Analog Audio Equalizer with Bass, Mid, and Treble Control

(EE – 213L)

November 19, 2025

Syeda Fatima Alam

Syeda Sidrah Bilal Hashmy

Rafay Ahmed Khan

Contents

I. Project Goal

The goal of this project is to design and implement a three-band analog audio equalizer that takes an input sound signal and allows the user to adjust the bass, mid, and treble frequencies independently. The circuit uses active filters and operational amplifiers to isolate and control different frequency bands, providing real-time tonal customization. The processed output is amplified through a TL071 amplifier and played via a speaker. This project aims to offer a hands-on understanding of audio signal processing and analog filter design while delivering an interactive and high-quality sound experience.

II. Introduction

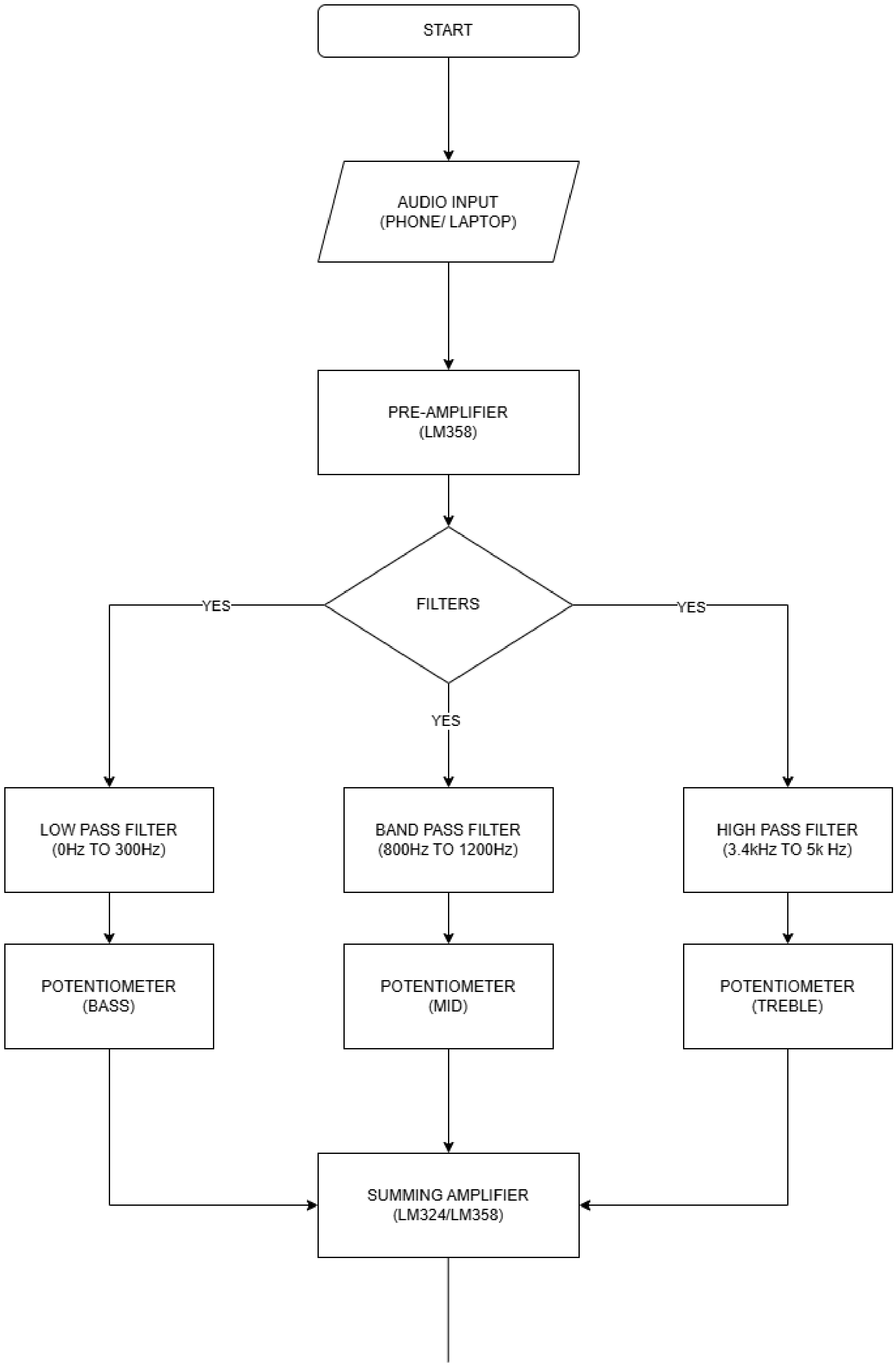
Audio equalization is a key process in sound engineering, allowing selective amplification or attenuation of specific frequency ranges to improve sound quality.
In this project, we designed a passive multi-band filter system that divides an input audio signal into three major bands: low (bass), mid, and high (treble) using a combination of low-pass, band-pass, and high-pass filters.
Each filter is implemented using operational amplifiers to achieve controllable gain and precise cutoff frequencies. This system models the working of equalizers found in music players, amplifiers, and communication devices.

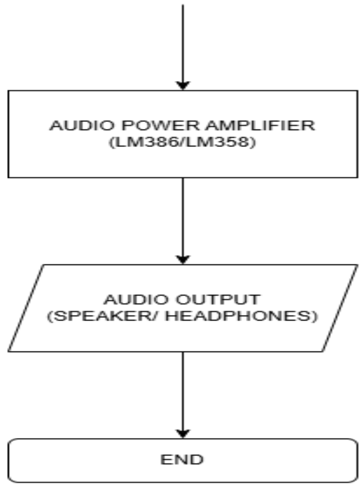
III. Real World Impact

In modern audio systems, sound quality often varies depending on the environment, speaker characteristics, and the type of content being played. Many low-cost or compact devices lack effective tone control, which results in unbalanced sound, excessive bass, unclear vocals, or harsh trebles. This project addresses this limitation by developing an analog audio equalizer that allows users to adjust the bass, mid, and treble components of a music signal in real time.

