Lab 14 Basic Audio Equalizer

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Abstract

In this lab, the objective was to build an audio amplifier with three sub-systems: an adjustable equalizer, volume control, and power amplifier. The circuit should maintain an output of 100 millivolts RMS (mVrms) with ±10% tolerance at the output of the volume control when the input frequency could be changed to 200 Hz, 2 kHz, and 10 kHz at 1 volt peak-to-peak (Vpp). I calculated the values for each capacitor and resistor for the filters in the adjustable equalizer and tested each filter with frequency analyses separately. After the filter tests were done, I continued testing with the volume control and power amplifier one by one. Finally, all sub-systems passed the tests and were connected together, then the integrated entire circuit passed the tests.

1. Objectives

The objective of this project was to use filters, superposition, and power amplifiers to build an audio amplifier. It was constructed by three sub-systems: an adjustable equalizer, a volume control, and a power amplifier.

1.1 Objectives for Filter Design

The adjustable equalizer was built with three different filters: bass filter for low frequency, mid filter for medium frequency, and treble filter for high frequency. Three designed frequency ranges were less than 320 Hz (Bass filter), between 320 Hz and 3200 Hz (Mid filter), and larger than 3200 Hz (Terble filter) with ±10% tolerance. Three test frequencies were 200 Hz, 2 kHz, and 10 kHz with ±10% tolerance as well. The bass filter and the Terble filter should have the -3 dB cutoff at 320 Hz ±10% and 3.2 kHz ±10% respectively, and the Mid filter should have the -3 dB bandwidth from 320 Hz ±10% to 3.2 kHz ±10%.

1.2 Objectives for Gains

Let Vamp be the voltage at the output of the volume control. When three filters were connected together, the input was 1 Vpp, and the volume control and all equalizer knobs were set at the maximum, the Vamp should maintain 100 mVrms ±10% at three different test frequencies (200 Hz, 2 kHz, and 10 kHz).

When three filters were connected together, the input was 1 Vpp, the volume control was set at the maximum, and all equalizer knobs were set to minimum, the Vamp should maintain less than 15 mVrms ±10% at three different test frequencies (200 Hz, 2 kHz, and 10 kHz).

When all equalizers were at maximum, the difference of the maximum of RMS of Vamp should be less than 15 mV from 200 Hz to 10 kHz (Ripple measuring).

1.3 Objective for the Power Amplifier

The amplifier output power should be greater than 400 mW from 200 Hz to 10 kHz.

2. Theory

2.1 Theory of Filters

2.1.1 Low Pass Filter

When we apply an AC signal to a capacitor, the capacitor will have some impedance which is like the resistance to resist the current to flow. There is also a voltage across the capacitor, and the impedance of the capacitor is based on the frequency of the signal, so we can get a relation between the frequency and the portion of the voltage that the capacitor gets from the source based on the voltage division (See the example of a low pass filter below). The portion of the voltage that the capacitor gets from the source can be obtained by the transfer function. Equation 2.1.1 is the transfer function for a low pass filter,

$$H(f) = \frac{V_{out}}{V_{in}} = \frac{Z_C}{Z_C + Z_R}$$

(Eq 2.1.1)

where the output is across the capacitor, and Zc and ZR can be represented by:

$$Z_C = \frac{1}{j2\pi fC}, Z_R = R$$

If we plug in those expressions into Eq 2.1.1 and simplify, we can get the transfer function of a low pass filter:

$$|H(f_c)| = \frac{1}{\sqrt{1 + (2\pi fRC)^2}}$$

(Eq 2.1.2)

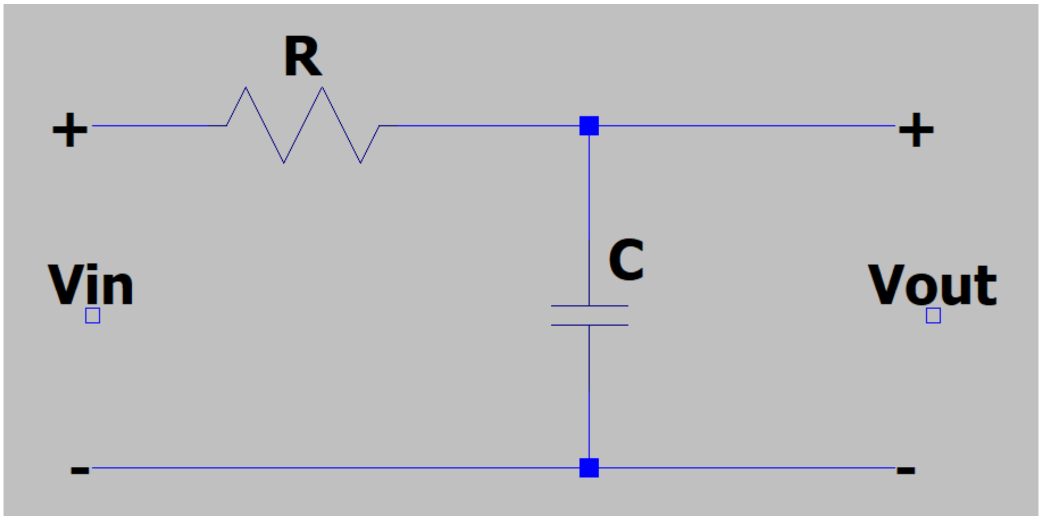

Figure 2.1.1: Schematic of a low pass filter.

The unit of power can also be dB. The level of dB power gain can be represented by:

$$X_{dB} = 10log\frac{P_{out}}{P_{in}} = 10log\frac{\frac{V_{out}^2}{R_{out}}}{\frac{V_{in}^2}{R_{in}}} = 10log(\frac{V_{out}}{V_{in}})^2 = 20log|\frac{V_{out}}{V_{in}}|$$

(Eq 2.1.3)

When the output power is half of the input power, the gain is approximate -3dB. From Eq 2.1.3, Let Rout equal to Rin will have the maximum power transfer. We know the portion of Vout over Vin is just the transfer function, so when the cutoff is -3 dB:

$$10log\frac{P_{out}}{P_{in}} = 10log\frac{1}{2} = 20log(H)$$

Simplify:

$$|H| = \frac{1}{\sqrt{2}}$$

(Eq 2.1.4)

If we equate Eq 2.1.4 and Eq 2.1.2 and simplify, we can get:

$$|H| = \frac{1}{\sqrt{2}} = |H(f_c)| = \frac{1}{\sqrt{1+(2\pi f RC)^2}}$$

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

(Eq 2.1.5)

where R and C have infinite combinations, and f is the frequency we want to cut off.

2.1.2 High Pass Filter

Now if we do the same procedure for a high pass filter (its schematic, its transfer function, and its relation between RC and frequency), we can get:

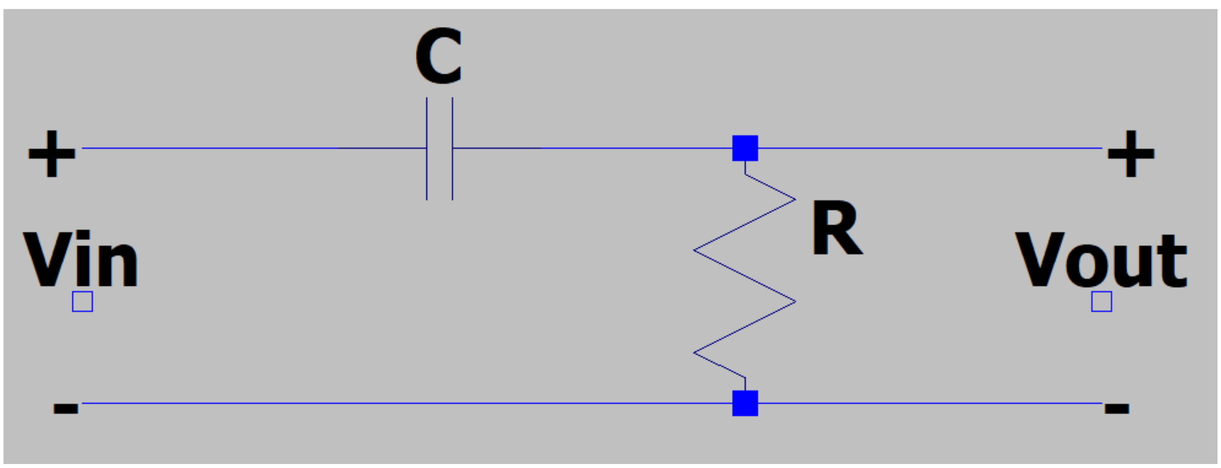

Figure 2.1.2: Schematic of a high pass filter.

And the functions:

$$H(f) = \frac{V_{out}}{V_{in}} = \frac{Z_R}{Z_C + Z_R} \quad Z_C = \frac{1}{j2\pi fC}, Z_R = R$$

$$|H(f_c)| = \frac{1}{\sqrt{1+\left(\frac{1}{2\pi fRC}\right)^2}}$$

$$|H| = \frac{1}{\sqrt{2}} = |H(f_c)| = \frac{1}{\sqrt{1 + (\frac{1}{2\pi fRC})^2}}$$

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

(Eq 2.1.6)

By observing Eq 2.1.5, Eq 2.1.6, Figure 2.1.1, and Figure 2.1.2, we can see that the equations are the same. By switching the position of the output, we can switch the type of the filter from low to high or high to low.

2.1.3 Mid Pass Filter

If we connect a low pass filter and a high pass filter in series, we can get a mid pass filter. The shape of the gain on the plot looks like a hill, where the left side is rising and the right side is falling. Since the left side is rising, the lower bound of the frequency cutoff design should be a high pass filter. The right side is falling, then the upper bound of the frequency cutoff design should be a low pass filter (i.e., higher than the lowest frequency, and lower than the highest frequency). The calculation of R and C of each filter is the same as before.

