Basic Audio Equalizer

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002

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Abstract

This project required the development of an analog audio equalizer that required filters, op-amps, and inverted amplifiers, with power amplifiers to tweak and change the bass, treble, and high frequencies of the sound waves that passed through this audio equalizer. These filters and amplifiers must go through specific qualifications through specific frequencies and RMS Voltages to properly work. With proper analysis of the circuit, finding the specific voltages and resistances needed to meet these conditions, this audio equalizer was developed. The reason this was developed is to apply all the skills and topics that were taught in this course (i.e., Ohm's Law, Sinusoidal, etc.) The tools used in this project were the Oscilloscope, Digital Multimeter (DMM), Wave Generator, and Power Supply. The Oscilloscope was used to measure and plot the specific data needed to determine the values needed for the audio amplifier. The DMM and the Power Supply were used to measure and give voltage to the op-amps and the filters, while the Wave Generator was used for the Voltage Input of the Audio Equalizer.

Objectives

1.1 Find The Values Needed for the Equalizer

For this task, design a circuit of the equalizer and find the values of each capacitance and resistance of the resistors and the capacitors in the circuit by using different equations and Laws that we learned. The objective of this is to essentially find the corresponding resistances and capacitances so that the audio equalizer does not burn or blow out the speaker, therefore the values we calculate must go with the constraints that were given.

1.2 Construction and Testing of the Volume Control Subsystems

The objective of this task is to construct the Volume Control Subsystems and the amplifier and use the oscilloscope to test it and see if the output wave is a clean sine wave with no cut-off or anything so that the audio amplifier does not output a bad signal to the speaker making the sound quality poor. This is also important because this system will control the volume and the signal output to the speaker, which also directly dictates if the speaker can handle the signal and the volume.

1.3 Construction and Testing of the Independent Filter

The Objective of this task is to construct the independent filters of the bass treble and high signals. This is particularly important because these filters are the core to audio equalizers: the ability to change difference frequencies in a sound input to make it sound lower or higher depending on equalizer filters. To measure if this system is going by the constraints, an oscilloscope is used to measure the Voltage RMS for each filter.

1.4 Measurements of The Subsystems and the Filters

The objective of this task is to essentially get the measurements of the subsystems and the filters using the oscilloscope, by plotting the gain voltage on the oscilloscope based on the frequency of each filter (low, mid, and high pass.) This task is particularly important in analyzing how the audio equalizer works because these plots show how the filters are behaving based on the different frequencies the oscilloscope uses in the input wave signal.

Theory

2.1 The Analog Audio Amplifier

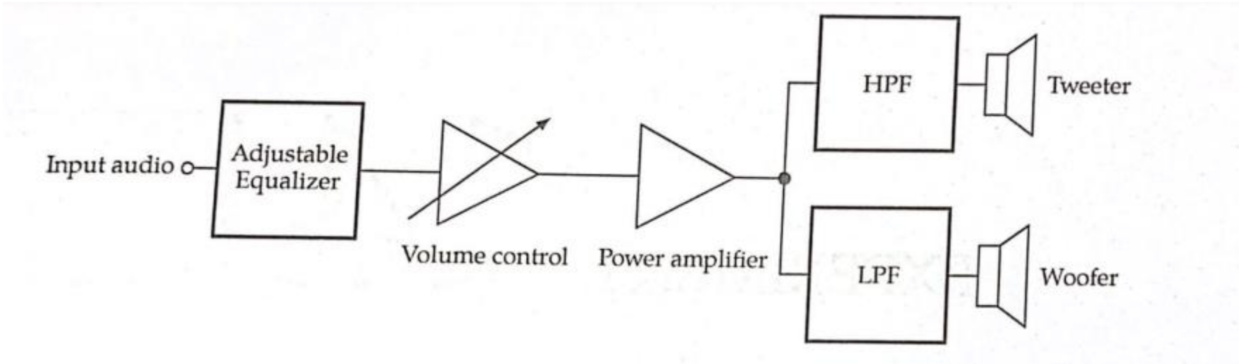


Figure 2.1.1: Basic Audio Amplifier Block Diagram

This whole development of the Audio Equalizer was mainly based on the block diagram shown above in Figure 2.1.1. The equalizer adjusts the frequency content of the audio to the listener's preference while the volume control sets the overall loudness. The power amplifier delivers the signal to the low-impedance speakers, and the crossover splits to the low and high-frequency speakers.

2.2 Equalizer Sub-System

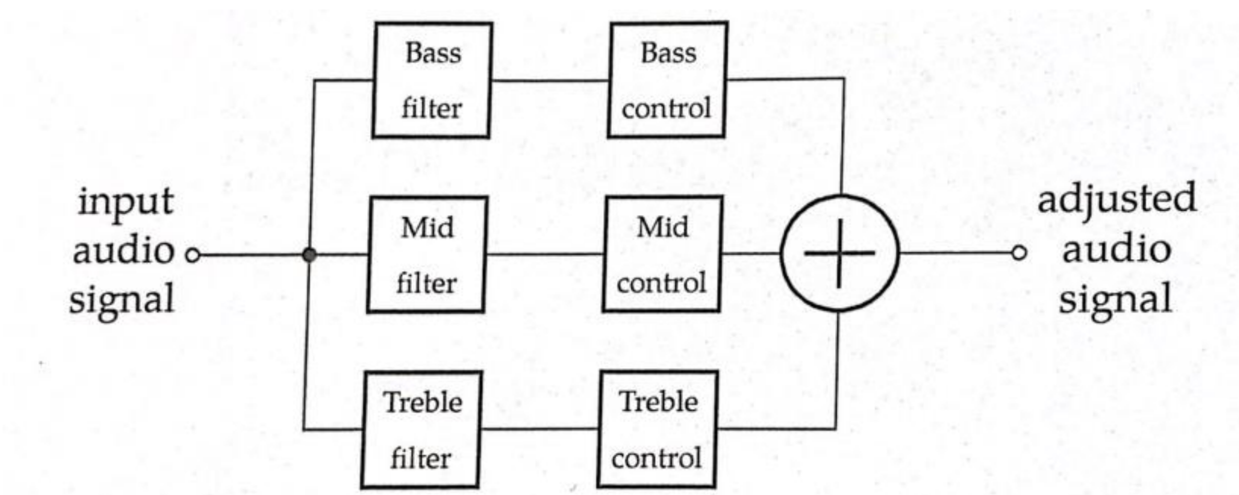


Figure 2.2.1: The Audio Equalizer Sub-System Block Diagram

For this project, designing the equalizer circuit and volume control was crucial to the development of the Analog Amplifier. The purpose of the audio equalizer is to adjust the individual loudness of various frequency bands such that the overall sound is preferable to the listener. As shown in Figure 2.2.1, a three-band equalizer can be built using that configuration. It contains three filters with adjustable gain. These filters can increase or decrease the amount of bass, mid, and treble in an audio signal based on the knobs of the system.

