Final Project Report: Audio Equalizer

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Contents

1 Abstract/Introduction

1.1 Definition and Purpose of the project (objectives)

The objective of this final project was to use principles and knowledge from past labs to create an **audio equalizer and amplifier**. The concepts required to complete this project were signal filters, operational amplifiers, oscilloscope techniques, and breadboard usage.

Students were required to show a working demo of the circuit. First, we had to construct and test each filter, then volume control, and then integrate the power and summation amplifiers. All of these functions were first tested with a voltage signal, and at the very end plugged into a speaker to play processed sound.

1.2 Key Functions of the audio equalizer

As mentioned briefly in the previous section, the audio equalizer is divided into five stages.

1. Input Stage - The input signal is fed into the circuit
2. Filtering Stage - The input signal is split into different filters where it gets separated by frequency
3. Adjustment Stage - The signals get adjusted by altering their gain through boosting (increasing volume) or cutting (reducing volume)
4. Recombination Stage - The modified frequency bands are combined into a single, cohesive audio signal again
5. Output Stage - The signal is amplified and outputted

1.3 Applications of audio equalizers

Audio equalizers have direct real-world applications such as phones, Bluetooth speakers, and musical instrument amplifiers. They are especially significant in music production where they are used to adjust the timbre (tone quality) of individual instruments and voices [1].

These applications make it an important circuit to understand and learn.

2 Theory

2.1 General filters

The circuit uses High-pass, Mid-pass, and Low-pass passive filters. These are important in the filtering stage of the circuit, and are passive because they rely on circuit reactivity rather than a powered element [2].

The first filter under discussion is the High-pass Filter. This is an RC filter circuit that only allows signals above the selected cut-off frequency point [3]. Here, the resistor and capacitor are in series, and the output voltage is taken across the resistor, as shown in Fig. 1.

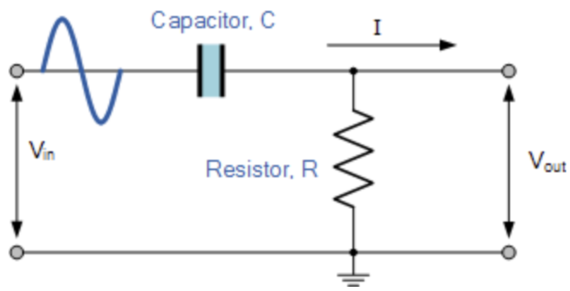

Figure 1: High Pass Filter Circuit[3]

This filter works because the impedance of the capacitor is high at low frequencies, and blocks the input voltage until the cut-off frequency point is reached. At the cut-off point, the capacitor acts more like a short circuit. The cut-off frequency is calculated using the equation-

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

Next, the low-pass filter is RC filter circuit allows only low frequency signals below its cut-off frequency [4]. This circuit it also passive and includes a resistor and capacitor placed in parallel, with the V_{out} across the capacitor, as seen in Fig. 2.

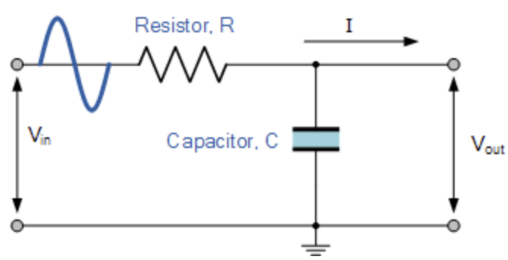

Figure 2: Low Pass Filter Circuit[4]

This filter works because the impedance of the capacitor becomes much larger than the resistance of R. This means that there is a much larger voltage drop across the capacitor. The operation of this circuit is similar to that of high-pass but opposite. Hence, the equation to find the cut-off frequency is also the same. The cut-off frequency is calculated using the equation-

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

Finally, the Mid-pass filter, also known as a Band Pass Filter is an RC circuit that is used to isolate frequencies that lie within a range of frequencies. The width of this "band" of frequencies is known as the Bandwidth of the circuit [5]. This filter is made by connecting a high-pass filter and a low-pass filter in series, as seen in Fig. 3.

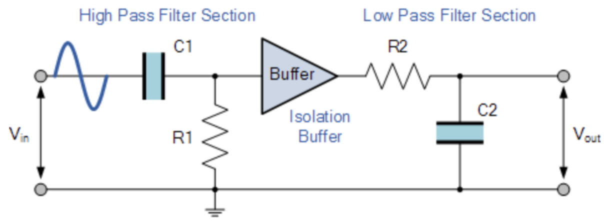

Figure 3: Mid-Pass Filter Circuit[5]

The above figure also shows a buffer in-between, which is a non-inverting operational amplifier. It's purpose is to isolate the two stages and define the overall voltage gain of the circuit [6].

The cut-off frequency is calculated using the equation-

$$f_C = f_H - f_L$$

The low-pass filter is used as a the Bass Filter, the Band-pass Filter is used as the Mid filter and the High-pass filter is used as the Treble filter.

2.2 Operational Amplifier

Operational amplifiers or op-amps are integrated circuits (ICs) that amplify the voltage difference between its two inputs. Hence, depending on the configuration of the the inputs, the IC has varied functions such as amplifiers, buffers and comparators, etc [7].

This device has 3 terminals, 2 inputs and 1 output. It operates with a dual positive (+V) and a corresponding negative (-V) DC supply.

2.2.1 Buffers

It's first application in this audio equalizer circuit is as a buffer. Here, there is a direct connection between the output voltage and the inverting input (v_-). This means that $v_{out} = v_{in}$ and due to the large resistance between them, the input is isolated from the output. This removes the loading as a likely issue in the circuit [8].

Fig. 4 is the circuit diagram of the op-amp as a buffer.

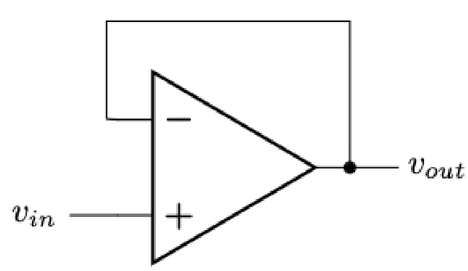

Figure 4: Op-amp as a Buffer [8]

In this audio equalizer circuit, the buffer is used between the phases of the mid-pass filter.

2.2.2 Inverting Amplifiers

Other than buffers, this circuit uses op-amps as inverting amplifiers. The input is connected to the inverting input, the non-inverting input is grounded, and a voltage divider is placed between the input and output, as seen in Fig. 5.

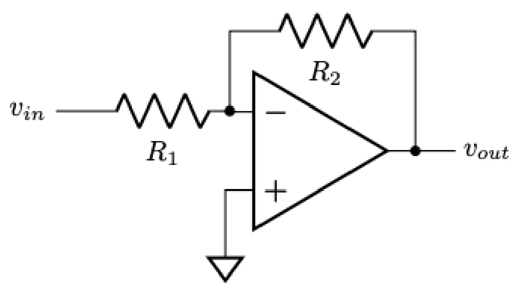

Figure 5: Inverting Amplifier [8]

The gain is the the amount by which the signal is amplified, and here the equation for it is -

$$v_{out}/v_{in} = -R_2/R_1$$

The negative sign implies that the signal is 180 degrees out of phase.

