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Five Band Audio Equalizer

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Abstract
Our project focuses on the design and implementation of a five-band audio equalizer, enabling control over specific frequency ranges. The design uses a 4th-order Butterworth filter with multiple feedback(MFB) topology for each frequency band. Gain control in each band is achieved through inverting amplifiers with variable resistors in the feedback loop. All operational amplifiers used in the circuit are powered by an external power supply built using a center tapped transformer. The power supply can provide +15V and -15V to each operational amplifier. To display the volume level of each band, we use five LED bars driven by LM3914 LED bar display drivers. The equalizer uses 3.5mm AUX ports for input and output, ensuring compatibility with standard audio devices.

Abbreviations and Acronyms

OPAMP Operational Amplifier

LED Light Emitting Diode

AUX Auxiliary

CAD Computer Aided Design

PCB Peinted Circuit Board

IC Integrated Circuit

Contents

1 Introduction

Audio equalizers are essential tools in sound processing, allowing users to modify the tonal balance of audio signals by adjusting specific frequency ranges. This project focuses on designing a five-band analog audio equalizer with the goal of providing both precision and simplicity. Each frequency band is carefully tuned to cover a specific range, enabling users to boost or attenuate bass, midrange, or treble frequencies based on their preference. The use of multiple feedback (MFB) topology for the filters ensures accurate and stable performance, while visual feedback for volume levels is provided using LED bar displays. The system is designed to work with standard audio devices via 3.5mm AUX ports, making it versatile and user-friendly.

2 Functionality

The five-band audio equalizer operates by dividing the audio signal into five distinct frequency bands, each controlled by a 4th-order Butterworth filter in MFB topology. Users can adjust the gain of each band using potentiometers connected to inverting amplifiers. The equalizer is powered by an external ±15V dual power supply, built using a center-tapped transformer. Visual feedback for the volume level of each band is provided by LED bar displays, driven by LM3914 ICs. Audio signals are input to the system via a 3.5mm AUX port, processed through the filters, and output through another AUX port, making the equalizer compatible with a wide range of audio devices.

Frequency Band	**Range**	**Mid Frequency**
Band 1 (Bass)	20 - 300Hz	77.46Hz
Band 2 (Lower Midrange)	300 - 1,000Hz	547.72Hz
Band 3 (Mid Range)	1 - 4kHz	2kHz
Band 4 (PUpper Midrange)	4 - 10kHz	6.32kHz
Band 5 (Treble)	10 - 20kHz	14.14kHz

Table 1: Frequency Bands and Their Ranges

2.1 System Architecture

This explains how different components, such as filters, amplifiers, power supply, and visual indicators, are integrated to create a functioning five-band equalizer. Here is the functional block diagram to illustrate the relationship between those components and the signal flow through them.

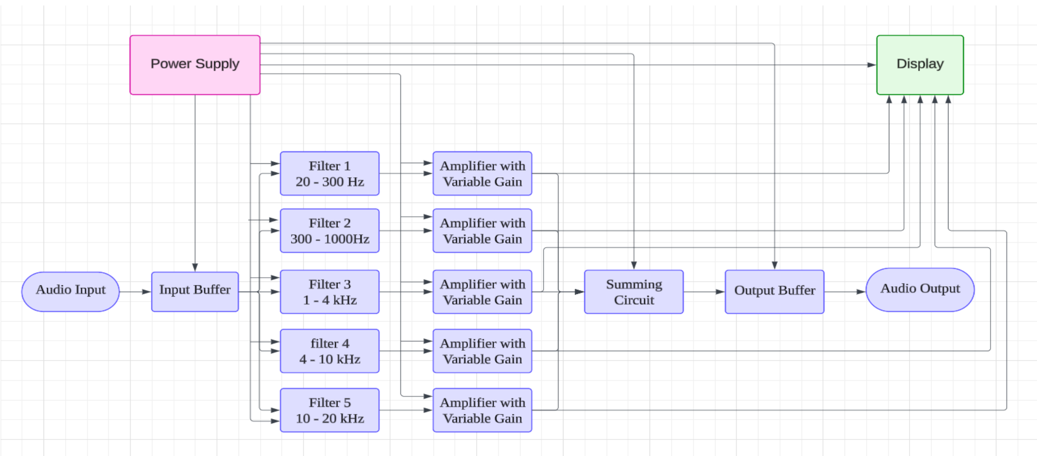

Figure 1: Functional Block diagram.

2.2 Buffer Circuit

A buffer circuit is used to isolate different stages of the equalizer to ensure high input impedence. It also helps improve the overall performance and reliability of the circuit by minimizing loading effects.

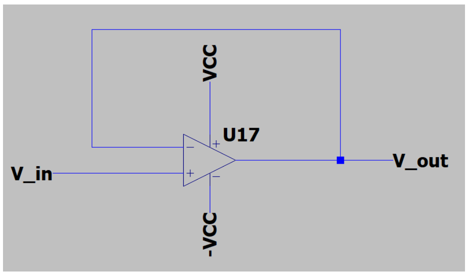

Figure 2: Input Buffer.

2.3 Filters

In this project, we implemented bandpass filters for isolating specific ranges of the audio spectrum. The design process involved selecting suitable filter types,

Active vs. Passive Filters
The initial design choice was between active and passive filters. Active filters, which use operational amplifiers in combination with resistors and capacitors, were chosen for their superior performance and precise frequency response. Unlike passive filters, active filters allow for amplification and do not suffer from significant signal loss, making them ideal for our application.

Filter Topologies
Two main active filter topologies were considered:

- Sallen-Key Topology
- Multiple Feedback(MFB) Topology

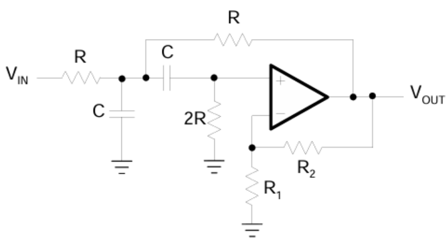

Figure 3: Sallen-Key Topology.