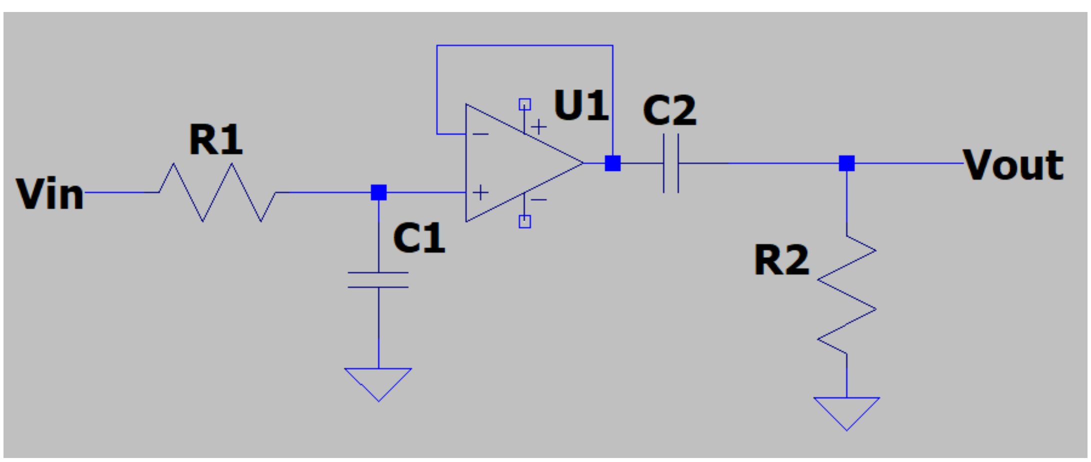

Figure 2.1.3: Schematic of a mid filter

2.2 Theory of Gains of each Filter and Volume Control

In this project, we used two amplifiers between any one of the filter output and the Vamp.

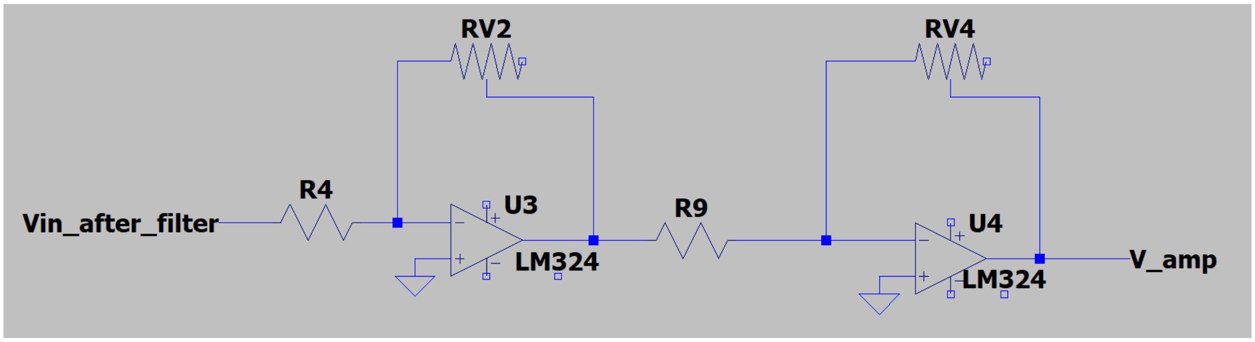

Figure 2.2.1: Schematic between the filter output and the Vamp

Since we want the input to be 1 Vpp, and output to be 100 mVrms, the overall gain can be obtained by:

$$Gain = \frac{V_{out}}{V_{in}} = \frac{100mV_{RMS}}{1Vpp/\sqrt{2}} \approx \frac{100}{355}$$

Since there are two amplifiers, the overall gain is the product of gains from every amplifier, where Rv is the potentiometer with the maximum value of 10kΩ:

$$Gain \approx \frac{100}{355} = \frac{R_{V2}}{R_4} \cdot \frac{R_{V4}}{R_9}$$ (Eq. 2.2.1)

2.3 Theory of Power Amplifier

The power amplifier we used is LM386 which had a minimum gain of 20. The desired Vamp is 100 mVrms, so the expected output should be 20 times larger, which should be 2 Vrms. From the datasheet of LM386, we can know that when the output load is 8Ω, and we want 2 Vrms, so the power supply should be around 7V in DC. By using the power equation, we can find that the power of the load is its voltage squared divided by the resistance of load, which should be 500 mW. The minimum power output is 400 mW, so the requirement should be met.

3. Procedure

The following circuit was built step by step. The filters were built and tested separately first, then the volume control and the power were built and tested. Finally, everything was connected and tested together.

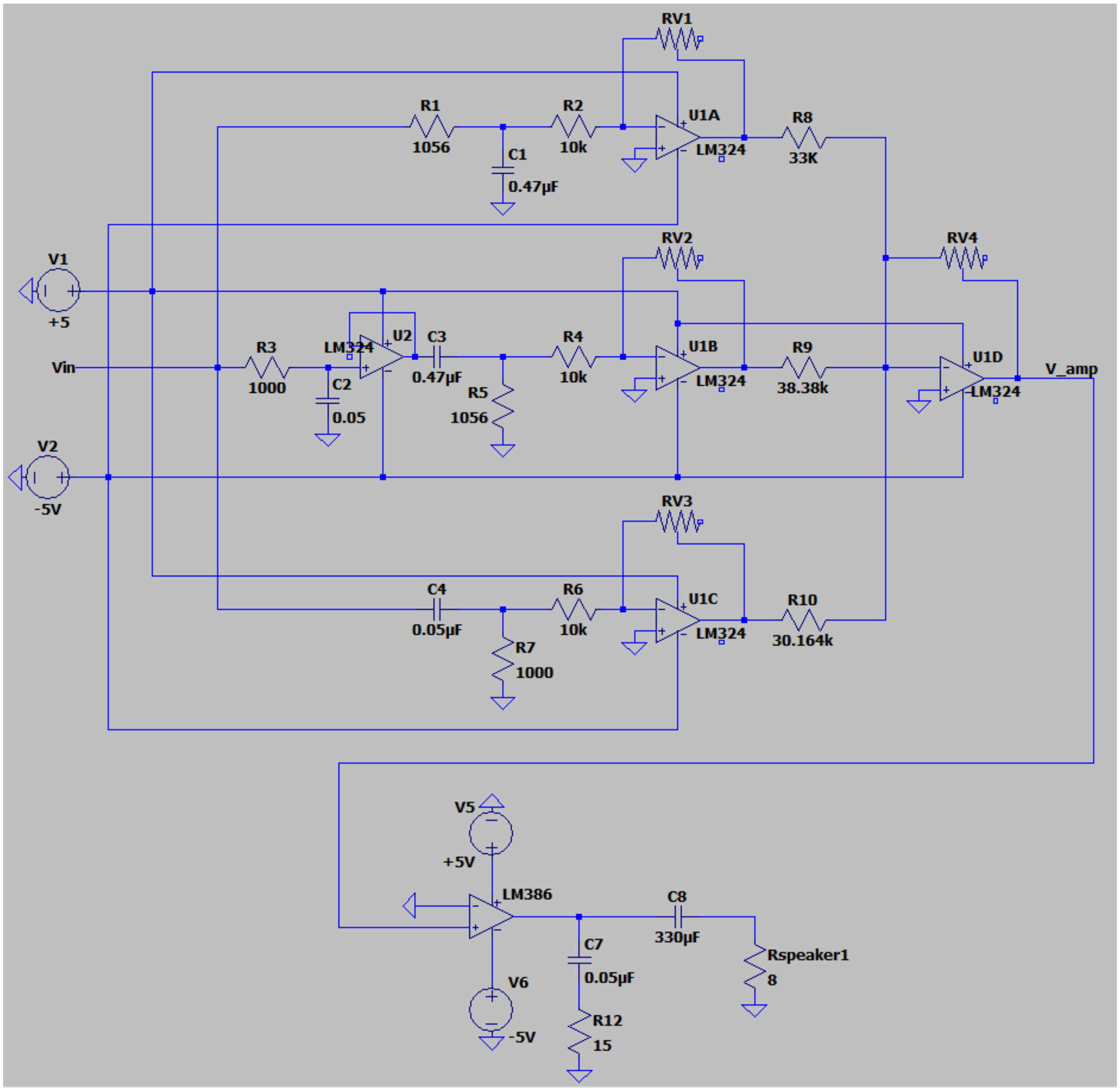

Figure 3: The complete circuit schematic of this project.

3.1 Filters

To find the values for 320 Hz and 3200 Hz, I used Eq 2.1.5 and Eq 2.1.6 to find the values.

Table 3.1: The following values were used for filters:

Bass Filter	R1=1056Ω	C1=0.47uF	-	-
Mid Filter	R3=1kΩ	C2=0.05uF	C3=0.47uF	R5=1056Ω
Terble Filter	C4=0.05uF	R7=1000kΩ	-	-

After each filter was built, the filters were tested through the frequency analysis on the oscilloscope with the range from 10 Hz to 100kHz and the steps of about 200. Each filter was controlled by RV1 (bass filter), RV2 (mid filter), and RV3 (terble filter).

Resistance combinations: R1=R5=1000Ω+56Ω

Capacitor combinations: C2=C4=0.05uF=0.1uF || 0.1uF

3.2 Volume Control and Gains

The volume control was built, tested on the oscilloscope, and connected to three filters. The knobs of the equalizer were at the maximum, set the frequencies to 200 Hz, 2 kHz, and 10 kHz, and measure if the Vamp,rms is around 100 mVrms. Then the knobs were at the minimum, set the frequencies to 200 Hz, 2 kHz, and 10 kHz, and measure if the Vamp,rms is less than 15 mVrms.

The ripple was measured through Analog Discovery 2 (AD2).

Table 3.2: The following values were used for volume Control and Gains:

Bass Filter Line	R2=10kΩ	R8=33kΩ
Mid Filter Line	R4=10kΩ	R9=38.38kΩ
Terble Filter Line	R8=10kΩ	R10=30.164kΩ

The values of R8, R9, and R10 were not exactly from Eq 2.2.1. To meet the requirement described in section *1.2 Objectives for Gains*, we had to change those values.