In this circuit, the inverting amplifier is used to cut and boost the specific frequency bands with R_2 being a potentiometer. This allows the magnitude of the gain to be varied.

It is also used as a Summing Amplifier to combine the different frequencies and amplify them.

2.3 Power Amplifier

A Power Amplifier, or large signal amplifier delivers power to the load, with the output signal power being larger than the power of the input signal. In the audio equalizer circuit it is used to drive the loudspeaker [9].

It works by converting the DC power drawn into an AC voltage signal delivered to the load. The amplification is high, however the efficiency is not. As a comparison, it acts like an engine adding energy to the input signal.

In this case, the LM 386 was used. Fig. 6 shows the pin-outs for the IC. Pin 6 is where the external DC power supply was connected to.

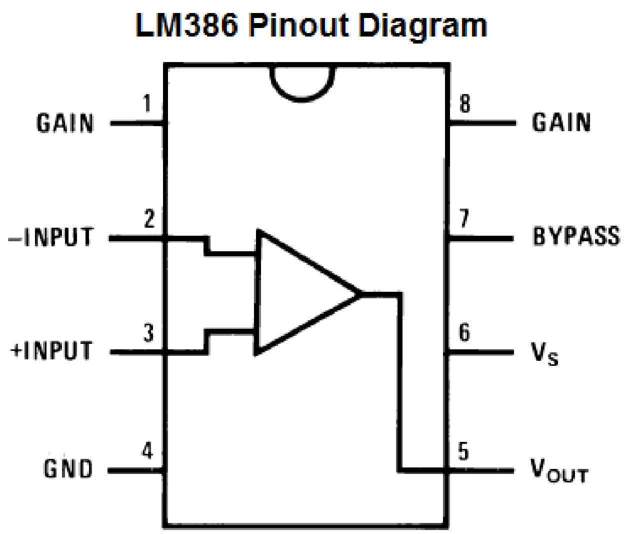

Figure 6: Power Amplifier

3 Procedure

3.1 Schematic of the audio equalizer

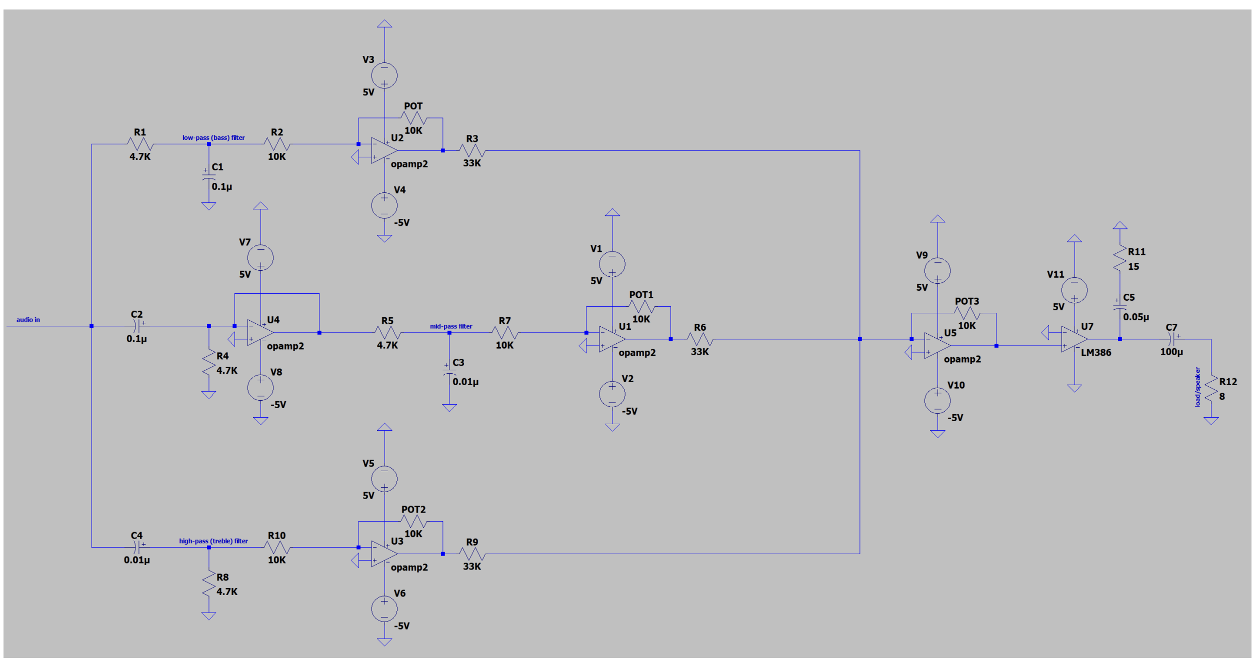

Figure 7: Audio Equalizer Circuit

3.2 Design parameters

3.2.1 Filters (Low pass, high pass, mid pass)

The cutoff frequency of an RC filter is given by $f_c = \frac{1}{2\pi RC}$. For the required cutoff frequencies specified in the task, suitable values of R and C were selected such that their product satisfied this relationship.

For the **bass (low-pass) filter** with a cutoff frequency of 320 Hz, the value of RC is:

$$RC = \frac{1}{2\pi \cdot 320} = 4.97 \times 10^{-4}$$

A capacitor value of $C = 0.1$ μF was chosen. The corresponding resistor value is:

$$R = \frac{RC}{C} = \frac{4.97 \times 10^{-4}}{1 \times 10^{-7}} = 4973\ \Omega$$

An approximation of this value was implemented using 4.7 kΩ, a resistor value available in the lab kit.

For the **mid-pass filter**, a combination of high-pass and low-pass filters was used to allow frequencies between 320 Hz and 3200 Hz. For the low-pass section at 320 Hz, a capacitor value of $C_1 = 0.1$ μF was selected, giving a resistor value of approximately $R_1 \approx 4.7$ kΩ.

For the high-pass section at 3200 Hz, the value of RC is:

$$RC = \frac{1}{2\pi \cdot 3200}$$

A capacitor value of $C_2 = 0.01$ μF was chosen, resulting in a resistor value of approximately $R_2 \approx 4.7$ kΩ.

For the **treble (high-pass) filter** with a cutoff frequency of 3200 Hz, the same relationship was used:

$$RC = \frac{1}{2\pi \cdot 3200}$$

A capacitor value of $C = 0.01$ μF was selected, giving a resistor value close to 4.97 kΩ, which was implemented using 4.7 kΩ.

Thus, the component values were chosen to closely match the required cutoff frequencies while ensuring practical implementation given the limitations of the lab kit and common component values.

3.2.2 Volume control circuits

For volume control, a an op-amp with maximum gain of -1 was used. This was done with a 10 kΩ potentiometer and a 10 kΩ resistor. The formula for gain is-

$$Gain = -R_2/R_1$$

And in this case, the R_2 is the potentiometer. The maximum gain is -1 and minimum is 0. This is because resistance of the potentiometer can be modified by moving the wiper. When the resistance is increased, the signal is boosted and the volume increases. When the resistance is decreased, the signal gets cut and the volume decreases. The formula for the V_{out} of the potentiometer is-

$$V_{out} = V_{in} * R_{wiper}/R_{total}$$

The 10 kΩ potentiometer was chosen because it was given in the lab kit.

