

Audio Equalizer Final Project

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ECE 20007: EE Fundamentals I Lab

Pujary (007)

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Introduction

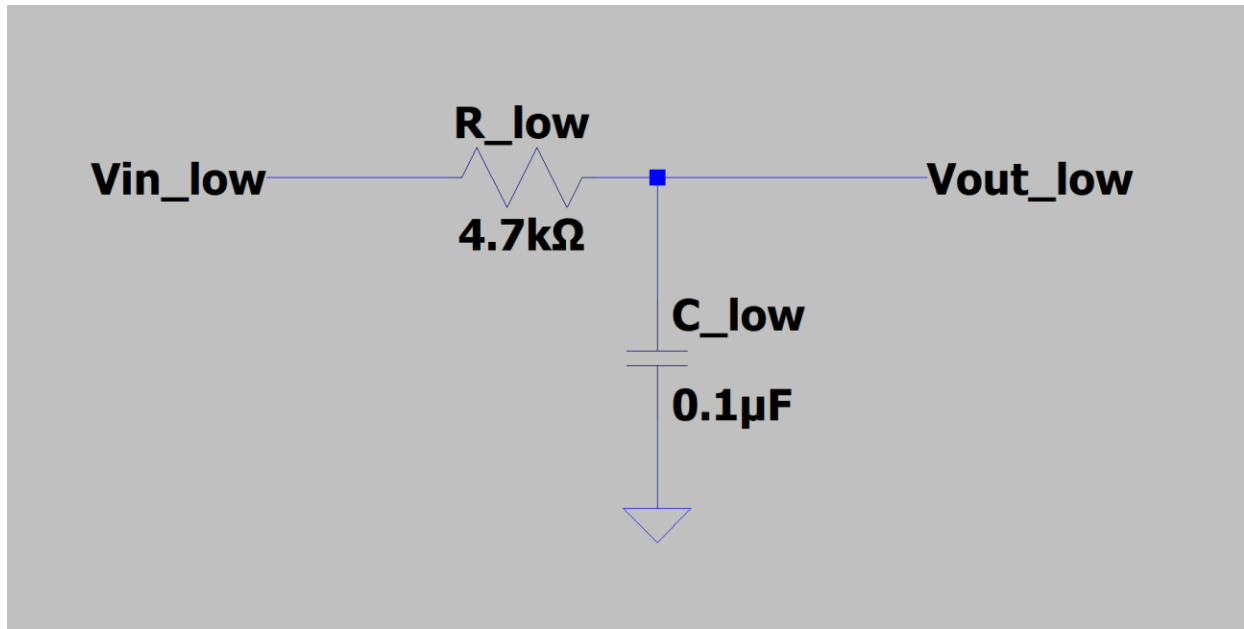
The purpose of this project is to design, construct, and analyze a functional three-band audio equalizer that is capable of adjusting the low, mid, and high frequency components of an input signal. This circuit uses a high-pass, low-pass, and band-pass filters, operational amplifiers, and a power amplifier to deliver a signal output to an 8-ohm speaker. The main objective is to demonstrate a wide variety of electronic behavior such as analog filter design, amplifier operation, and signal recombination. The circuit design aligns with given constraints including cutoff frequencies of the filters, gain limits, and ripple constraints.

More specifically, there are 5 objectives to this project. Firstly, the project tests filter design and implementation where a high-pass, low-pass, and band-pass RC filter stages are constructed and capable of separating an input audio signal into bass (below ~ 320 Hz), midrange (320–3200 Hz), and treble (above ~ 3200 Hz) frequency bands within a $\pm 10\%$ tolerance. Next is the signal amplification and control stage in which the circuit constructed utilizes operational amplifiers along with potentiometers to adjust the gain for each individual frequency band. After the 3 independent filter + amplifier stages, the circuit demonstrates signal recombination where the three independently controlled stages are connected to a single audio output with acceptable ripple characteristics around 15 mV. The final stage of the circuit objectives is the implementation of a power amplifier that is capable of delivering greater than 400 mW of power to the 8-ohm speaker across the entire audio frequency of 100 to 10k Hz. The last objective of the audio equalizer project is to experimentally measure frequency response curves (FRA), voltage RMS values, ripple levels, and output power to confirm that the designed circuit has met all specifications outlined in the project requirements.

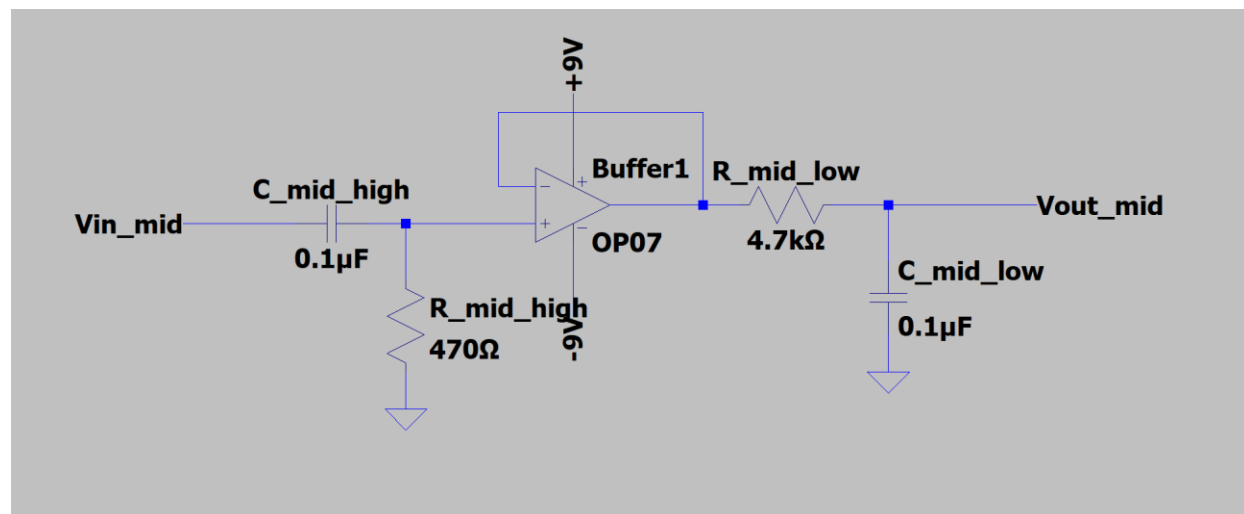
There are several key functions of the audio equalizer starting with the frequency band separation which is completed by building 3 filters, a high, a low, and a band-pass filter. These filters act as gates in this circuit where each filter only allows certain audio frequencies through (Engineering LibreTexts). The low-pass focuses on bass, band-pass on mid, and high-pass on treble frequencies. The second function of the audio equalizer is the adjustable gain control where each frequency band can be boosted and attenuated by a potentiometer-control operational amplifier. The final stage of the audio equalizer is the signal recombination and amplification stage which combines all three audio signals from each filter and op-amp into one using a summing amplifier and then the recombined signal is sent to a power amplifier that drives the audio signal to the speaker load (Fox).

The applications of audio equalizers are widespread, but are mainly used in consumer audio equipment, car audio systems, and instrument amplifiers. They allow the user to manipulate the audio playback to different environments, improve the clarity of audio signals, and enhance different aspects of an audio signal like adding bass.

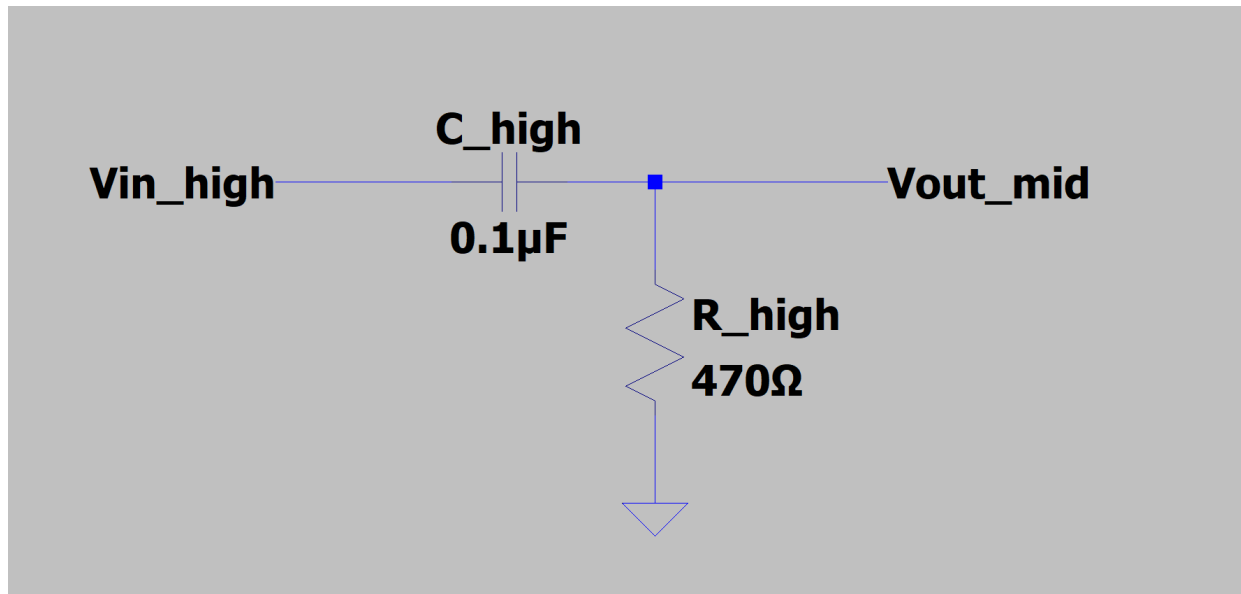
Theory



Low-Pass Filter Circuit Schematic



Band-Pass Filter Circuit Schematic



High-Pass Filter Circuit Schematic

Passive filters are frequency-dependent circuits that rely on resistors and capacitors to allow only a range of signals to pass through while blocking others without any external power or active components. In this project three types of first-order RC filters are used. A low-pass filter passes through low frequencies and attenuates frequencies above its cutoff. Similarly, a high-pass filter passes high frequencies and attenuates frequencies below its cutoff. Finally, the band pass filter combines a high and low pass filter and allows a band of frequencies to pass while attenuating frequency both below and above this range. The cutoff point where the output voltage drops to 70.7% of the input amplitude is at -3 dB for these filters.

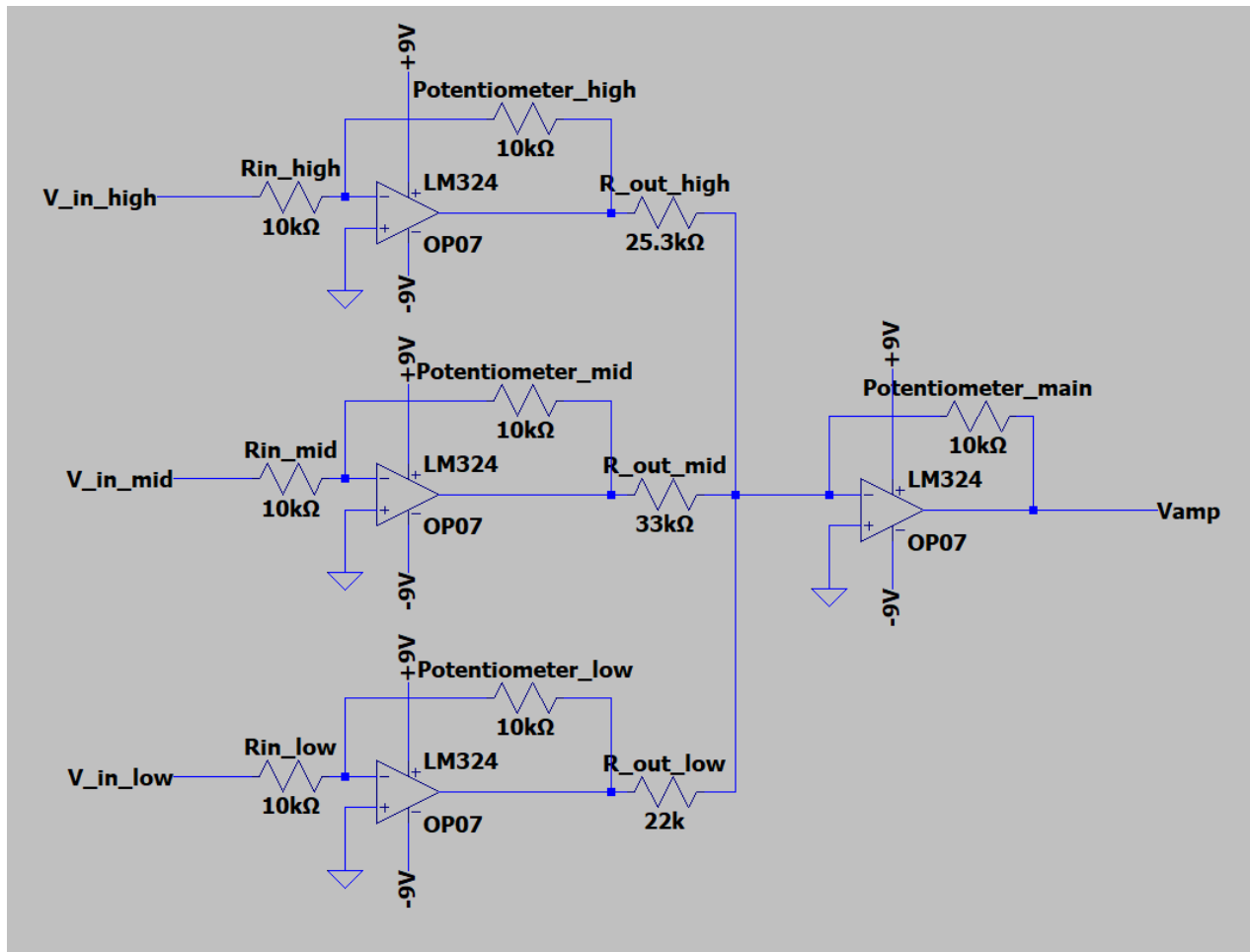
Related Equations for Passive Filters:

