Department of Electronic & Telecommunication Engineering, University of Moratuwa, Sri Lanka.

Five Band Audio Equalizer

Group Members:

210169L	Fernando.W.W.R.N.S
210179R	Gammune.D.J.T
210707L	Wickramasinghe.M.M.M

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EN 2091 Laboratory Practice and Projects

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Abstract
This report describes the design of a 5-band analog audio equalizer, which can control and customize an audio signal across five frequency ranges. In this design, five filters, five amplifiers, and an adder are implemented using Op-amps, capacitors, and resistors. The supply voltages are +12V and -12V. Additionally, an ESP32 is used to implement the display.

Contents

1 Introduction and Functionality

In this project, we were asked to build a five-band equalizer that can divide the audio spectrum into different frequency bands and have amplifiers for each band.With these amplifiers we can change the gain of the each band.Here, the frequency spectrum was then recombined using an adder circuit.For the filters, we use op-amps, capacitors,and resistors.And we use power transistor regulator circuit to get +12V,-12V as a supply voltages. For both audio input and output, we employ a 3.5mm audio jack.Variable resistors are used to adjust the gain.With the help of a MD0166 - MAX7219 LED 8x8 Matrix Module for Arduino and a ESP32 board we can see the gain of each frequency band.

2 System Architecture

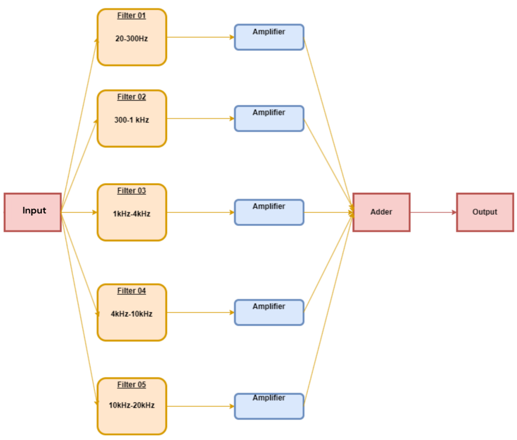


Figure 1: Flow Chart

2.1 Table and Figure

2.1.1 Filters

The decision to choose active filters over passive filters was motivated by several advantages, including a 0dB gain for the passband, high input and low output impedance, which ensures that load impedance variations do not affect filter performance, and the ability to cascade multiple filters without a decrease in gain. Active filters, being active devices, can be configured to boost signals in the passband and maintain performance irrespective of the connected load. The choice of the multiple feedback topology for the active filter was based on its simplicity and reliability in implementing a bandpass filter, particularly below a quality factor (Q) of 20. The fourth-order implementation was selected to achieve sharp filter edges while balancing the complexity of calculation and ease of implementation. This choice is well-suited for applications such as equalization, analysis, and tasks like a Sound to Light converter or a vocoder.

Filter	**Band**	**resistors**	**capacitors**
Filter 01	20-300Hz	12kΩ, $39k\Omega, 3.3k\Omega, 22k\Omega$, 68kΩ, $10k\Omega$	100nF(4)
Filter 02	300-1kHz	3.3kΩ, $2k\Omega, 10k\Omega, 1.5k\Omega, 910\Omega$, 4.7kΩ	100nF(4)
Filter 03	1-4kHz	9.1kΩ, $7.5k\Omega, 27k\Omega, 3.6k\Omega$, 3kΩ, $11k\Omega$	10nF(4)
Filter 04	4-10kHz	3.6kΩ, $1.2k\Omega, 11k\Omega, 1.8k\Omega$, 620Ω, $5.6k\Omega$	10nF(4)
Filter 05	10-20kHz	20kΩ, $3.6k\Omega, 56k\Omega, 12k\Omega$, 2.2kΩ, $36k\Omega$	1nF(4)

Table 1: Filters.

2.1.2 Amplifier

We were asked to change the gain of each frequency band.For that, we implemented separate amplifiers for each band. For the amplifiers also choose TL072CP. Because this is specified for audio processing.Here we use inverting amplifiers because after this we need implement the adder.Adder will invert the phase of the audio signal that's why we use inverting amplifiers.

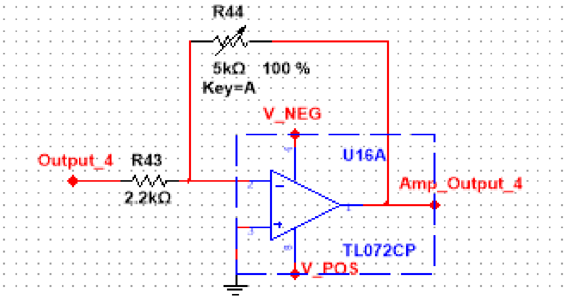


Figure 2: Amplifier

2.1.3 Adder

After we process the frequency spectrum separately, we need to recombine the bands to get the audio signal. For that, we need to implement the adder circuit. For the adder circuit, we give each separate frequency band signal as the input. For this purpose also use TL072CP opamp.