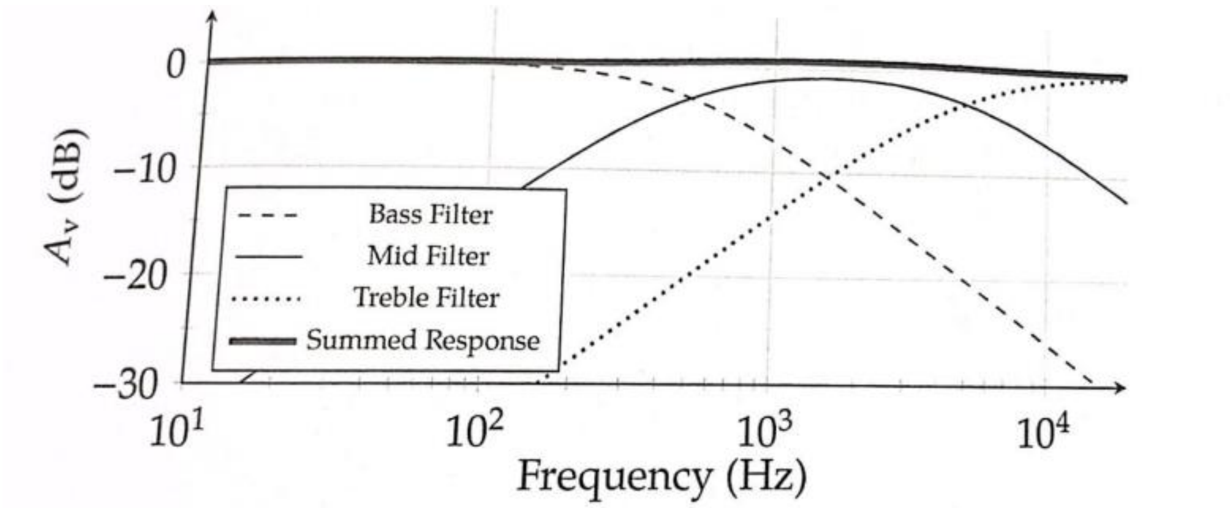


Figure 2.2.2: Equalizer Frequency response with controls set to the maximum (max knobs)

As you can see in Figure 2.2.2, the low-pass, high-pass, and band-pass all split the signal and the sum all together in the same value as before when the knobs are adjusted at the same level. Each band has a filter to isolate the frequencies and a knob to control the amplification of the signal. The output of the filters is a combination of all the frequencies.

When the equalizer knobs are not adjusted to the same level, the frequency response, however, will not be a straight approximate line like in Figure 2.2.2. Instead, it will be in a nonlinear fashion as shown in Figure 2.2.3 below. In the figure below, there is a net effect of increased bass and decreased Mids. The equalizer settings can be used to tune the audio system sound to sound correct based on the listener.

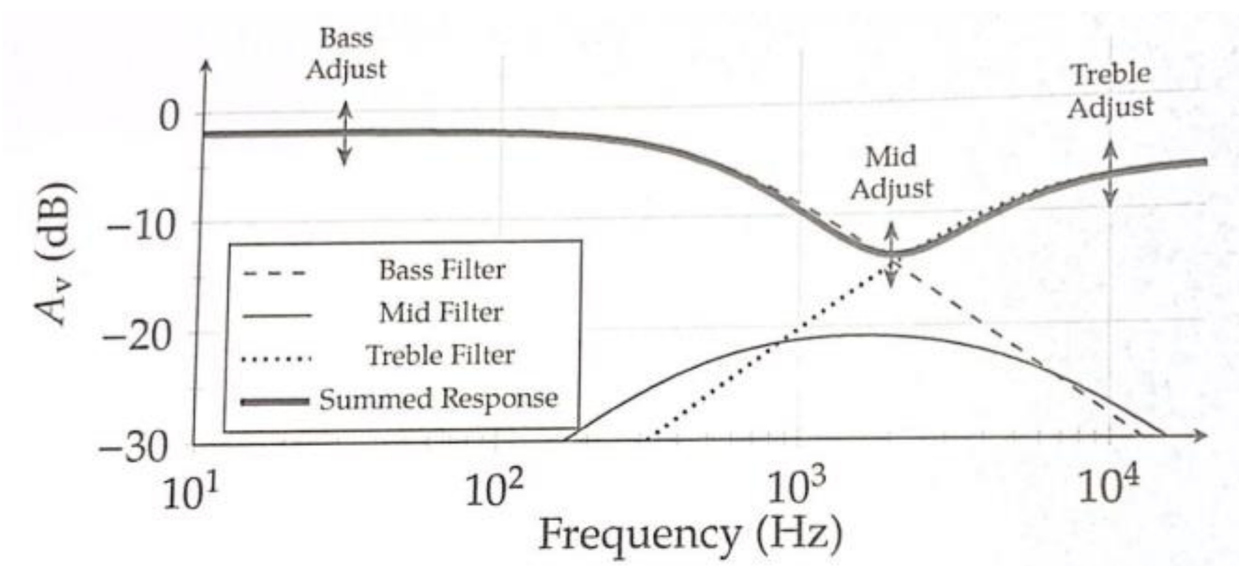


Figure 2.2.3: Equalizer frequency response that shows the bass-boosted and the mid-cut

2.3 Volume Control

The volume control's purpose is to adjust the overall loudness of the audio signal after each band is adjusted and recombined by the equalizer. This system ensures that the output of the equalizer never exceeds the input maximum of the power amplifier. If the output is large enough, the volume control only needs to attenuate the signal.

2.4 Power Amplifier

A power amplifier is a circuit that essentially takes low-power signals and amplifies them to the amount of power needed to drive a given load. Since the speaker that is implemented in this circuit has a resistance of 8 Ohms, the power amplifier must be able to provide sufficient voltage to that speaker to output sound from the speaker.

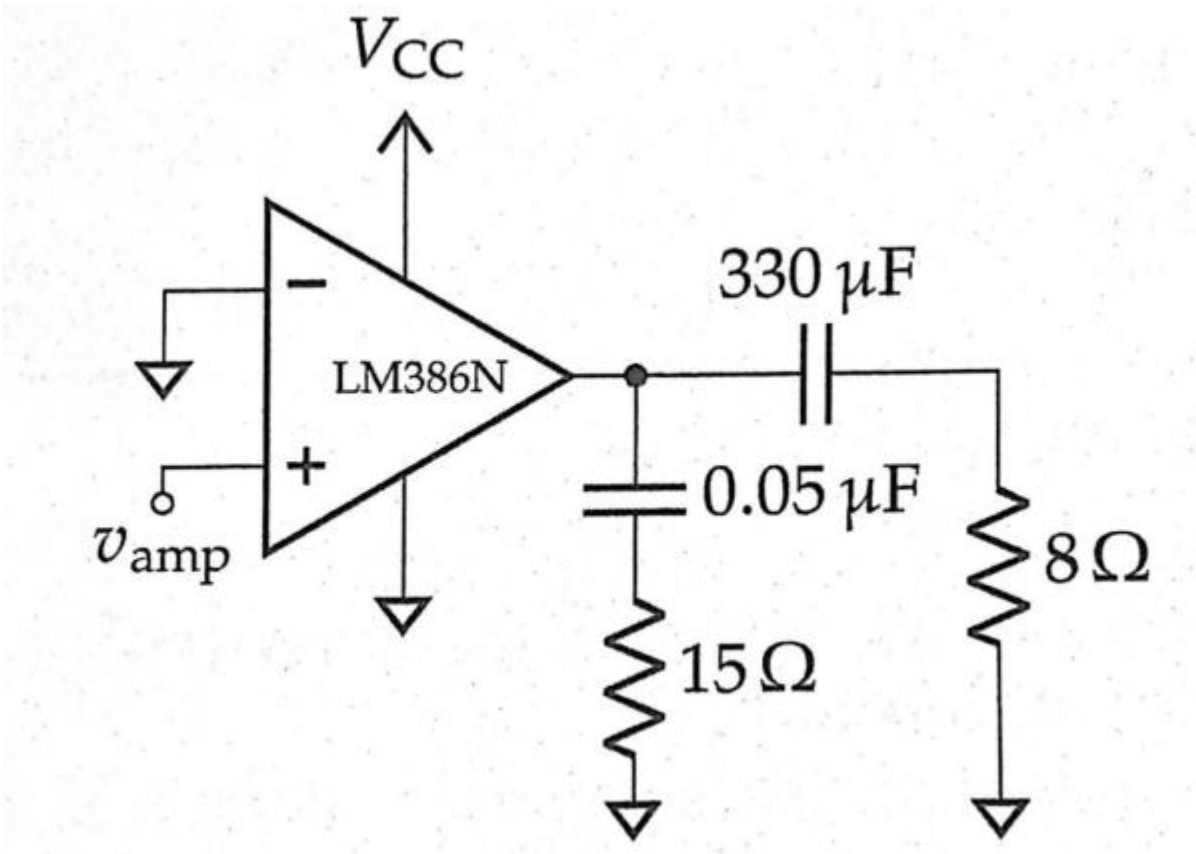
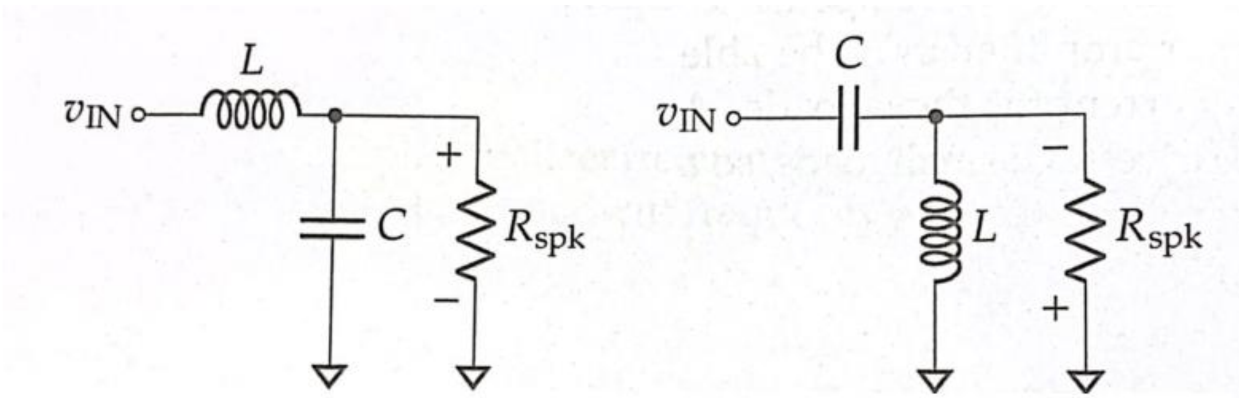