Resistance combinations:

R9=38.38kΩ=33kΩ+4.7kΩ+680Ω

R10=30.164kΩ≈10kΩ+10kΩ+10kΩ+150Ω

3.3 Power Amplifier

The power amplifier was built and tested on the oscilloscope.

Table 3.3: The following values were used for the power amplifier

Component value	Combination
C7=0.05uF	0.1uF || 0.1uF
C8=330uF	100uF || 100uF || 100uF || 22uF || 10uF

3.4 Measurement

The following plots were processed:

A plot that shows the adder, a plot(s) that shows low, medium, and high total volume, and a plot(s) that shows the power amplifier functions correctly.

4. Result

4.1 Filter Test Results

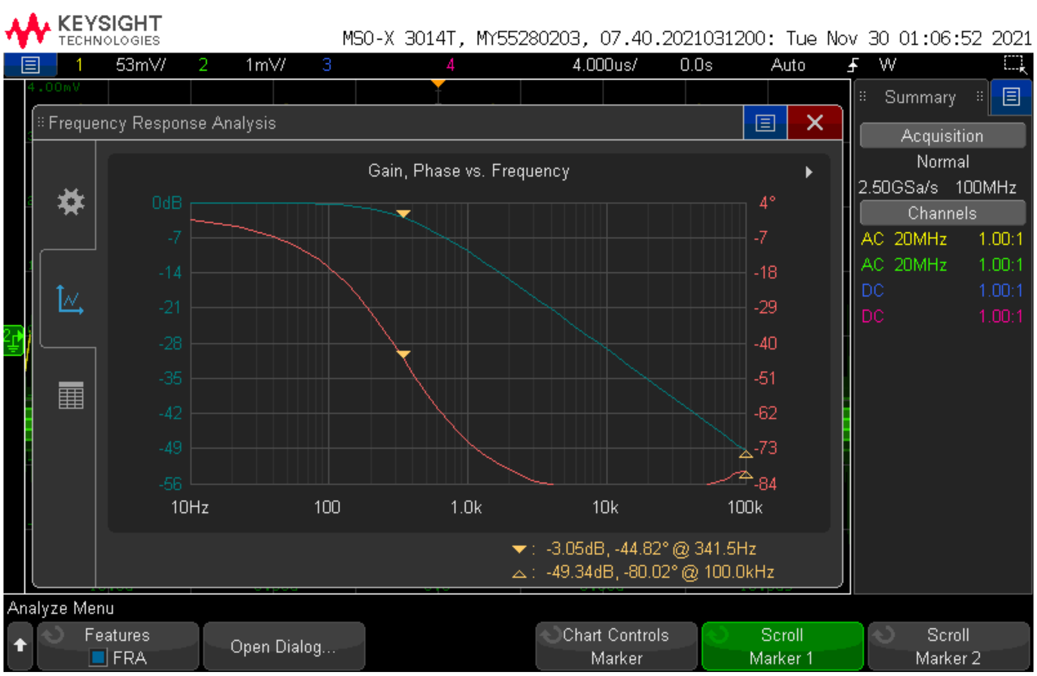

Figure 4.1.1: Bass Filter Frequency Analysis. The blue curve is the gain, inverted solid triangle points at -3dB, the frequency is shown.

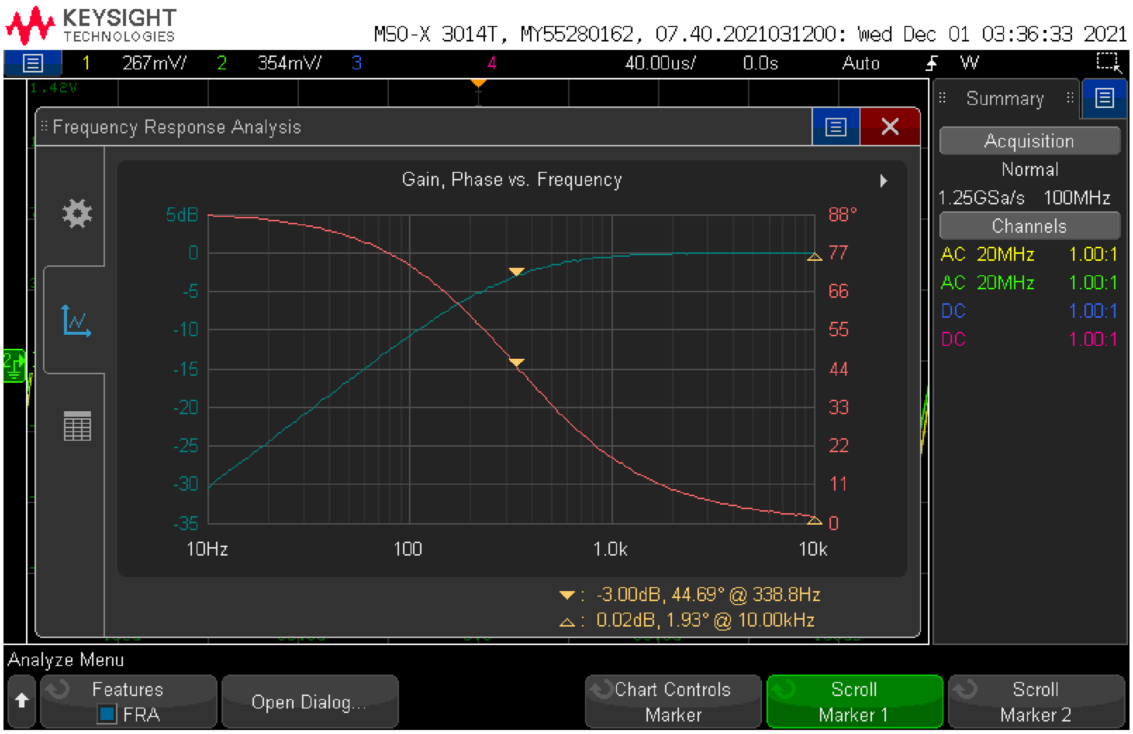

Figure 4.1.2.1: Mid Filter Frequency Analysis part 1 (left part of the curve). The blue curve is the gain, inverted solid triangle points at -3dB, the frequency is shown.

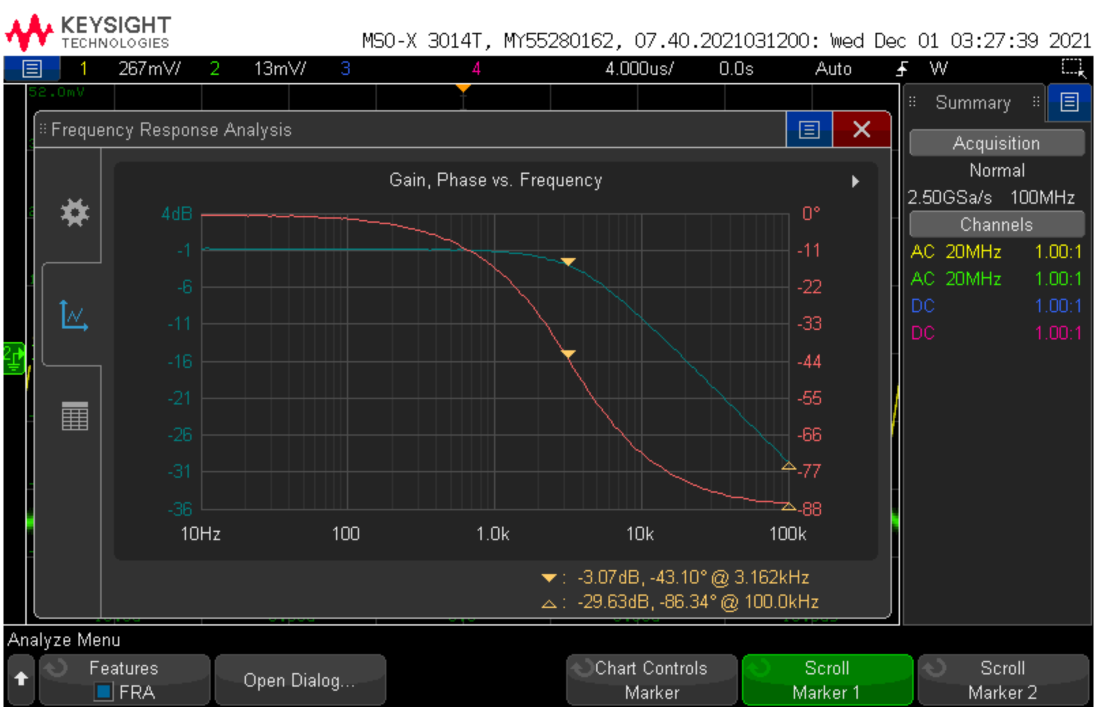

Figure 4.1.2.2: Mid Filter Frequency Analysis (right part of the curve). The blue curve is the gain, inverted solid triangle points at -3dB, the frequency is shown.