This was repeated across all signals; low-pass, mid-pass, and high-pass so that the user would be able to individually adjust each of their volumes.

3.2.3 Signal recombination stage

The signal recombination stage refers to the summing amplifier being used to combine all the signals (after volume modification). The output volume and gain of the op-amp can be adjusted using a 10 kΩ potentiometer. The output of the of summing amplifier is given by -

$$V_{\text{out}} = -R_{pot} \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right)$$

The input resistors R_1, R_2, and R_3 are kept equal at 33 kΩ which ensures that each band contributes proportionally to the final signal.

3.3 Operation

Overall, this audio equalizer circuit operates by first splitting the input audio signal into three parallel paths for bass, mid, and treble frequencies. These frequencies are isolated using RC filters: a low-pass filter for bass (up to 320 Hz), a band-pass filter for mid frequencies (320 Hz to 3200 Hz), and a high-pass filter for treble (above 3200 Hz).

After filtering, each signal passes through an op-amp with a potentiometer which allows for the quantity of each signal to be modified by boosting or reducing it.

Following this, all three branches are combined using an inverting summing amplifier. A potentiometer is used again so that the overall gain of the combined signal could be modified. This allows the user to adjust the overall volume.

Finally, the combined signal is sent to the LM386 power amplifier, which increases the power of the signal so that it can drive the speaker and an output can be heard.

4 Results

4.1 Low-pass Filter's FRA curve

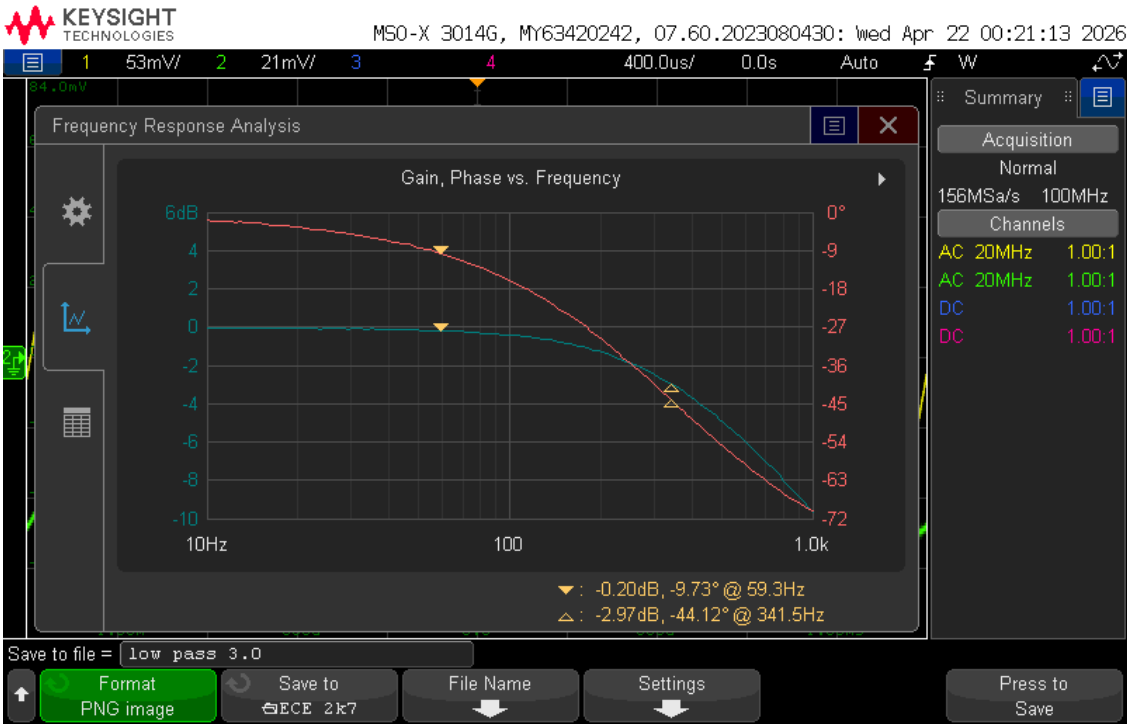

Figure 8: FRA Plot for the Low-pass Filter

Fig. 8 is the FRA plot for the low-pass filter. As the graph shows there is an initial low frequency region (the pass band), then the gain drops to -3dB at the cut-off frequency (≈ 320 Hz), and finally the there is a high frequency region where gain decreases as the frequency increases.

4.2 Mid-pass filter's FRA curves with explanation

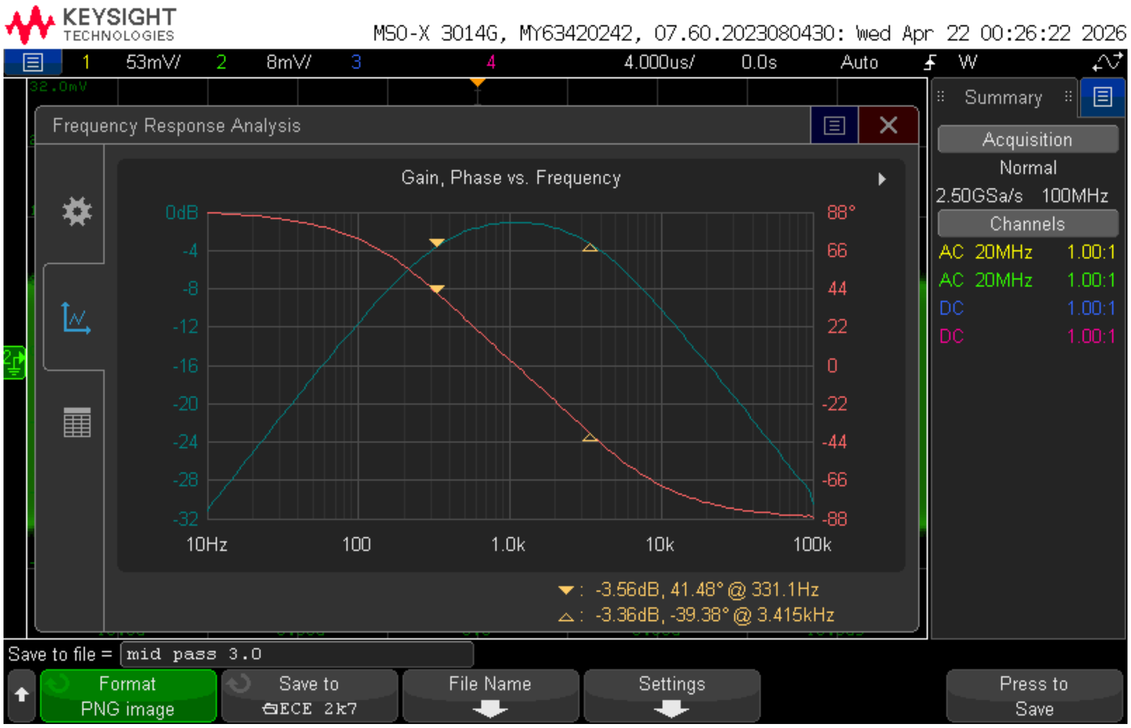

Figure 9: FRA Plot for the Mid-pass Filter

Fig. 9 is the FRA plot for the mid-pass filter. As the graph shows there are two cut-off frequencies, 320 Hz and 3200 Hz, this is where the gain drops to -3 dB. Initially, the graph has a low-frequency region where the gain is low. Then in the middle region, there is the pass band between f_L and f_H where the gain is constant. Finally, on the right there is the high frequency region where the gain decreases again.