Figure 2.4.1 A Simple LM386N-4 audio amplifier

The amplifier that was used for this project is a low-voltage audio power amplifier; a similar amplifier is shown in Figure 2.4.1. This amplifier above has a gain of 20 and can drive a speaker as low as 4 Ohms. The simplicity of this amplifier is a pro, while there are cons because of how simple it is. To calculate Vcc, the peak-to-peak output voltage, a data sheet was used to calculate the power specifications and load impedance.

2.5 Crossover

A set of filters that split the high-power output so that only energy in the frequency range, is a crossover. The filters overlap such that the overall frequency response is flat and the equivalent impedance is as constant as possible across the audio band. In Figure 2.5.1 it shows the circuit schematics of the crossover filters that were used in this Analog Audio Amplifier. This crossover is designed to have a flat response when the low pass is added to the high-pass response.



a) Low Pass Filter

b) High Pass Filter

Figure 2.5.1 The Crossover Filters. Rspk is the speaker

The high-pass and low-pass versions of the circuit have the same values with the position of the inductor and capacitor reversed. The high-pass filter has a 180-degree phase shift with respect to the low-pass filter. To calculate the inductor and the capacitor values given the desired cutoff frequency and the speaker resistance the equations in Figure 2.5.2 were used.

$$L = \frac{R_{spk}}{\pi f_c}$$

$$C = \frac{1}{4\pi f_c R_{spk}}$$

Figure 2.5.2 Equations to calculate the corresponding Inductance and Capacitance

These values are calculated by solving for the transfer function of the circuit and finding values that satisfy $Q = RCw_0 = ½$ and $w_0 = 1/\sqrt{LC}$. This value Q aligns the cutoff frequency at the -6dB point, which allows for the two frequency responses to sum together perfectly.

Procedure

Conditions: All specifications are given assuming volume control is set to maximum with an input 1 $V_{p\text{-}p}$ sine wave. v_{amp} is defined as the voltage at the *input* to the amplifier.

Specification	Requirement
Speaker resistance	8 Ω
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	3.2 kHz ±10%
v_{amp} with all equalizer knobs turned to minimum settings	< 15 mV_{RMS} @ 200 Hz, 2 kHz, and 10 kHz
v_{amp} with all equalizer knobs at 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

Figure 3.1.1 The Specifications for the Analog Audio Amplifier

1. Design and Calculations

As shown above, in Figure 3.1.1, we were given specifications and specific constraints for each filter and Vamp setting for the Audio Amplifier and based on these constraints we had to calculate specific resistance and capacitance values for each filter and power amplifier. After the calculations, we designed and built the circuit on a breadboard.

2. Building the Circuit

After the calculations from procedure 1, we got our breadboard and started to build our circuit. Logically, we built the filters first, then the volume control, then the power amplifier, then the crossover, then the connections to the speaker and auxiliary cord port (AUX Cord) to play music through the speaker. Initially, it was going smoothly but there were problems with our potentiometers which were used as knobs for the filters and the volume (connection issue with the breadboard). After building each portion of the circuit, we tested each filter and section to see if the filters were outputting ideal values using an oscilloscope.

3. Measuring and Data Collection

When we verified that our circuit works, we started without data collection with the oscilloscope captures and plots for each band pass, in addition to plots for the Voltage gain when the knobs are set to a specific setting on the potentiometer. After getting all the plots and screen captures needed at specific frequencies, the audio equalizer was finally put to test by using the AUX Cord and playing music through the equalizer and speaker. Initially, it outputted very inconsistent quality of sound, but we were eventually able to get clear good sound from the speaker, with our knobs working properly.