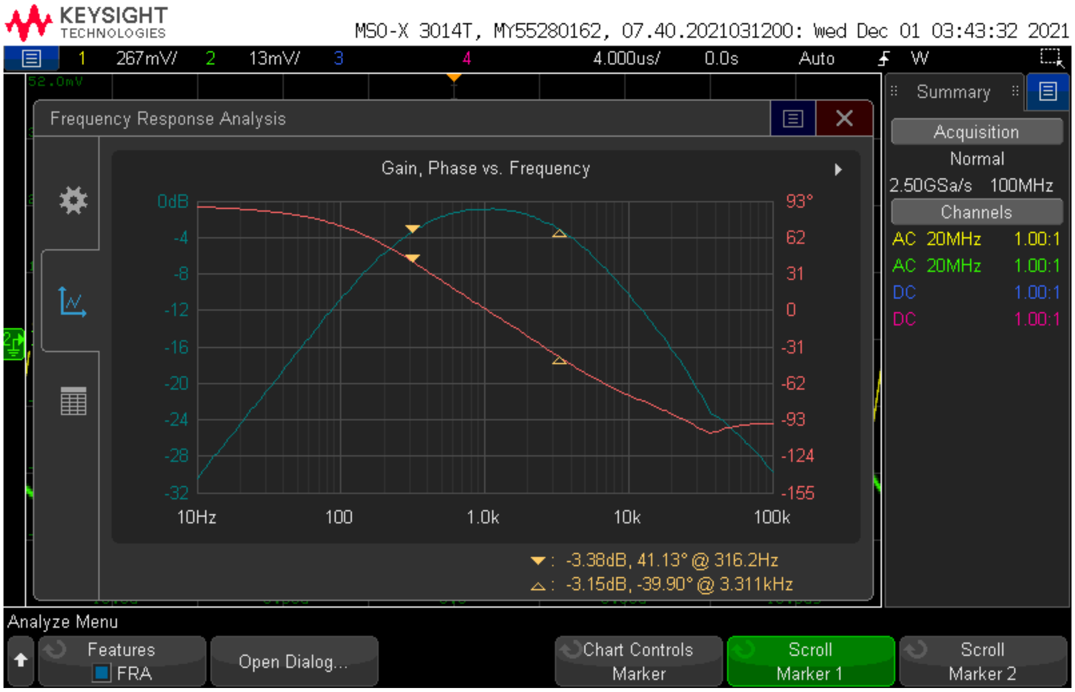

Figure 4.1.2.3: Mid Filter Frequency Analysis with amplifier U2. The blue curve is the gain. Two triangles are pointing at -3dB, the frequencies are shown.

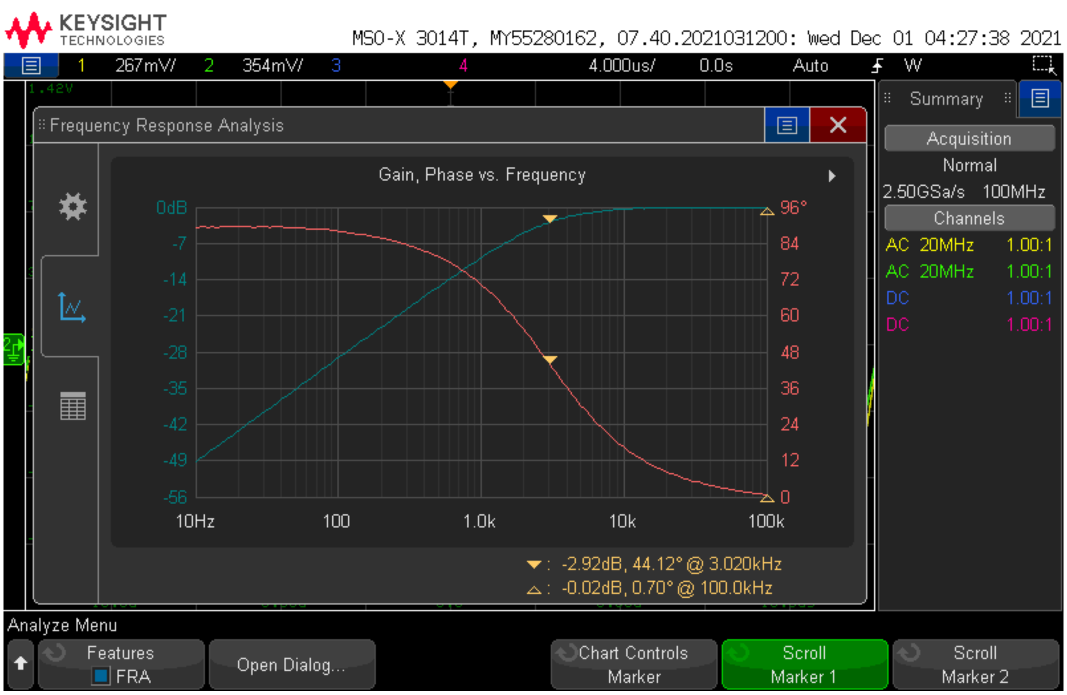

Figure 4.1.3: TerbleFilter Frequency Analysis. The blue curve is the gain, inverted solid triangle points at -3dB, the frequency is shown.

Table 4.1: Filter test results

Filter type	Designed frequency (Hz)	Measured frequency (Hz)	Allowed range (Hz)	Result
Bass Filter	320	341.5	288 to 352	Pass
Mid Filter	320 to 3200	316.2 to 3311	288 to 352, 2880 to 3520	Pass
Terble Filter	3200	3020	2880 to 3520	Pass

4.2 Gain Test Results

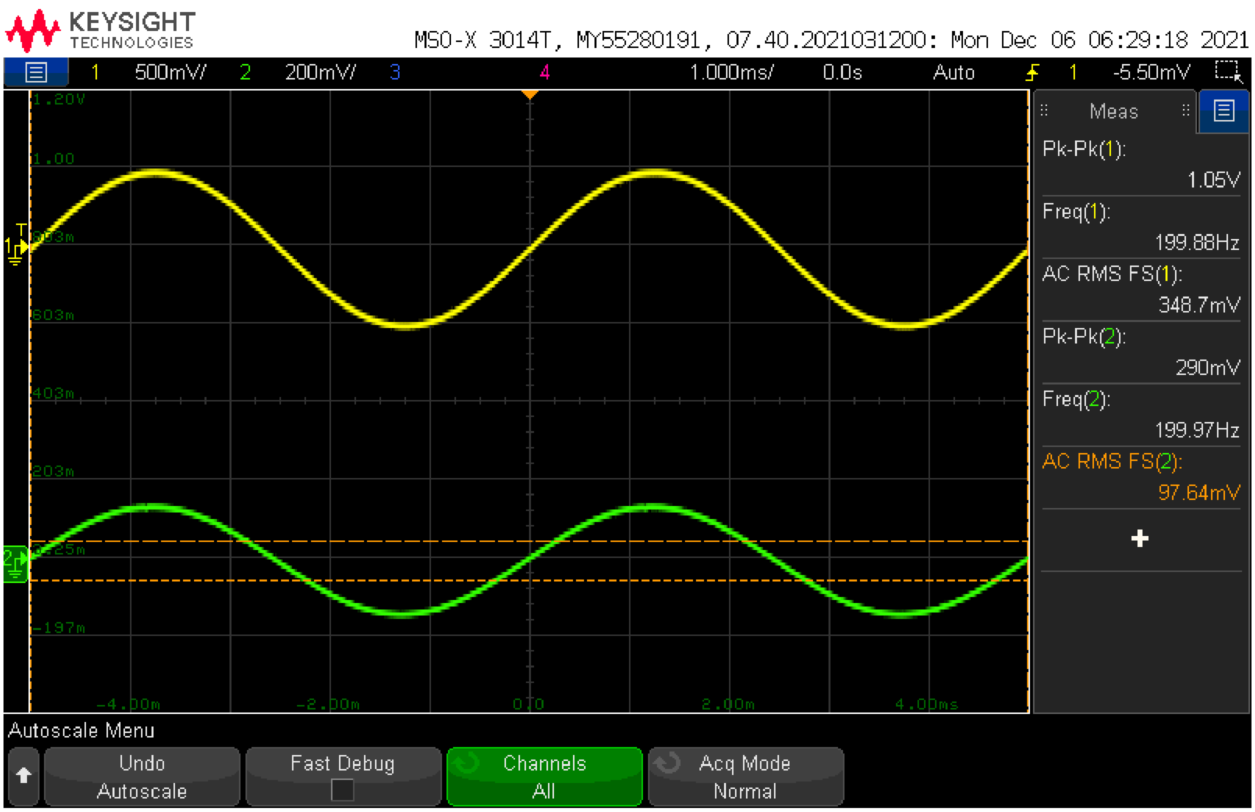

Figure 4.2.1: Yellow wave was the input, and the green wave was the output Vamp when the knobs of the equalizer were at maximum and frequency was 200 Hz.

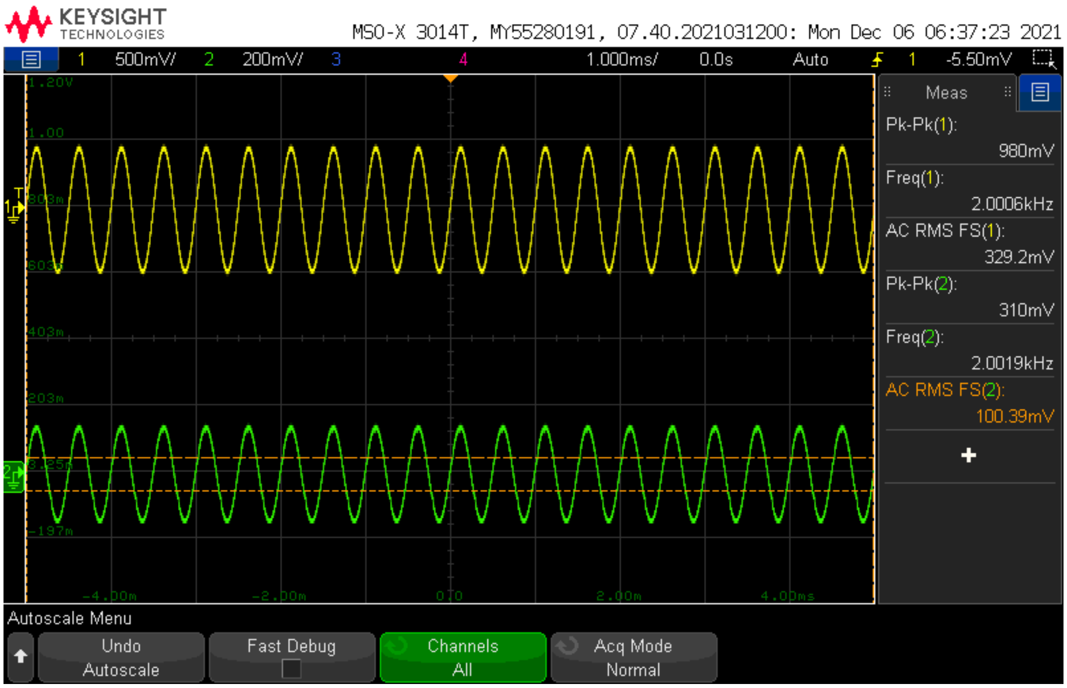

Figure 4.2.2: Yellow wave was the input, and the green wave was the output Vamp when the knobs of the equalizer were at maximum and frequency was 2000 Hz.

