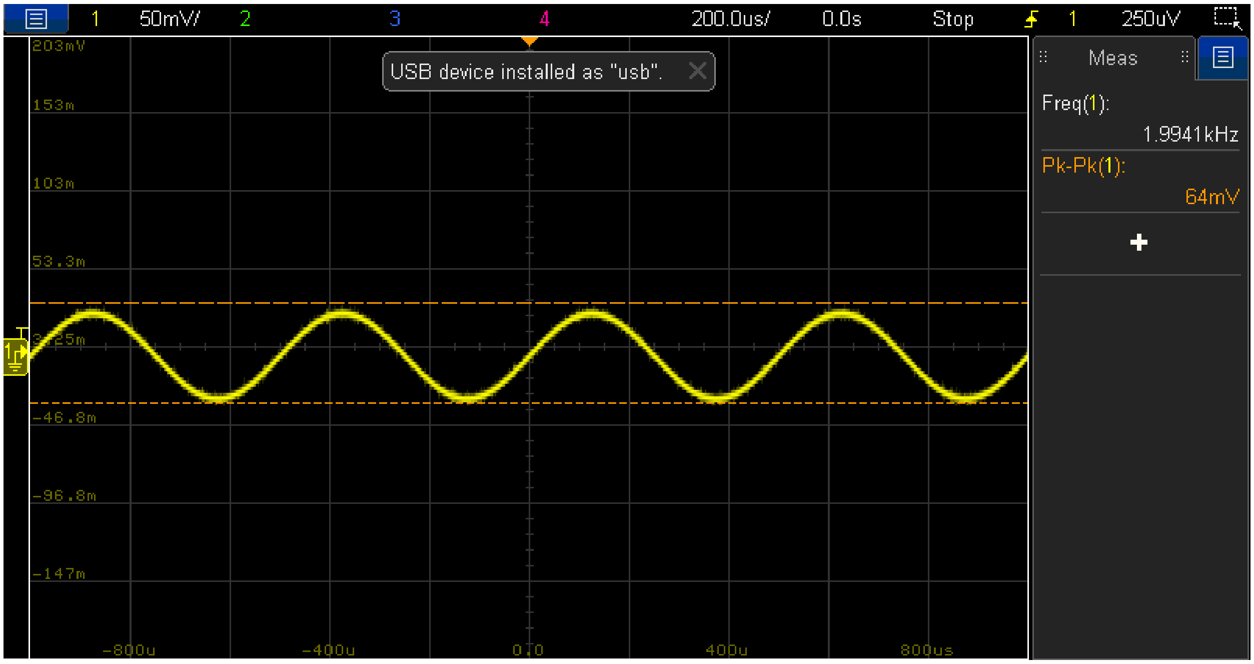

Figure 4.11 Medium Volume @ 2 kHz

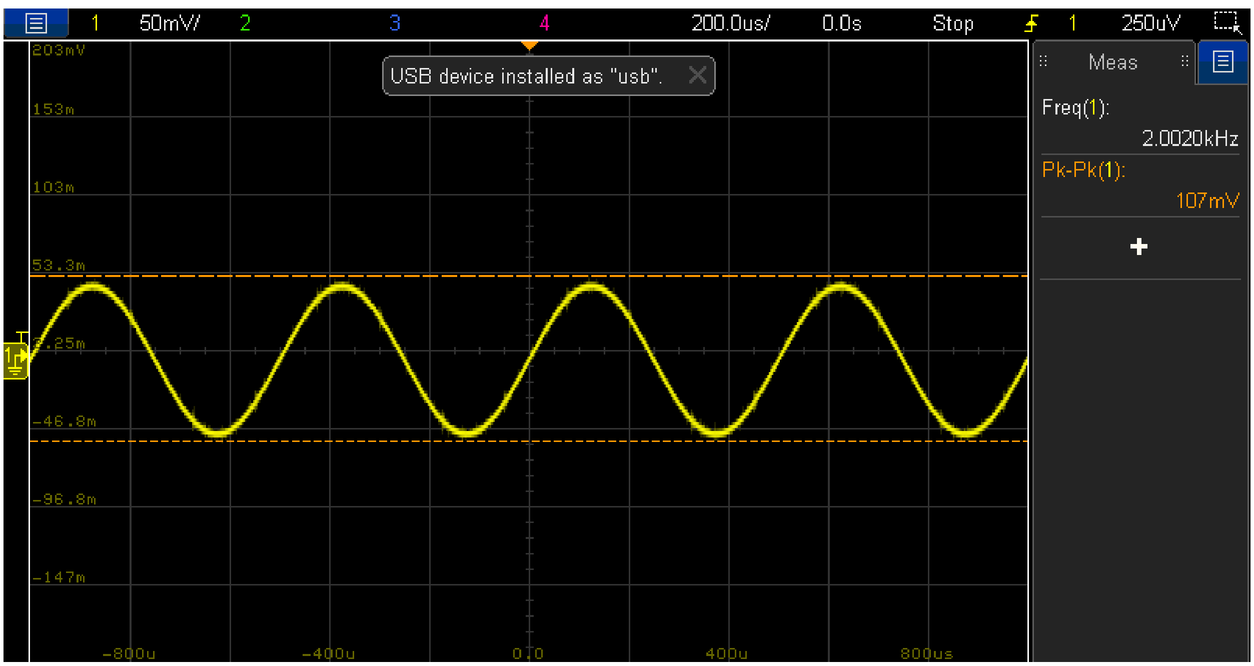

Figure 4.12 Maximum Volume @ 2 kHz

The maximum ripple with the equalizer set to maximum power was measured to be 11 mV_{RMS}, with the maximum voltage being 106 mV and the minimum being 95 mV. The ripple data measured at points varying between 200 Hz and 10 kHz was graphed using Python Matplotlib. The results are shown in *Figure 4.13*. The amplifier output power was also within the specifications, being above 400 mW from 200 Hz to 10 kHz. The recorded data was also graphed using Python Matplotlib and is shown in *Figure 4.14*.