4.3 High pass filter's FRA curves with explanation

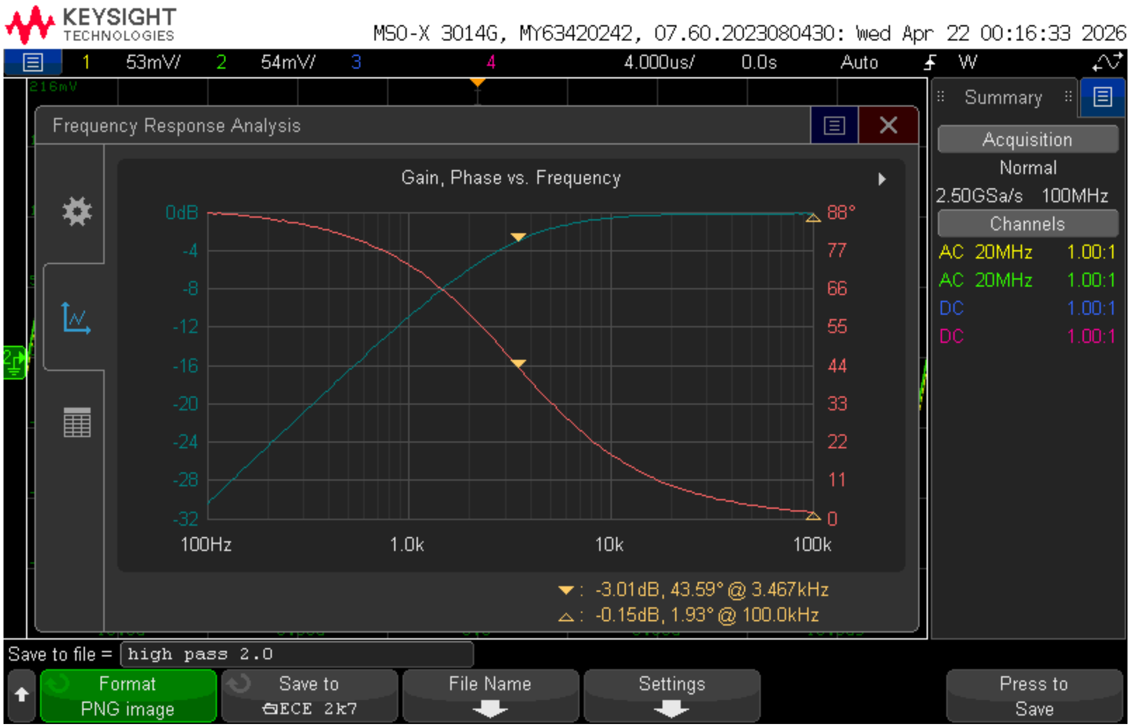

Figure 10: FRA Plot for the High-pass Filter

Fig. 10 is the FRA plot for the high-pass filter. As the graph shows, there is a low-frequency region on the left side, where the frequency and gain increase. Then, at the cut-off frequency ($\approx$ 3200 Hz) the gain is -3 dB. And finally on the right, the high frequency region (the pass band) where the gain is constant.