Frequency Cutoff (Hz):

$$F_{\text{high, low}} = \frac{1}{2\pi RC}$$

Band Pass Band Width (Hz):

$$BW = f_{\text{high}} - f_{\text{low}}$$



Operational Amplifiers Circuit Schematic

Operational amplifiers (op-amps) are active electronic devices that are designed to amplify input voltage signals. In this circuit, these op-amps are operated with negative feedback which stabilizes the gain and allows for the user to change the amplification factor themselves using external resistors and potentiometers (Texas Instruments). In this project, op-amps are used for three reasons. Firstly, the op-amp in the band-pass filter is used to isolate circuit elements and prevent loading between filter stages. This ensures that cutoff frequencies remain stable across all three filters. Next, 3 op-amps are used at each frequency band, combined with a potentiometer, to control amplification or attenuation of each band. In an audio equalizer this allows the user to boost or reduce bass, midrange, or treble independently. Finally, the like op-amp is used in the recombination stage that acts as a summing amplifier that adds the three independent frequency bands into a single output signal which is then can to be amplified by the power amplifier.

Related Equations for Operational Amplifiers:

Inverting Amplifier Voltage Gain:

$$A_v = - \frac{R_f}{R_{in}}$$

Where:

R_f is the feedback resistance (Potentiometer)

R_{in} is the resistor between the inverting input and filters

Inverting Summing Amplifier (Signal Recombination)

$$V_{out} = - R_f \left(\frac{V_{low}}{R_{low}} + \frac{V_{mid}}{R_{mid}} + \frac{V_{high}}{R_{high}} \right)$$

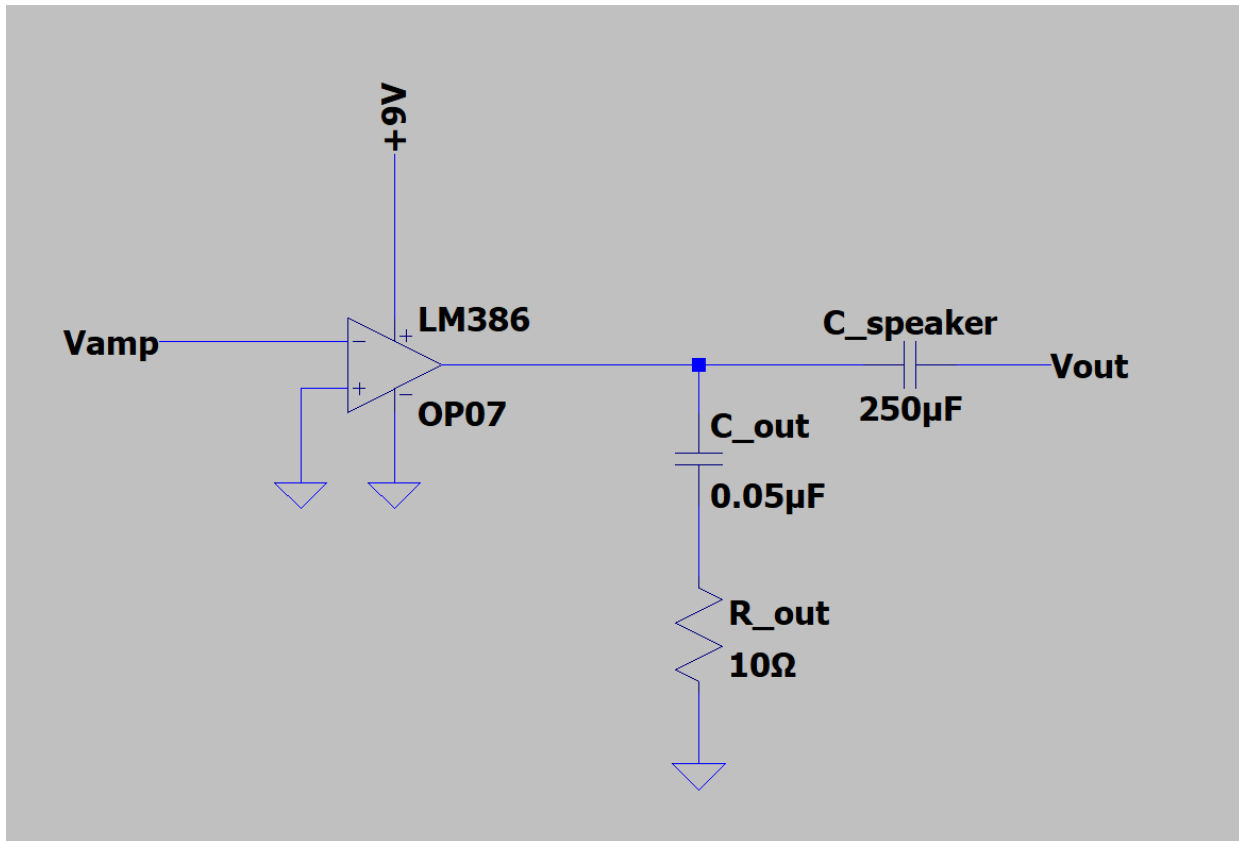
Where:

V_{low} , V_{mid} , V_{high} are the voltages from the low, mid, and high frequency channels

R_{low} , R_{mid} , R_{high} are the respective summing resistors

R_f is the feedback resistance (Potentiometer)

By selecting appropriate resistor values for each stage, weighting and isolation occur so that each signal contributes correctly to the recombined output.



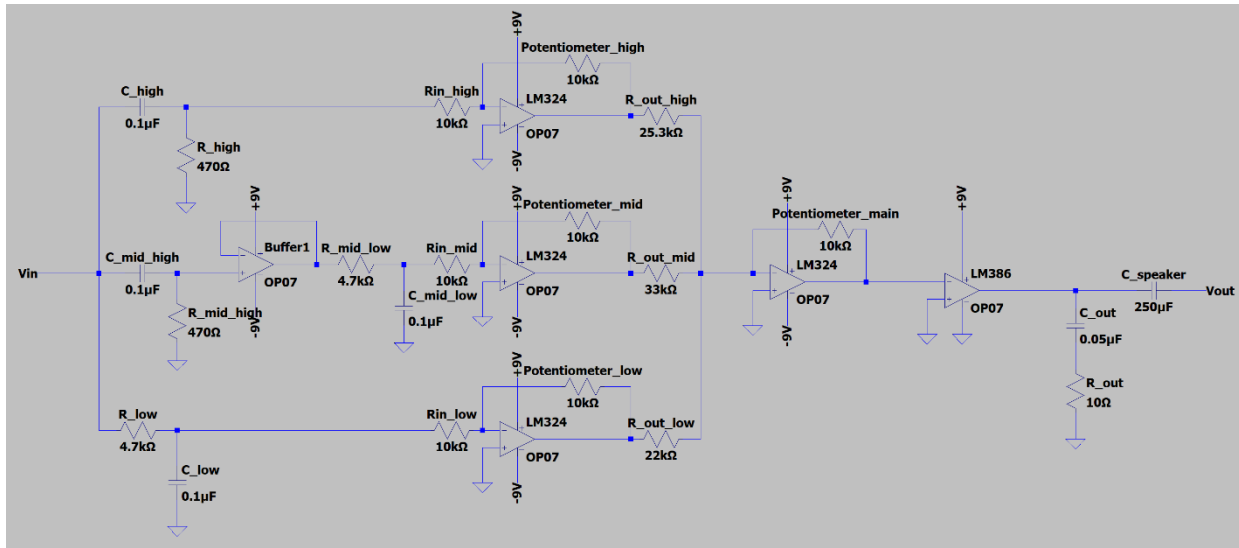
Power Amplifier Circuit Schematic

The power amplifier stage of the audio equalizer is responsible for boosting the low V_{amp} audio signal from the op-amp signal recombination stage and boost the voltage to a level that drives the 8-ohm speaker load. The reason a power amplifier is needed for this circuit is that input voltage audio signal passed through the filters and op-amps is relatively small voltage around 0.5V which is not sufficient to drive a speaker to produce an audio sound. Looking closer that the LM386 amplifier, the input audio signal from the summing amplifier enters the LM386 which triggers an internal transistor amplification stage to provide voltage gain and current boosting (Digi-Key Electronics). The output transistor pair then supplies sufficient current to drive the speaker load. The power delivered to the speaker is determined by the output RMS voltage of the LM386 and the load resistance of the speaker.

$$P_{avg} = \frac{V_{rms}^2}{R} = \frac{V_{rms}^2}{8}; R_{speaker} = 8\Omega$$

For this audio equalizer, the specification guidelines indicate a minimum of 400 mW is needed across the 100 Hz to 10kHz frequency range.

Experimental Procedure



Audio Equalizer Circuit Schematic

Audio Equalizer Design Parameter Calculations:

1. Filter Parameters

a. High Pass ($>3200 \text{ Hz} \pm 10\%$)

Parameter	Calculated Value	Equation/ Reasoning
R_{high}	470 Ω	$f = \frac{1}{2\pi RC} = 3386 \text{ Hz}$
C_{high}	0.1 μF	$f = \frac{1}{2\pi RC} = 3386 \text{ Hz}$

b. Band Pass (320-3200 $\text{Hz} \pm 10\%$)

Parameter	Calculated Value	Equation/ Reasoning
R_{mid_high}	470 Ω	$f = \frac{1}{2\pi RC} = 3386 \text{ Hz}$
C_{mid_high}	0.1 μF	$f = \frac{1}{2\pi RC} = 3386 \text{ Hz}$
R_{mid_low}	4.7 k Ω	$f = \frac{1}{2\pi RC} = 338.6 \text{ Hz}$
C_{mid_low}	0.1 μF	$f = \frac{1}{2\pi RC} = 338.6 \text{ Hz}$

c. Low Pass ($<320 \text{ Hz} \pm 10\%$)

Parameter	Calculated Value	Equation/ Reasoning
R_{low}	4.7 k Ω	$f = \frac{1}{2\pi RC} = 338.6 \text{ Hz}$
C_{low}	0.1 μF	$f = \frac{1}{2\pi RC} = 338.6 \text{ Hz}$

2. Volume Control

Parameter	Calculated Value	Equation/ Reasoning
R_{in} (3x for all filters)	10k Ω	$A_v = -R_f/R_{\text{in}} = 0 \rightarrow 1$ Stage gain of amplifier ranges from 0 \rightarrow 1
R_f (3x for all filters)	10 k Ω Potentiometer	$A_v = -R_f/R_{\text{in}} = 0 \rightarrow 1$ Stage gain of amplifier ranges from 0 \rightarrow 1

3. Signal Recombination

Parameter	Calculated Value	Equation/ Reasoning
$R_{\text{out_high}}$	25.3 k Ω (22 k Ω + 3.3 k Ω)	Provides isolation & weighting into summing node
$R_{\text{out_mid}}$	33 k Ω	Provides isolation & weighting into summing node
$R_{\text{out_low}}$	22 k Ω	Provides isolation & weighting into summing node
Potentiometer_main	10 k Ω Potentiometer	Changes the total V_{amp} output after recombination of low, medium, and high amplifiers. This demonstrates overall volume control.