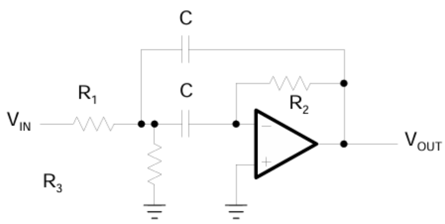

Figure 4: Multiple Feedback Topology.

After evaluating the characteristics of each topology, the Multiple Feedback (MFB) topology was selected. MFB filters are well-suited for applications requiring higher-order filters, as they offer better control over the quality factor and stability.

Selection of Filter Type
The next step was to choose the appropriate filter response type. The options considered were:

- **Butterworth**: flat passband with no ripples, providing a smooth and distortion-free response.

- **Chebyshev**: Offers a steeper roll-off but introduces ripples in the passband.
- **Bessel**: Offers a steeper roll-off but introduces ripples in the passband.
  The Butterworth filter was selected due to its flat passband and lack of ripples, ensuring a uniform response within the desired frequency range. However, since the Butterworth filter's roll-off is not as steep as some other filter types, we increased the filter order to achieve the required performance.

So, in final design we implemented 4th order butterworth bandpass filter using cascaded two 2nd order MFB bandpass filters.

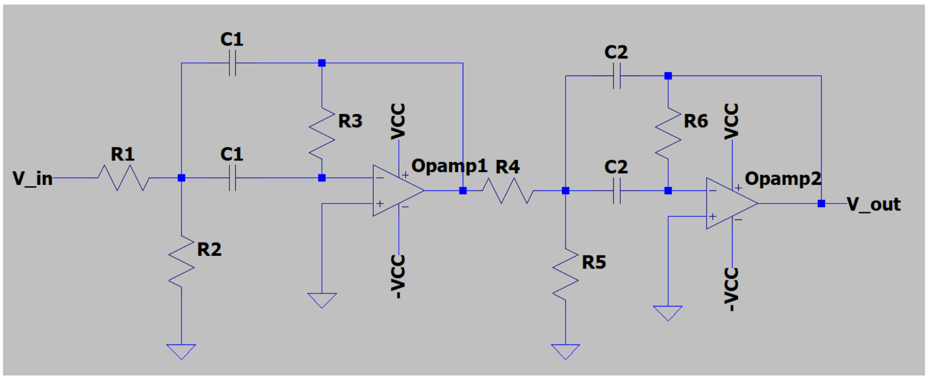

Figure 5: 4th Order Bandpass Filter.

2.3.1 Filter Analysis

Derivation of the transfer function of second order multiple feedback bandpass filter

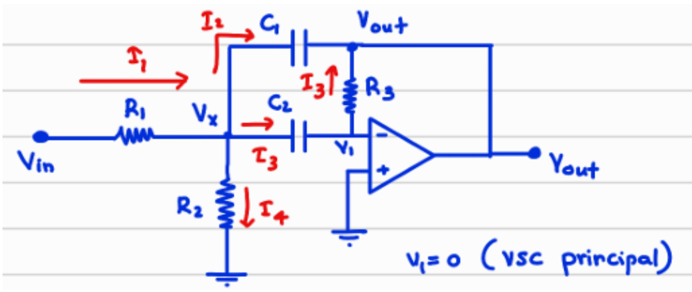

Figure 6: 2nd Order Bandpass Filter.

Applying KCL at the node:

$$\frac{V_{\text{in}} - V_x}{R_1} = (V_x - V_{\text{out}})j2\pi f C_1 + \frac{V_x}{R_2} + V_x j2\pi f C_2 \tag{1}$$

Same I_3 current goes through capacitor C_2 and R_3:

$$V_x j2\pi f C_2 = -\frac{V_{\text{out}}}{R_3} \implies V_x = -\frac{V_{\text{out}}}{j2\pi f C_2 R_3} \tag{2}$$

Substitute V_x from (2) into (1):

$$\frac{V_{\text{in}}}{R_1} + \frac{V_{\text{out}}}{j2\pi f C_2 R_1 R_3} = \frac{-V_{\text{out}}}{j2\pi f C_2 R_3}\left(j2\pi f C_1 + \frac{1}{R_2} + j2\pi f C_2\right) - V_{\text{out}} j2\pi f C_1$$

Simplify:

$$\frac{V_{\text{in}}}{R_1} = -V_{\text{out}}\left[\frac{1}{j2\pi f C_2 R_1 R_3} + \frac{C_1}{C_2 R_3} + \frac{1}{j2\pi f C_2 R_2 R_3} + \frac{1}{R_3} + j2\pi f C_1\right]$$

Reorganizing for $\frac{V_{\text{out}}}{V_{\text{in}}}$:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{-\frac{1}{R_1}}{\left[\frac{1}{j2\pi f C_2 R_3}\left(\frac{1}{R_1} + \frac{1}{R_2}\right) + \frac{C_1+C_2}{C_2 R_3} + j2\pi f C_1\right]}$$

Further simplified:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{\frac{j2\pi f}{R_1 C_1}}{(j2\pi f)^2 + j2\pi f\left(\frac{C_1+C_2}{C_1 C_2 R_3}\right) + \frac{1}{C_1 C_2 R_3}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)} \tag{3}$$

Standard Form

This can be written in the standard transfer function form:

$$H(j\omega) = \frac{-H\omega_0(j\omega)}{(j\omega)^2 + \alpha\omega_0(j\omega) + \omega_0^2} \tag{4}$$

We can cascade two second-order filters to create a fourth-order filter.

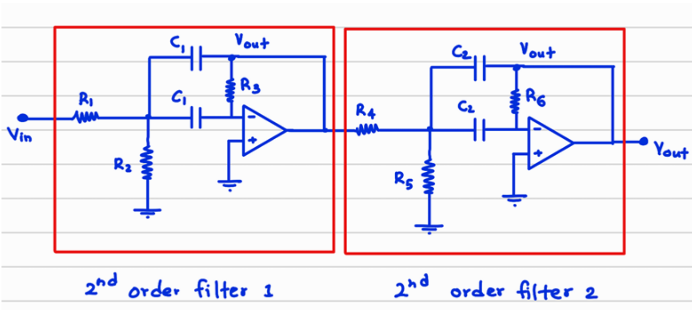

Figure 7: 2 Stages of 4th Order Bandpass Filter.