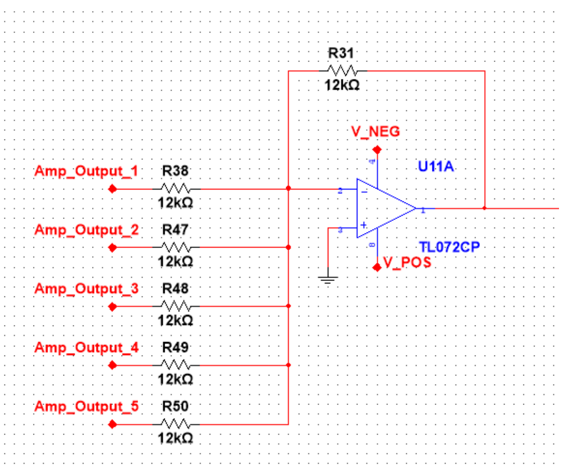


Figure 3: Adder

2.2 Equations

2.2.1 Filter Equations

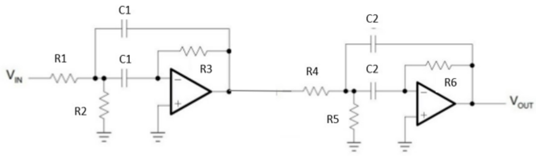


Figure 4: 4th order filters

Filter	Frequency Range	Mid frequency	
		Stage 1	Stage 2
Filter 1	0 - 300 Hz	82.231 Hz	311.32 Hz
Filter 2	300 - 1kHz	437.269 Hz	966.225 Hz
Filter 3	1 - 4 kHz	1.6021 kHz	3.9011 kHz
Filter 4	4 - 10 kHz	5.1265 kHz	9.5581 kHz
Filter 5	10 - 20 kHz	11.8014 kHz	19.0656 kHz

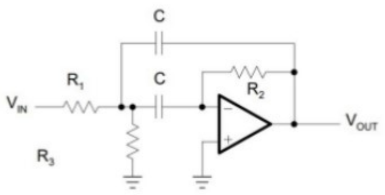
Figure 5: Mid frequencies of each filter

We have got these components values using filterpro software. After getting those values we checked whether the resistor values are available in the country or not. If it is not available created those resistor values using two or more resistors connecting series.

	R1	R2	R3	R4	R5	R6	C1	C2
Filter 1	12k	68k	39k	3.3k	22k	10k	100nF	100nF
Filter 2	3.3k	2k	10k	1.5k	910	4.7k	100nF	100nF
Filter 3	9.1k	7.5k	27k	3.6k	3k	11k	10nF	10nF
Filter 4	3.6k	1.2k	11k	1.8k	620	5.6k	10nF	10nF
Filter 5	20k	3.6k	56k	12k	2.2k	36k	1nF	1nF

Figure 6: Component table

2.2.2 Bode Plots



$$A(s) = \frac{-\frac{R_2R_3}{R_1+R_3}C\omega_m \cdot s}{1+\frac{2R_1R_3}{R_1+R_3}C\omega_m \cdot s+\frac{R_1R_2R_3}{R_1+R_3}C^2 \cdot \omega_m{}^2 \cdot s^2}$$