Description of Operation:

The audio equalizer designed above operated first by inputting a low voltage audio signal from an external source such as a computer, phone, or waveform generator. This signal is then sent through 3 parallel RC filters, each of which are dedicated to a specific frequency range

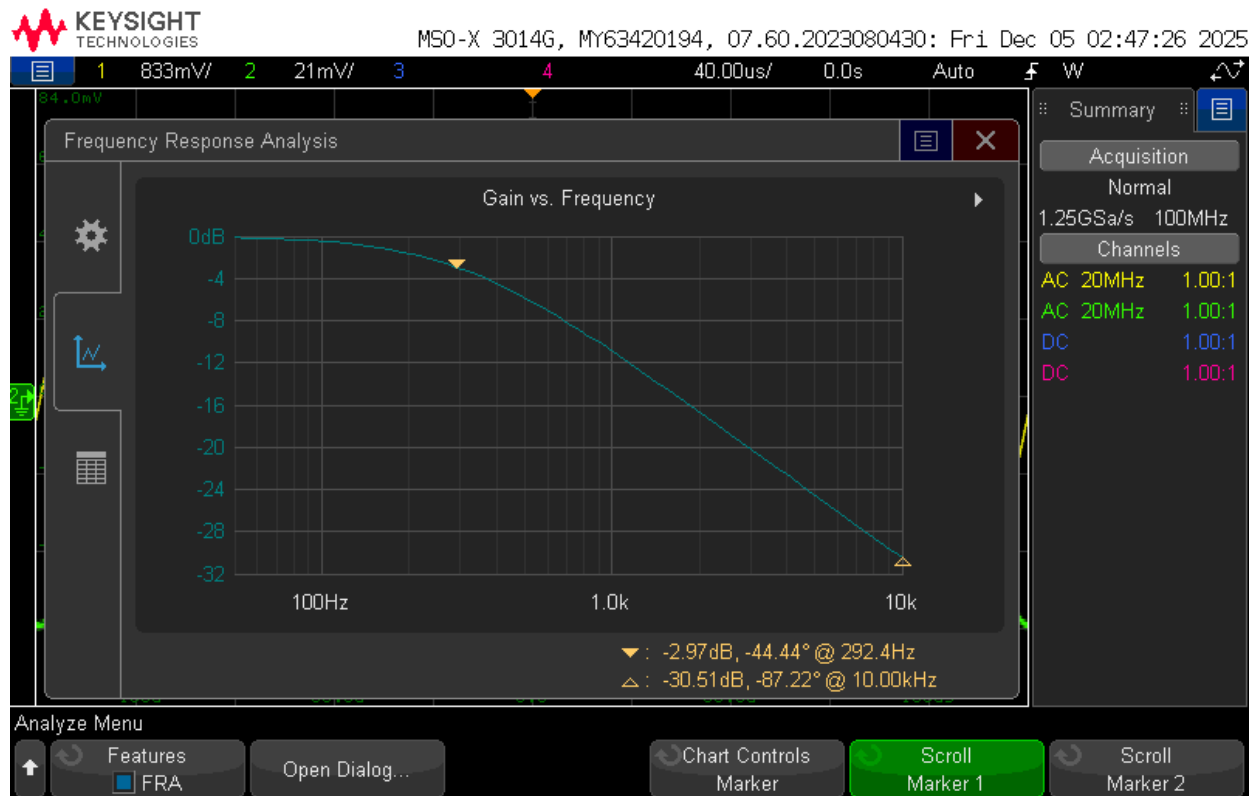
(bass, midrange, or treble). The low-pass extracts frequencies below 320 Hz, the band-pass at between 320 to 3200 Hz, and the high-pass at any frequencies above 3200 Hz.

After the filters, each filtered signal enters its own inverting operational amplifier with a potentiometer-based feedback loop. These stages provide the user with a way to adjust the gain control of each frequency band independently. For example, if the user wants to increase the bass of the audio signal, they can adjust the gain on the low-pass op-amp using the respective potentiometer.

The three channels are then reconnected into one using appropriate isolation resistors into an inverting summing amplifier which recombines the individual audio signals into one. The potentiometer on its feedback loop controls the overall volume of the output signal, and weighting resistors balance the contribution of each frequency band which minimizes the output ripple.

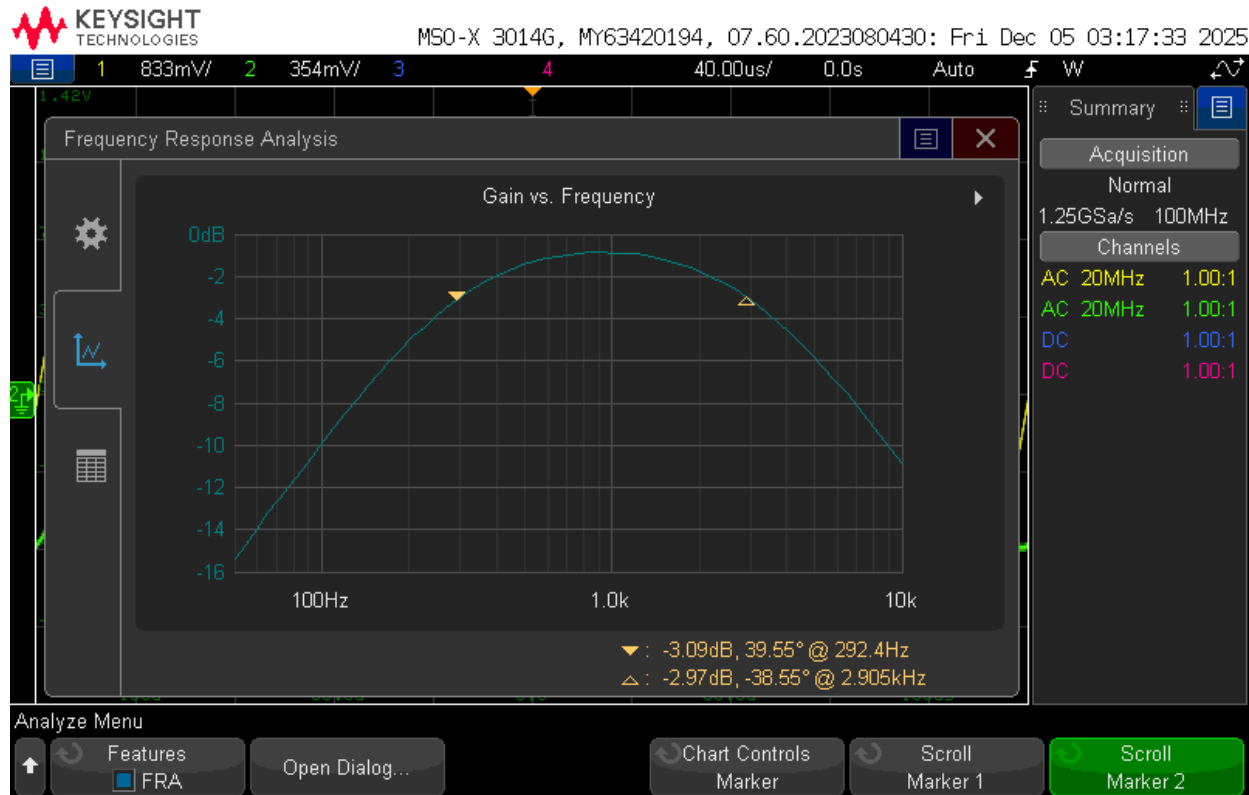
Finally, after recombination, the signal enters a LM386 power amplifier that boosts the current of the signal to a level that can be used by the 8-ohm speaker load. An output coupling capacitor blocks DC voltage from reaching the speaker.

Results



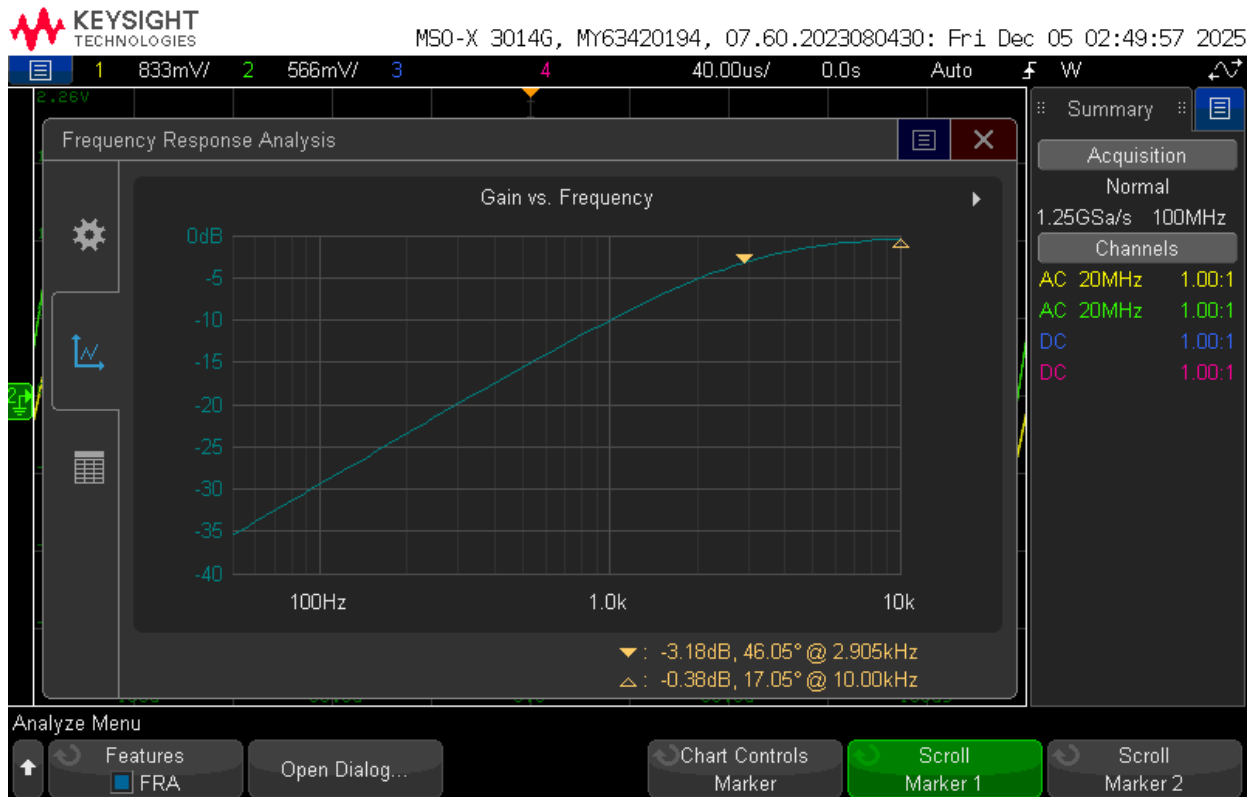
Low-Pass Filter Frequency Response Analysis Plot

The low-pass filter FRA plot shows at low frequency a decibel reading above -3 dB and then decreases beyond the cutoff region as the frequency increases. The measured -3 dB cutoff occurs around 292.4 Hz which indicates that our low-pass filter was built using the correct resistor and capacitor of 4.7 k Ω and 0.1 μ F respectively as our specification was 320 Hz cutoff \pm 10%.