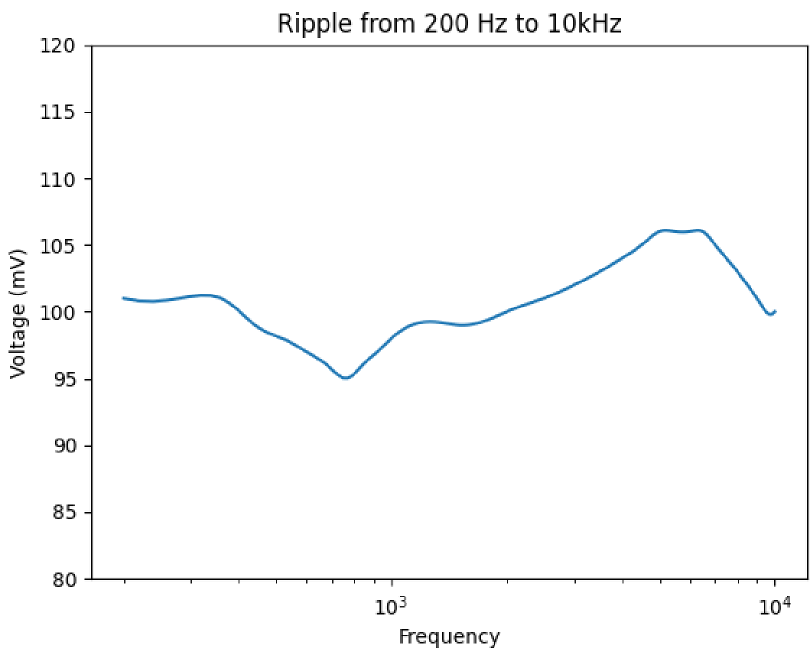

Figure 4.13 Ripple from 200 Hz to 10 kHz

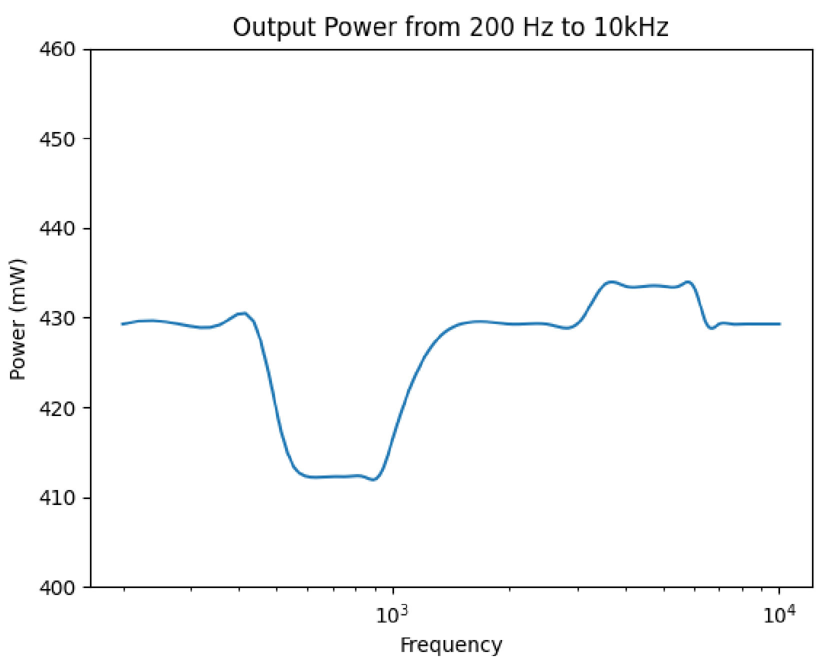

Figure 4.14 Amplifier Output Power from 200 Hz to 10 kHz

Finally, the summing amplifier was shown in *Figure 4.15* to function by graphing the output of each filter as well as the total output of the amplifier.

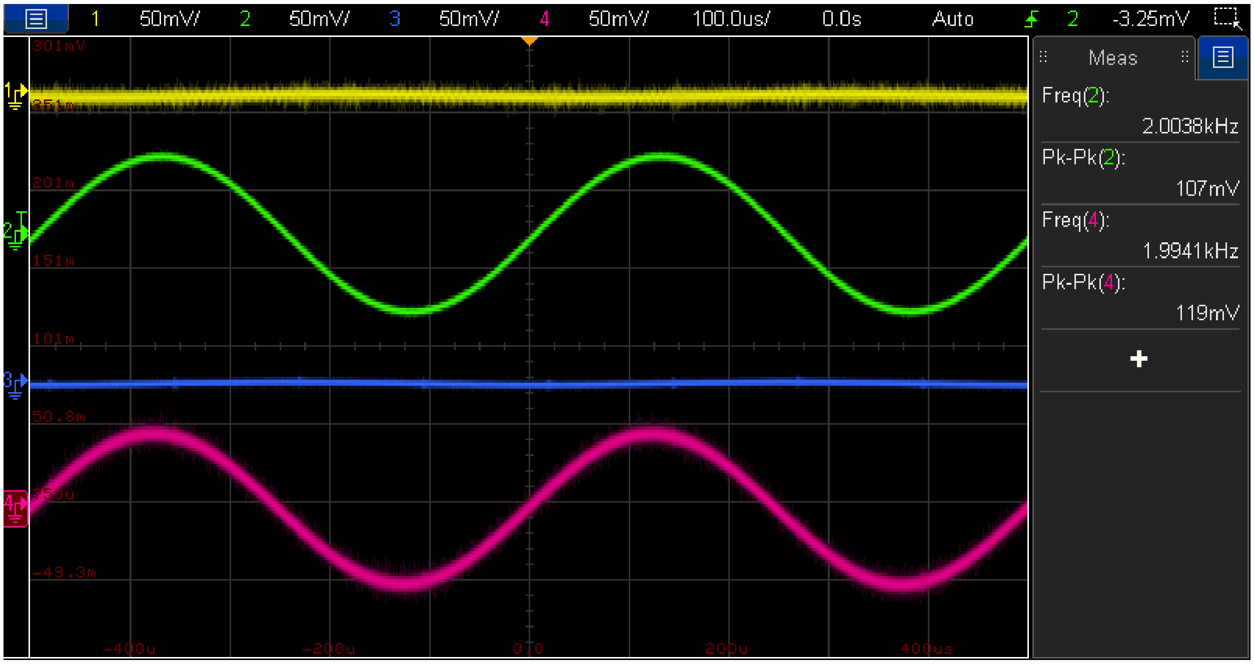

Figure 4.15 Summing Amplifier Output

The results prove that the chosen circuit topography and component values meet the specifications that were given.

Conclusion:

The audio equalizer circuit displaying the utilization of passive signal filters and operational amplifiers was successfully designed, built, and tested. The high and low pass passive filters, amplifiers, and buffers were all successfully integrated together into a complete circuit. The circuit met all the given specifications and displayed the expected behavior and outputs. Although it would have been difficult to meet the specifications exactly, by using theory, known formulas, and datasheets, all of the specifications were met within the allowed margin of error of no greater than plus or minus ten percent. Overall, the circuit performed as expected and all objectives were met.

References:

[1] Balmos, A. D., Hathorn, S. R. (2019). *Electrical Engineering Fundamentals Laboratory I*. Balmos Hathorn.

[2] Allred, R. (2015). *Digital filters for everyone*. Creative Arts & Sciences House.

[3] Texas Instruments, "LMx24-N, LM2902-N Low-Power, Quad-Operational Amplifiers," SNOSC16D datasheet, Mar. 2000 [Revised Jan. 2015]