Figure 7: Gain of the filters

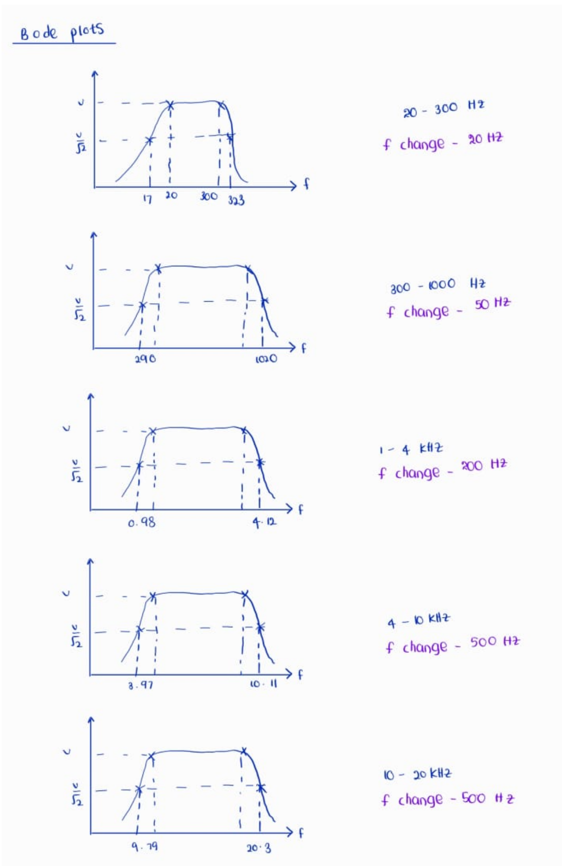


Figure 8: Bode plot of filters

3 Component Selection

The success of our audio equalizer project hinged on meticulous component selection. For operational amplifiers (op-amps), we carefully considered factors such as slew rate, a critical aspect for handling audio frequencies, and input offset voltage, which directly impacts distortion levels. Recognizing the importance of signal integrity, we opted for the NE5532p and TL072CPA op-amps, known for their optimal performance in these areas.

1. NE5532p:
- The NE5532 is a dual high-performance, low-noise operational amplifier that is commonly used in audio applications. It has a wide frequency response, low distortion, and good common-mode rejection ratio (CMRR). Here are some reasons for choosing NE5532p for filters 3, 4, and 5:

- Low Noise: NE5532p is known for its low noise, which is crucial in audio applications to maintain signal clarity and quality.

- High Slew Rate: The NE5532p has a high slew rate, making it suitable for applications where fast signal transitions are important, such as audio signals.

- Wide Bandwidth: With a wide bandwidth, the NE5532p is well-suited for handling audio frequencies, including those in the higher range.

2. TL072cp:
- The TL072 is another dual operational amplifier known for its versatility and low noise performance. Here are reasons for choosing TL072cp for filters 1 and 2:

- Cost-Effectiveness: The TL072CP is a more cost-effective option compared to some other op-amps, making it a practical choice for filters where extremely low noise might not be as critical.

- Low Noise: While not as low-noise as the NE5532, the TL072CP still offers good noise performance, making it suitable for general-purpose audio applications.

- Wide Common-Mode Range: The TL072CP has a wide common-mode input voltage range, making it flexible for different input conditions.

- Low power consumption

- High input impedance

- Common-Mode Input Voltage Range Includes 12V

Our selection of resistor selection was equally comprehensive. To address the challenge of obtaining rare resistor values, we employed a combination of strategies. First, we creatively utilized series connections to construct equivalent values from available resistors. Additionally, we imported 5-band resistors, ensuring precision and accuracy in the circuit's resistive elements.

In selecting capacitors, we struck a balance between precision and practicality. During the design phase using Filter Pro, we opted for commercially available capacitor values to streamline procurement. While this introduced minor deviations in response characteristics, it reflected a pragmatic decision that prioritized component accessibility without compromising circuit integrity.

4 PCB Design

After checking the circuit with the bread board, we designed the circuit using Altium Designer. And we send the gerber files to the PCB printers to print the PCB. After we got the PCBs we soldered the components on it and checked it.