Transfer Function in Laplace domain

$$H(s) = \left[\frac{-\frac{s}{R_1 C_1}}{s^2 + \frac{2s}{C_1 R_3} + \frac{1}{C_1^2 R_3}(\frac{1}{R_1} + \frac{1}{R_2})}\right]\left[\frac{-\frac{s}{R_4 C_2}}{s^2 + \frac{2s}{C_2 R_6} + \frac{1}{C_2^2 R_6}(\frac{1}{R_4} + \frac{1}{R_5})}\right] \tag{5}$$

The general transfer function for the filter design is:

$$A(s) = \left[\frac{\frac{A_{mi}}{Q_i}\alpha s}{s^2 + \frac{\alpha s}{Q_i} + \alpha^2}\right]\left[\frac{\frac{A_{mi}}{Q_i \alpha} s}{s^2 + \frac{s}{Q_i \alpha} + \frac{1}{\alpha^2}}\right] \tag{6}$$

where:

$$A_{mi} = \text{mid frequency gain}, \quad Q_i = \text{Pole quality factor}, \quad Q = \frac{f_m}{\text{BW}}$$

The mid-frequencies of individual filters are derived as:

$$f_{m_1} = f_m \alpha, \quad f_{m_2} = \frac{f_m}{\alpha}$$

For both filters:

$$Q_i = \frac{Q\big((1+\alpha^2)b_1\big)}{\alpha a_1}, \quad A_{mi} = \frac{Q_i}{Q}\sqrt{\frac{A_m}{b_1}}$$

For Butterworth Filters

For Butterworth second-order filters:

$$a_1 = 1.4142, \quad b_1 = 1$$

The value of α is determined by successive approximation using the equation:

$$\alpha^2 + \frac{\alpha \Delta\Omega a_1}{b_1(1+\alpha^2)} + \frac{1}{\alpha^2} - 2 - \frac{(\Delta\Omega)^2}{b_1} = 0 \tag{7}$$

where:

$$\Delta\Omega = \text{normalized bandwidth} = \frac{1}{Q}$$

Component Selection

To design individual filters, we can choose C_1, C_2. Then, based on those, $R_1, R_2, R_3, R_4, R_5, R_6$ can be calculated as follows:

For filter stage 1:

$$R_3 = \frac{Q_i}{\pi f_{m1} C_1} \tag{8}$$

$$R_1 = \frac{R_3}{2A_{mi}} \tag{9}$$

$$R_2 = \frac{A_{mi} R_1}{2Q_i^2 + A_{mi}} \tag{10}$$

For filter stage 2:

$$R_6 = \frac{Q_i}{\pi f_{m2} C_2} \tag{11}$$

$$R_4 = \frac{R_6}{2A_{mi}} \tag{12}$$

$$R_5 = \frac{A_{mi} R_4}{2Q_i^2 + A_{mi}} \tag{13}$$

2.3.2 Tables

After calculating the required values, we plotted the transfer functions using MATLAB. However, we observed slight differences in the results. We might not achieve the desired gain and cutoff frequencies due to the constraints of the analysis we performed earlier. Specifically, the analysis was based on high Q values, while in our project, many of the frequency bands have lower Q values. As a result, we had to arbitrarily adjust the parameters through a trial-and-error process to obtain the desired transfer function in MATLAB.

Frequency Band	C_1	R_1	R_2	R_3	C_2	R_4	R_5	R_6
20 - 300 Hz	10nF	33kΩ	180kΩ	150kΩ	100nF	15kΩ	270kΩ	82kΩ
300-1000 Hz	100nF	3.3kΩ	4.7kΩ	12kΩ	100nF	1.5kΩ	1.5kΩ	4.7kΩ
1 - 4 kHz	10nF	3.3kΩ	5.6Ω	10kΩ	100nF	820Ω	2.2kΩ	3.3kΩ
4 - 10 kHz	10nF	1.8kΩ	820Ω	5.6kΩ	20nF	1.8kΩ	820Ω	5.6Ω
10 -20 kHz	3.3nF	3.3kΩ	820Ω	10kΩ	33nF	560Ω	150Ω	1.8kΩ

Table 2: Example of a 5x7 Table

2.3.3 Plots

The plots show the magnitude responses of the transfer functions for each filter, generated using MATLAB.

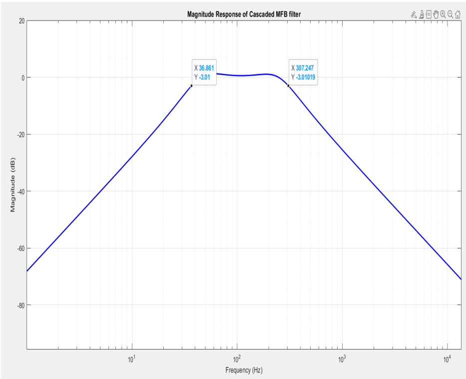

Figure 8: 20 - 300 Hz Band.

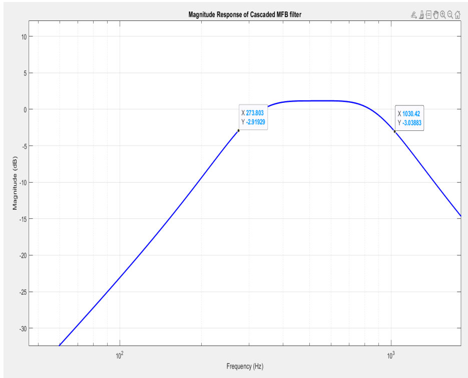

Figure 9: 300 - 1000 Hz Band.