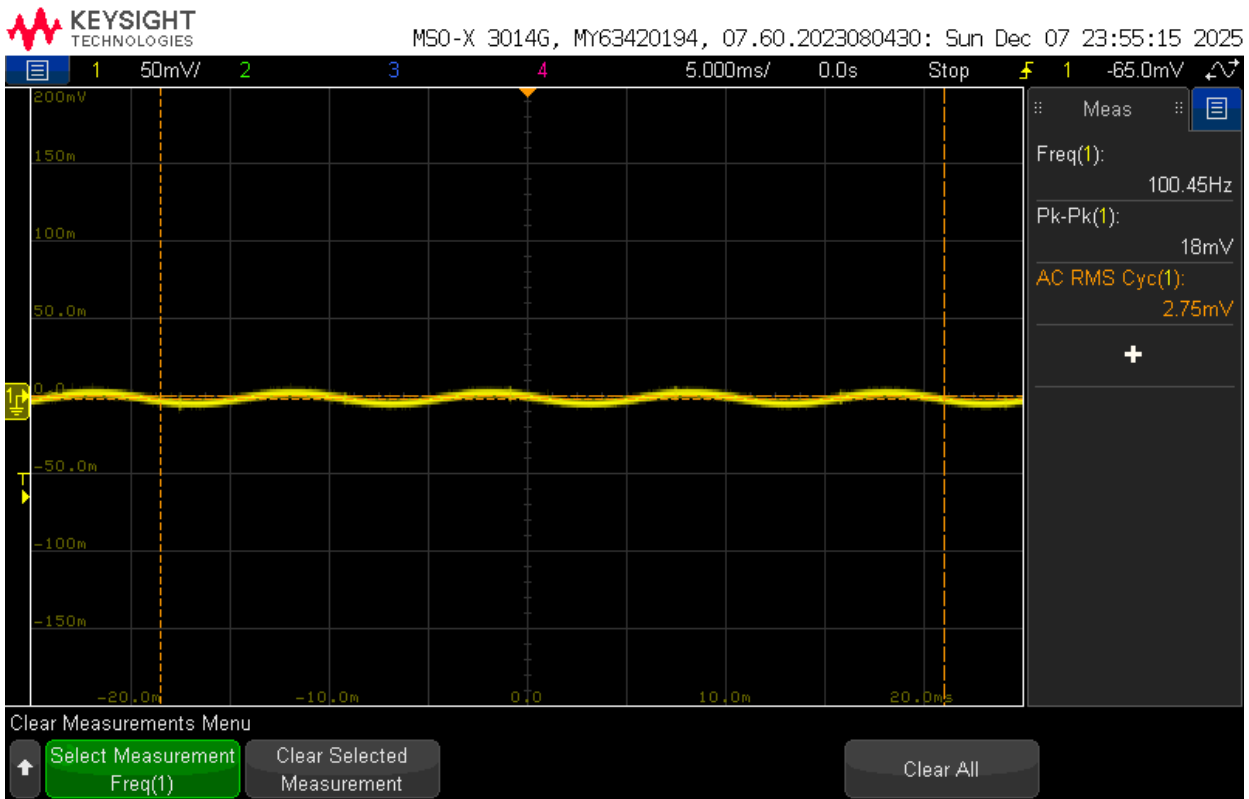
Band-Pass Filter Frequency Response Analysis Plot

The band-pass FRA demonstrates the signal passing through within the midrange frequency band while attenuating frequencies outside of this range on either side. The cutoff frequencies occur at a -3 dB level like the low-pass filter. The lower cutoff can be seen to be around 292.4 Hz and the upper cutoff is around 2.905 kHz. Both these experimental values fit within the desired specifications for this filter which is 320 Hz cutoff \pm 10% for the lower bound and 3200 Hz cutoff \pm 10% for the upper bound.

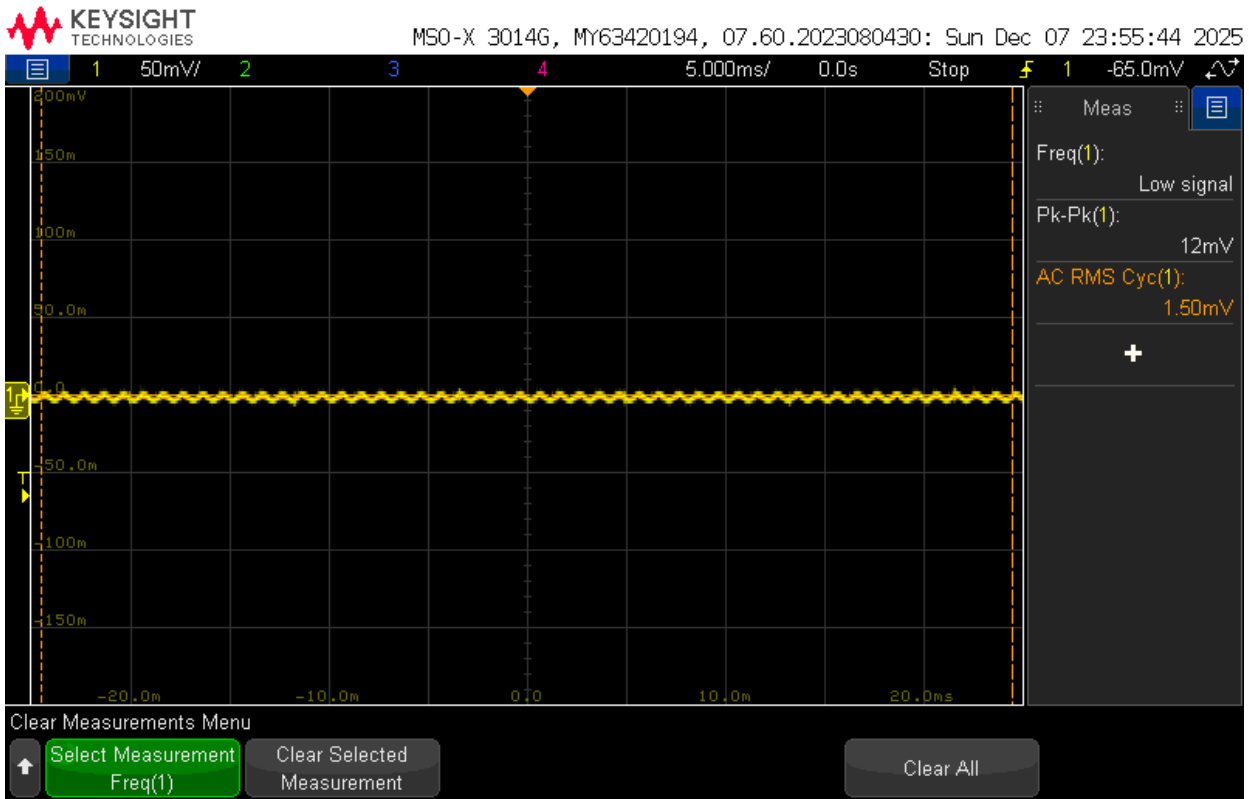


High-Pass Filter Frequency Response Analysis Plot

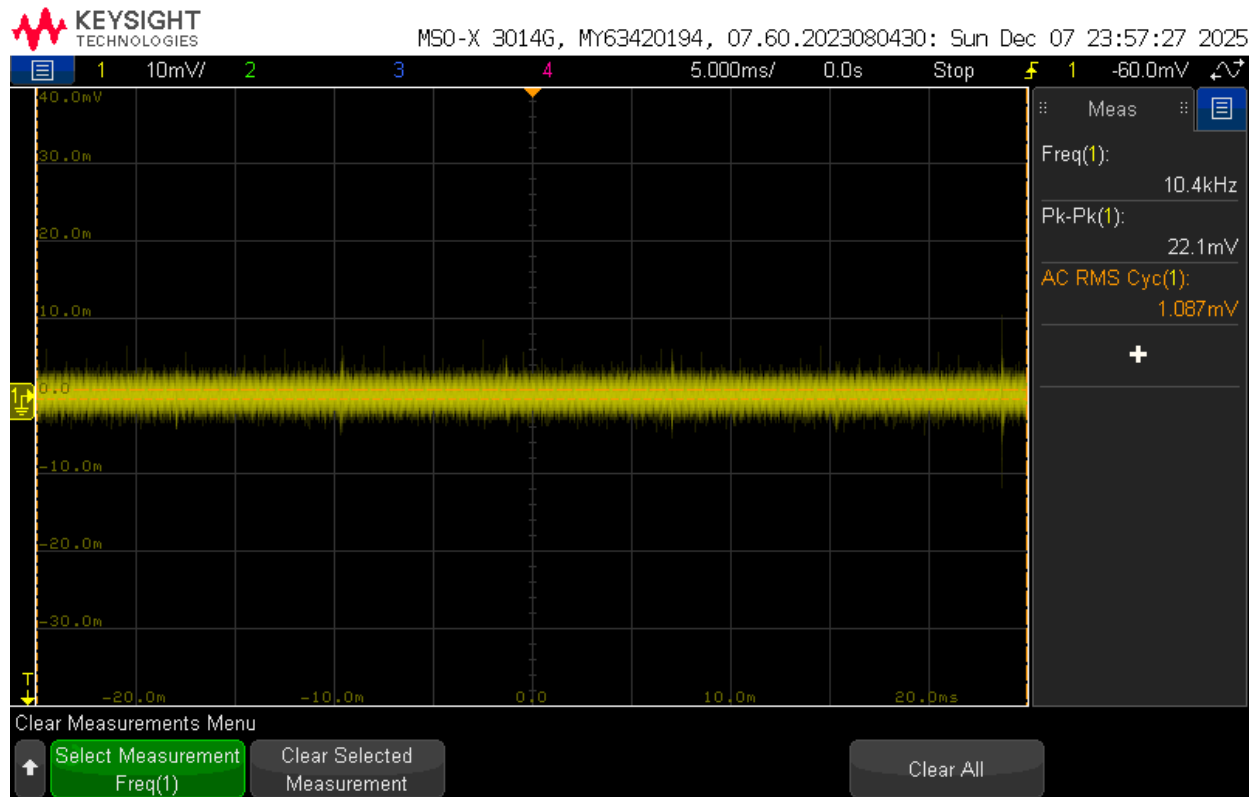
The high-pass filter FRA plot clearly shows the expected behavior of attenuating the lower frequencies and passing through frequencies above the cutoff at -3 dB which is around 2.905 kHz. The high-pass filter was built with resistor and capacitor values to allow frequencies above 3200 Hz to pass through and stop all others. This plot indicates a correct design for the high-pass filter using a 470 Ω resistor with a 0.1 μ F capacitor as the cutoff was within 10% of the desired cutoff frequency of 3200 Hz.