By integrating passive filter circuits and an amplification stage, the system enhances listening quality and provides users with greater control over how audio is perceived. Such a design finds practical application in car audio systems, portable speakers, home entertainment setups, and even professional mixing consoles, where precise sound adjustment is essential. Additionally, this project demonstrates the core principles of signal processing, filter design, and op-amp applications, making it valuable for both educational and practical engineering purposes.

IV. Block Diagram





V. Description

- **Audio Input:**
  The song enters through a 3.5mm audio jack breakout board from your laptop.
- **Pre-Amplification Stage:**
  Boosts the small input signal to a usable level and makes sure the filters receive a strong enough input for proper tone control.
- **Filter Section:**
  The signal is split into three paths on the breadboard, each containing a different passive filter:

  -Low-pass filter → passes bass frequencies (below ~1k Hz)

  -Band-pass filter → passes mid frequencies (~1k Hz to 10k Hz)

  -High-pass filter → passes treble frequencies (above ~10 kHz)

- **Gain Control (Potentiometers):**
  Each path includes a potentiometer to adjust how loud that frequency range is just like the *Bass, Mid, and Treble knobs* on a music system.
- **Mixing Stage:**
  The outputs from all three filters are recombined into a single mixed output using a summing amplifier.
- **Amplification (TL071):**
  The mixed audio signal is fed into an TL071 amplifier to boost the sound to a level suitable for driving a small speaker.

- **Audio Output:**
  The amplified signal passes through another 3.5mm audio jack breakout board and finally to a speaker or headphones, where you can hear the filtered (equalized) audio.

VI. Complex Engineering Activity Challenges

1. No Sound Output After the Amplifier

- Checked if the DC biasing capacitor was blocking the entire signal.
- Confirmed the coupling capacitor orientation and value.
- Verified the op-amp power rails and ground connections.
- Ensured the input jack breakout board was wired correctly (identified L, R, Ground manually with continuity tests).

2. Distorted Signal at the Filter Output

- Tested the amplifier gain stage to ensure the output was within the op-amp's linear range.
- Reduced gain to avoid clipping.
- Measured the bias voltage to ensure the op-amp wasn't saturating.
- Replaced the TL072 with a fresh IC to rule out damage.

3. Filters Not Responding to Frequency Changes

- Rechecked resistor and capacitor values in each band (bass, mid, treble).
- Verified that the cutoff frequencies matched the calculated ranges (Bass 20–1k Hz, Mid 1k–10k Hz, Treble 10k kHz–50 kHz).
- Ensured potentiometers were working properly by measuring variable resistance with a multimeter.
- Confirmed correct wiring of the band-pass and high-pass sections.

4. Hum or Noise in Output

- Checked all ground connections and ensured a common ground among the amplifier, filters, and input jack.
- Shortened long jumper wires to reduce noise pickup.
- Added decoupling capacitors across op-amp supply rails.
- Removed a ground loop between amplifier and filter circuits.

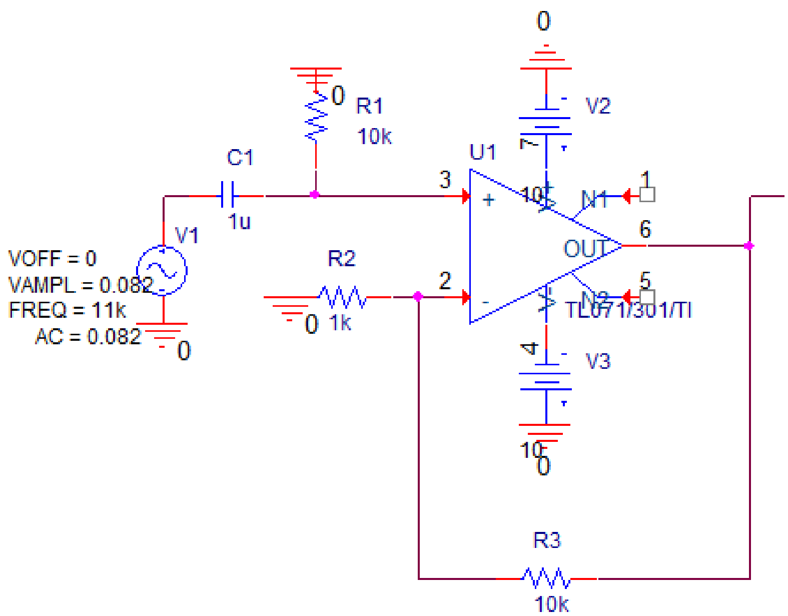
5. Weak or Very Low Output Volume

- Ensured the output of the amplifier was properly coupled into the filter stage.
- Fixed missing decoupling capacitor at the end of the amplifier that was causing DC mixing.
- Confirmed the load (speaker/earphones) was not too low impedance for the op-amp.
- Increased gain slightly after confirming no clipping occurred.

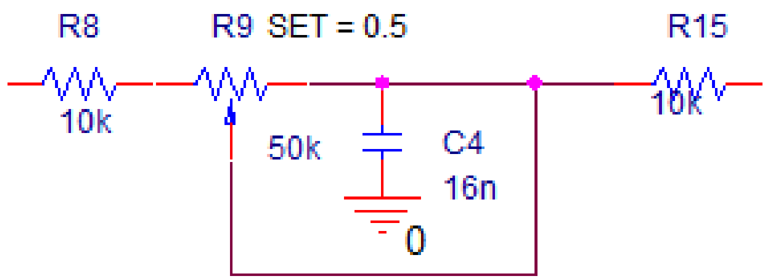
VII. Schematic

The final schematic will be the combination of all different stages into one big circuit as shown in the block diagram.