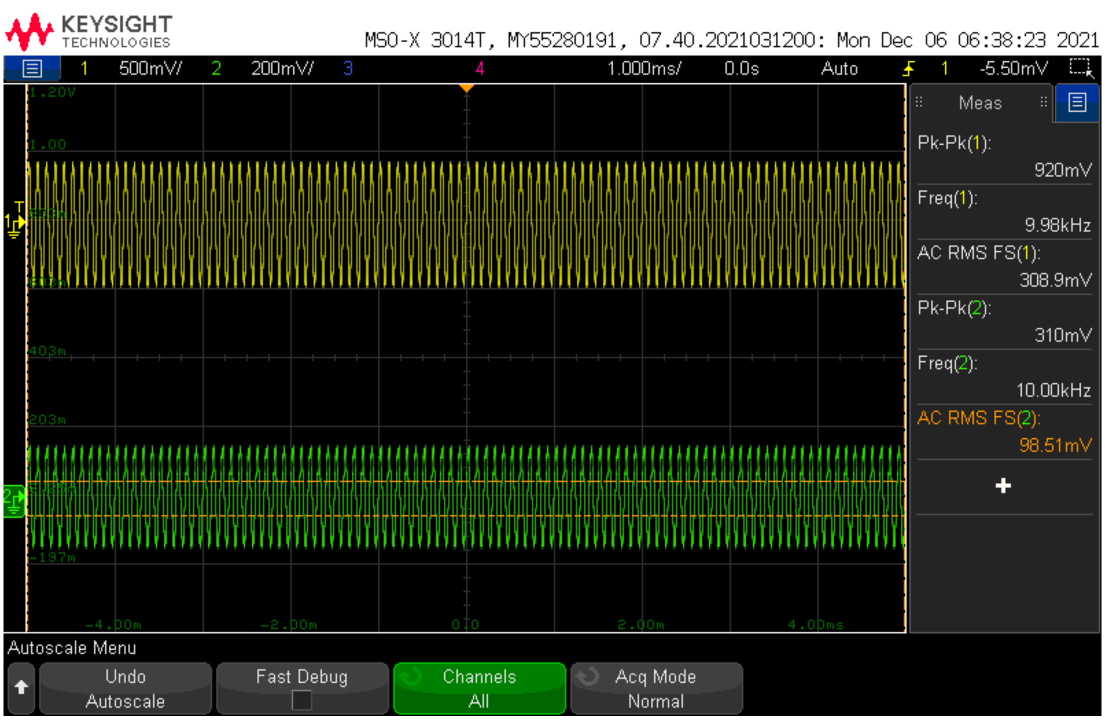

Figure 4.2.3: Yellow wave was the input, and the green wave was the output Vamp when the knobs of the equalizer were at maximum and frequency was 10 kHz.

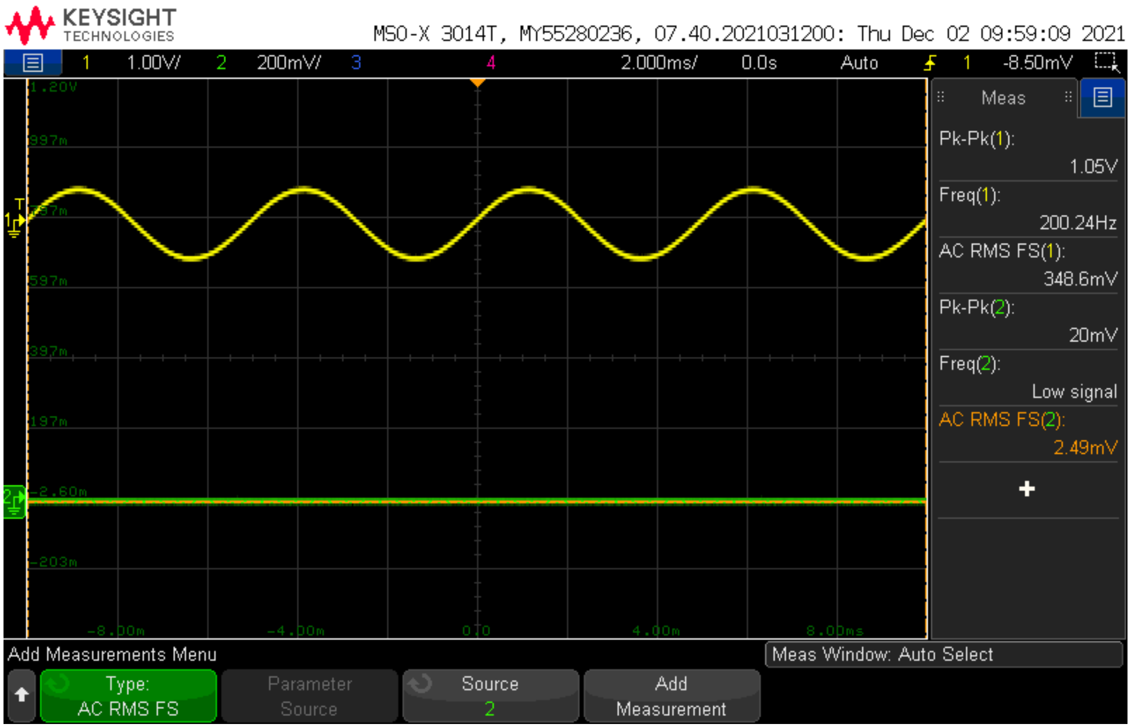

Figure 4.2.4: Yellow wave was the input, and the green wave was the output Vamp when the knobs of the equalizer were at minimum and frequency was 200 Hz.

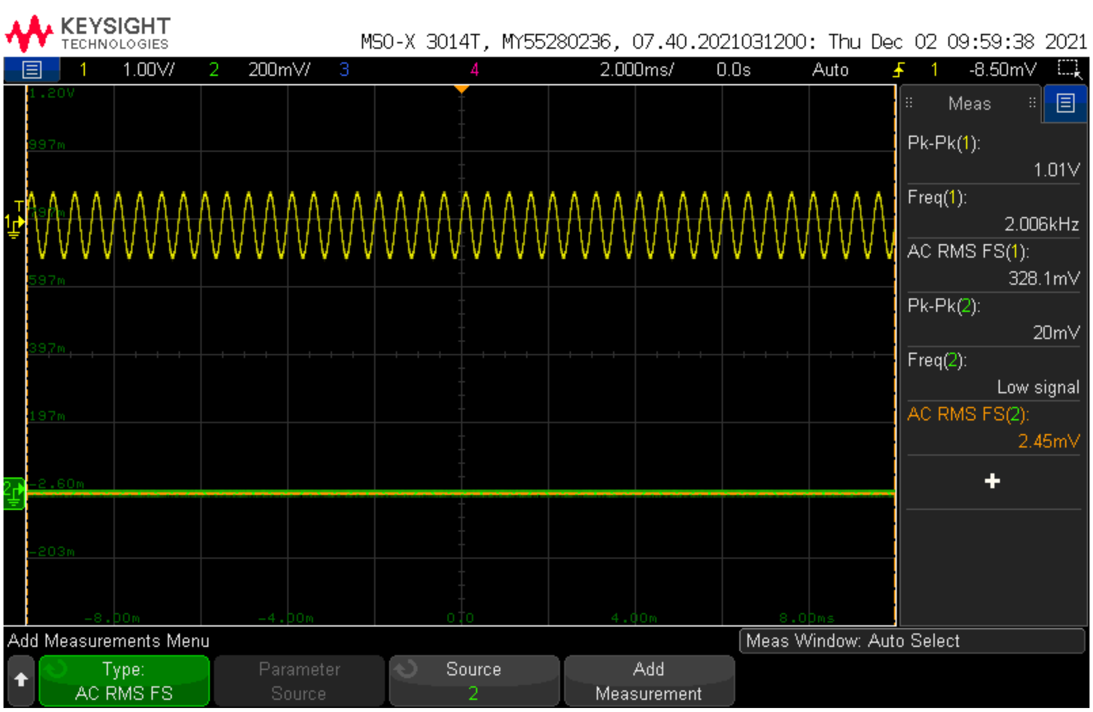

Figure 4.2.5: Yellow wave was the input, and the green wave was the output Vamp when the knobs of the equalizer were at minimum and frequency was 2000 Hz.