V_{amp} Plot on Minimum Settings at 100 Hz



V_{amp} Plot on Minimum Settings at 1 kHz

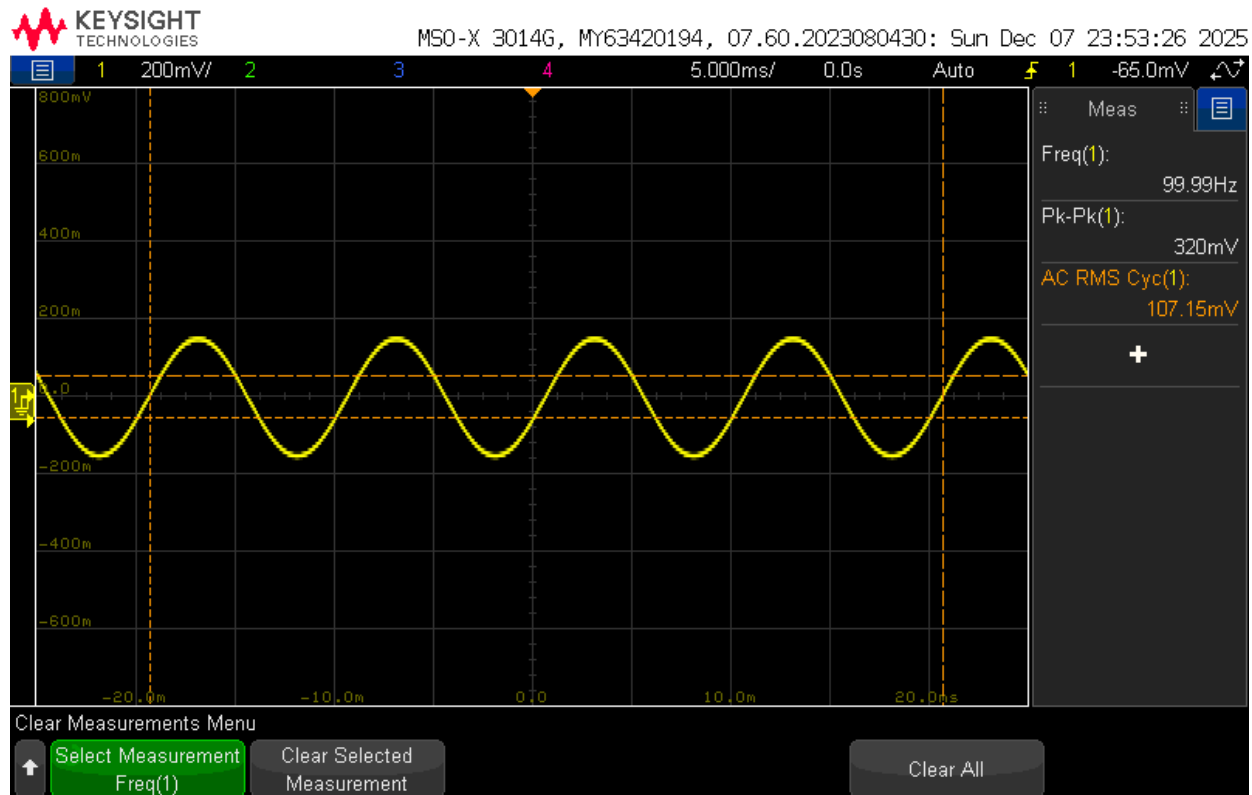
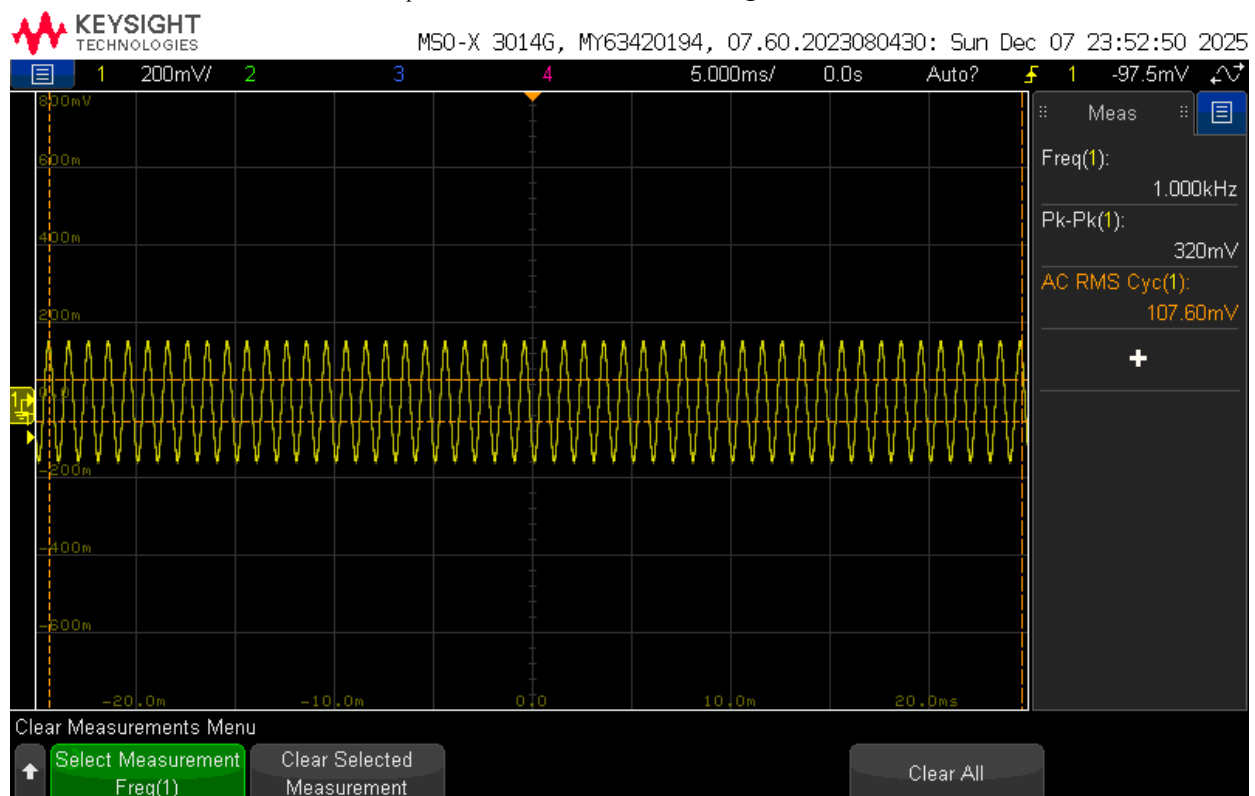


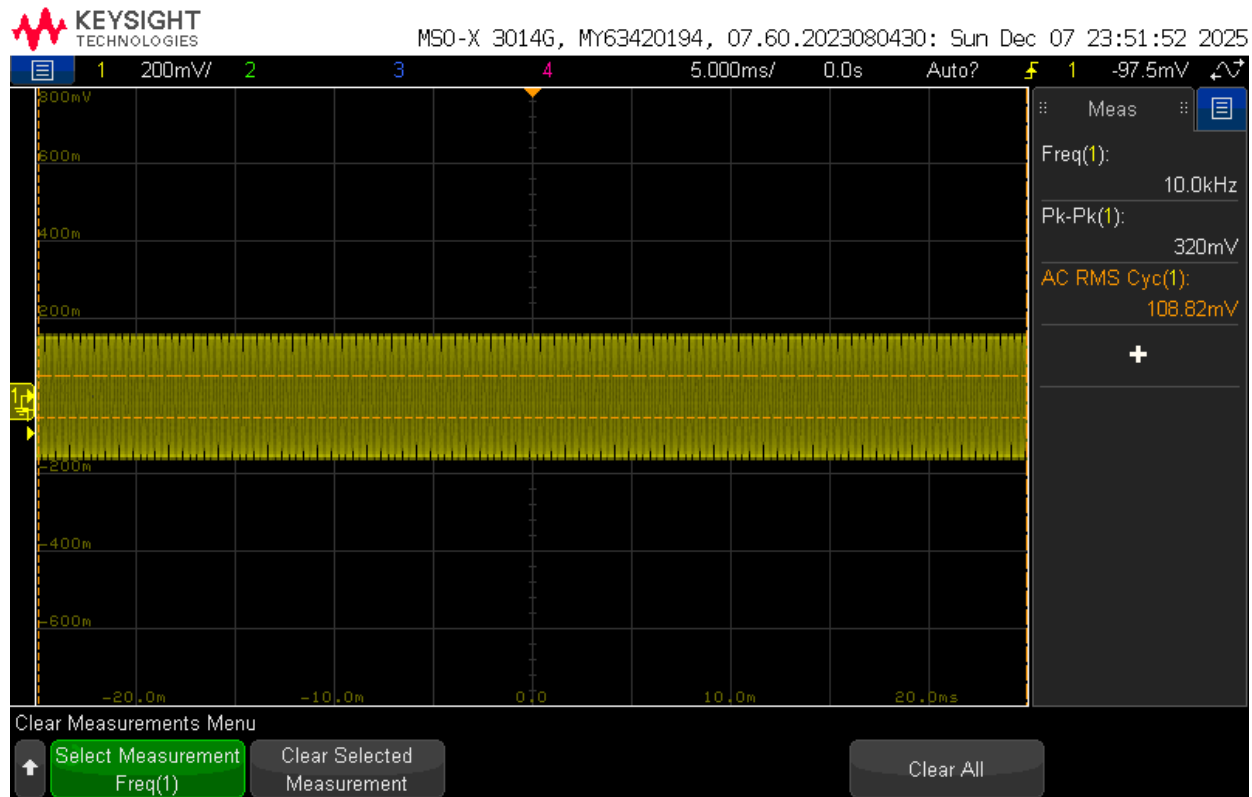
V_{amp} Plot on Minimum Settings at 10 kHz

Frequency (Hz)	V_{amp} (mV _{rms})	$V_{amp} < 15$ mV _{rms}
100	2.75	Yes
1000	1.50	Yes
10000	1.087	Yes

V_{amp} on Minimum Settings

With all the audio equalizer controls (potentiometers) set to the minimum positions, the measured input voltage into the power amplifier, V_{amp} , remained below the 15mV limit at all frequencies (100, 1k, and 10k Hz). These results indicate the correct design and testing of the filter, and op-amp portion of the audio equalizer where the output is minimal when muted. The low voltage values confirm that correct behavior of the volume control amplifiers for all frequency bands.

 V_{amp} Plot on Maximum Settings at 100 Hz V_{amp} Plot on Maximum Settings at 1 kHz