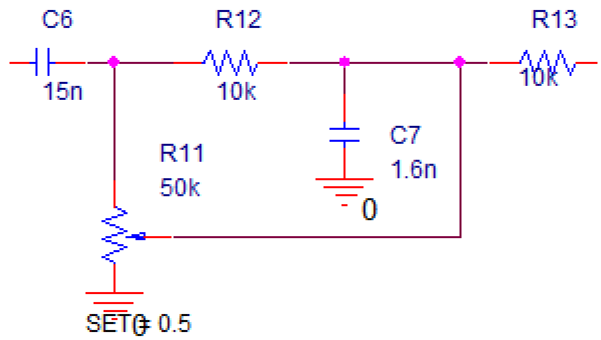
Pre-Amplifier



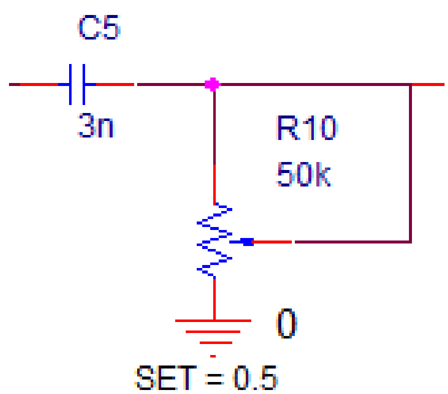
Passive Low-Pass Filter



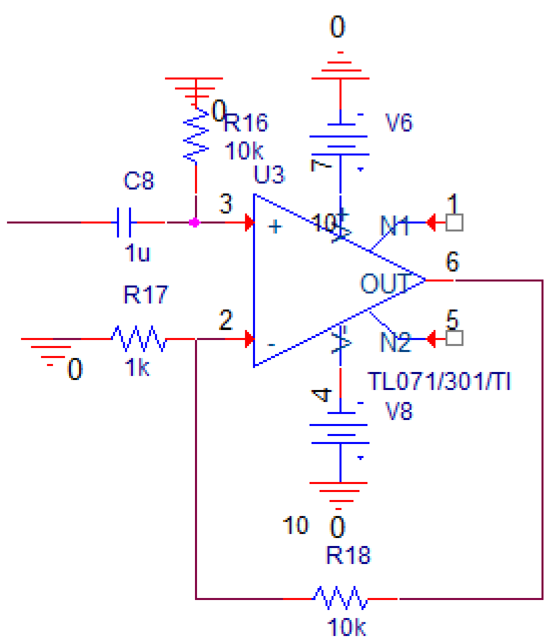
Passive Band-Pass Filter



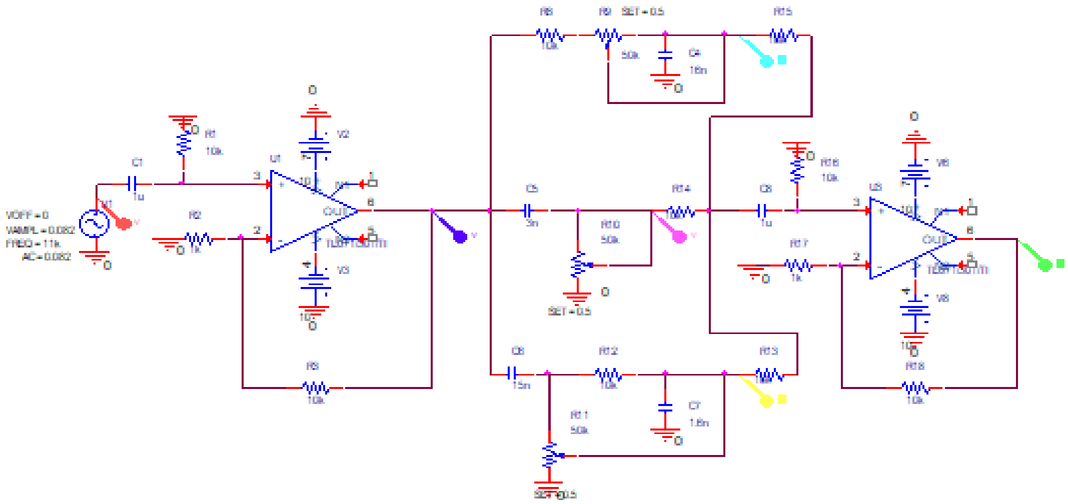
Passive High-Pass Filter



Summing Amplifier

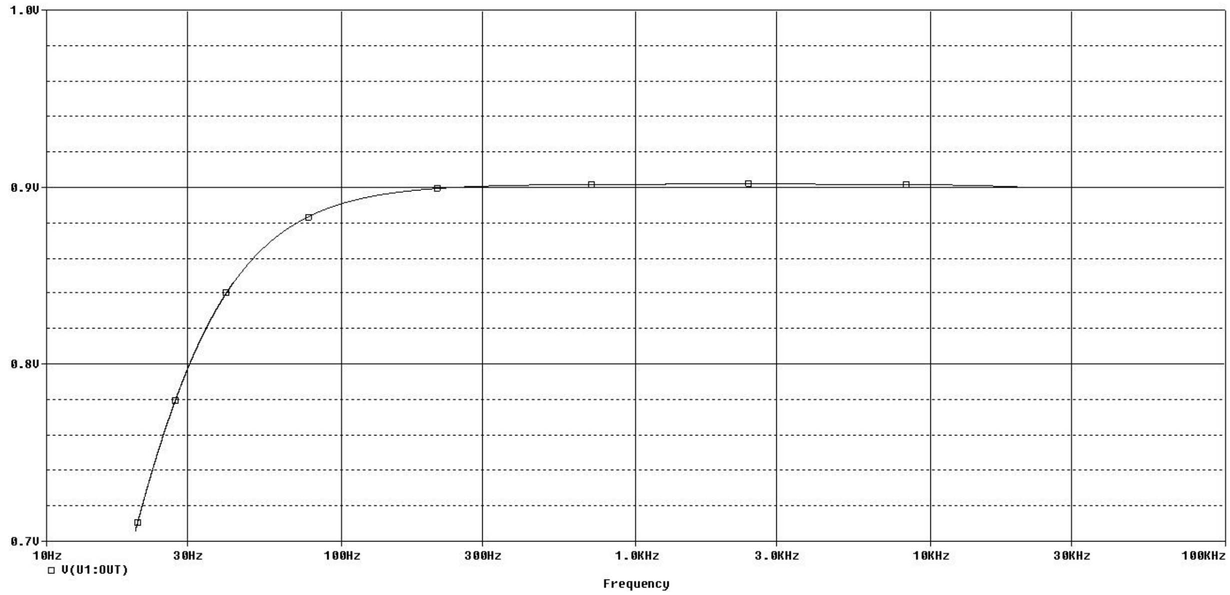