Results

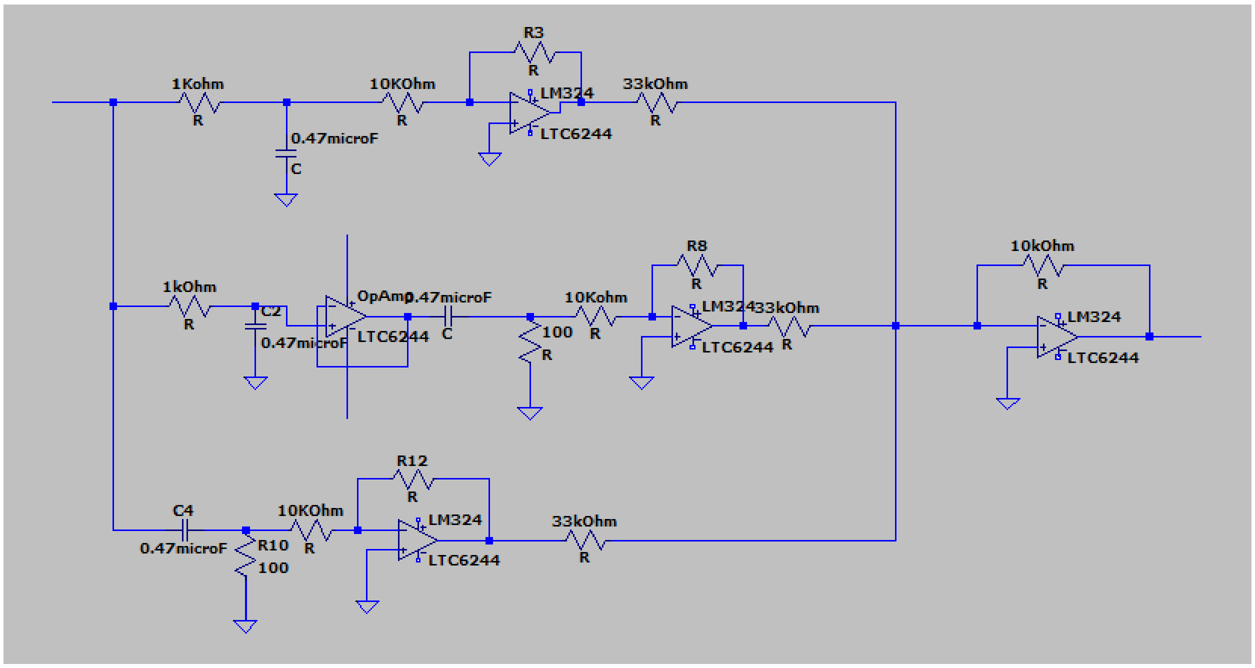
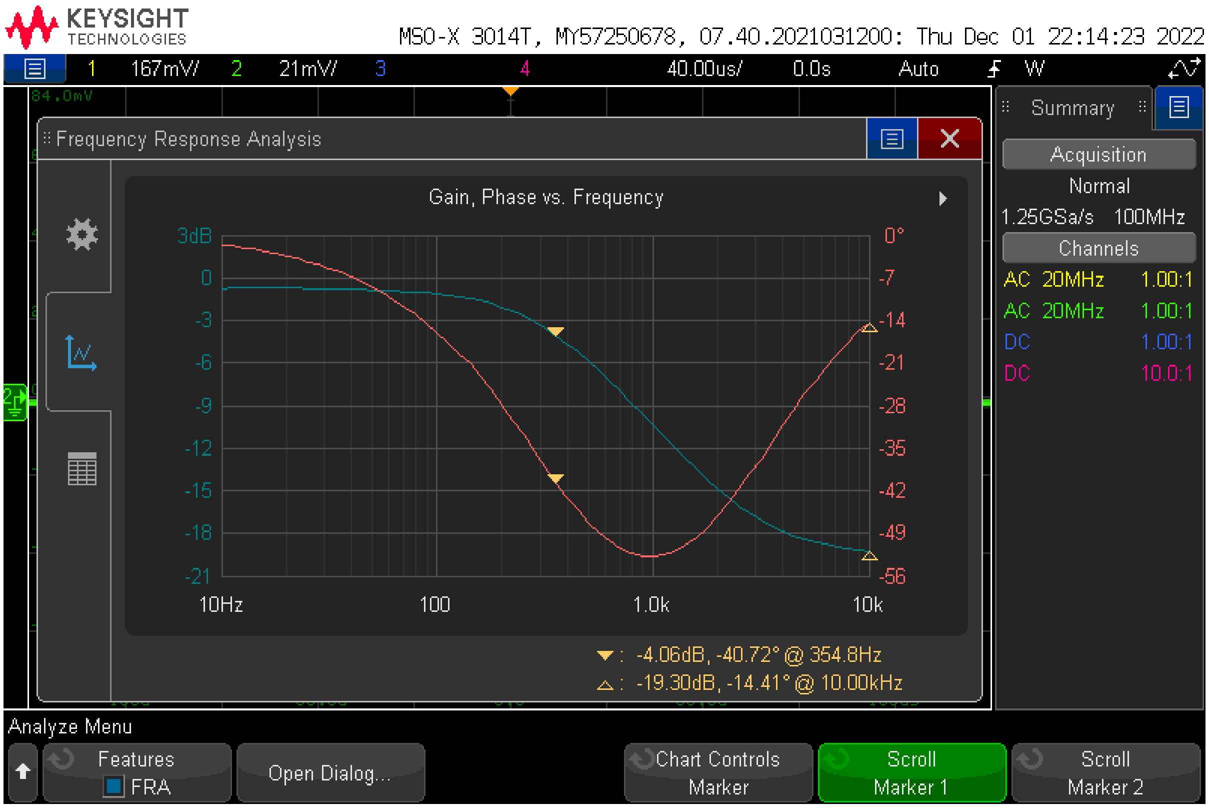
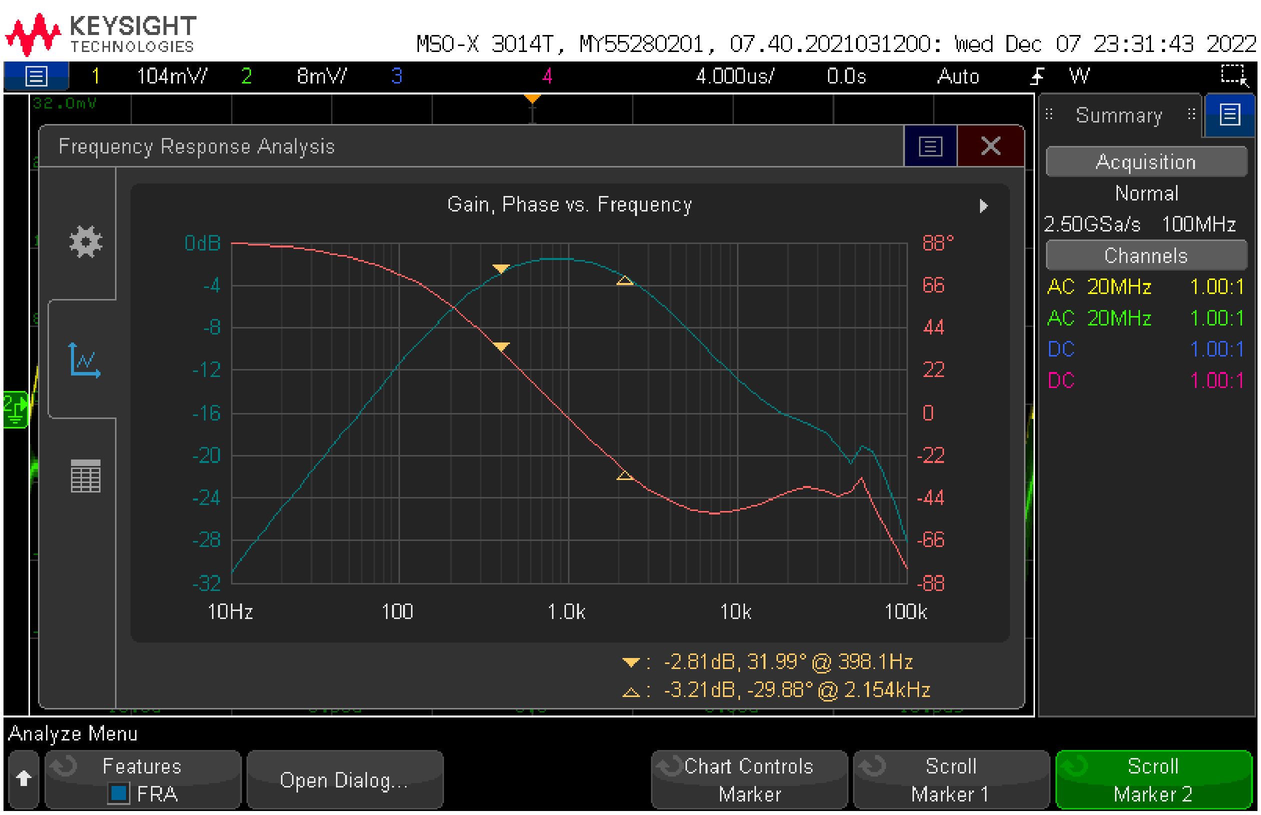