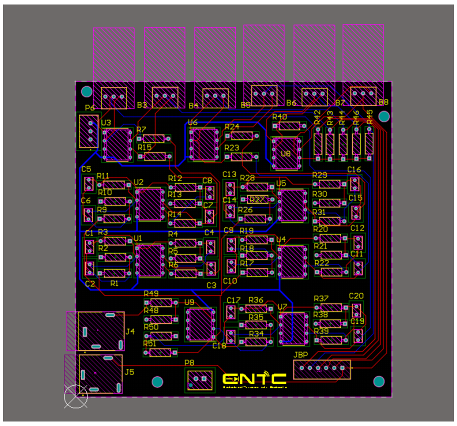


Figure 9: Functional PCB Design

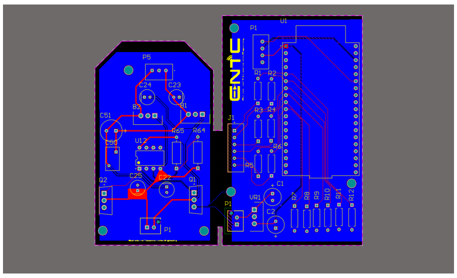


Figure 10: Power PCB Design

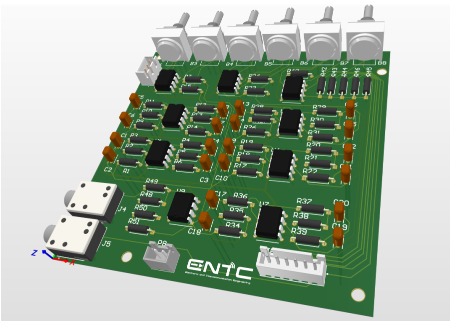


Figure 11: Functional PCB Design with 3D Models

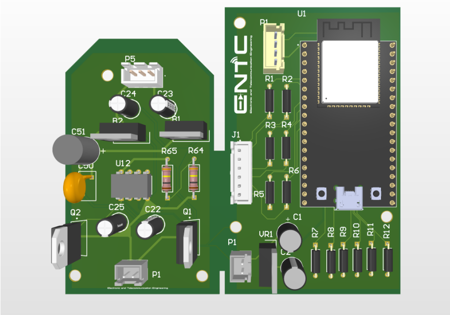


Figure 12: Power PCB Design with 3D Models

5 Enclosure Design

We used solidworks for designing the enclosure for our project. After getting printed we joined them using screws. We created our enclosure in two parts one for lid and one for the base. Following figures show the images of the enclosure designs

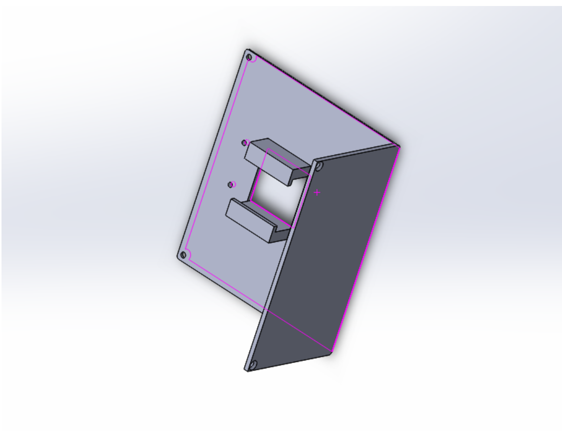


Figure 13: Enclosure Top Design

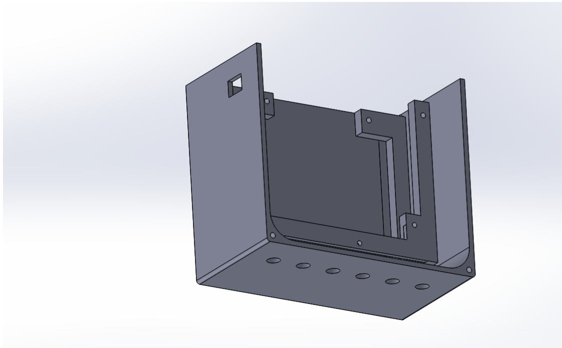


Figure 14: Enclosure Inside Deisgn

Figure 15: Final Prototype Design

6 Software Simulation and Hardware Testing

To create a versatile audio equalization system that could adjust audio frequencies across five bands, we employed a combination of software simulations and hardware testing. Multisim, a software simulation tool, enabled us to optimize the circuit design and analyze its performance before constructing it physically. We meticulously assembled the circuit on breadboards during the laboratory testing phase to verify that the simulation results accurately reflected real-world performance. This dual approach of software simulations and practical hardware testing allowed us to refine the equalizer's performance, address any issues, and successfully implement the five-band analog equalizer.

To achieve precise audio equalization across five bands, we integrated forth-order Butterworth filters designed using Filter Pro software. This software proved invaluable in crafting and optimizing filters for each equalizer band. Utilizing Filter Pro's capabilities, we meticulously adjusted the Butterworth filter parameters to attain the desired frequency response characteristics. The implementation of second-order Butterworth filters elevated the precision of our equalization system, amplifying its ability to isolate and fine-tune specific frequency ranges.