Main Schematic

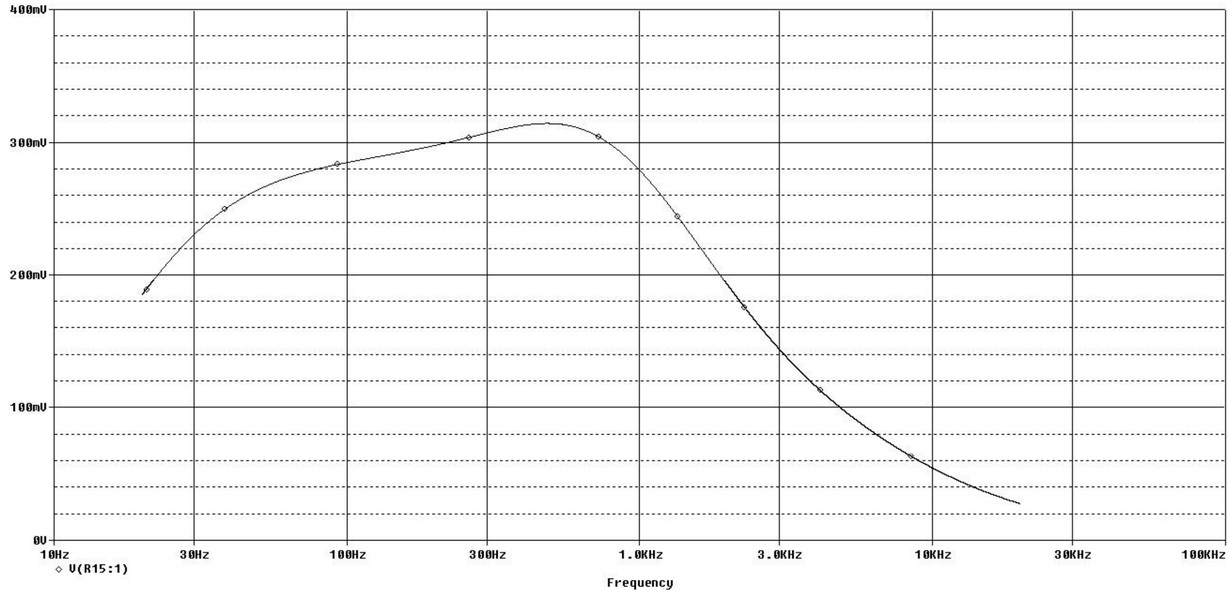


VIII. Simulation

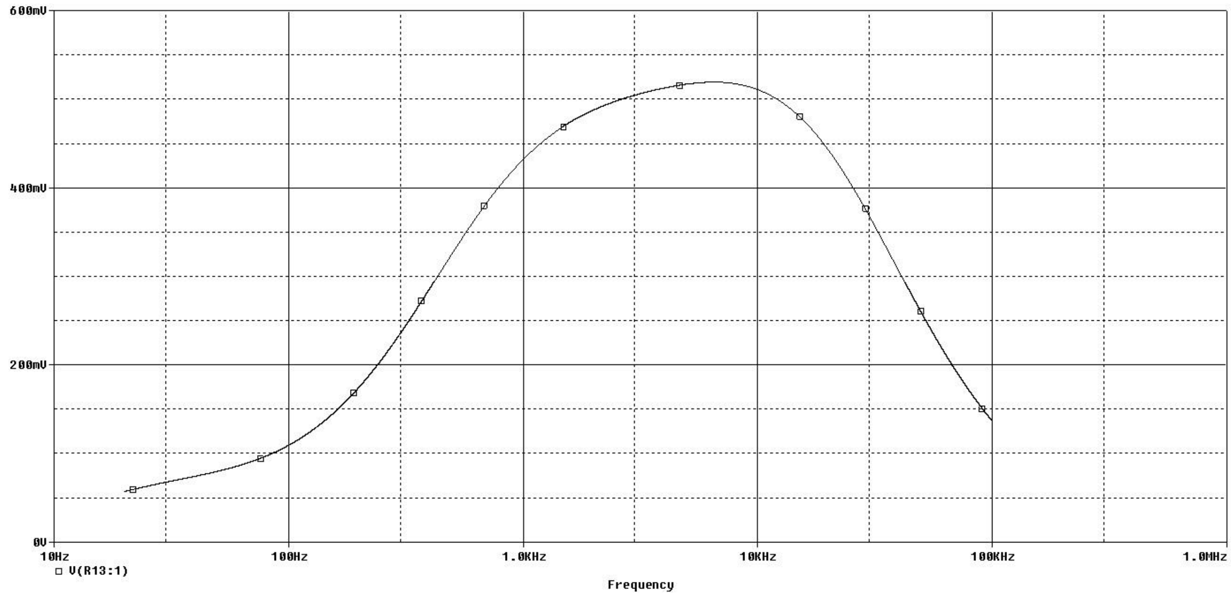
Pre-Amplifier



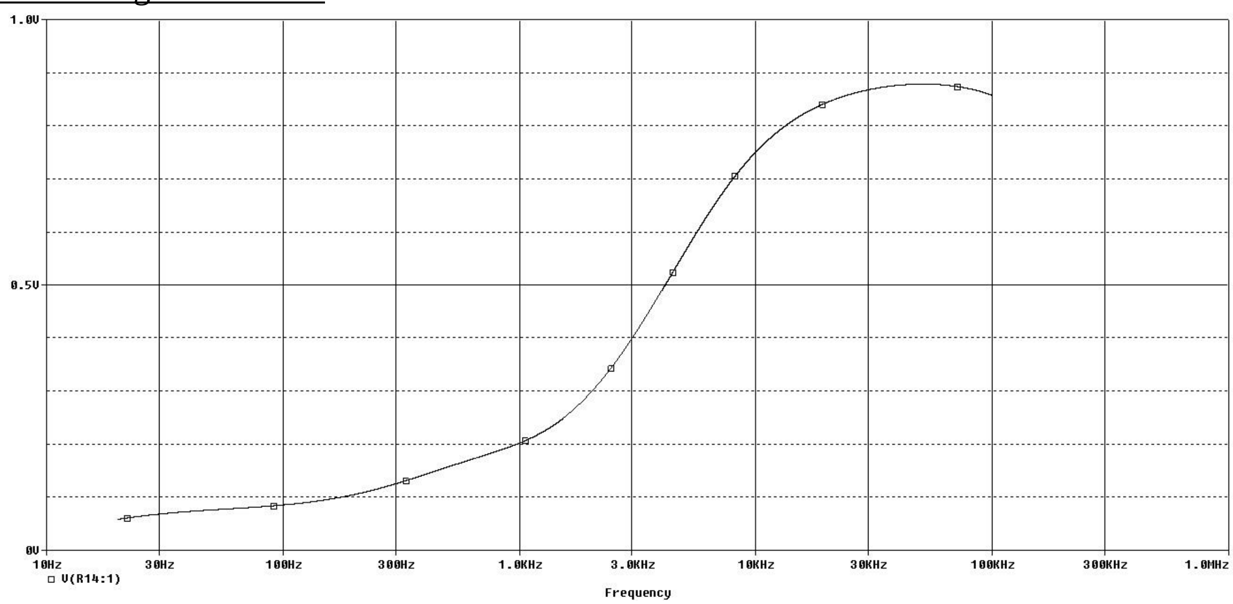
Passive Low-Pass Filter



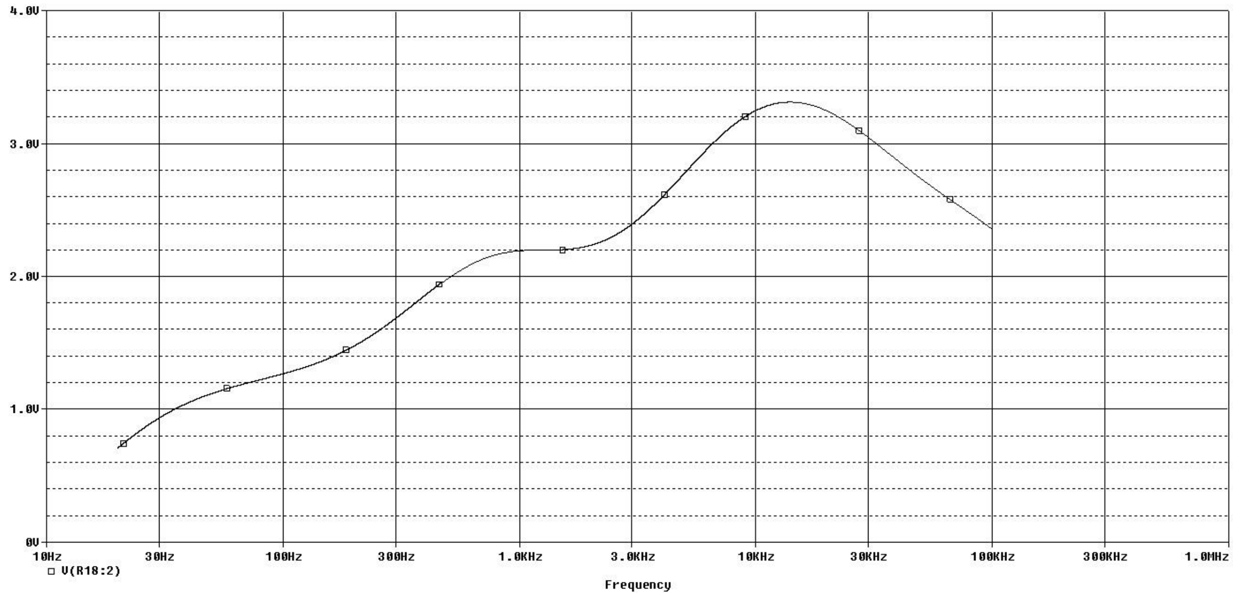
Passive Band-Pass Filter



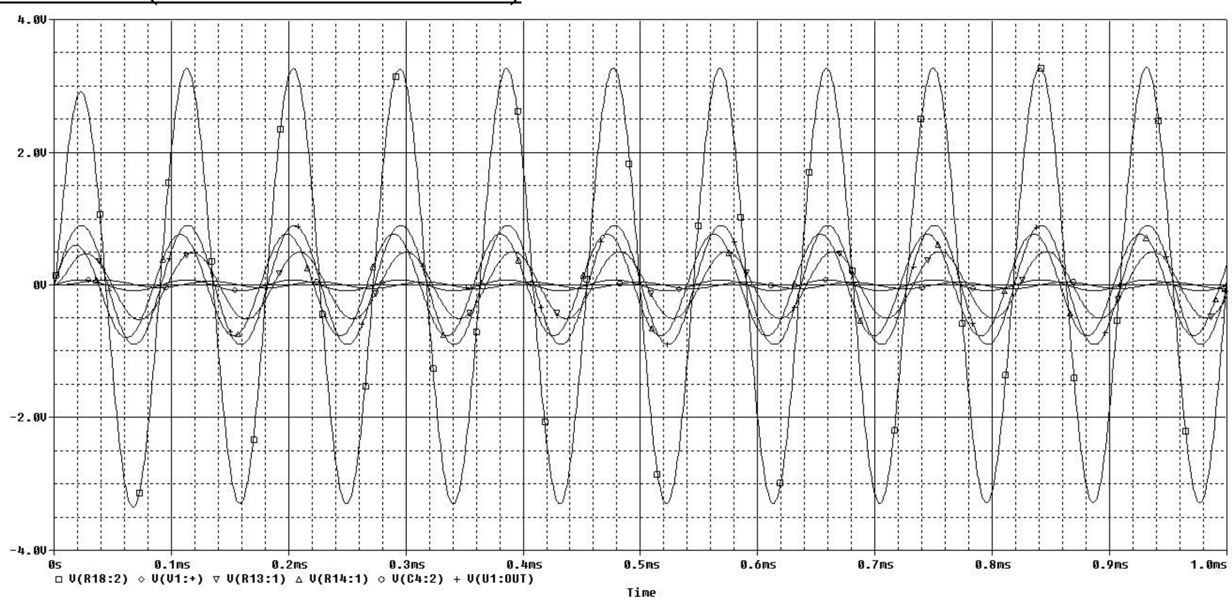