Figure 4.1 The Circuit Schematic

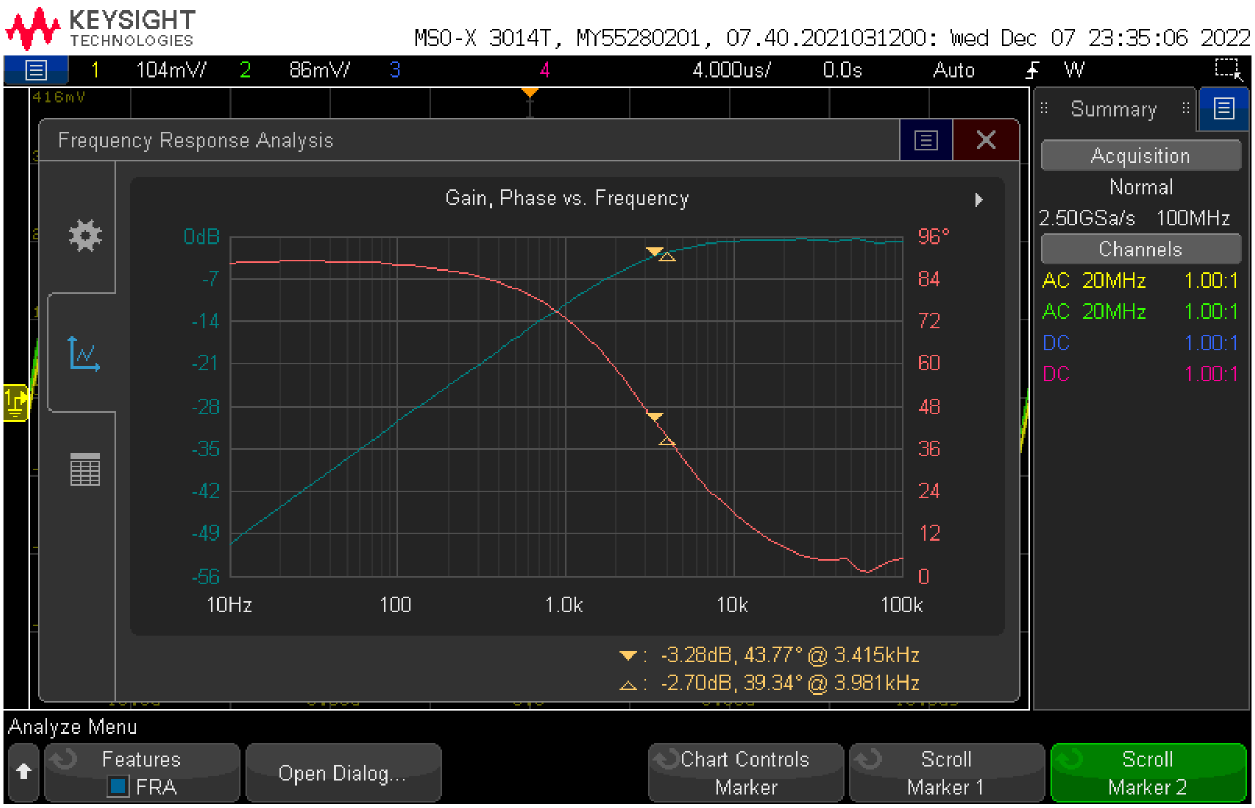
After the development of the circuit from Figure 4.1, the measurements and the results were processed at the lab. As seen in the figure, the input wave from the wave generator goes through the top left loose wire and the signal travels through the 3 filters and the power amplifier, then out through to the loose wire on the right of the power amplifier, that connects to the speaker.