4.4 V_{amp} at Minimum Settings

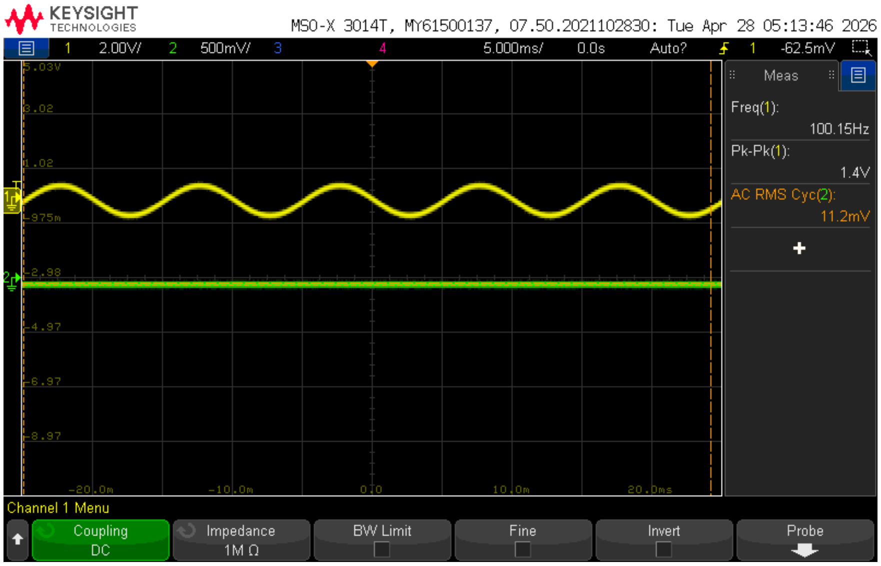

Figure 11: V_{amp} at 100 Hz with minimum settings

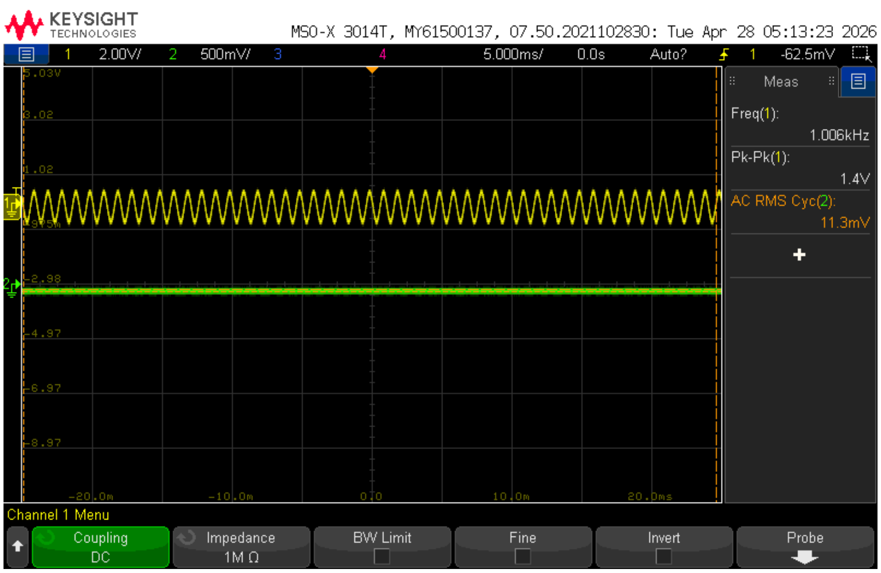

Figure 12: V_{amp} at 1 kHz with minimum settings

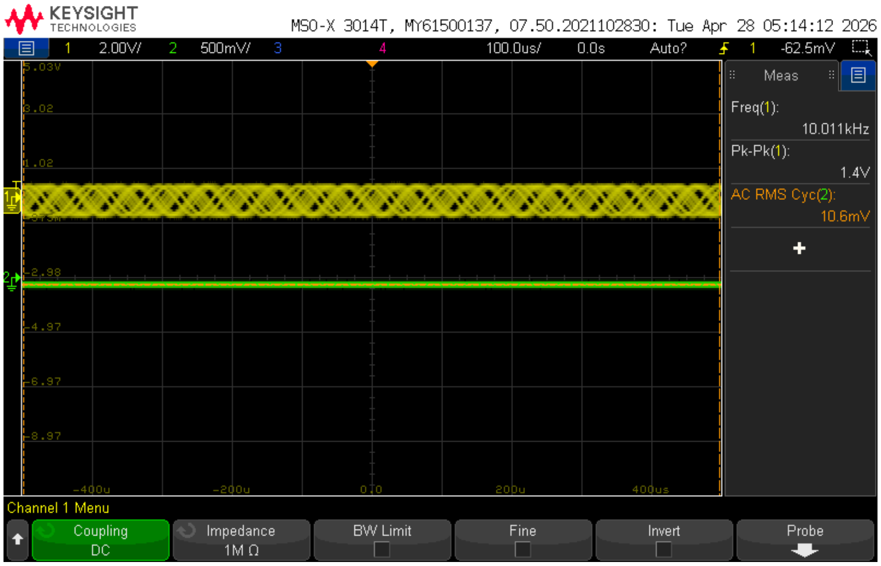

Figure 13: V_{amp} at 10 kHz with minimum settings

When the equalizer settings are at their minimum positions, the potentiometers diminish the incoming signals from the base, mid, and treble filters. Since each branch output is small, the overall signal output from summing amplifier is also reduced.

By performing this test, we were able to verify that the potentiometers and summing amplifier were performing as expected. Fig. 11, Fig. 12, and Fig. 13 show the V_{amp} to be $<$ 15 mV for 100 Hz, 1 kHz, and 10 kHz respectively.

4.5 V_{amp} at Maximum Settings

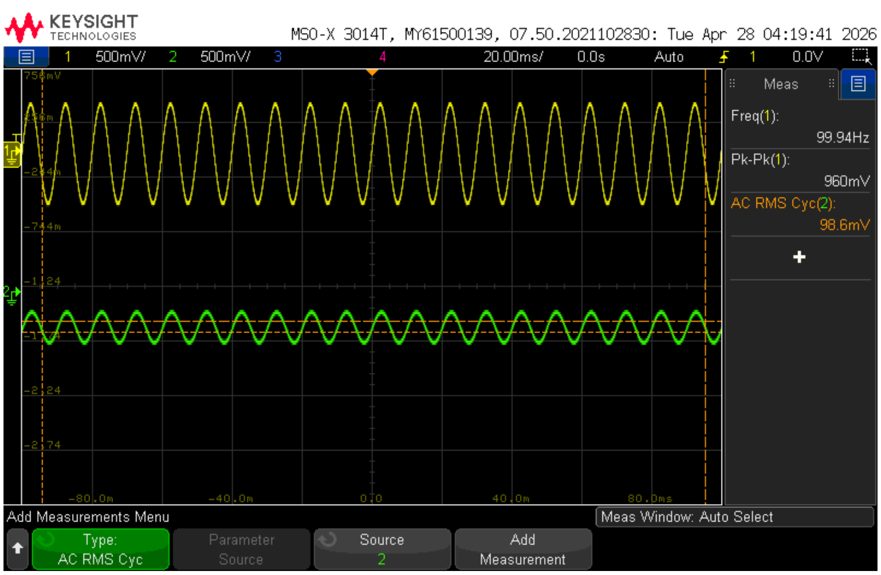

Figure 14: V_{amp} at 100 Hz with maximum settings

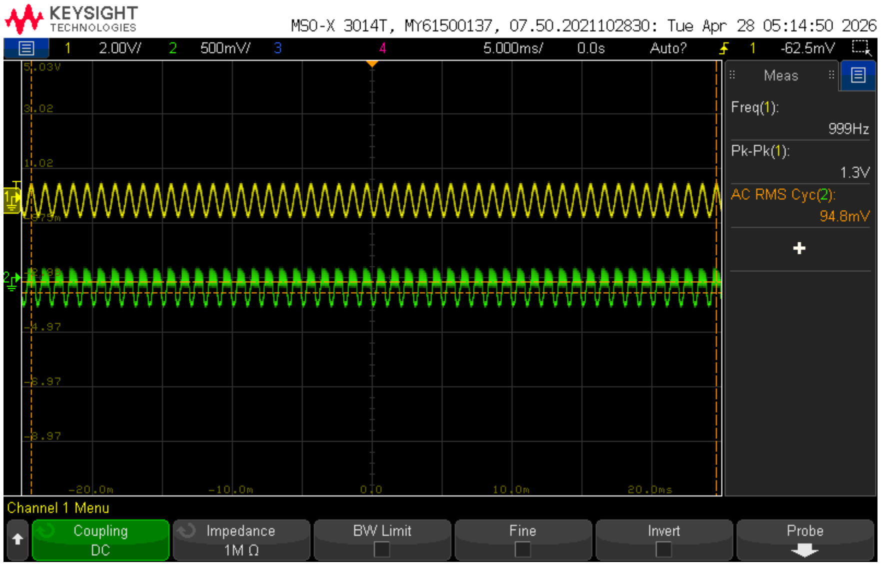

Figure 15: V_{amp} at 1 kHz with maximum settings

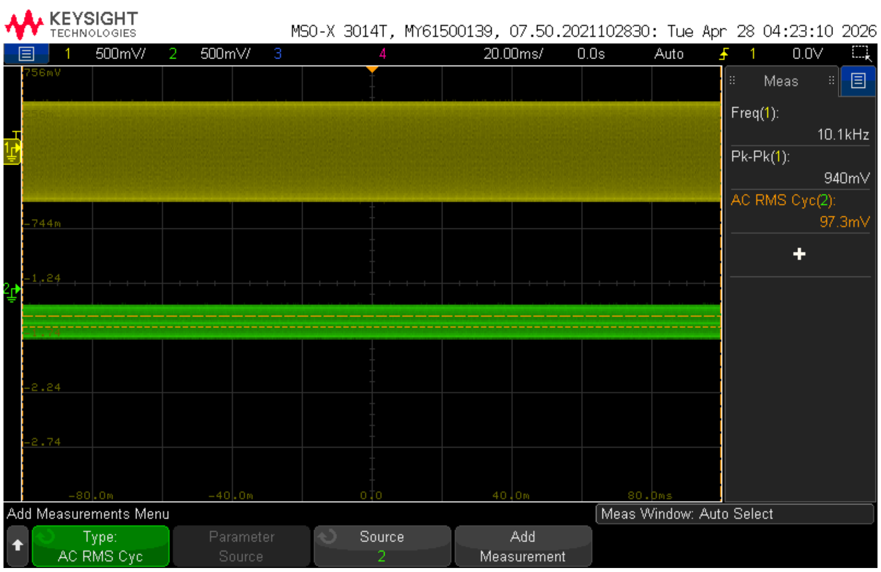

Figure 16: V_{amp} at 10 kHz with maximum settings

When all the equalizer controls are set to their maximum positions, the potentiometers allow the maximum signal from each of the filter branches and into the summing amplifier. This means that the measured output V_{amp} is approximately 100 mV_{rms} for all frequencies. 100 mV comes from the 33 kΩ resistors used with the summing amplifier, which made the V_{out} = $V_{in}/3$, where V_{in} was 320 mV_{rms}.