Passive High-Pass Filter



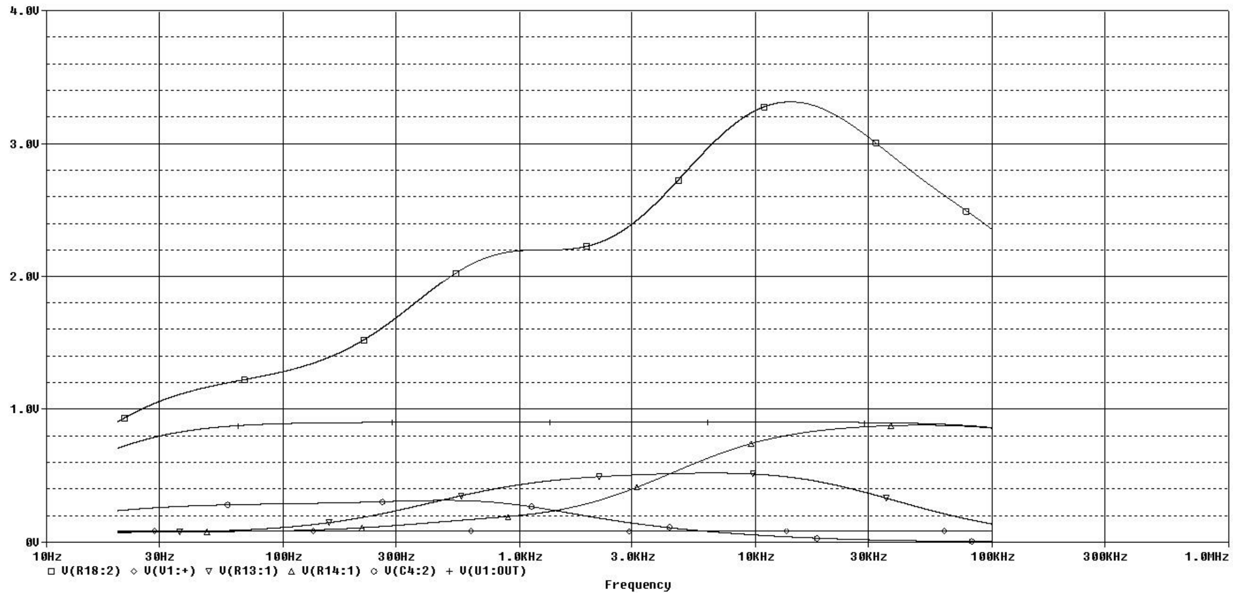
Summing Amplifier



Simulation (Time Domain / Transient)

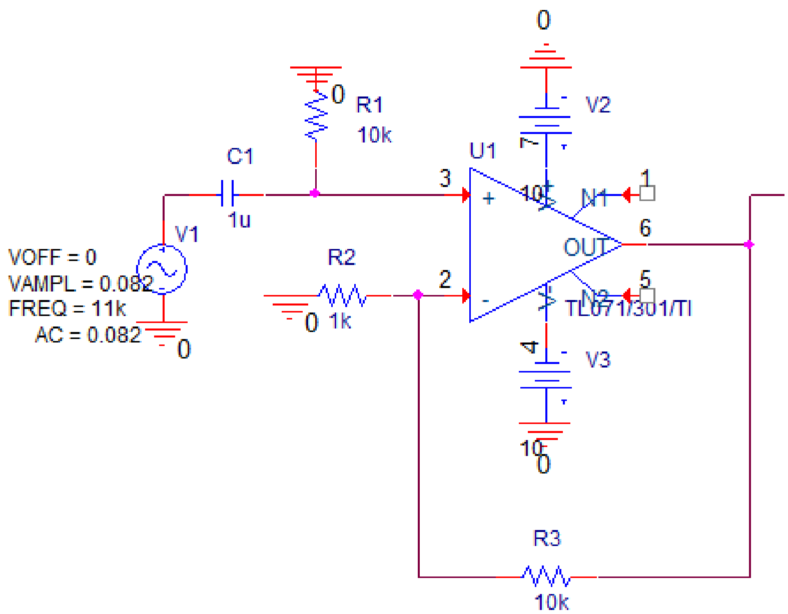


Simulation (AC Sweep)



IX. Calculations

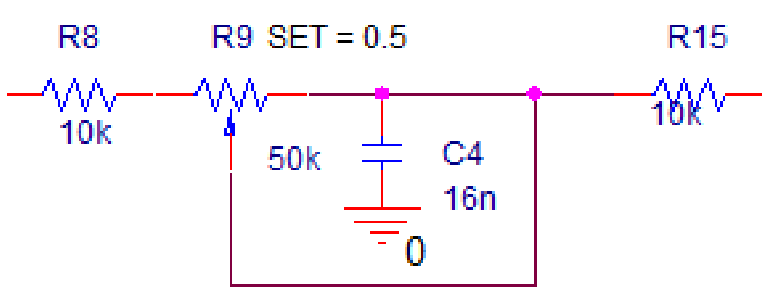
Pre-Amplifier



Circuit Configuration

- IC Used: TL071CP
- Configuration: Non-inverting amplifier
- Input: VSIN for simulation / Audio Signal in hardware
- Gain Formula: $A = 1 + \frac{Rf}{Ri}$
- Cutoff Formula: $fc = \frac{1}{2\pi RC}$
- Gain: $A = 1 + \frac{10k}{1k} = 1 + 10 = 11$
- Capacitor Value: $C = \frac{1}{2\pi(10k)(11k)} = 1.02u$