6.1 Filter Pro Simulations

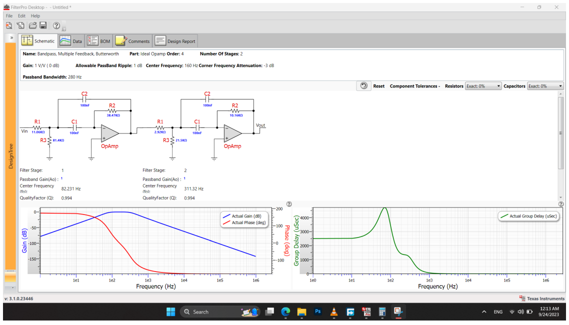


Figure 16: Filter 1 - Filter Pro Design

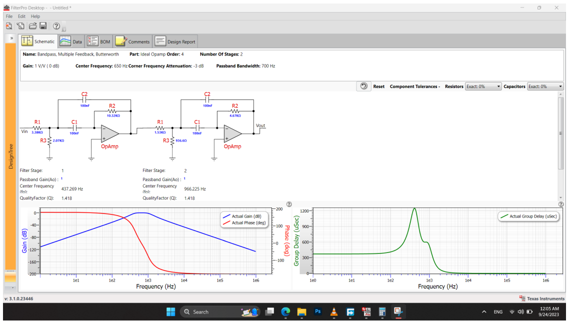


Figure 17: Filter 2 - Filter Pro Design

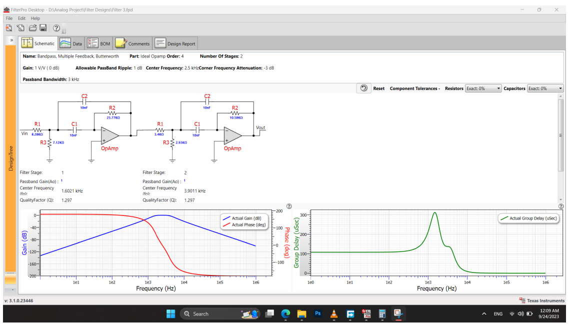


Figure 18: Filter 3 - Filter Pro Design

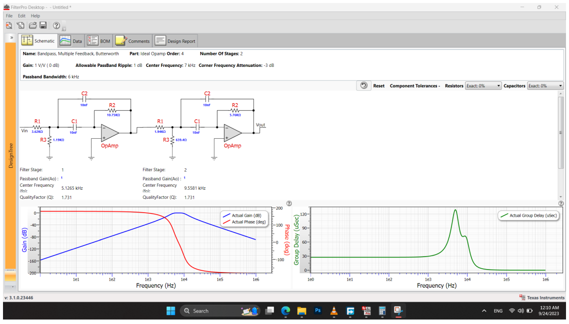


Figure 19: Filter 4 - Filter Pro Design

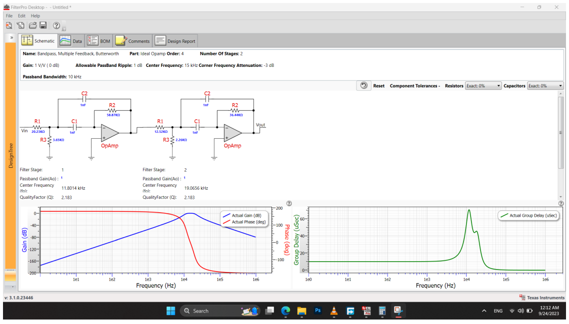


Figure 20: Filter 5 - Filter Pro Design

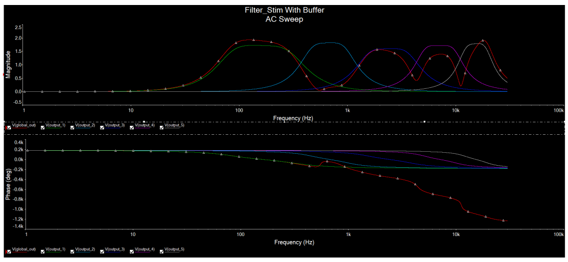


Figure 21: Stimulation Bode Plots

6.2 Multisim Simulations

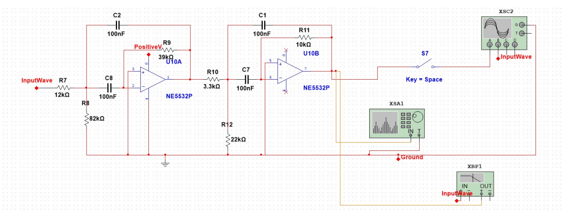


Figure 22: Filter 1 - Multisim Design

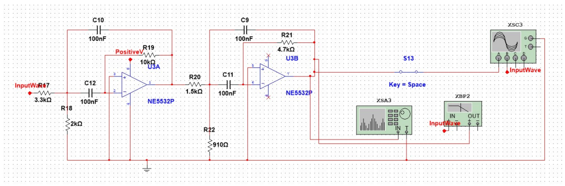


Figure 23: Filter 2 - Multisim Design

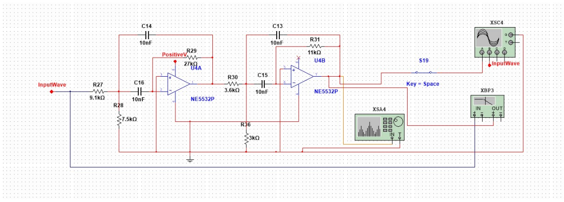


Figure 24: Filter 3 - Multisim Design

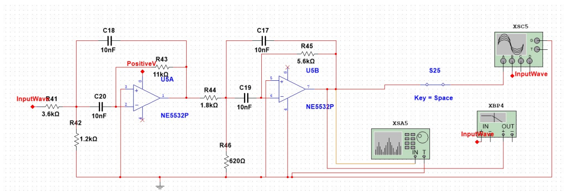


Figure 25: Filter 4 - Multisim Design

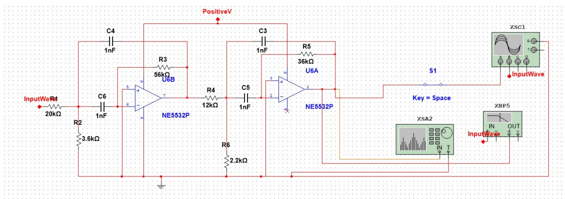


Figure 26: Filter 5 - Multisim Design

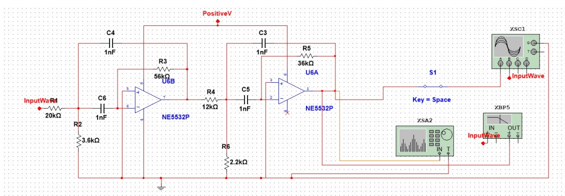


Figure 27: Complex Signal Generation 5 - Multisim Design

6.3 Hardware Testing

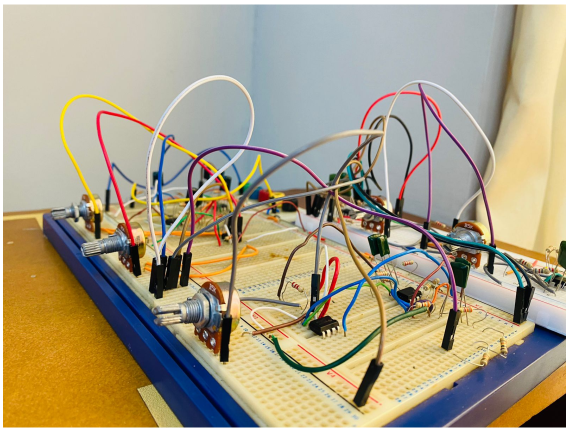


Figure 28: Hardware Testing

7 Final Product

Figure 29: Final Product

Figure 30: Final Product

8 Conclusion & Future Works

In conclusion, the design and implementation of the 5-band analog audio equalizer represent a successful integration of advanced signal processing techniques. The system's versatility allows users to finely tailor audio output across distinct frequency ranges, enhancing the overall listening experience. The incorporation of Op-amps, capacitors, and resistors in the filter and amplifier circuits, coupled with the dual power supply, ensures robust performance.

In the pursuit of continuous improvement, the project's future endeavors hold promising avenues. One key focus area involves the reduction of noise within the audio equalizer system. Employing advanced noise reduction techniques and refining the existing circuitry will be instrumental in achieving a cleaner and more pristine audio output.