By performing this test we were able to verify that each filter, and the summing amplifier worked as intended. Fig. 14, Fig. 15, and Fig. 16 show the V_{amp} to be within 10% of 100 mV for 100 Hz, 1 kHz, and 10 kHz respectively.

4.6 Ripple Measurements

First, an FRA plot from 100 Hz to 10 kHz across the output of the summing amplifier was taken. The frequencies at maximum and minimum gain were then found. As seen in Fig. 17, these frequencies are 100 Hz and 1.9 kHz.

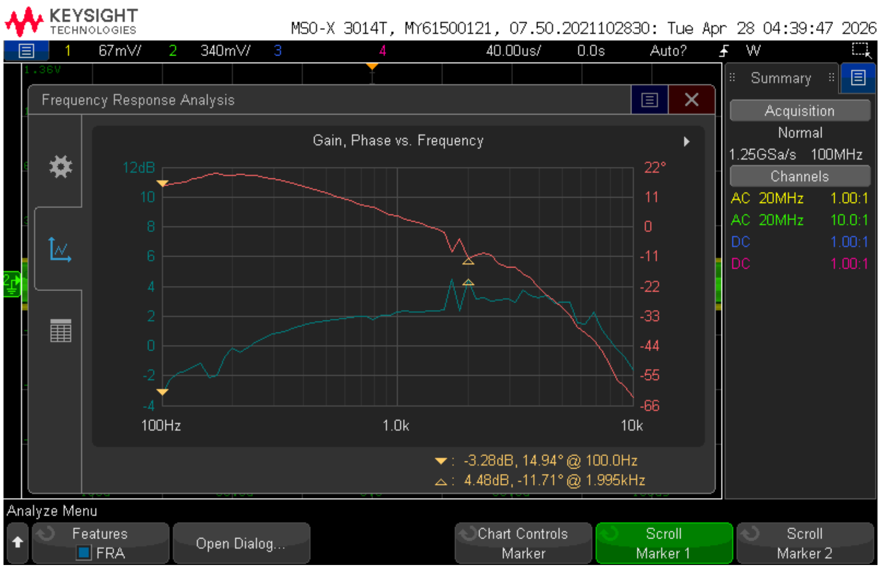

Figure 17: FRA plot to find $V_{amp,max}$ and $V_{amp,min}$

Fig. 18 shows the V_{amp} at 100 Hz, the minimum, which was 110.4 mV.

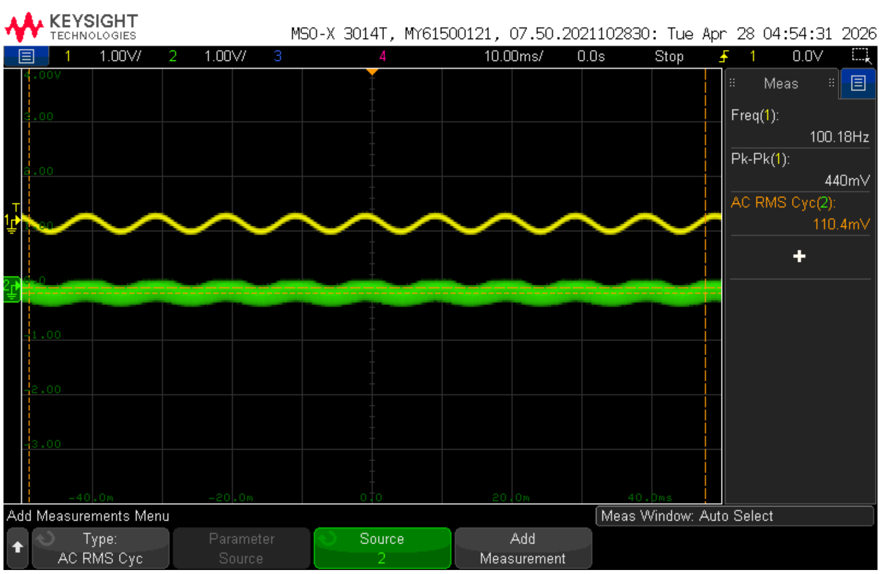

Figure 18: $V_{amp,min}$ at 100 Hz

Fig. 19 shows the Vamp at 1.9 kHz, the maximum, which was 116.8 mV.

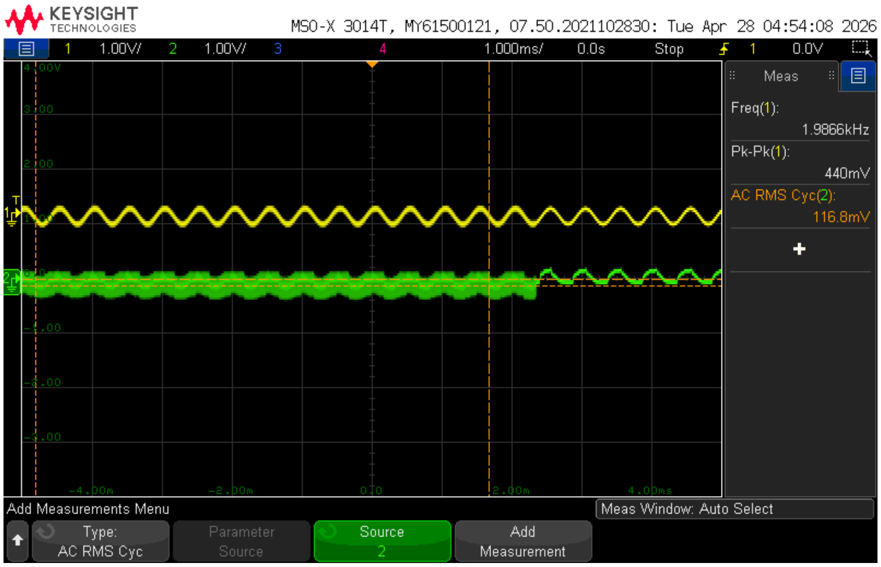

Figure 19: $V_{amp,max}$ at 1.9 kHz

The equation for the Ripple is given by-

$$Ripple = V_{\max} - V_{\min}$$

The Ripple in our circuit was -

$$Ripple = 116.8 - 110.4 = 6.4mV$$

6.4 mV < 15 mV, the acceptable ripple, which means the output of the circuit is smooth and stable.