Passive Low-Pass Filter



Circuit Configuration

- Input: TL071 Pre-Amplifier
- Cutoff Frequency Formula: $fc = \frac{1}{2\pi RC}$
- Transfer Function: $H(\omega) = \frac{Vout}{Vin} = \frac{1}{1+j\omega RC}$
- Capacitor Value:
  - POT = 0.001, f=1k Hz

$$C = \frac{1}{2\pi(0.001 + 10k)(1000Hz)} = 15.915n = 16n$$

  - POT = 25k, C=16nF

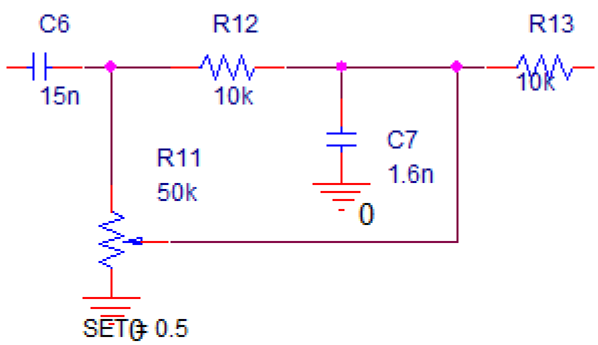
$$f = \frac{1}{2\pi(25k + 10k)(16n)} = 284.205\ Hz$$

  - POT = 50k, C=16nF

$$f = \frac{1}{2\pi(50k + 10k)(16n)} = 165.786\ Hz$$

- Transfer Function: $H(\omega) = \frac{702.36m}{901.98m} = 0.778$

Passive Band-Pass Filter



Circuit Configuration

- Input: TL071 Pre-Amplifier
- Cutoff Frequency Formula: $fc = \frac{1}{2\pi RC}$
- Transfer Function: $H(s) = \frac{Vout}{Vin} = \frac{sR1C1}{(1+sR1C1)(1+sR2C2)}$
- Capacitor Value:
  - POT = 0.001, f=10k Hz

$$C = \frac{1}{2\pi(10k + 0.001)(10k)} = 1.591n = 1.6n$$

- POT = 25k, C=1.6nF

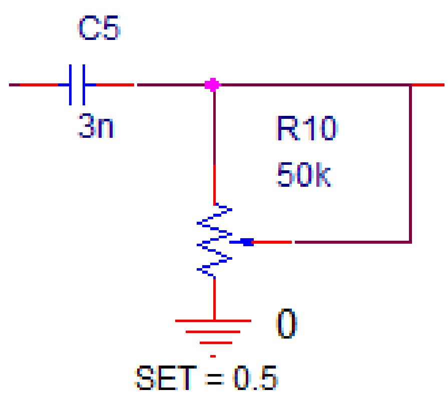
$$fc = \frac{1}{2\pi(10k + 25k)(1.6n)} = 2842.052\ Hz$$

- POT = 50k, C=1.6nF

$$fc = \frac{1}{2\pi(10k + 50k)(1.6n)} = 1657.863\ Hz$$

- Transfer Function: $H(s) = \frac{Vout}{Vin} = \frac{615.045m}{901.97m} = 0.681$

Passive High-Pass Filter



Circuit Configuration

- Input: TL071 Pre-Amplifier
- Cutoff Frequency Formula: $fc = \frac{1}{2\pi RC}$
- Transfer Function: $H(\omega) = \frac{Vout}{Vin} = \frac{RC}{1+RC}$
- Capacitor Value:
  - POT = 0.001, f=1k Hz

$$fc = \frac{1}{2\pi(0.001)(3n)} = 53.051M\ Hz$$

  - POT = 25k, C=16nF

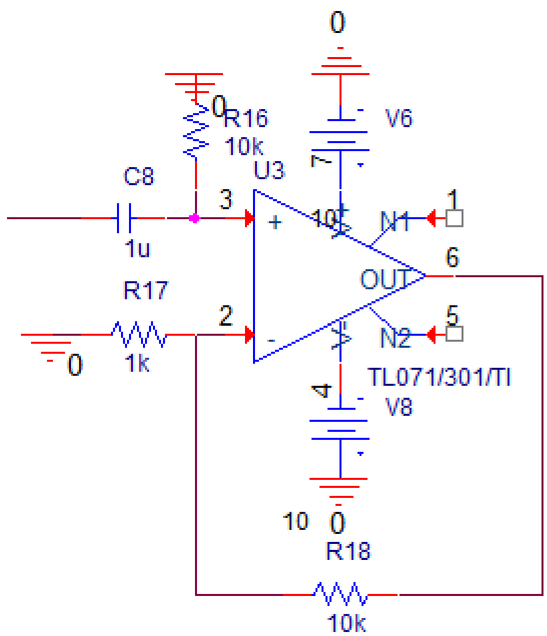
$$fc = \frac{1}{2\pi(25k)(3n)} = 2122.065\ Hz$$

  - POT = 50k, C=16nF

$$fc = \frac{1}{2\pi(50k)(3n)} = 1061.032\ Hz$$

- Transfer Function: $H(\omega) = \frac{Vout}{Vin} = \frac{615.868m}{901.841m} = 0.682$

Summing Amplifier



Circuit Configuration

- IC Used: TL071CP
- Configuration: Non-inverting amplifier
- Input: Sum of three filters (low + band + high)
- Cutoff Frequency Formula: $fc = \frac{1}{2\pi RC}$
- Gain: $A = 1 + \frac{Rf}{Ri} = 1 + \frac{10k}{1k} = 1 + 10 = 11$
- Capacitor Value: $\mathrm{C} = \frac{1}{2\pi(10k)(11k)} = 1.02\mathrm{u}$

X. List of Components

Components	Purpose
OP-AMPs (TL071, LM324, LM358, LM386, LM741)	Used for preamplifier, summing amplifier stage and power audio amplification.
Capacitor	Define filter frequency response, coupling/decoupling signals, stabilize power supply.
Resistor	Set filter cutoff frequencies, op-amp gain, and voltage divider for biasing Vref.
Potentiometer	Act as adjustable gain controls for Bass, Mid, and Treble (tone control knobs).
Audio Jack Breakout Board	One for input (from phone/laptop) and one for output (to speaker/headphones).
Breadboard	For assembling the circuit hardware.
Power Supply / 9V Batteries	Powers the entire circuit (both op-amps and amplifier).
Laptop	To generate or record audio signals and documentation.
Speaker/Headphones	Outputs the filtered and amplified audio signal.
Connecting Wires	Used to interconnect all components on the breadboard.
PCB	For assembling the circuit hardware.
Veroboard	For assembling the circuit hardware.
Multimeter	To measure voltage, current, and resistance at various points.
Oscilloscope	To visualize and analyze input/output audio waveforms.
Function Generator	To provide test input signals (e.g. sine waves at different frequencies).
Soldering Iron	For soldering components onto the PCB.
Soldering Wire	Used to make electrical connections between components.
Cutter	To cut wires.
Plier	To hold and place components on the breadboard.
Stripper	To cut the edges of the wires.