a) Bass Pass Plot



b) Mid Pass Plot

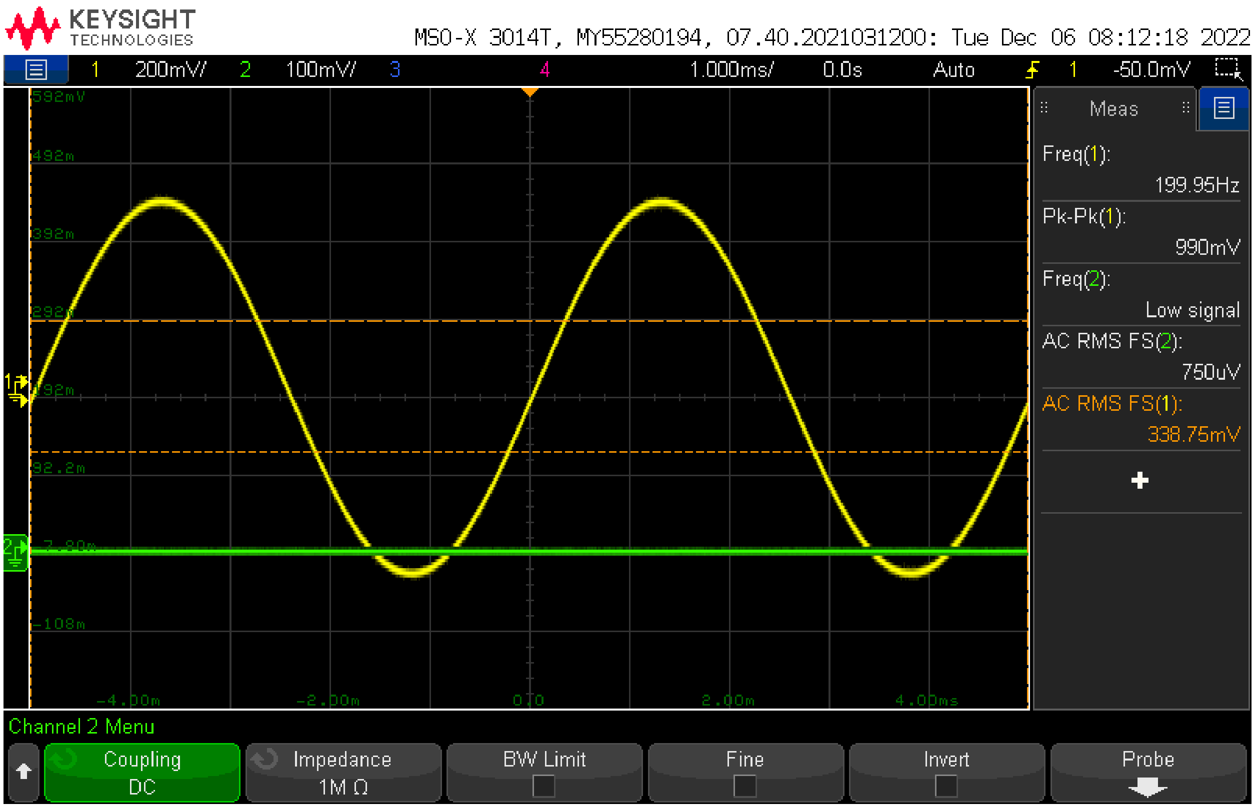


c) High Pass Plot

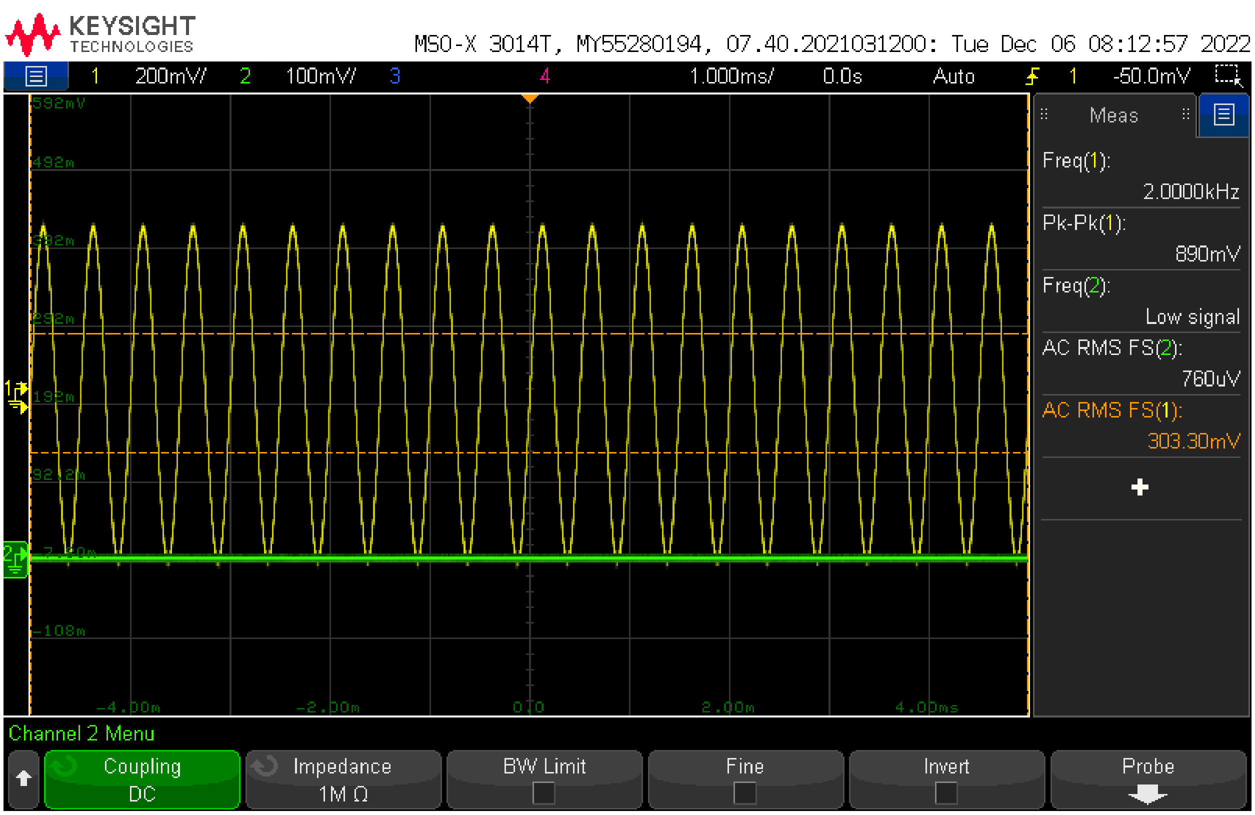
Figure 4.2 The Plots of Each Filter

After the construction of each filter, we tested out each filter and obtained a plot of each filter using the Oscilloscope. As you can see from each plot, the path of the blue line takes the shape of an ideal curve for each filter, and each filter is in the acceptable frequency range from the specific requirements that were given. For example, in the high pass, you can see that the frequency is in the 3.2 kHz range with a 10% error (value of 3.415 kHz as seen in the plot.) From these plots, we were able to deduce that the filters were indeed working properly.

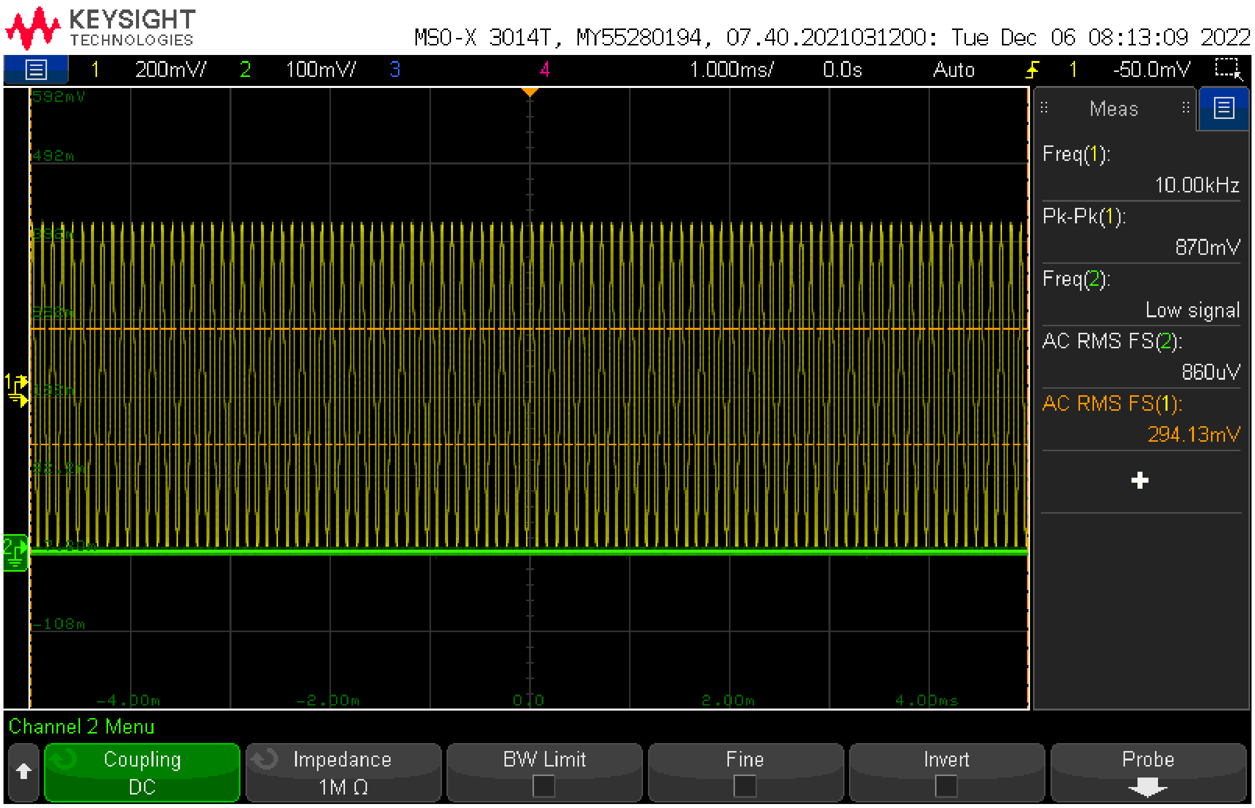
After our filters passed the specific constraints, the Voltage Amplifier plots were obtained while the knobs were at a specific setting for each plot. As seen in Figure 4.3, these are screen captures from the Oscilloscope that show the input wave and the output voltage from the amplifier. In this case, the knobs were turned to the minimum settings and the constraints were that the Voltage needed to be below 15mV at 200Hz, 2kHz, and 10kHz. From the Screen Captures below you can see that the power amplifier at the lowest settings does pass and clear the required constraints. In fact, the output voltage is nearly close to being 0V which is very ideal.