4.7 Power Amplifiers Output

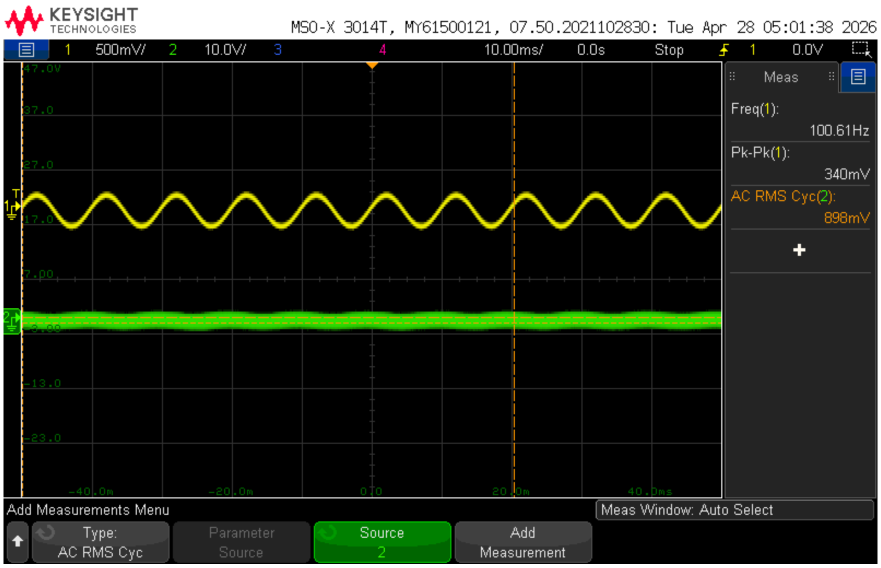

Figure 20: Power Amplifier Output at 100 Hz

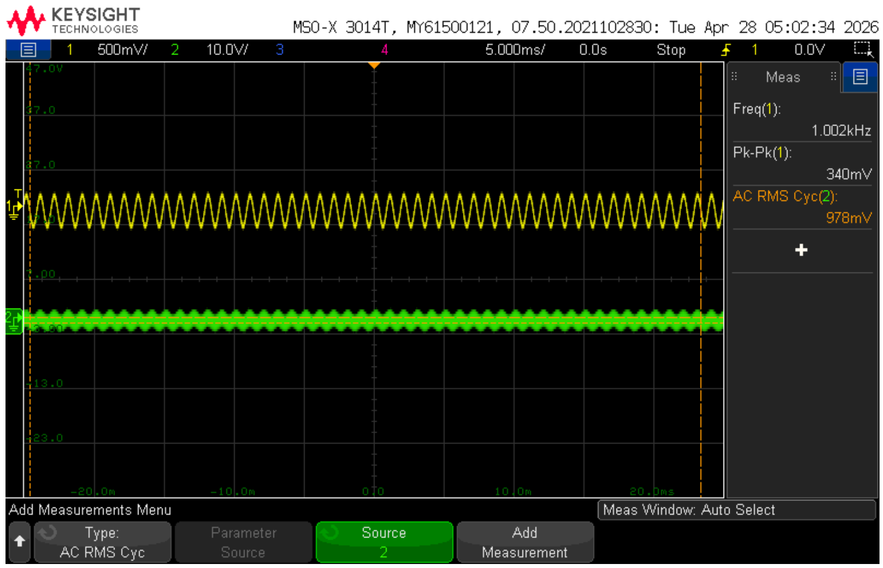

Figure 21: Power Amplifier Output at 1 kHz

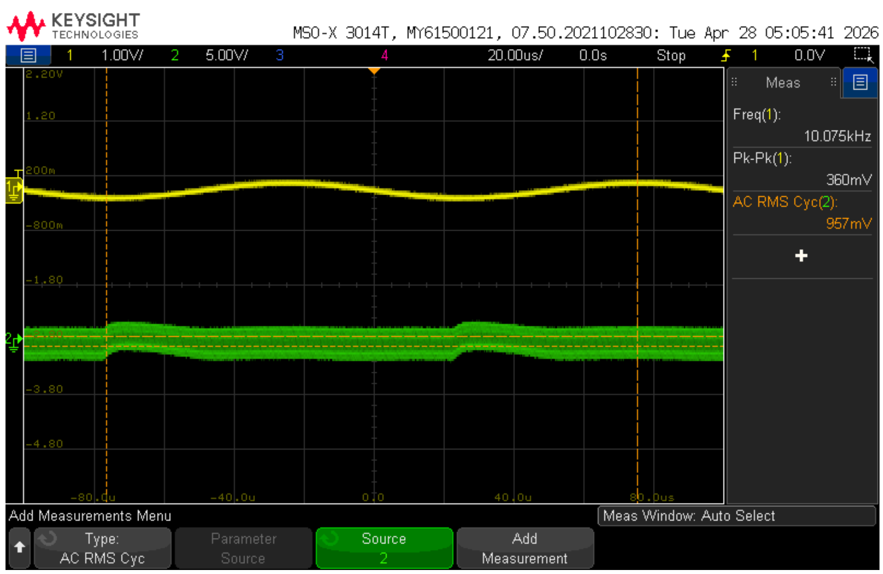

Figure 22: Power Amplifier Output at 10 kHz

The above figures are measures of the Voltage across the 8 Ω resistor at different frequencies (100 Hz to 10 kHz).

The output power delivered to the load is calculated using:

$$P = \frac{V_{\text{rms}}^2}{R}$$

where $R = 8\ \Omega$.

At 100 Hz Measured:

$$V_{\text{rms}} = 898 \text{ mV} = 0.898 \text{ V}$$

$$P = \frac{(0.898)^2}{8} = \frac{0.806}{8} = 0.1008 \text{ W} \approx 101 \text{ mW}$$

At 1 kHz Measured:

$$V_{\text{rms}} = 978 \text{ mV} = 0.978 \text{ V}$$

$$P = \frac{(0.978)^2}{8} = \frac{0.957}{8} = 0.1196 \text{ W} \approx 120 \text{ mW}$$

At 10 kHz Measured:

$$V_{\text{rms}} = 957 \text{ mV} = 0.957 \text{ V}$$

$$P = \frac{(0.957)^2}{8} = \frac{0.916}{8} = 0.1145 \text{ W} \approx 115 \text{ mW}$$

The calculated output power is consistent across the tested frequency range, indicating stable amplifier performance. However, this value is < 400 mW, the expected value, which meant that there was an error somewhere in our circuit.

4.8 Volume Control

The AC RMS output voltage directly relates to the loudness of the circuit. As the potentiometer position is increased, the gain of the map increases, which results in a higher RMS output voltage and a louder sound from the speaker, and vice versa.

The following plots demonstrate the variation of the AC RMS value with changing position of the summing amplifier potentiometer wiper.