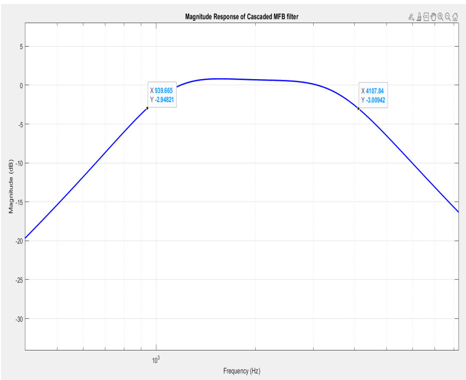

Figure 10: 1 - 4 kHz Band.

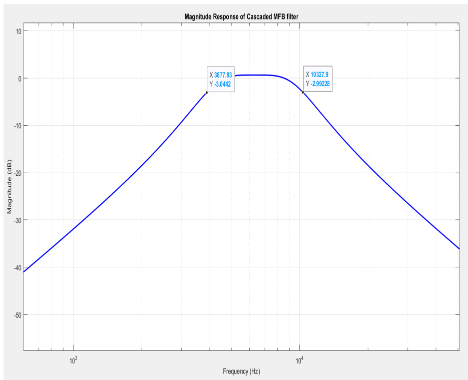

Figure 11: 4 - 10 kHz Band.

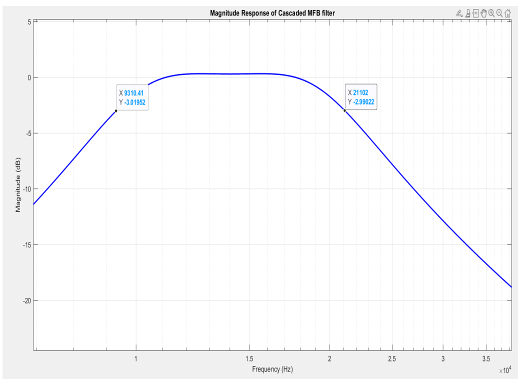

Figure 12: 10 - 20 kHz Band.

2.4 Amplifiers with variable Gain

In this project, we need to control the gain of each frequency band separately to allow precise adjustments to increase or attenuate specific ranges. To achieve this, we use operational amplifiers configured as inverting amplifiers with a variable resistor (potentiometer) in the feedback loop.

Configuration
An inverting amplifier configuration is selected for its simplicity. The gain of the amplifier is determined by the ratio of the feedback resistor to the input resistor.

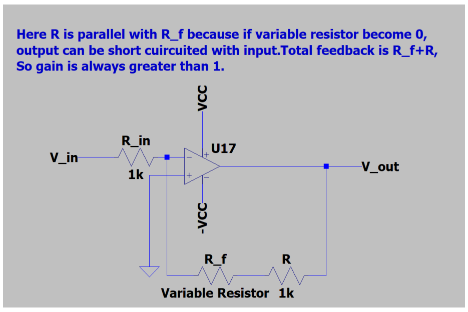

Figure 13: Amplifier with Variable Gain.

$$\text{Gain (A)} = -\frac{R_f}{R_{in}} \tag{14}$$

Here, R_f is the feedback resistor, and R_{in} is the input resistor. In this project, a 5kΩ potentiometer is used as the feedback resistor R_f. Upon adjustment of the potentiometer, the effective resistance in the feedback loop changes, allowing the gain to be varied smoothly.

2.5 Adder Circuit

In this project, a scaling adder circuit is used to combine the outputs of the individual frequency bands into a single output signal. The adder circuit sums the amplified signals from all five bands, ensuring that the adjusted frequencies are properly mixed while maintaining the overall balance of the audio signal.

Configuration
A scaling adder is implemented using a single operational amplifier (op-amp) in the inverting configuration. This type of circuit combines multiple input signals, each scaled by a specific factor(Here we use 1 as the scaling factor). The scaling factor is determined by the input resistors connected to each input signal.

The output of the scaling adder is given by the equation:

$$V_{\text{out}} = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_4}{R_4} + \frac{V_5}{R_5} \right) \tag{15}$$

Here, $R_1, R_2, R_3, R_4, R_5, R_f$ are 1kΩ

$$V_{\text{out}} = -(V_1 + V_2 + V_3 + V_4 + V_5) \tag{16}$$

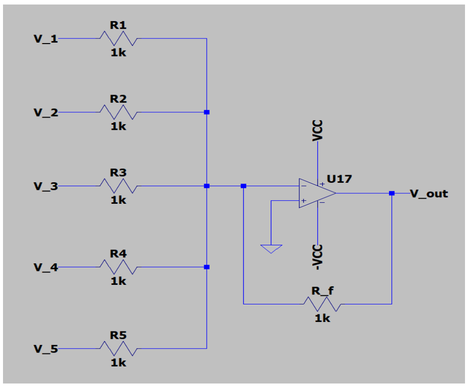

Figure 14: Scaling Adder.

2.6 Power Supply

We use a dual power supply of +15V and -15V to power all the operational amplifiers and the display circuit. A center-tapped transformer is used to step down the 230V AC input.

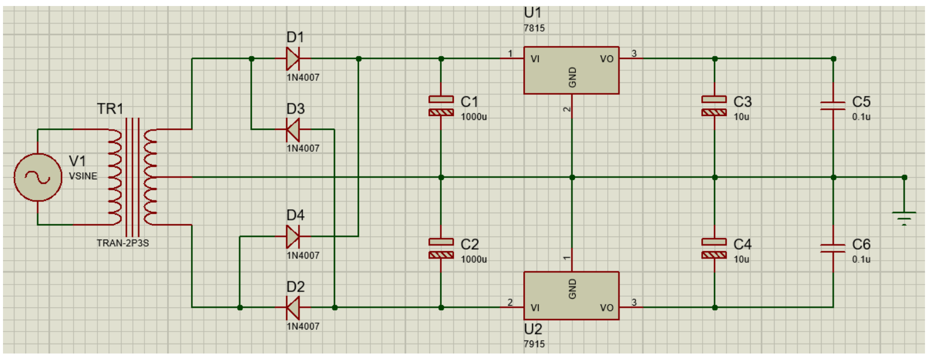

Figure 15: Power Supply Circuit

2.7 Display

The LED bar display, driven by the LM3914 LED driver IC, is used to visually illustrate the voltage levels of each frequency band. The LM3914 converts the analog voltage output from each band into a corresponding LED display, providing a clear and intuitive representation of the signal strength. This allows users to easily monitor and compare the levels of each frequency band in real time.