XI. Expected Outcomes

Functional 3-Band Audio Equalizer Circuit
The project is expected to produce a working audio equalizer capable of dividing an input audio signal into three distinct frequency bands — bass (low), mid, and treble (high). Each band can be independently adjusted using potentiometers to control gain, allowing for precise tone shaping.

Clear Signal Amplification through Preamplifier Stage
The preamplifier (implemented using an op-amp TL071CP) is expected to successfully boost the weak input audio signal from the source to a sufficient level for further processing without introducing distortion or noise.

Smooth Frequency Control via Tone Adjustment Knobs
The bass, mid, and treble knobs will enable smooth and continuous adjustment of each frequency band's intensity.

Increasing the bass knob enhances low-frequency sounds (e.g. drums, bass guitar).

Increasing the mid knob enhances vocals and mid-range instruments.

Increasing the treble knob enhances high-frequency components (e.g. cymbals, strings).

Accurate Summation of Frequency Bands
The summing amplifier stage will combine the three processed signals into a single composite audio output without phase distortion or signal loss. This ensures that the modified sound maintains clarity and balance across all frequencies.

Audible Output through Power Summing Amplifier Stage
The TL071CP audio amplifier will amplify the summed signal sufficiently to drive a small speaker. The expected output is a clear and adjustable audio playback reflecting the chosen bass, mid, and treble settings.

Visualization and Testing
Using an oscilloscope, the waveform of the processed audio signal should display noticeable amplitude variations corresponding to different knob positions. The frequency response curves should confirm effective separation and control of low, mid, and high bands.

Stable and Low-Noise Operation
The entire circuit is expected to operate stably under the given supply voltage (9–12V), with minimal background noise, hum, or distortion during playback.

User-Friendly and Compact Design

The final prototype is expected to be compact, easy to operate, and demonstrate a clear understanding of audio signal processing, filtering, and amplification concepts.

XII. Division of Tasks

The project was divided among team members to ensure efficient workflow and proper coordination between design, simulation, and hardware implementation stages. Each member will contribute according to their area of expertise and interest, as outlined below:

Tasks	Description	Member(s)
Problem Identification & Research	Researching real-world issues related to audio filtering and deciding on the equalizer design concept.	Syeda Fatima Alam
Circuit Design & Calculations	Designing low-pass, band-pass, and high-pass filter circuits; calculating component values (resistors, capacitors) and gain.	Syeda Sidrah Bilal Hashmy, Rafay Ahmed Khan
Simulation (PSpice)	Building and simulating the circuit on PSpice to verify cutoff frequencies, gain, and frequency response.	All
Hardware Implementation	Constructing the circuit on breadboard/Veroboard, wiring components neatly, and ensuring proper grounding.	All
Testing & Troubleshooting	Measuring output using oscilloscope and function generator; comparing practical and simulated results.	All
Report Writing & Documentation	Preparing project proposal, progress reports, and final documentation including data analysis and results.	All
Presentation & Demonstration	Preparing and delivering the final presentation and explaining the project operation to evaluators.	All

A. References

References in IEEE standard format.

[1] R. Klee and D. McIntosh, “Audio Effects Project,” GitHub repository, 2018. [Online]. Available: https://github.com/robertklee/AudioEffectsProject. [Accessed: Oct. 26, 2025].

[2] R. Teja, “Summing Amplifier,” *ElectronicsHub*, Apr. 2, 2024. [Online]. Available: https://www.electronicshub.org/summing-amplifier/. [Accessed: Oct. 26, 2025].

[3] “Simple Mic Amplifier Circuit using IC LM358,” *Circuit-Ideas*, [Online]. Available: https://circuit-ideas.com/simple-mic-amplifier-circuit-using-ic-lm358/. [Accessed: Oct. 26, 2025].

[4] “Build a Great-Sounding Audio Amplifier with Bass Boost from the LM386,” *CircuitBasics*. [Online]. Available: https://www.circuitbasics.com/build-a-great-sounding-audio-amplifier-with-bass-boost-from-the-lm386/. [Accessed: Oct. 26, 2025].

[5] “Summing Amplifier,” *ElectronicsHub*. [Online]. Available: https://www.electronicshub.org/summing-amplifier/. [Accessed: Oct. 26, 2025].

[6] N. V. (NirwanV), “Five-Band Equalizer,” GitHub repository, Oct. 2025. [Online]. Available: https://github.com/NirwanV/Five-Band-Equalizer/tree/main. [Accessed: Oct. 26, 2025].

B. Data Sheets

[1] Texas Instruments, “LM741 Operational Amplifier Datasheet (Rev. D),” Oct. 30, 2015. [Online]. Available: https://www.ti.com/lit/ds/symlink/lm741.pdf. [Accessed: Oct. 26, 2025]

[2] Texas Instruments, “LM358 Dual Operational Amplifiers Datasheet (Rev. J),” Mar. 14, 2022. [Online]. Available: https://www.ti.com/lit/ds/symlink/lm358.pdf. [Accessed: Oct. 26, 2025].

[3] Texas Instruments, “LM324 Quad-Operational Amplifier Datasheet (Rev. SLOS066AD – September 1975, Revised October 2024),” [Online]. Available: https://www.ti.com/lit/ds/symlink/lm324.pdf. [Accessed: Oct. 26, 2025].

[4] Texas Instruments, “LM386 Low Voltage Audio Power Amplifier Datasheet (Rev. D),” Aug. 31, 2023. [Online]. Available: https://www.ti.com/lit/ds/symlink/lm386.pdf. [Accessed: Oct. 26, 2025].

This page is intentionally left blank.