Additionally, the plan to transition from Butterworth filters to elliptic filters signifies a commitment to enhancing precision and accuracy in signal processing. Elliptic filters, known for their ability to achieve steeper roll-off rates with a controlled level of ripple in the passband and stopband, will likely contribute to a more refined frequency response across the five bands. This transition aligns with the project's dedication to achieving optimal audio customization.

By addressing noise concerns and incorporating elliptic filters, the future developments aim not only to meet but exceed the expectations of audio enthusiasts. These refinements underscore a commitment to staying at the forefront of audio processing technology, ensuring that the 5-band audio equalizer continues to deliver an unparalleled and immersive listening experience.

9 Contribution of Group Members

Member	Task Allocation	Contribution
210169L	Enclosure Design ,circuit testing, documentation	33.33%
210179R	PCB design ,circuit testing , documentation	33.33%
210707L	Circuit design and simulations , circuit testing ,documentation	33.33%

Acknowledgment

We would like to thank Dr. Perera M.T.U.S.K. Sampath first. since he helped us with this project.He provided us with the project's original concept and assisted us in continuing. We express our gratitude to Drs. Jayathu Samarawickrama, Pratapasinghe Dharmawansa, and Chamira U.S. Edussooriya. since they provided a very clear explanation of filters. We completed this project with the aid of the modules we taught in the third semester. Additionally, we are grateful to Akila Ayya for his unwavering guidance throughout the process. Lastly, non-academic staff members deserve our gratitude since they have supported us at various stages in various ways.