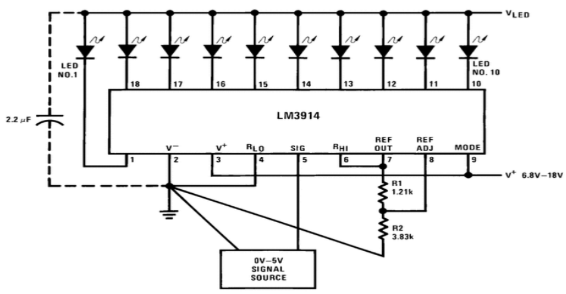

Figure 16: Display Driver IC

3 Component Selection

3.1 Operational Amplifiers

We have a wide range of operational amplifiers (op-amps) available in the market. Among them, several are specifically designed for audio applications, offering low noise, high linearity, and other desired properties to ensure high-quality audio performance. Here are some examples of popular audio op-amps along with their respective slew rates and noise levels:

OpAmp	Noise (nV/$\sqrt{Hz}$)	Slew Rate (V/μs)
TL072	18	13
NE5532	5	9
OPA2134	8	20
LM4562	2.7	10

Table 3: Operational Amplifiers for Audio Applications

We deal with signals ranging from 20 Hz to 20 kHz, with a maximum voltage of 5 V. The maximum rate of change of the signal is given by:

$$x(t) = Asin(2\pi ft)$$

$$\frac{dx(t)}{dt} = A2\pi fcos(2\pi ft)$$

$$\left[\frac{dx(t)}{dt}\right]_{max} = 5.2\pi 20000(1)$$

$$\left[\frac{dx(t)}{dt}\right]_{max} = 6.2832V/\mu s$$

So, the minimum slew rate needed is approximately 6.3 V/μ s. All of the op-amps mentioned above are suitable for our application. However, we chose TL072 because of its availability and ease of sourcing in Sri Lanka.

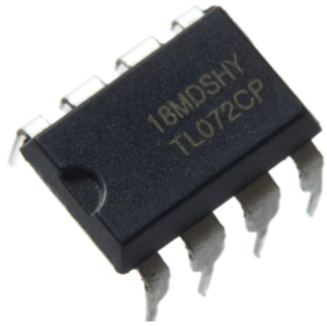

Figure 17: TL072 Operational Amplifier

3.2 Resistors and Capasitors

In our application, we use 10% tolerance resistors, which provide a balance between cost-effectiveness and acceptable performance for our design requirements. For coupling and decoupling purposes, we employ 10µF electrolytic capacitors, as they offer high capacitance values suitable for blocking DC components and stabilizing power supplies. For the filter stages, we utilize film capacitors, which are preferred due to their superior stability, low dielectric losses, and precise capacitance values, ensuring consistent performance in filtering applications.

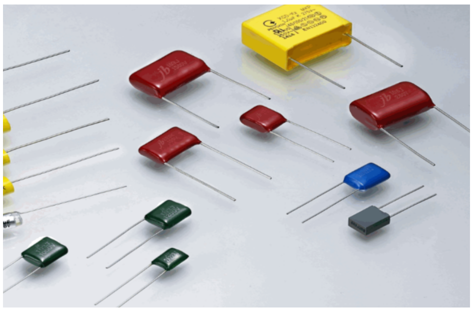

Figure 18: Film Capasitors.

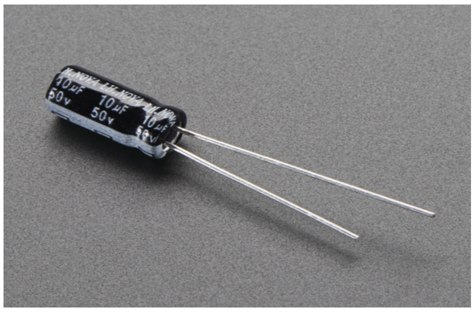

Figure 19: 10μF Electrolytic Capasitor.

3.3 Voltage Regulators

In our power supply design, we use LM7815 and LM7915 voltage regulators to provide stable +15V and -15V outputs, respectively. These regulators ensure a reliable dual power supply for components requiring positive and negative voltage rails, such as operational amplifiers in analog circuits. Additionally, we incorporate the LM7805 voltage regulator to supply a steady +5V output specifically for powering the LED bars.

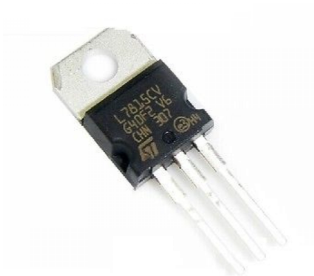

Figure 20: LM7815 Voltage Regulator.

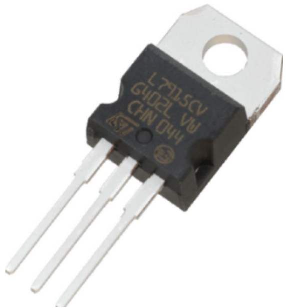

Figure 21: LM7915 Voltage Regulator.

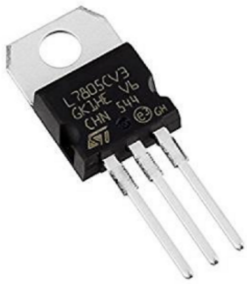

Figure 22: LM7805 Voltage regulator.

3.4 Display

In our display system, we use five 10-segment LED bar graph displays, each driven by an LM3914 driver IC. The LM3914 allows the LEDs to operate in either bar or dot mode, providing a clear and accurate visual representation of the signal levels.