a) Screen Capture at 200Hz



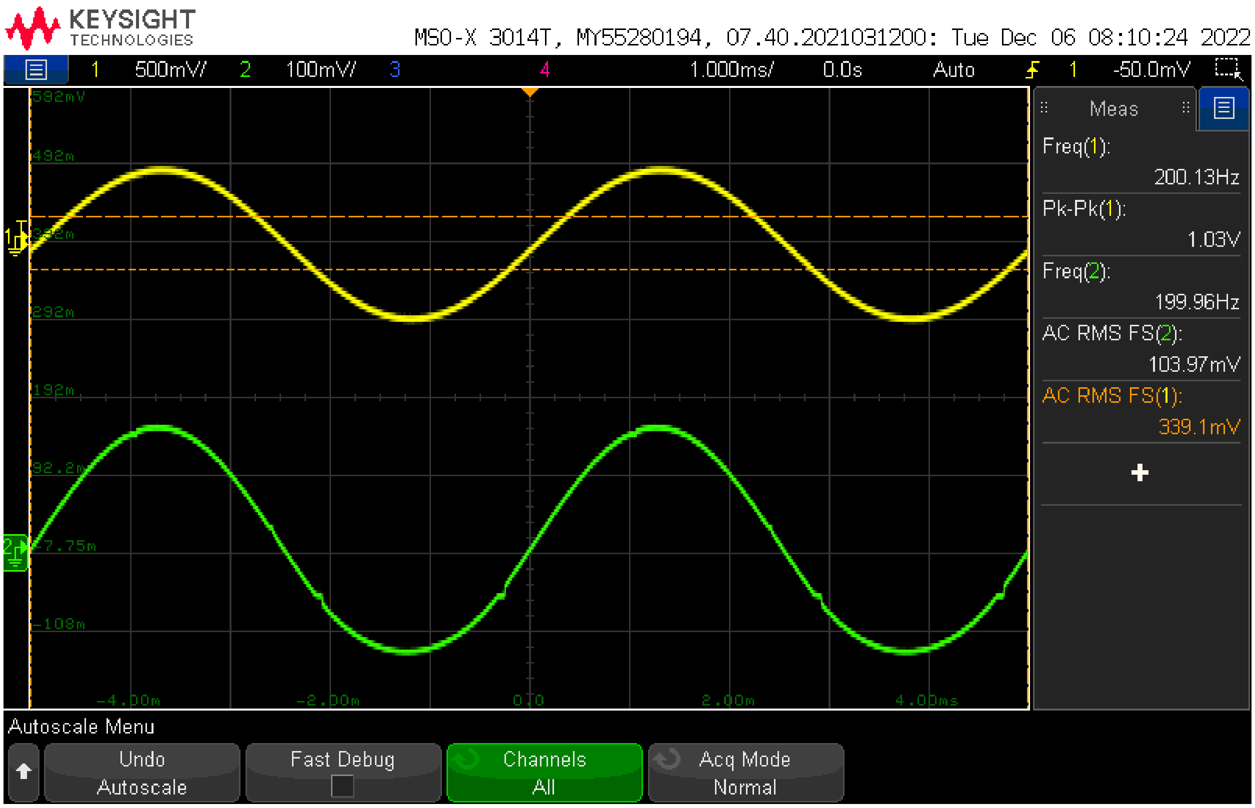
b) Screen Capture at 2kHz



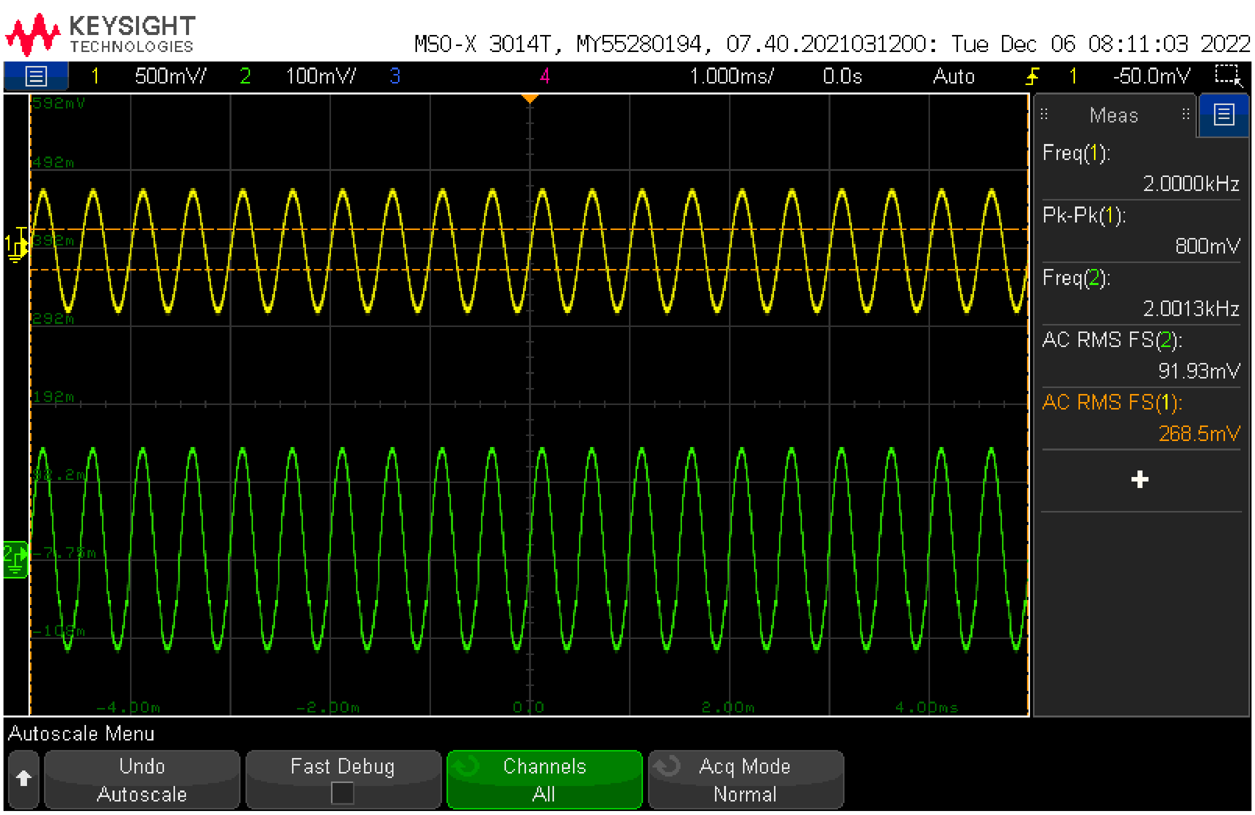
c) Screen Capture at 10kHz

Figure 4.3 Screen Captures for the Amplifier when settings are at their minimum

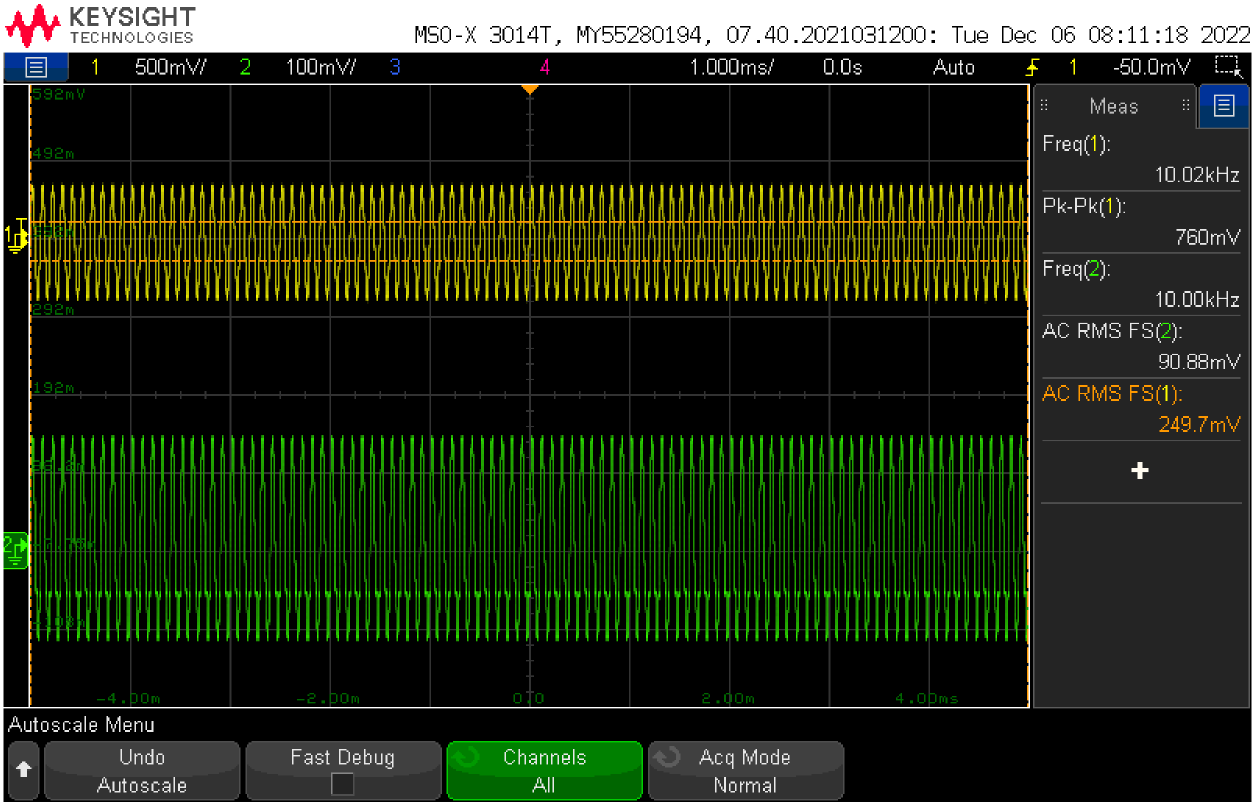
On the flip side, when the settings are at their maximum, the amplifier needs to output a voltage of 100mV with a 10% error in both directions at 200Hz, 2kHz, and 10kHz. Just like for the minimum settings, the oscilloscope was used to capture the waves and the readings that were needed for this measurement. From what we captured, as shown in Figure 4.4 below, we were able to determine that the amplitude indeed clears these constraints, with very good numbers that were close to 100mV. Even though there was some error, it was less than 10% and the values were acceptable.



a) Screen Capture at 200Hz



b) Screen Capture at 2kHz



c) Screen Capture at 10kHz

Figure 4.4 Screen Captures for the Amplifier when settings are at their maximum

With these acceptable values we obtained, measurements for the max ripple with the equalizer at max, were obtained. For this case, the values that were obtained needed to be around 15mVrms from 200Hz to 10kHz. With the same procedure that was used to obtain the plots for each filter, a plot for the ripple was developed as shown in Figure 4.5 below. Due to poor connection issues with the potentiometers and the breadboard, a clean wave was not developed because how the signal to the oscilloscope was always disrupted due to this issue during the analysis. Even though it was not a clean wave, we were able to gain good data and acceptable values from the analysis.

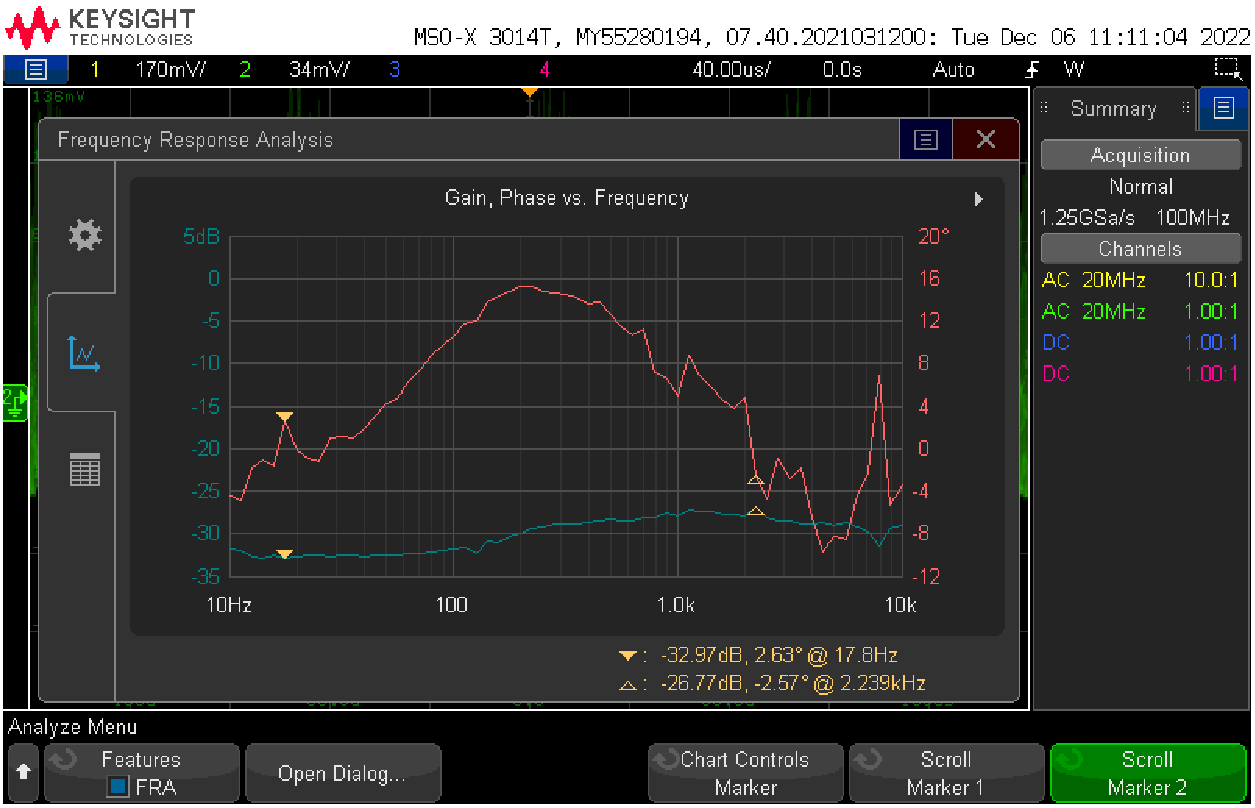


Figure 4.5 Plot of the Max Ripple with Equalizer at Max