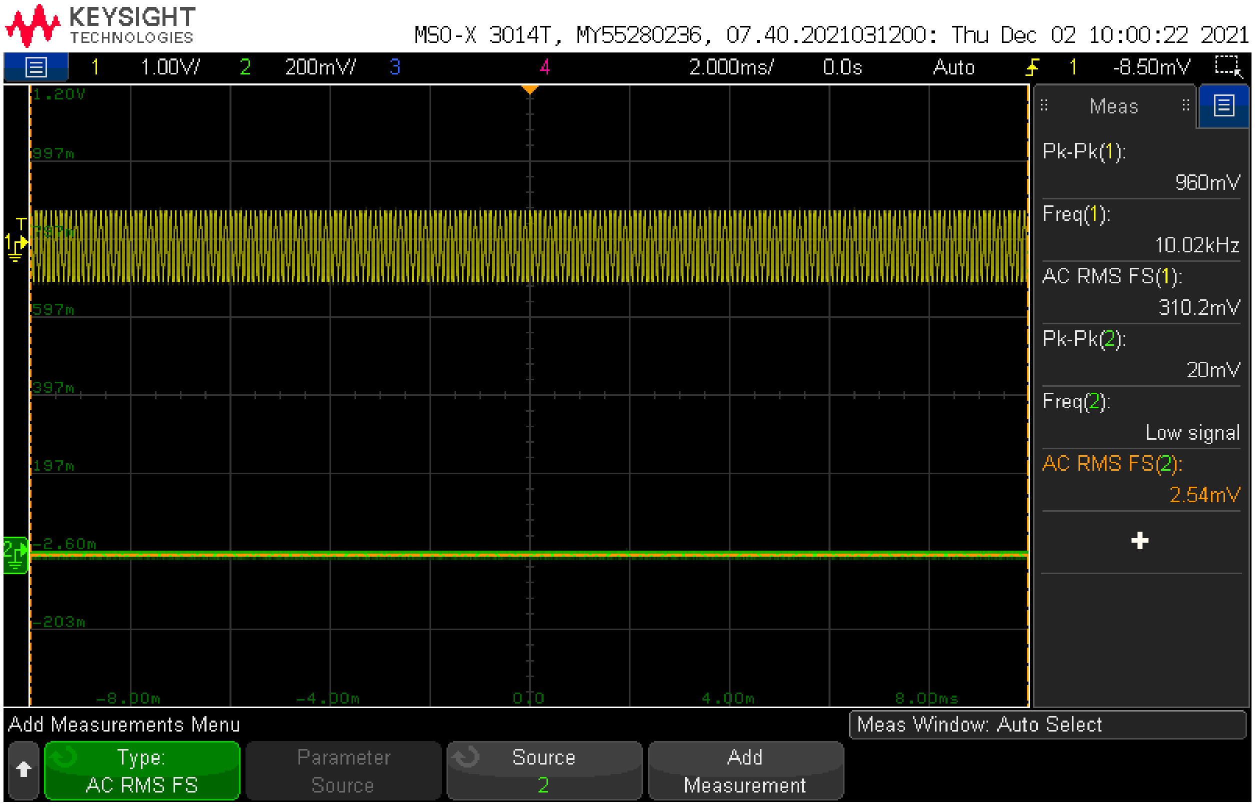

Figure 4.2.6: Yellow wave was the input, and the green wave was the output Vamp when the knobs of the equalizer were at minimum and frequency was 10 kHz.

Table 4.2: Volume Control and Gain Test Results

Equalizer	Frequency (Hz)	Measured Vamp,rms (mV)	Allowed range (mV)	Result
Max	200	97.64	90 to 110	Pass
Max	2,000	100.39	90 to 110	Pass
Max	10,000	98.51	90 to 110	Pass
Min	200	2.49	Less than 15	Pass
Min	2,000	2.45	Less than 15	Pass
Min	10,000	2.54	Less than 15	Pass

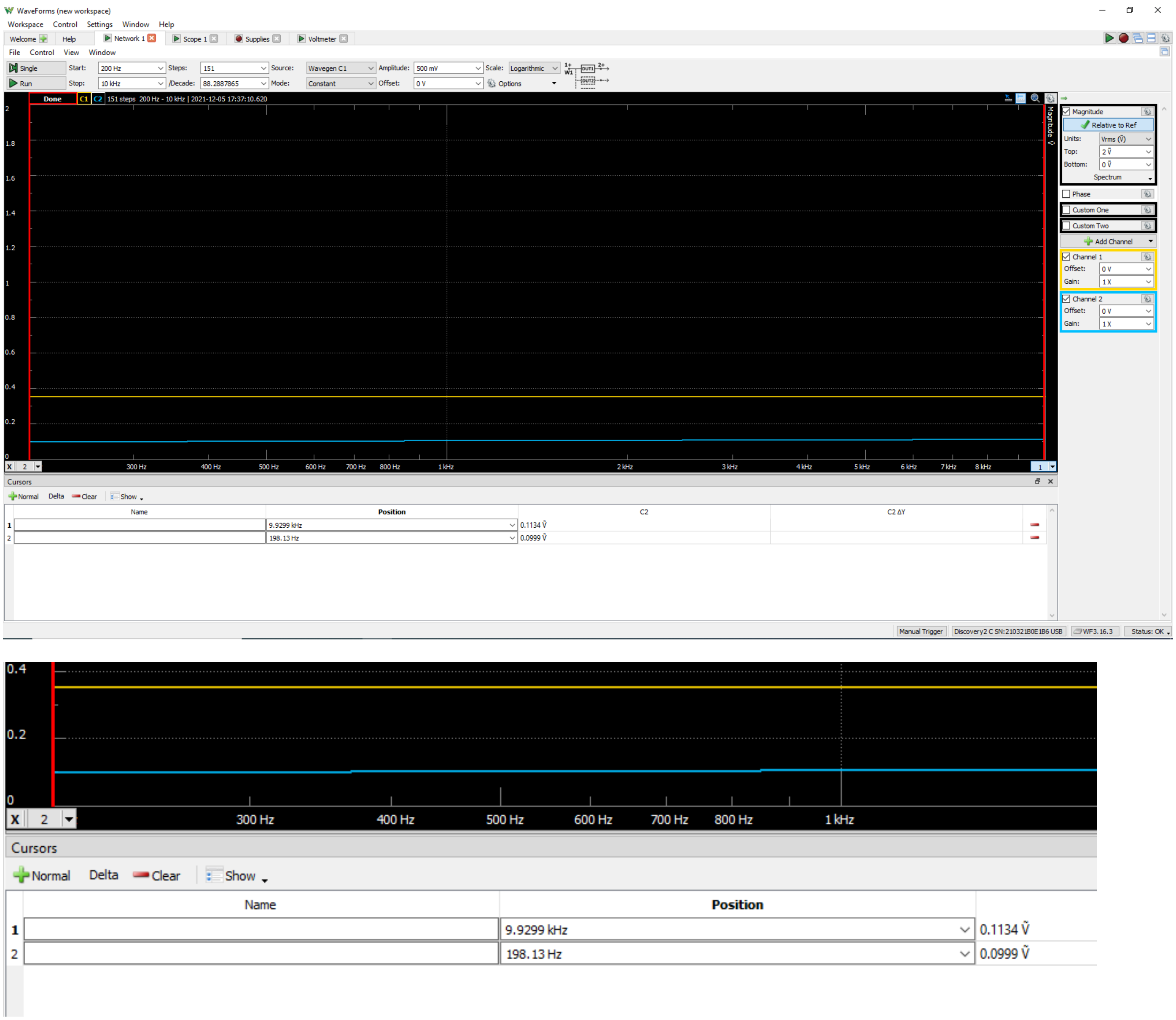

Figure 4.2.7: Ripple measurement with AD2. The blue curve is the output. The difference is 0.1134V-0.0999V=13.5mV.

4.3 Adder Test Result

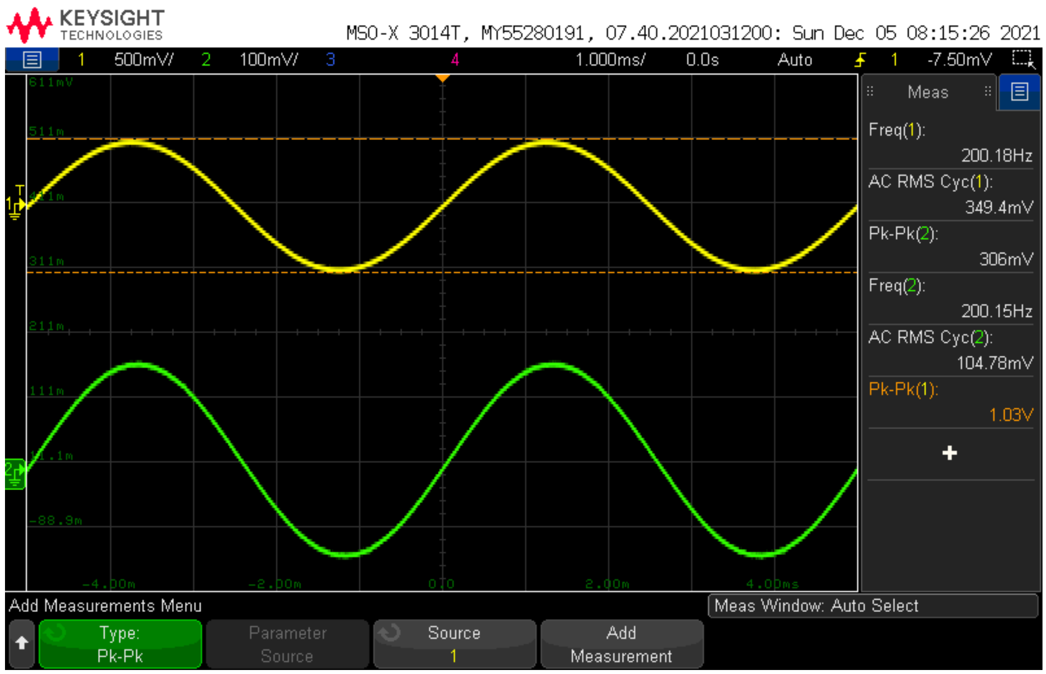

Figure 4.3.1: Yellow wave was the input, and the green wave was the output Vamp when the knobs of the equalizer and the adder were at maximum and frequency was 200 Hz.