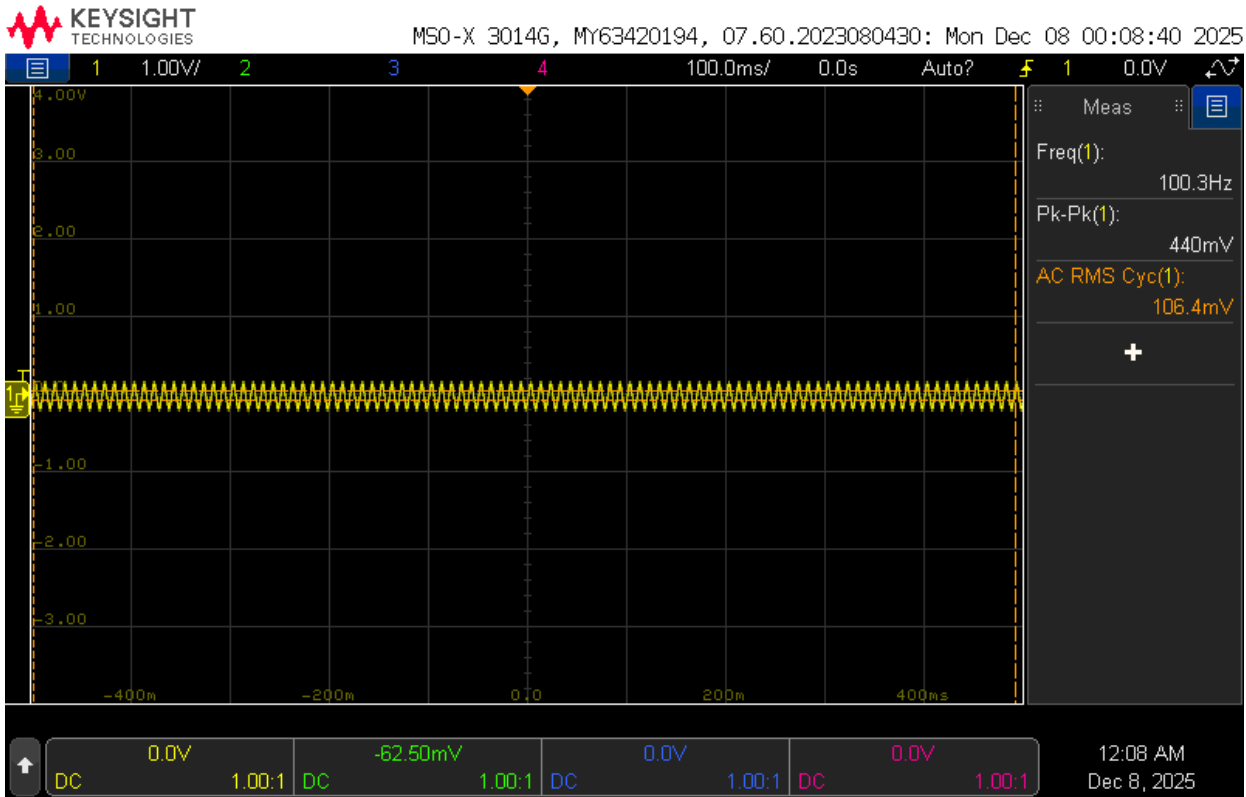


V_{amp} Plot on Maximum Settings at 10 kHz

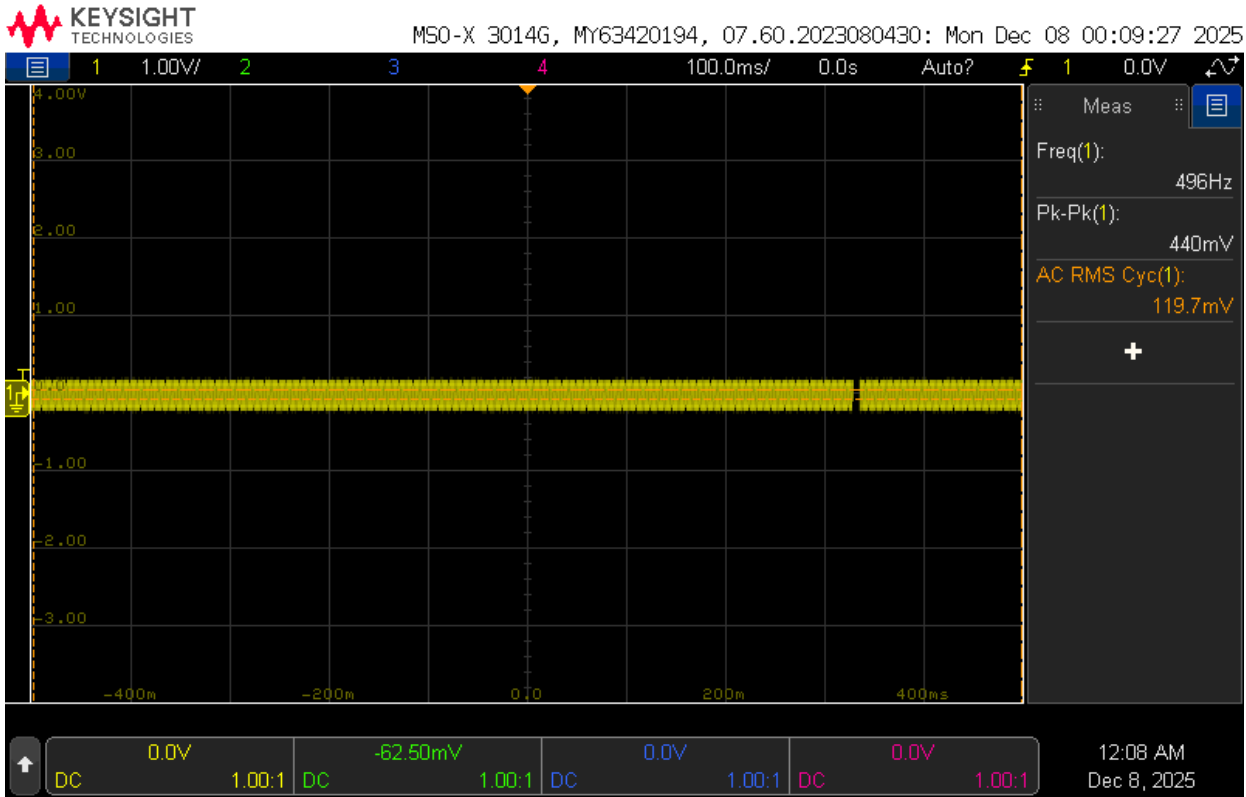
Frequency (Hz)	V_{amp} (mV _{rms})	$V_{\text{amp}} = 100 \text{ mV}_{\text{rms}} \pm 10\%$
100	107.15	Yes
1000	107.60	Yes
10000	108.82	Yes

V_{amp} on Maximum Settings

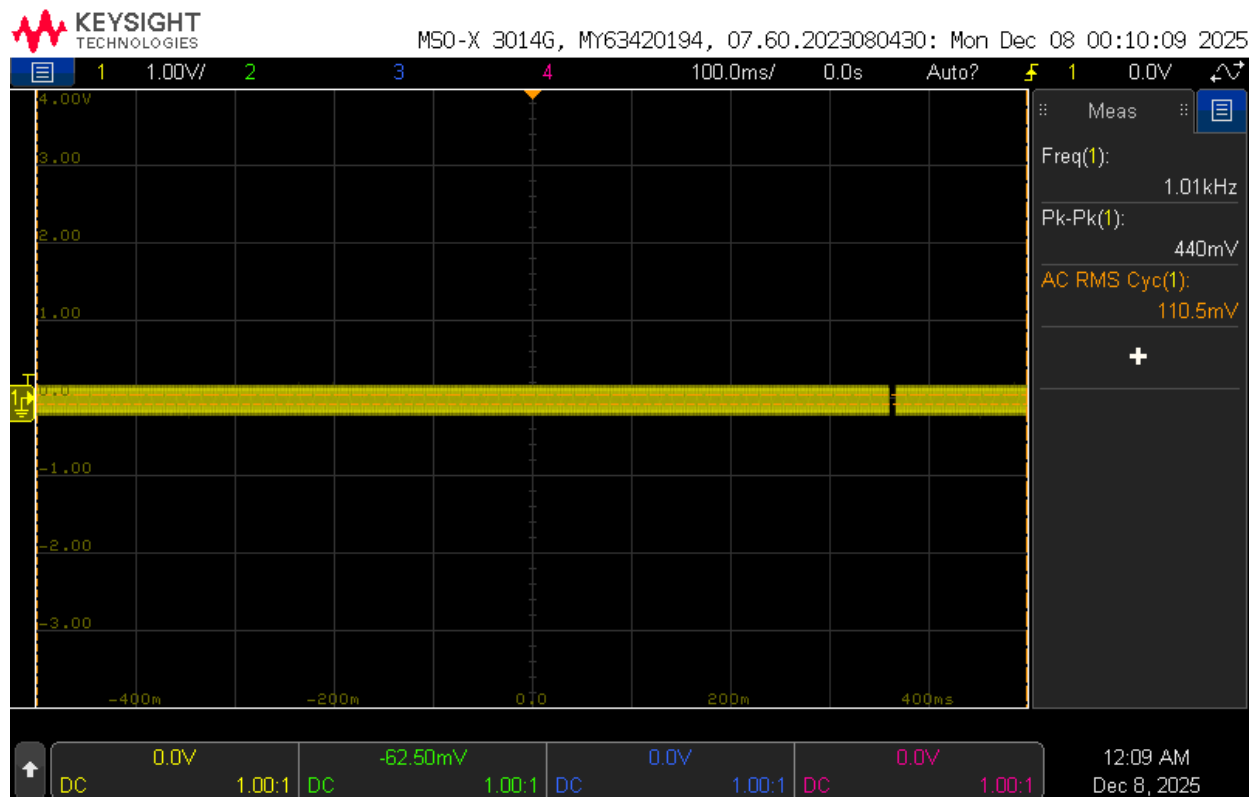
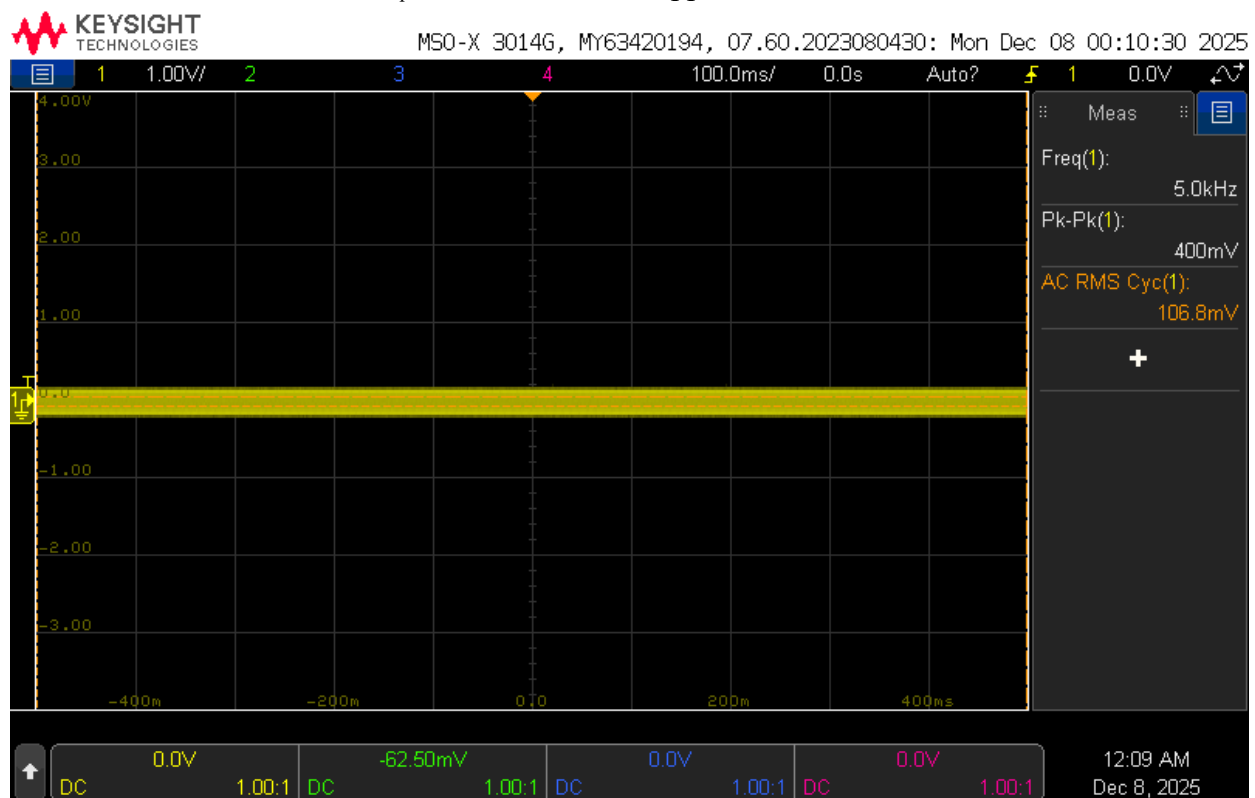
With all equalizer controls set to the maximum position now, V_{amp} was measured at the different frequency ranges (100, 1k, and 10k Hz) and fell between 107 – 109 mV_{rms} regardless of the frequency which indicates that there is minimal variation across the 3 channels. Overall, this means the recombination and channel weighting from the isolation/weighting resistors produces an almost uniform output amplitude which demonstrates proper expectations of the audio equalizer.

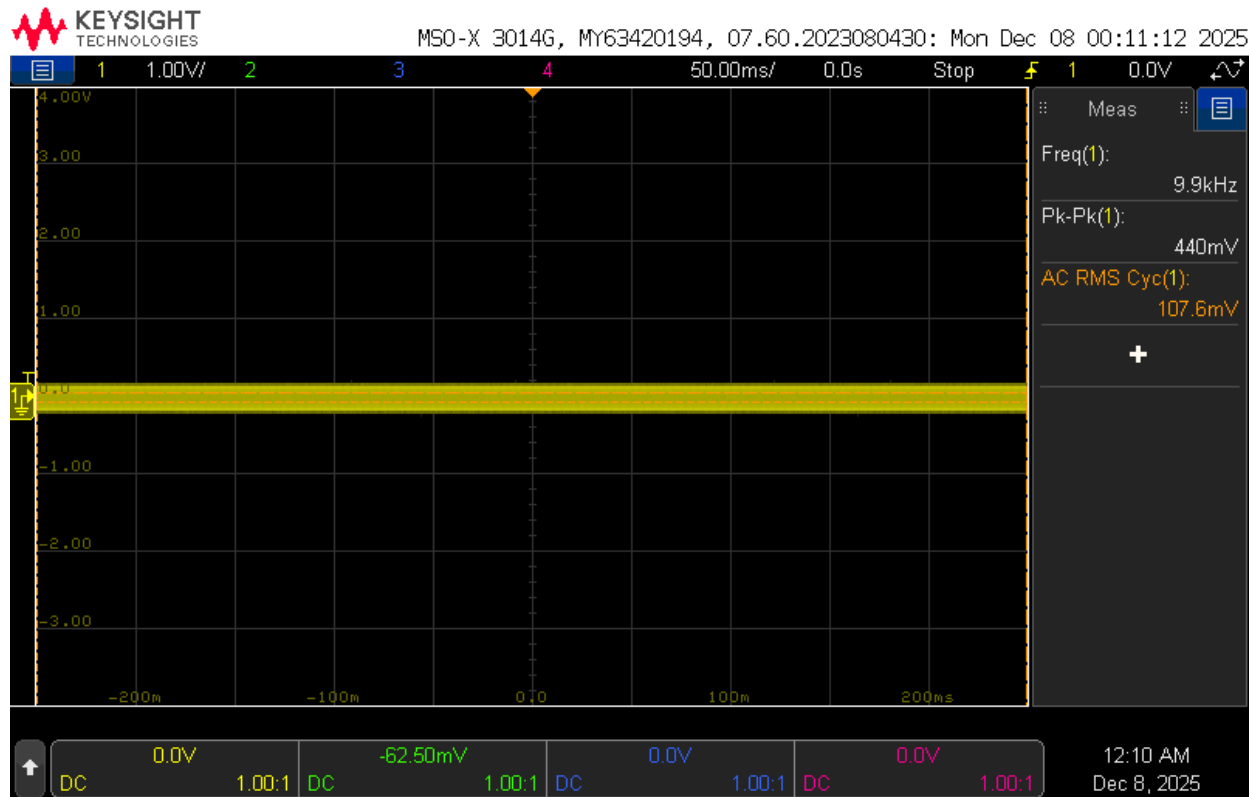


V_{amp} Plot at 100 Hz for Ripple Measurement



V_{amp} Plot at 500 Hz for Ripple Measurement

 V_{amp} Plot at 1 kHz for Ripple Measurement V_{amp} Plot at 5 kHz for Ripple Measurement