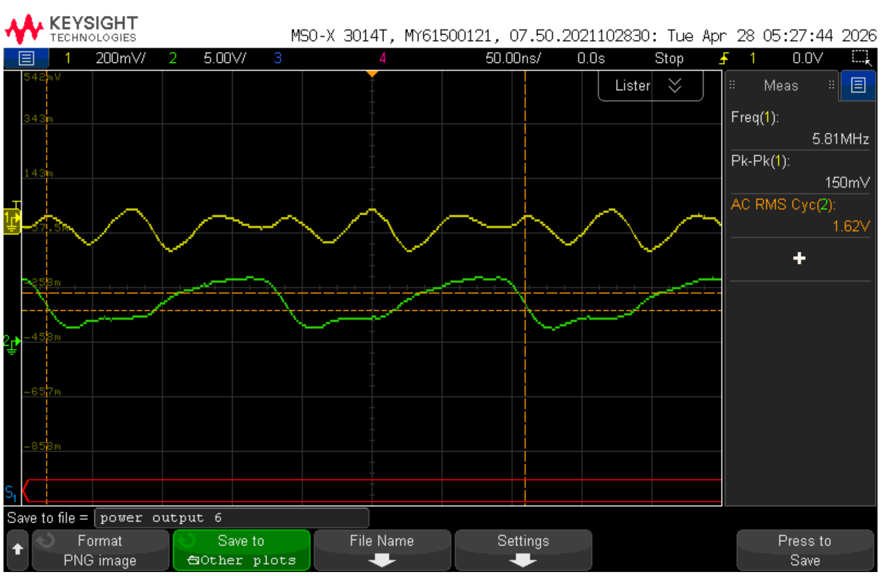

Figure 23: Output at Low volume

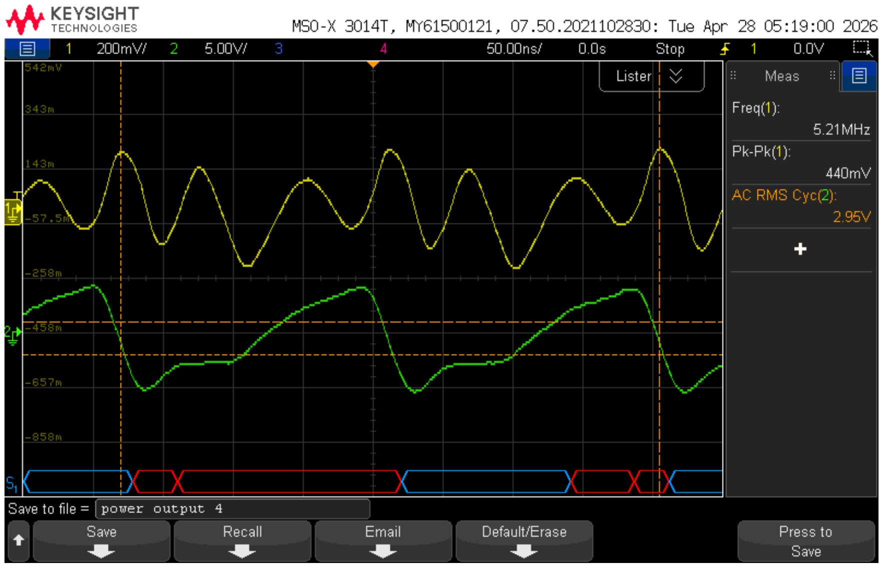

Figure 24: Output at Medium volume

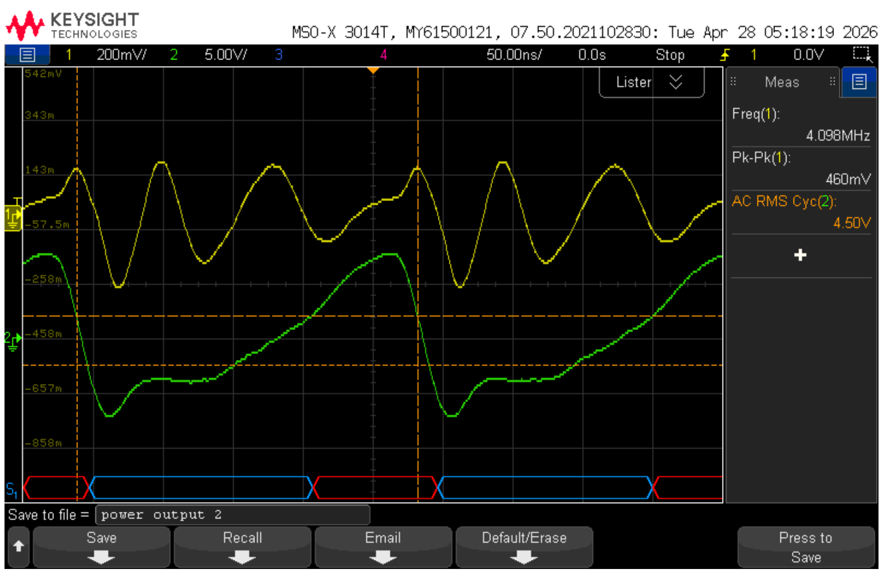

Figure 25: Output at High volume

4.9 Results justification, Errors

Overall, apart from the output power, most of the results were consistent with the theoretical behavior of the circuit. The cut-off frequencies, and output V_{amp} were within 10 % of the expected values.

The percentage error for the Output Power Calculation was

$$(400 - 100)/400 * 100\% = 75\%$$

This is a higher percentage difference, and in the future effort will be made to avoid such mistakes.

Other smaller deviations might have been due to resistor and capacitor tolerances, non-ideal behavior of the op-amps and LM386, loading effects between stages, and measurement inaccuracies.

We also had to make a few changes to the circuit due to these errors. These changes were -

- Replace the 4.7 kΩ with 4.7 kΩ + 390 Ω resistors
- Increase the 33 kΩ resistor in the Mid-pass branch to 33 kΩ + 22 kΩ + 6.8 kΩ.
- Took out the 100 µF capacitor at the end
- Increase the DC Voltage input into the Power Amplifier (from 5 V to 10 V)

5 Conclusion and reference

5.1 Conclusion

5.1.1 Idea and Findings

The objective of this project was to design and implement and audio equalizer with bass, mid, and treble control, which was achieved. The RC filters for low-pass, mid-pass, and high-pass showed cut-off frequencies close to the designed values (320 Hz - 3200 Hz), validating the filter design. The potentiometer-based volume control worked effectively, with the V_{amp} being $<$ 15 mV at minimum settings and approximately 100 mV at maximum settings. The ripple voltage was measured to be 6.4 mV, which is well below the acceptable limit of 15 mV, indicating a smooth and stable output signal. The power amplifier stage (LM386) functioned correctly in amplifying the signal to drive the signal and was consistent across frequencies. These results were the product of trial and error with resistor and capacitor values, which were decided upon through further experimentation.

5.1.2 Deviations and Explanation

However, the measured output power ($\approx$ 100–120 mW) was significantly lower than the expected 400 mW, resulting in a high percentage error of approximately 75%. This indicates that the gain of the amplifier stage was lower than required.

The discrepancy in output power can be attributed to factors such as:

- insufficient gain in the LM386 stage,
- signal attenuation in earlier stages (filters and summing),
- component tolerances,
- and non-ideal behavior of practical components.

Additionally, other measured parameters such as cutoff frequencies and output voltage showed deviations within approximately 10% of the expected values, which was acceptable.

5.2 Bibliography

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