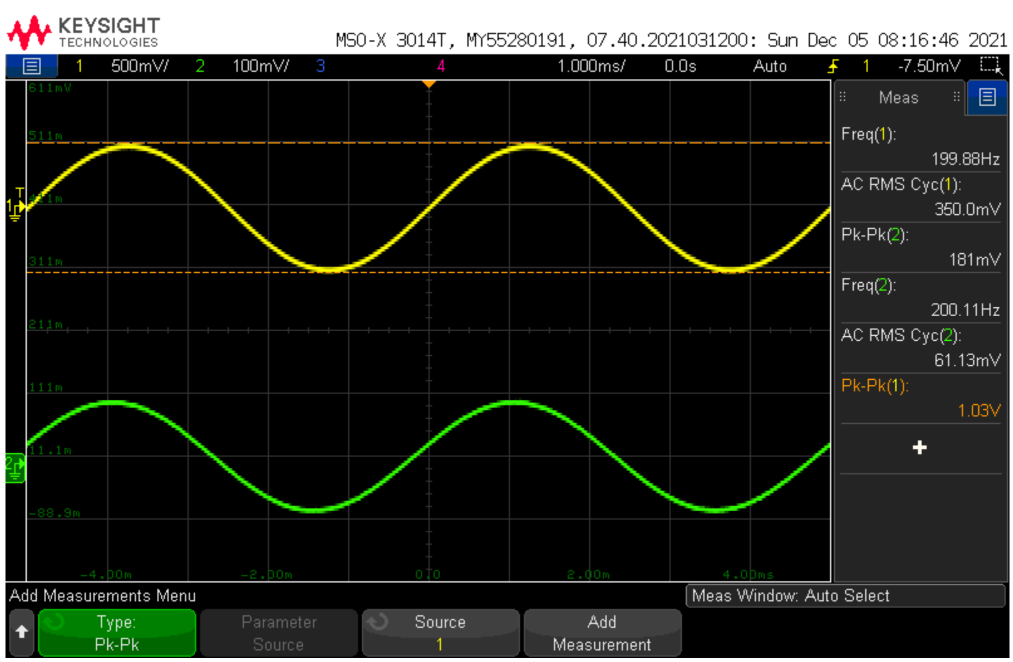

Figure 4.3.2: Compared to 4.3.1, the knob of the adder was adjusted, and the output decreased, so the adder was working. The yellow wave was the input, and the green wave was the output Vamp when the knobs of the equalizer, and frequency was 200 Hz.

4.4. Volume Test Result

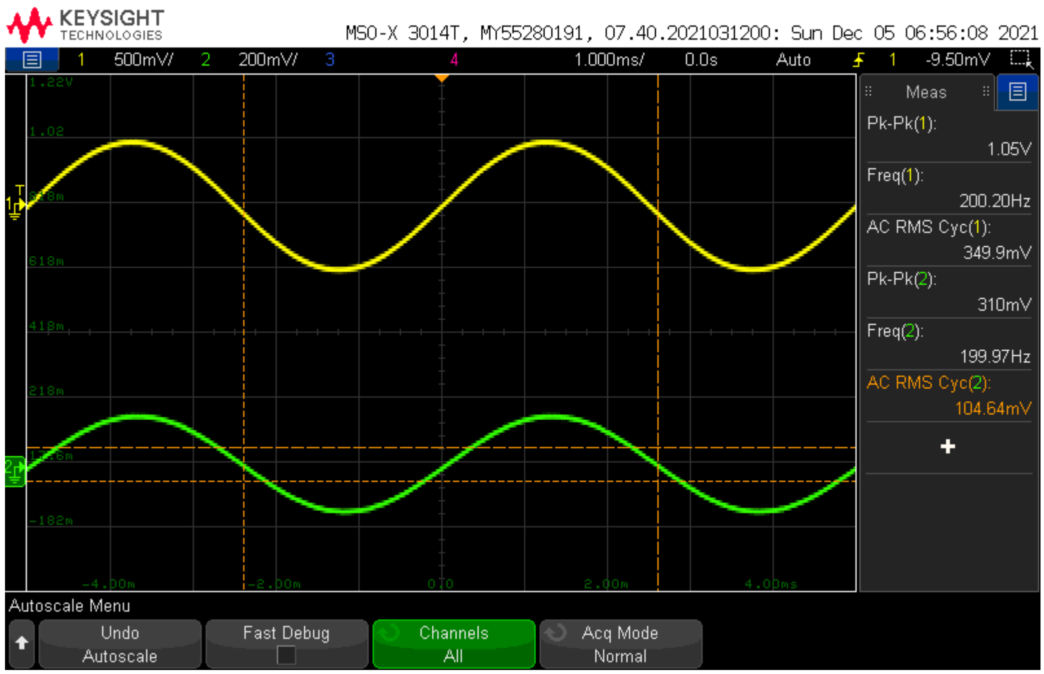

Figure 4.4.1: The yellow wave was the input, and the green wave was the output when the knobs of the equalizer and the volume control were at maximum, and frequency was 200 Hz.

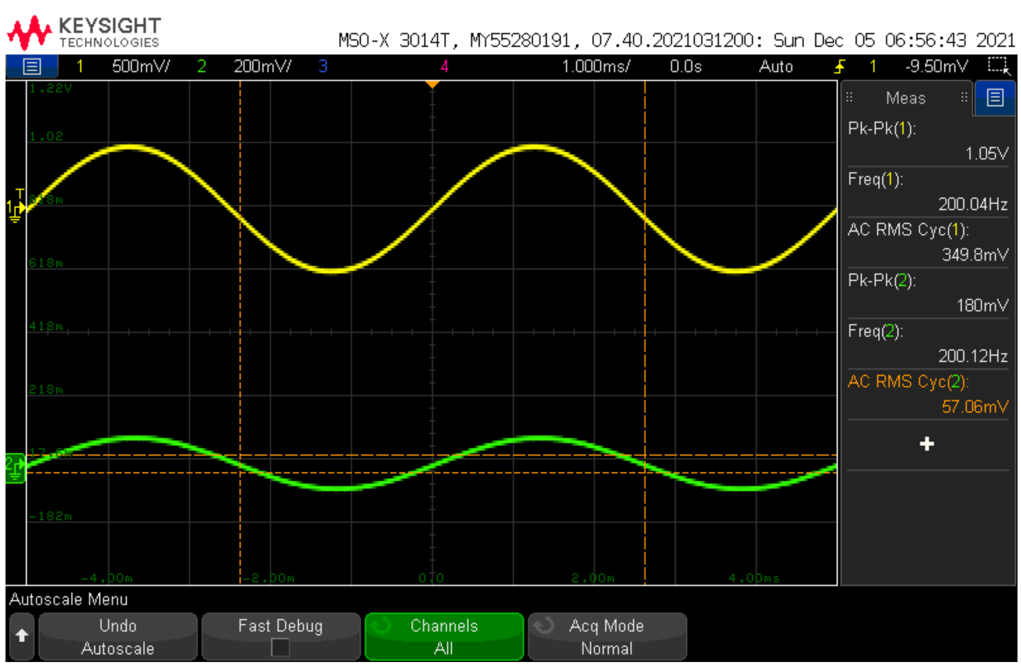

Figure 4.4.2: The yellow wave was the input, and the green wave was the output Vamp when the knobs of the equalizer were at maximum, the volume control was at medium, and the frequency was 200 Hz.

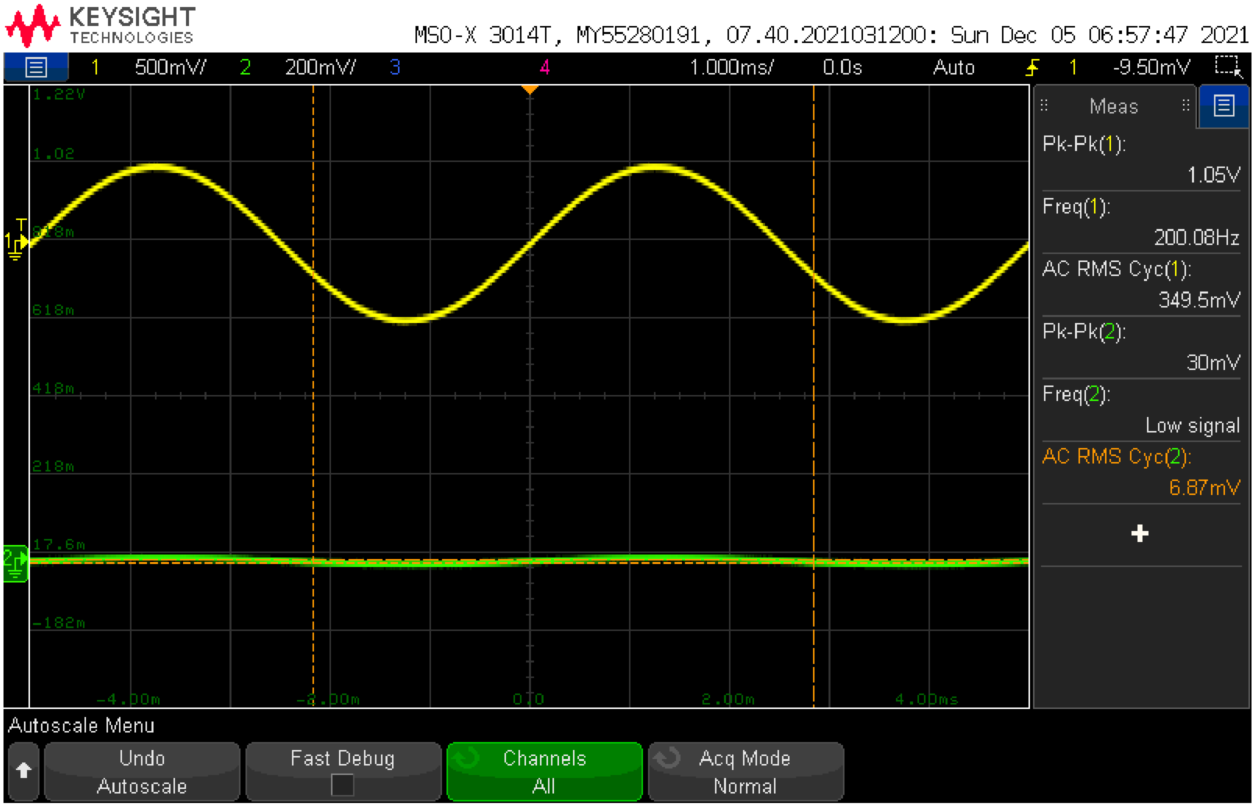

Figure 4.4.2: The yellow wave was the input, and the green wave was the output Vamp when the knobs of the equalizer were at maximum, the volume control was at low, and the frequency was 200 Hz.