After obtaining all the data needed, calculations for how much power the amplifier outputs were made. For the power, the amplifier needed to exceed 400mW at each frequency. With that in mind, the calculations in Figure 4.6 were made and it resulted in knowing that the amplifier produced 1.88W of power which does pass the specific condition.

$P = 10^{\frac{13.73}{10}} = P$

$0.08 \cdot 10^{\frac{13.73}{10}} = 1.88W$

Power in

$V_{in} = 0.1$

$R_{in} = 8\Omega$ - data sheet

$I_{in} = 0.8$

$P_{In} = 0.08$

Figure 4.6 Calculations for the Amplifier Output Power

Conclusion

After designing the circuit, calculating the corresponding capacitances, resistances, and other specific values needed to pass the given constraints, and constructing and using the amplifier to analyze and get readings, this project was a success. The design and calculations went smoothly, construction and testing went smoothly, and when the speaker was played through the computer with different songs, it worked perfectly. Using the theories that were taught in the class and in the lab, completing this project gave a new understanding of how these theories are applied to the real world, and it gave a new perspective on how electrical and computer engineering is a vital part of today’s society. However, there were some struggles, especially with the potentiometers and the breadboard. Due to the poor pins on the potentiometer, the connection issue with the breadboard has caused more trouble and it took time to fix the connection, causing the project to take longer than expected. In addition, multiple trials needed to take place due to this issue, because of how it affected the waves and plot lines on the screen captures and plot. With minor issues aside, however, this project was a success and the data and plots that were obtained in this project were acceptable and proper.