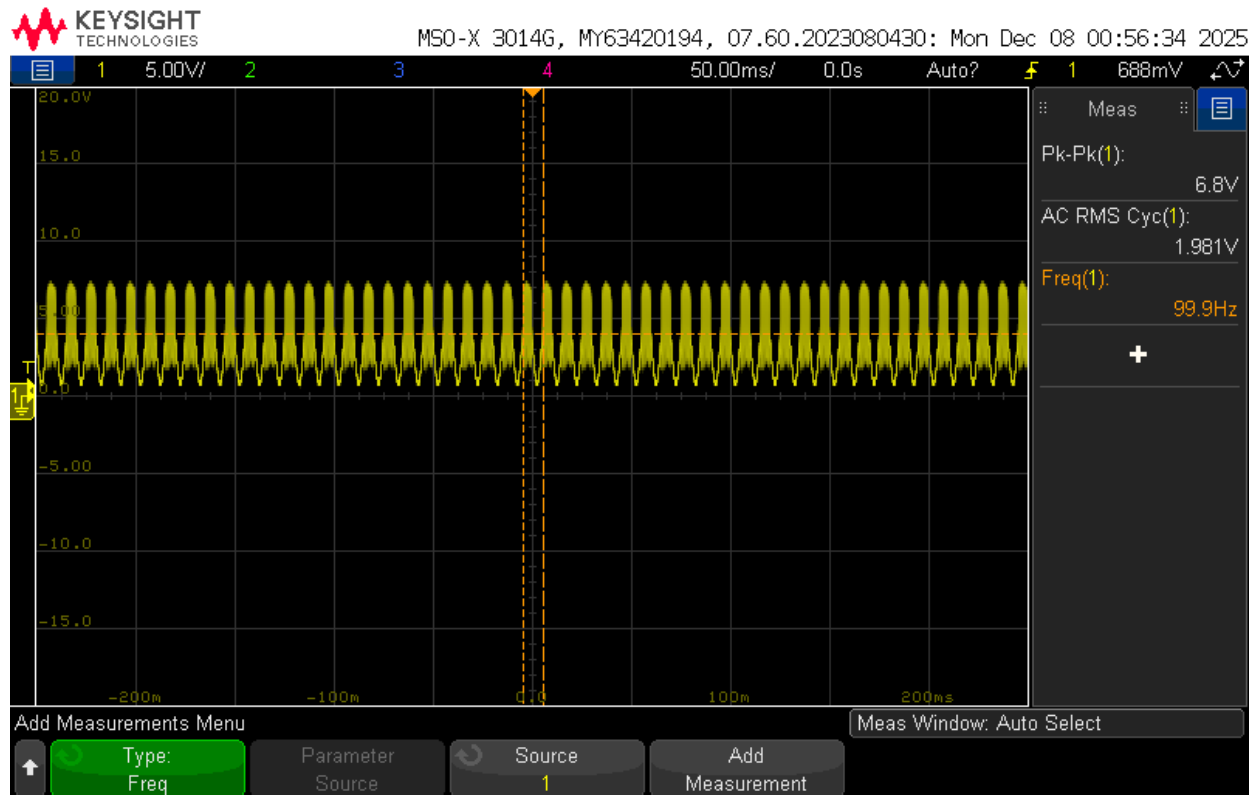
V_{amp} Plot at 10 kHz for Ripple Measurement

Ripple Measurement Calculations:

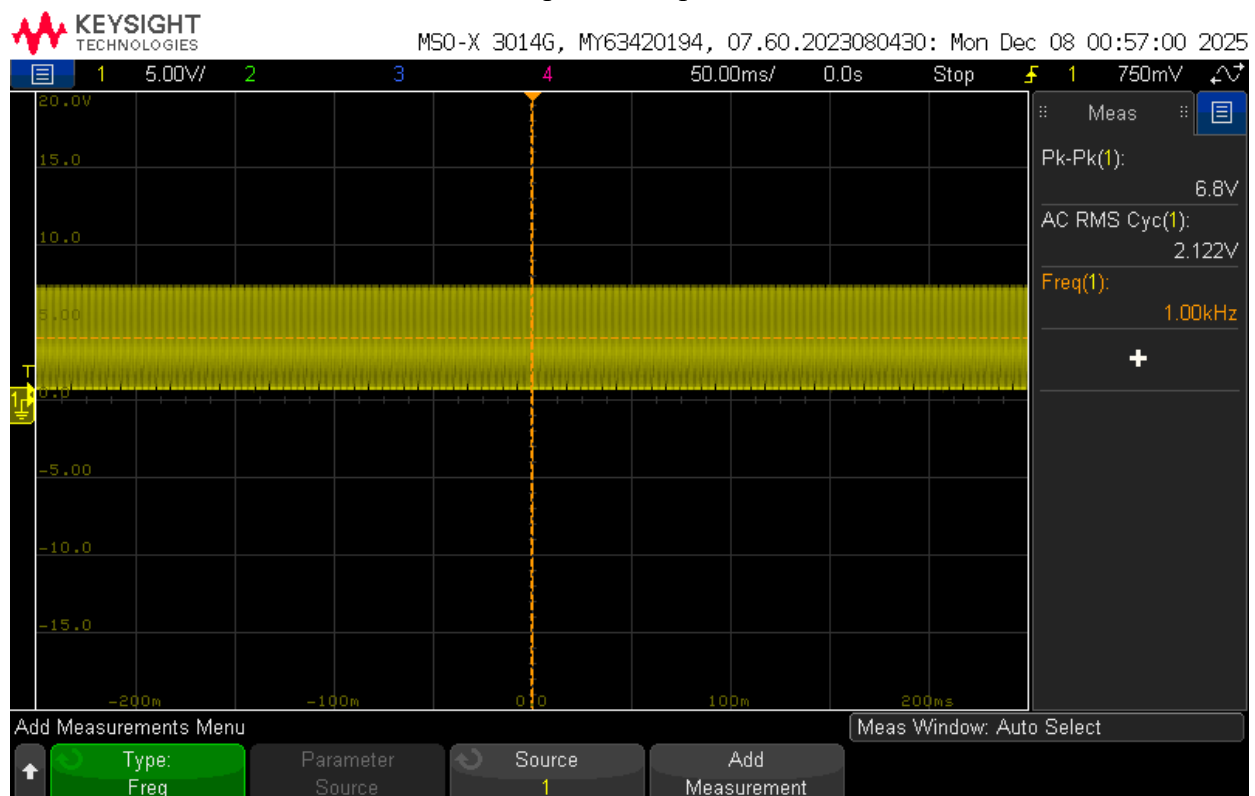
Frequency (Hz)	V_{amp} (mVrms)
100	106.4
500	119.7
1000	110.5
5000	106.8
10000	107.6

Maximum Ripple = $mV_{\text{rms}} (\text{max}) - mV_{\text{rms}} (\text{min}) = 119.7 - 106.4 = 13.3 \text{ mV}_{\text{rms}} \approx 15 \text{ mV}$
(Expected value)

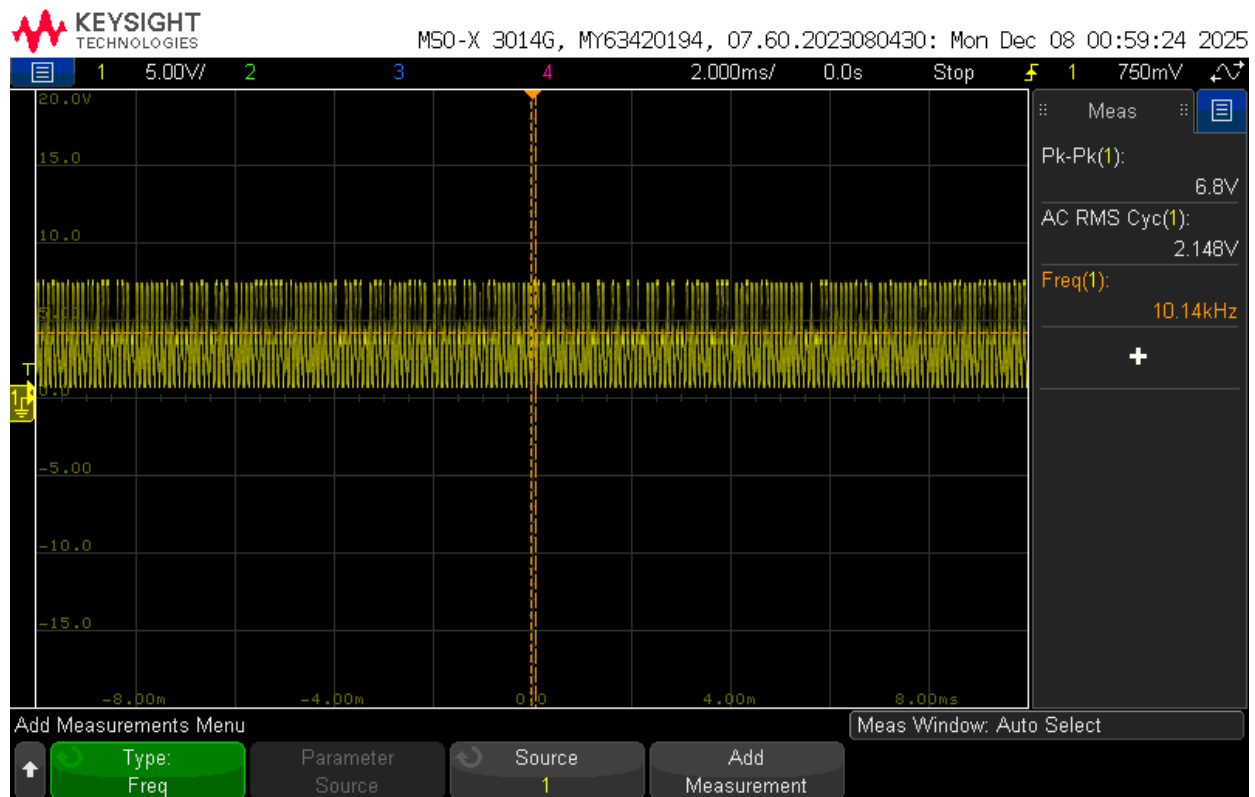
$$\% \text{ Error} = |15 \text{ mV} - 13.3 \text{ mV}| \div 15 \text{ mV} \times 100 = 11.3\%$$