Appendix

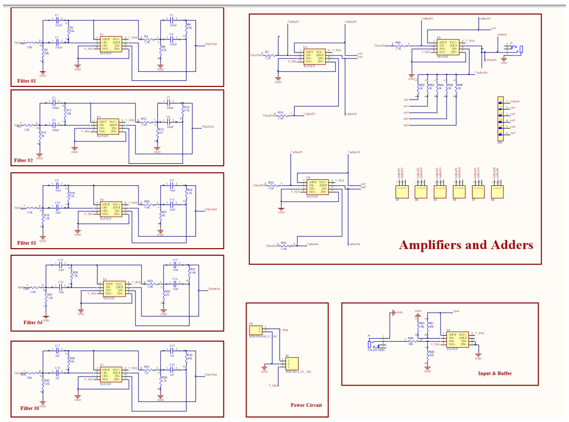
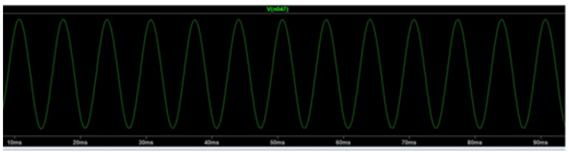
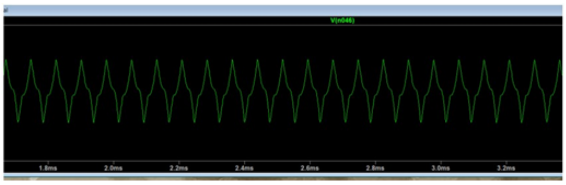


Figure 31: Schematic of the Output Circuit

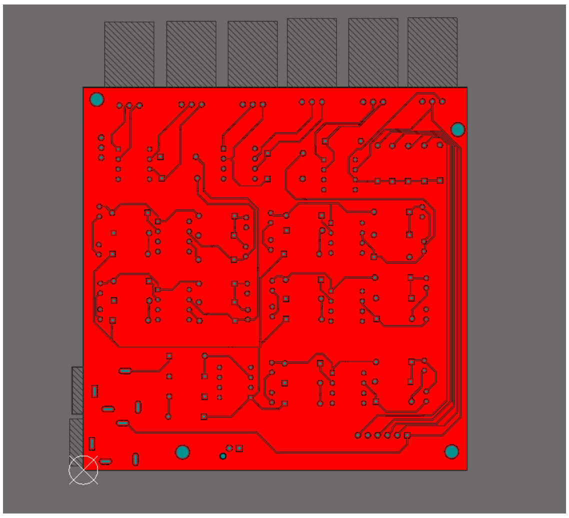


(a) Results for low frequency

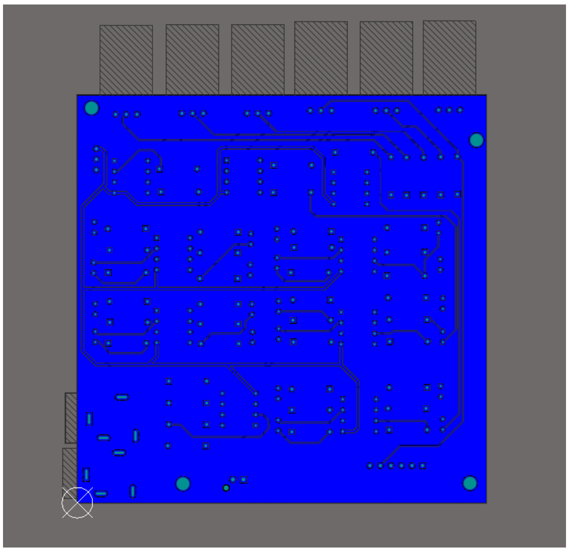


(b) Results for high frequency

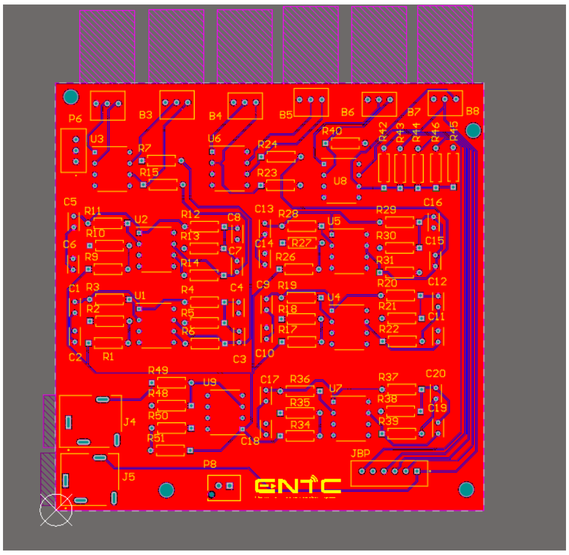
Figure 32: Results for Different Frequencies