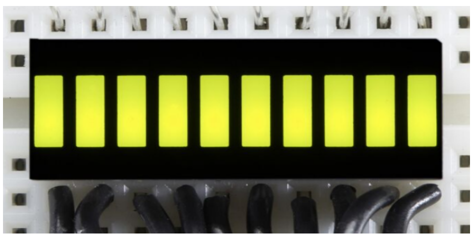

Figure 23: 10-Segment LED Bar Display.

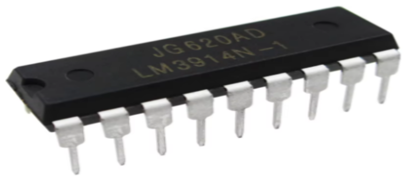

Figure 24: LM3914 Display Driver IC.

4 Software Simulation and Hardware Testing

The software simulations are done using LTSpice and Proteus, and the results are shown in the figures.

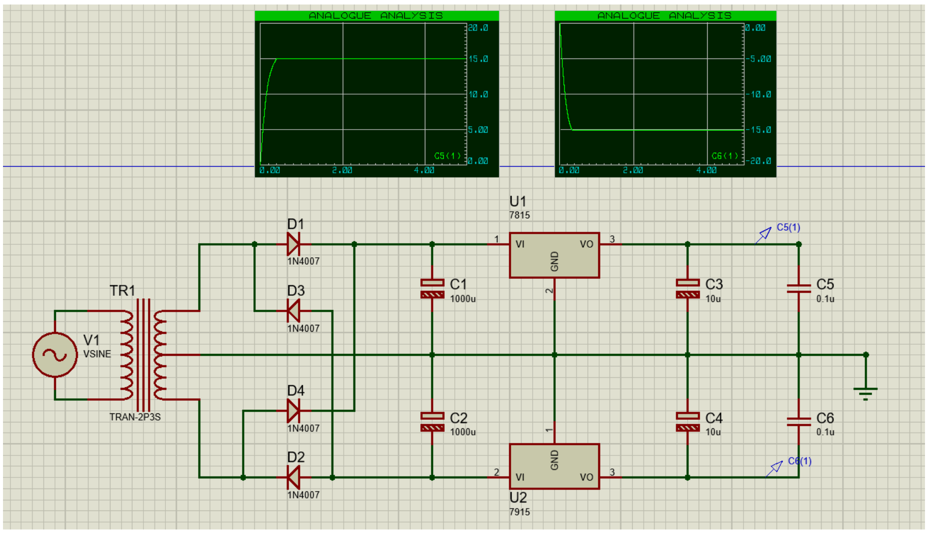

Figure 25: Simulation of Power Supply

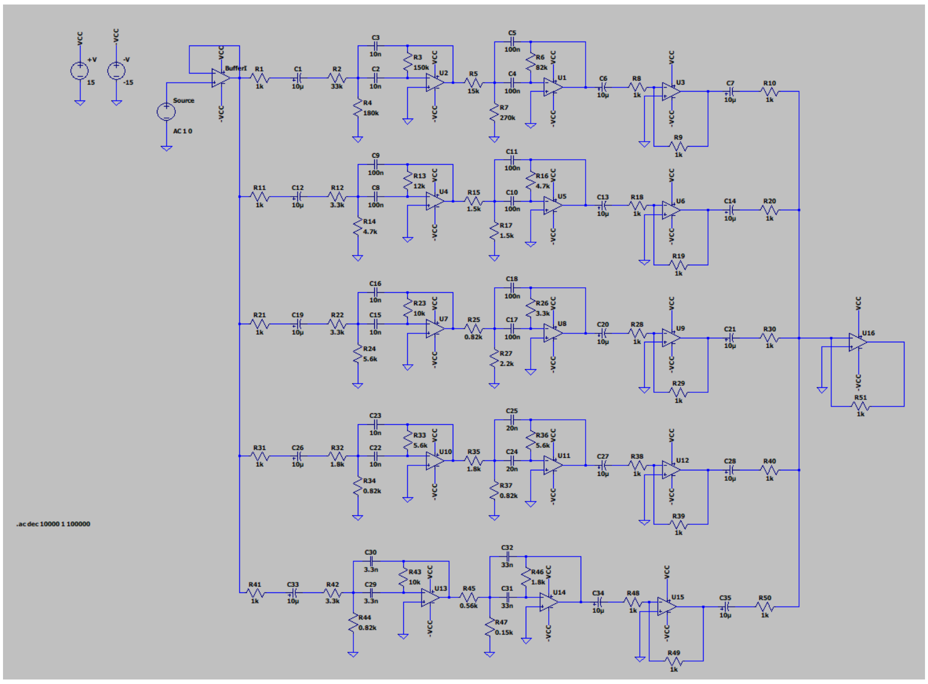

Figure 26: Simulation of Main Circuit.

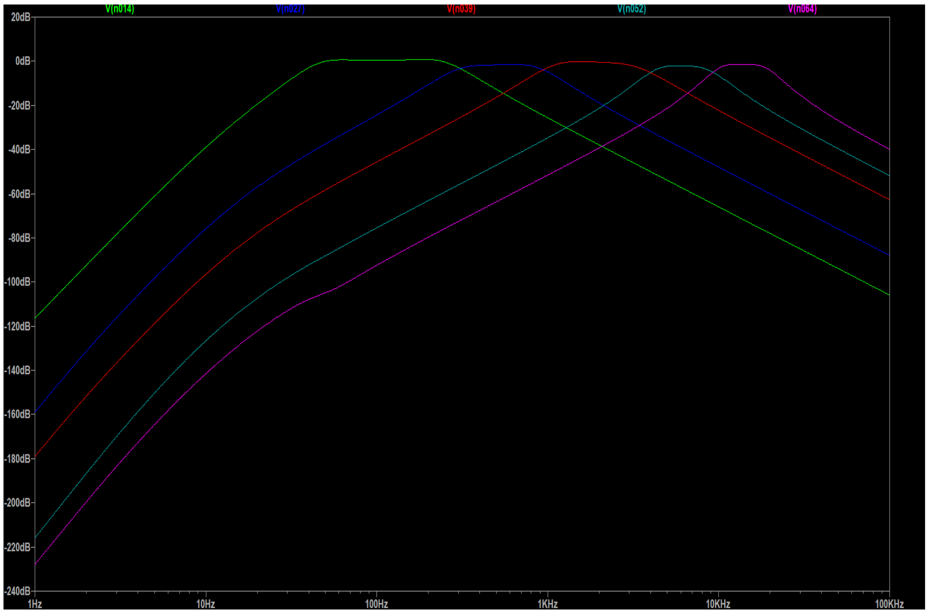

Figure 27: Filter responses.