Power Amplifier Output at 100 Hz



Power Amplifier Output at 1 kHz

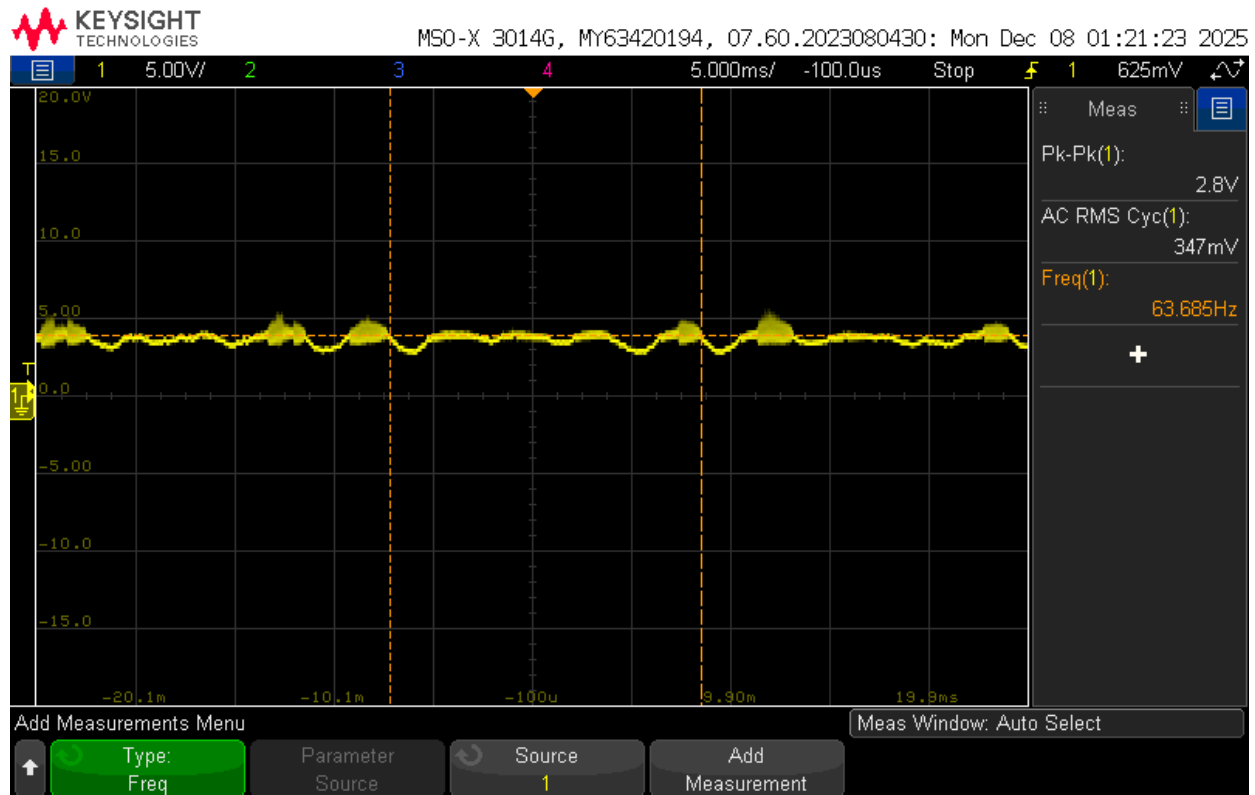


Power Amplifier Output at 10 kHz

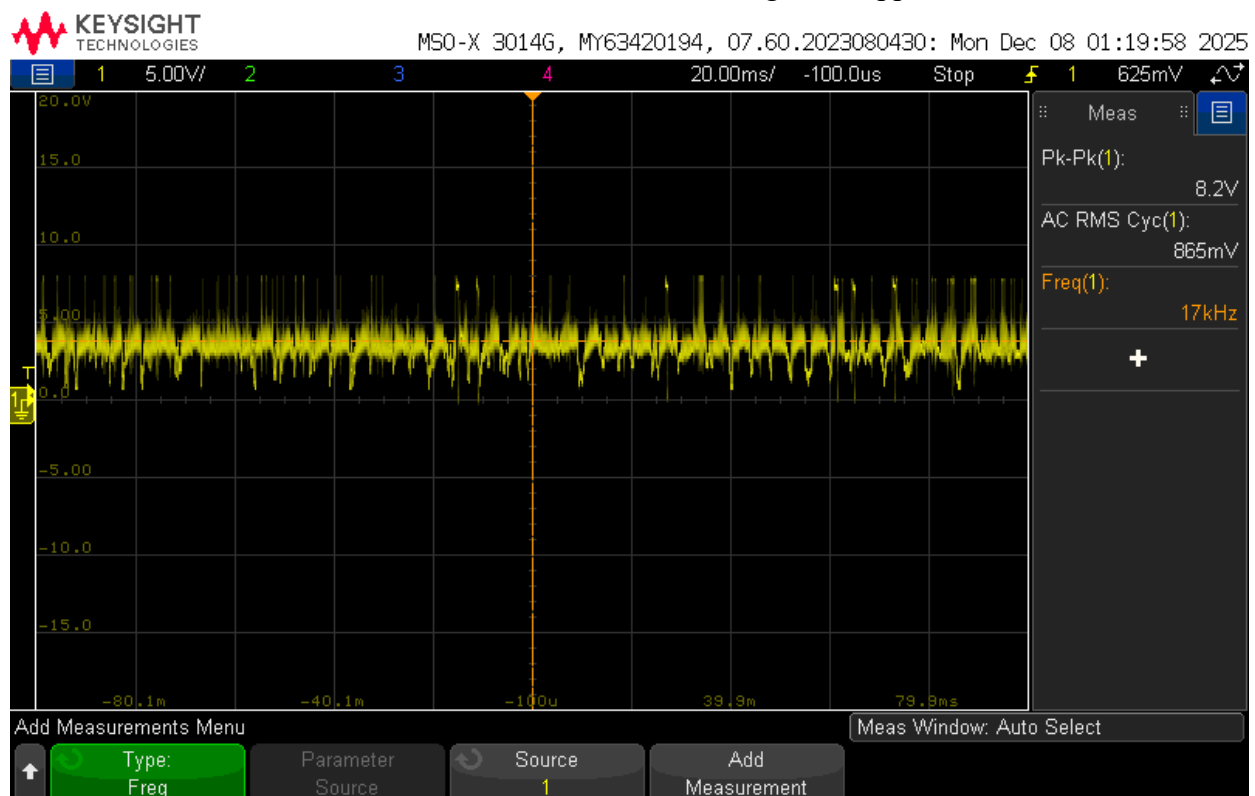
Power Output Calculations:

$$P_{\text{avg}} = \frac{V_{\text{rms}}^2}{R} = \frac{V_{\text{rms}}^2}{8}$$

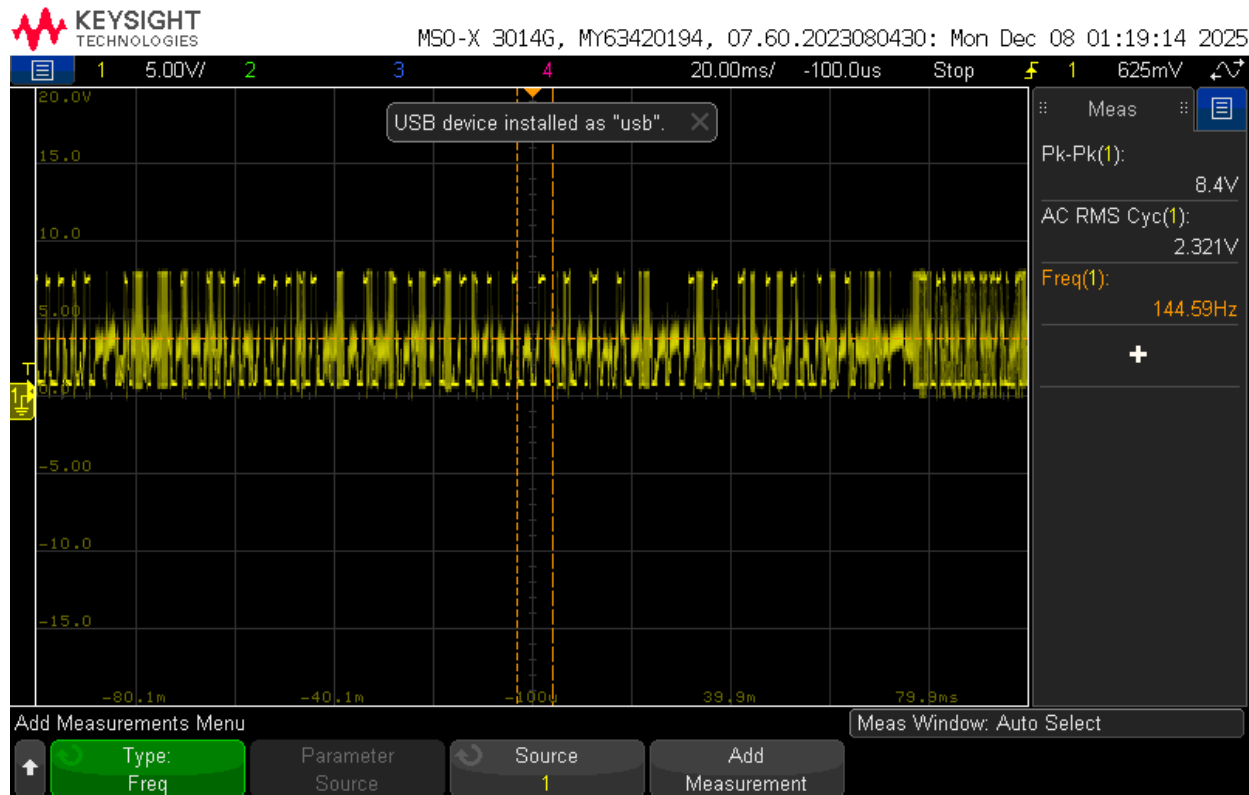
Frequency (Hz)	Vrms (V)	Power Output (mW)	$P_{\text{avg}} > 400 \text{ mW}?$
100	1.981	492.0	Yes
1000	2.122	562.9	Yes
10000	2.148	576.7	Yes



Low Volume Plot when an Audio Signal is Applied



Medium Volume Plot when Audio Signal is Applied



High Volume Plot when Audio Signal is Applied

Overall, the experimental results of each step verify the theoretical design specifications connect and match the measured performance of the fully completed audio equalizer. All the major specifications of the circuit were met and within tolerances such as the filter cutoff frequencies for all 3 passive filters, the controllable gain behavior of the operational amplifiers using variable resistors (potentiometers), a low output ripple of 15 mV_{rms}, and sufficient power delivery to the 8-ohm speaker load. The consistency of the results across the wide range of frequency inputs indicates that each part of the equalizer performed as expected and worked independently and as a part of a completely integrated circuit.

The frequency response analysis plots found that all three passive filters achieved cutoff frequencies within the allowed $\pm 10\%$ tolerance limits. Next, the measured voltage amplitudes entering the power amplifier (V_{amp}) was also valid and underlines correct behavior of the volume control and recombination stages. At minimums, V_{amp} measurements were well below the required 15 V_{rms} threshold across 100, 1k, and 10k Hz. At maximums, V_{amp} increased to approximately 107–109 V_{rms} across all frequencies which is within the required 100 mV_{rms} $\pm 10\%$ range. Continuing, the ripple measurements demonstrated correct behavior of the recombination op-amp. Ripple represents the voltage difference between the highest and lowest output amplitudes across the tested frequency range. The measured maximum ripple was approximately 13.3 mV_{rms} and is close to the specified 15 mV_{rms} limit. With such a low ripple, the circuit's output is uniform across the frequencies.

The LM386 power amplifier measurements confirmed that this stage successfully delivered more than the required 400 mW of power at all tested frequencies. The calculated power output ranged from 492 mW to 577 mW which is over the minimum requirement. The oscilloscope output waveforms displayed stable sinusoidal shapes without clipping or distortion. Minor variations in power output between frequencies can be caused by slight gain changes inside the LM386 op-amp.

Potential sources of measurement uncertainty are the oscilloscope probes, the RMS calculations accuracy using the measurement tool, and the waveform generator variation. All these sources of error can slightly modify cutoff frequency, voltages, and other measured values. Despite these factors, the similarity between measured data and theoretical expectations remained consistently strong throughout all tests indicating small sources of error throughout the experiment.

Conclusion and References

Conclusion

The objective of this project was to design, construct, and test the operations of a three-band analog audio equalizer with independently controlled gain through potentiometers for each frequency range, bass, midrange, and treble. The project sought to experimentally verify proper workings of the circuit including proper RC filters behavior with buffering, operational amplifier volume control and signal recombination, and a power amplifier stage to power an 8Ω speaker.

The experimental results of this report confirm that the completed audio equalizer design met all specifications. Starting with the FRA plot for each passive filter, all three filters had their filter cutoffs within the required $\pm 10\%$ tolerance. Next, the adjustable op-amp gain stages provided smooth control of volume over each low, medium, and high frequency channel which created user control of amplifying or attenuating different frequency ranges of an audio signal. The output V_{amp} was consistent across all frequency ranges at minimum and maximum op-amp configurations. The summing amplifier performed correctly as its output ripple was at the design requirement of $15 \text{ mV}_{\text{rms}}$. Finally, the LM386 power amplifier consistently delivered an output power of above 400 mW at all tested frequencies from 100 Hz to 10 kHz. All aspects of the audio equalizer matched the specification values and performed as expected when a music audio signal was applied.

There were slight deviations between the theoretical design expectations and experimental measurements such as with the filter cutoff frequencies and V_{amp} amplitudes. The cutoff points were slightly lower than expected and the V_{amp} amplitudes were 10% higher than nominal at max gain settings. However, the values were within the tolerances set by the design requirements.

These discrepancies are most likely due to the non-ideal electrical components in the audio equalizer, particularly the resistors and capacitors in the filters. These components have between a $\pm 1\text{-}10\%$ tolerance which shifts the cutoff frequencies for the filters. Another large source of error encountered during experimentation was the uncertainties from test instruments

such as oscilloscope RMS calculations and the probed used to measure the voltage output at certain stages.

Ultimately, the experimental results indicate that the audio equalizer designed in this report has met all operational requirements. The possible sources of measurement deviations were minimal, and all the experimental values were within tolerance levels. This project has successfully proven experimental design of an audio equalizer matches what is expected in a theoretical space by emphasizing proper passive filter design, stable op-amp gain, signal recombination, and output amplification.

References

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