(a) Top Layer

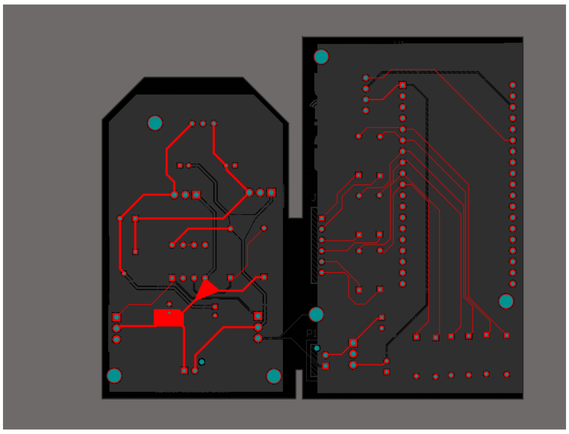


(b) Bottom Layer

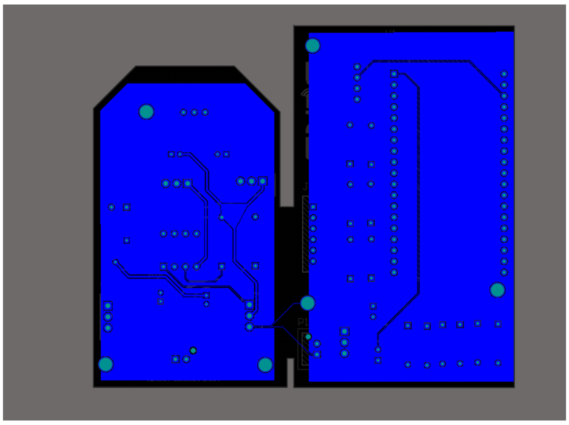


(c) Functional PCB Design

Figure 33: Functional PCB



(a) Top Layer



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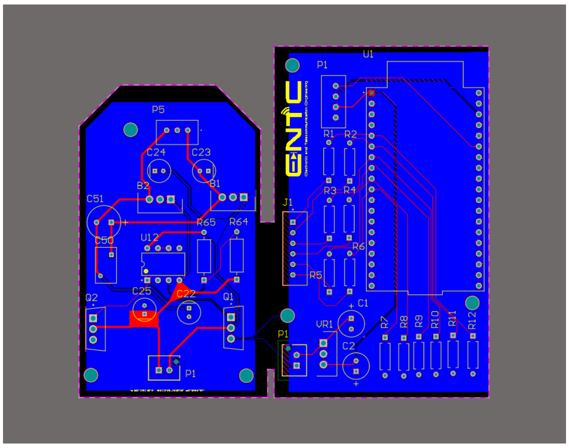
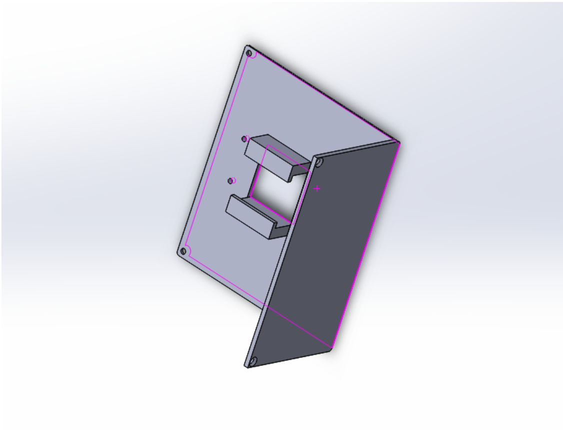
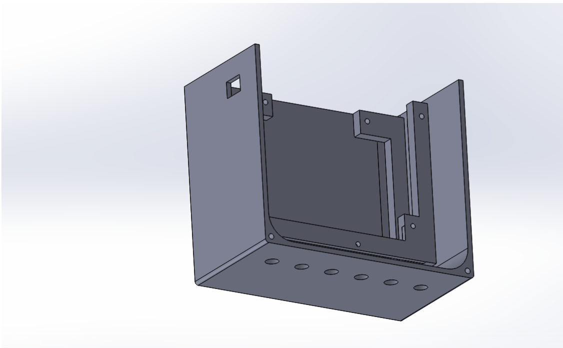


(c) Power and Display PCB Design

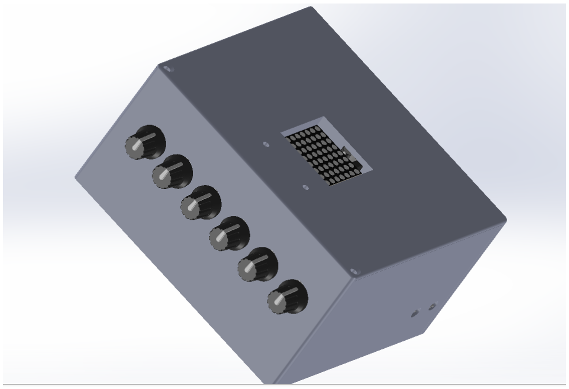
Figure 34: Power and Display PCB



(a) Enclosure Top Design



(b) Enclosure Inside Design



(c) Final Prototype Design

Figure 35: Enclosure Designs

References

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