Hardware testing is done using breadboards for circuit validation.

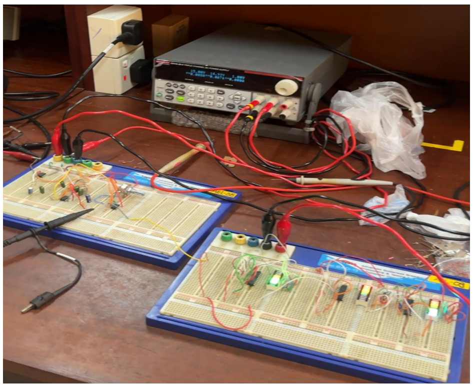

Figure 28: Breadboard Implementation.

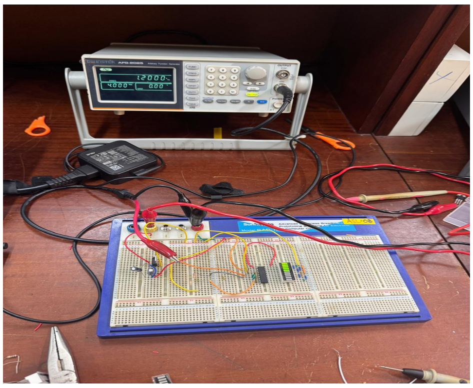

Figure 29: Breadboard Implementation.

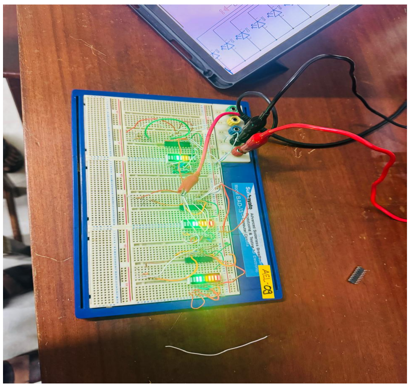

Figure 30: Breadboard Implementation.

5 PCB Design

Three seperate PCBs were designed using Altium Software for equalizer, display and power supply.

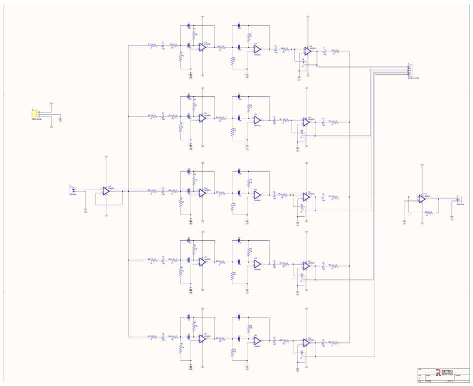

Figure 31: Schematic of Equalizer PCB.

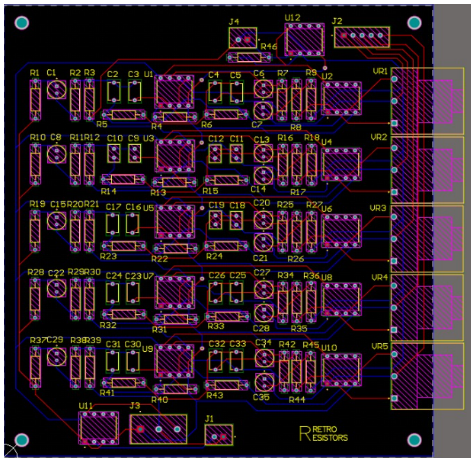

Figure 32: PCB Design of Equalizer.

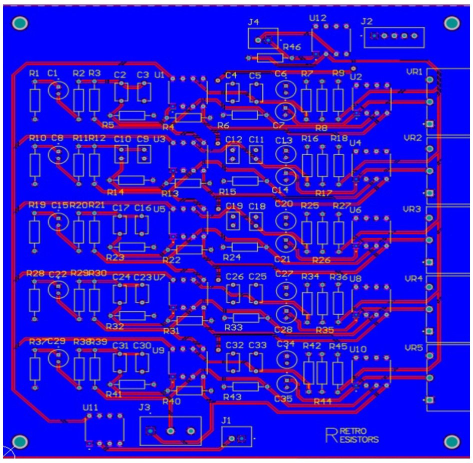

Figure 33: Top Layer of Equalizer PCB.

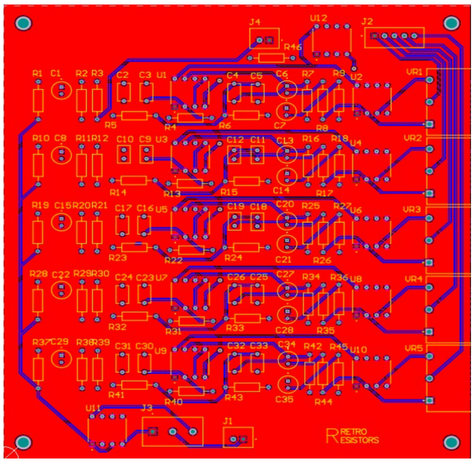

Figure 34: Bottom Layer of Equlizer PCB.

6 Enclosure Design

Enclosure design is done using CAD software SolidWorks.

Figure 35: Enclosure.

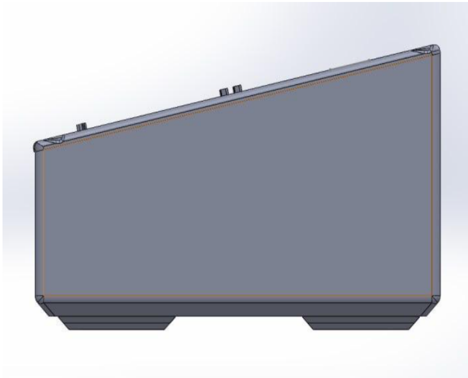

Figure 36: Side View.