Table 4.4: Vamp at different volume control settings:

Volume control	Vamp,rms (mV)
High	104.64
Medium	57.06
Low	6.87

4.5 Power Amplifier Test Results

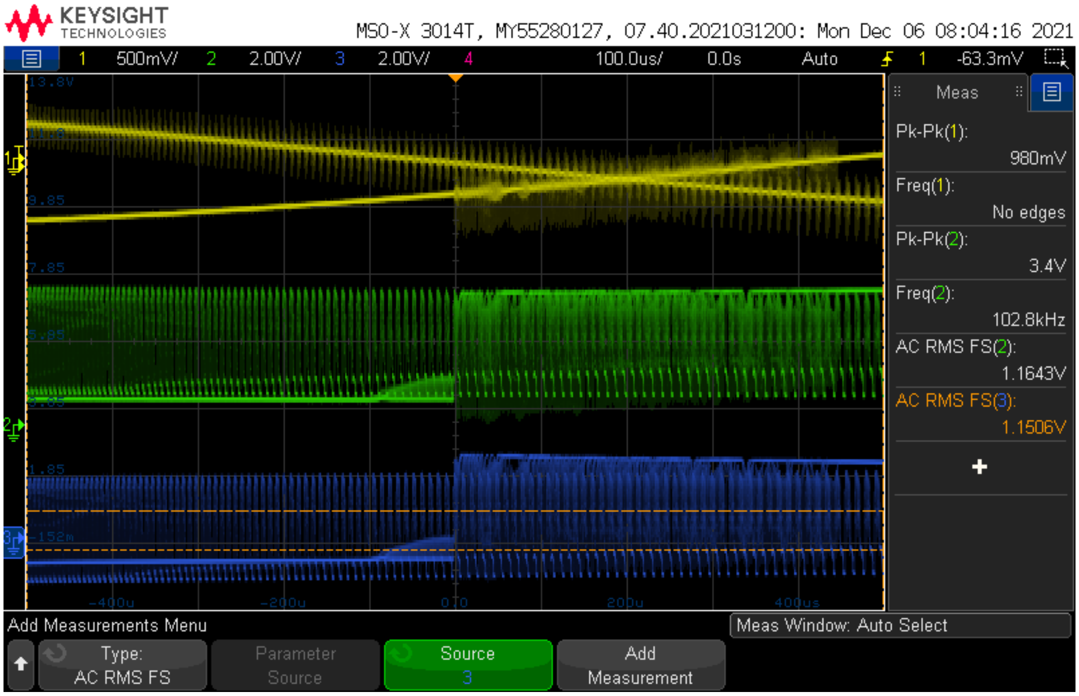

Figure 4.5.1: All knobs were at maximum. The yellow wave was the input, the blue wave was the voltage across the load. The frequency was 200 Hz.

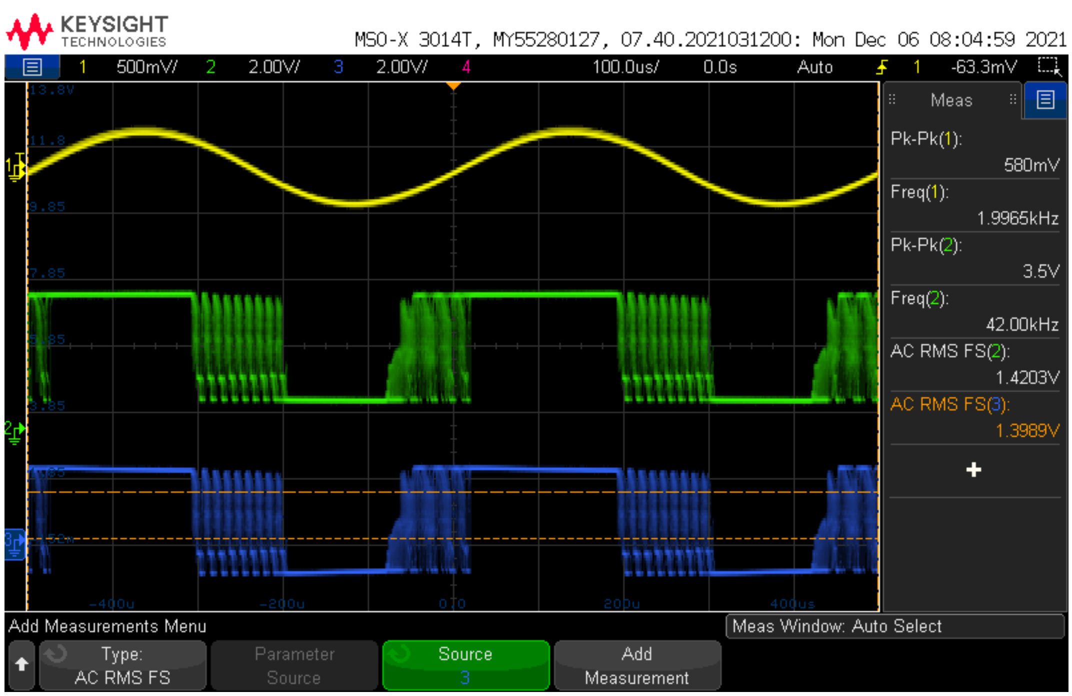

Figure 4.5.2: All knobs were at maximum. The yellow wave was the input, the blue wave was the voltage across the load. The frequency was 2000 Hz.

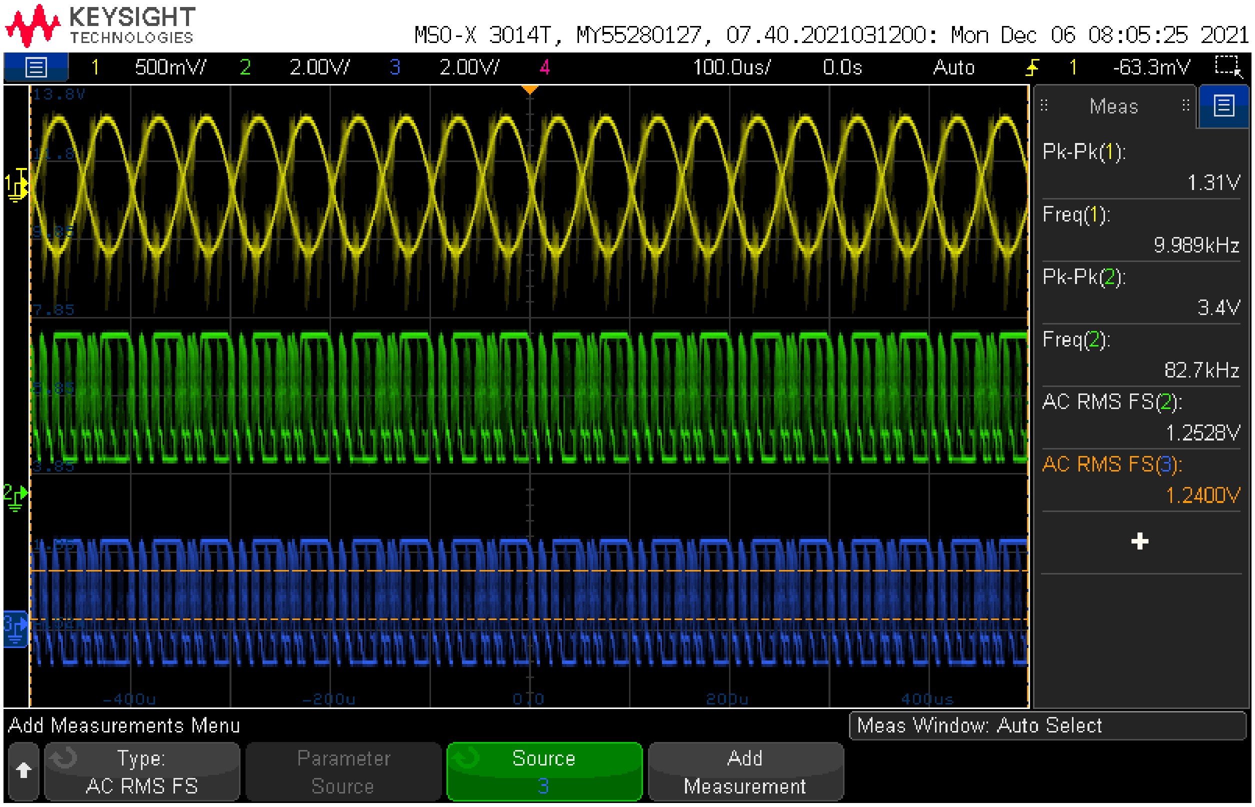

Figure 4.5.3: All knobs were at maximum. The yellow wave was the input, the blue wave was the voltage across the load. The frequency was 10 kHz.

Table 4.5: Power of the load (speaker)

Frequency (Hz)	Vrms,load (V)	Power (mW)
200	1.15	165.3
2000	1.39	241.5
10000	1.24	192.2

5. Conclusion

The circuit passed every test except the power test. The power supply for the power amplifier was 5V. We have changed the power to 7.5V, and the power we got was we expected.

The objectives were met.

Table 5: Test Result of All Components:

Item	Result
Bass Filter	Pass
Mid Filter	Pass
Terble Filter	Pass
Vamp around 100mVrms at 200 Hz (all max)	Pass
Vamp around 100mVrms at 2000 Hz (all max)	Pass
Vamp around 100mVrms at 10 kHz (all max)	Pass
Vamp less than 15mVrms at 200 Hz (all min)	Pass
Vamp less than 15mVrms at 2000 Hz (all min)	Pass
Vamp less than 15mVrms at 10 kHz (all min)	Pass
Ripple Measurement less than 15 mV	Pass
Adder	Pass
Volume Control	Pass
Power Amplifier	Pass