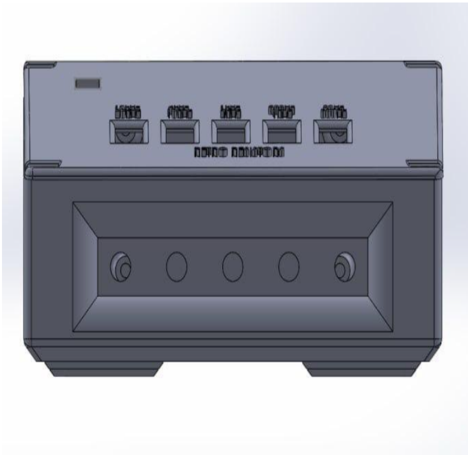

Figure 37: Front View.

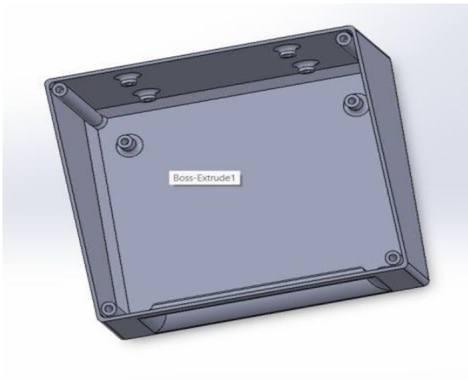

Figure 38: Interior.

7 Final Product and Soldered PCBs

Figure 39: Final Product.

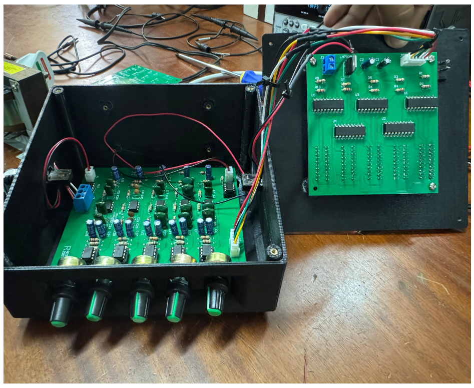

Figure 40: Interior of Final Product.

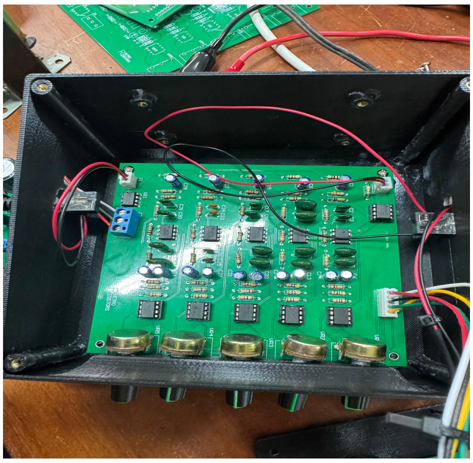

Figure 41: Equalizer PCB.

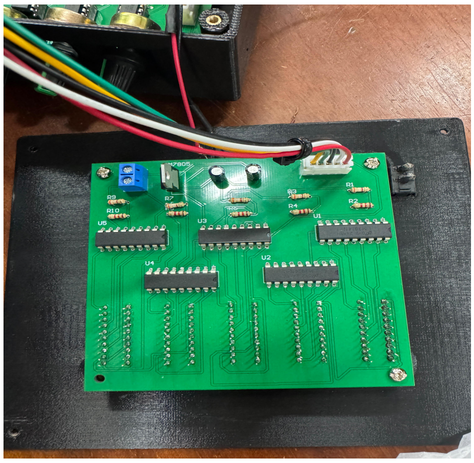

Figure 42: Display PCB.

8 Conclusion

In this project, we successfully designed and implemented a 5-band audio equalizer to process audio signals ranging from 20 Hz to 20 kHz. The equalizer effectively splits the input audio signal into five distinct frequency bands, allowing users to adjust the gain for each band as needed. A bar display, driven by the LM3914 LED driver IC, visually represents the output levels, enabling real-time monitoring of the signal strength for each frequency band.

The system uses carefully selected components, such as the TL072 op-amp, for signal amplification, ensuring low noise, good performance, and cost-effectiveness. The final design is reliable, easy to build, and suitable for basic audio applications, making it a useful tool for audio enthusiasts and learners.

9 Contribution of Group Members

Index No:	Name	Contribution
220350T	Kuruppuarachchi K.A.R.R.	PCB Design of equalizer, Testing and Debugging
220551K	Samaramanna M.A.	Circuit Design and Simulation, Documentation.
220059J	Bandara G.A.M.I.K.	PCB Design of Display and Power Supply, Testing and Debugging
220276V	Jayatissa M.P.N.V.	Enclosure Design, Testing and Debugging

Table 4: Individual Contribution.

Acknowledgment

I would like to express my sincere gratitude to everyone who supported us throughout this project. We are especially thankful to Dr. Perera M.T.U.S.K., Dr. Chameera Edussooriya and Dr. Wageesha manamperi for his valuable guidance, encouragement, and constructive feedback, which greatly contributed to the success of this work. I would also like to thank for my group members continuous support and motivation. Lastly, I appreciate the resources and tools that were made available to me, which enabled me to complete the design and implementation of the 5-band audio equalizer successfully.

References

[1] Texas Instruments. (2019). *TL072 Low-Noise JFET-Input Operational Amplifier*. [Online]. Available: https://www.ti.com

[2] Texas Instruments. (2017). *LM3914 Dot/Bar Display Driver*. [Online]. Available: https://www.ti.com

[3] https://www2.seas.gwu.edu/~ece121/Spring-11/filterdesign.pdf

[4] https://www.analog.com/media/en/training-seminars/design-handbooks/Basic-Linear-Design/Chapter8.pdf