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Volume Expander

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Abstract

This report provides an overview of the design and implementation of a real-time audio volume expander to enhance dynamic range of audio signals. The system employs a control voltage processor and voltage-controlled amplifier (VCA) architecture to perform upward expansion of signals exceeding a user-defined threshold. Key components of the system includes a custom signal processor, a customized VCA circuit achieving 3-4 dB gain, and a notch filter to eliminate power line interference. The implementation features a dual-layer PCB design, custom 3D-printed enclosure, and isolated power supply for powering ciruits. Hardware testing and LTspice simulations validated the system's functionality, demonstrating successful dynamic range enhancement for audio applications in Audio systems.

Contents

1 Introduction and Functionality

Dynamic range is a fundamental characteristic of an audio signals, it is the ratio between the loudest and quietest possible sounds in the audio signal. Maintaining a proper dynamic range of an audio signal is essential to achieve clarity, naturalness, and overall quality in audio reproduction. Due to recording limitations, signal processing, and noise, interference audio signals suffer from dynamic range compression leading to a loss of audio detail and reduced audio fidelity. [1]

A volume expander (commonly known as **Audio dynamic range expander**) is used to increase the dynamic range of an audio signal, by improving the difference between the quietest and loudest parts of the audio waveform. [2] This process restores the natural dynamics of an audio signal, reducing unwanted background noise and enhancing audio clarity. This report details the design and implementation of a custom audio dynamic range expander capable of real-time signal processing for applications in recording, broadcasting, and live sound systems. [3]

Volume Expander Functions by analyzing the Input audio signal and applying gain adjustments based on its amplitudes relative to a given threshold. Our implementation supports upward expansion of the audio signals which amplifies the levels of signals that exceeds the given threshold. The core functionality of the system is implemented through a control voltage processor which outputs a control voltage to a Voltage controlled amplifier (VCA), where gain applied to the audio signal is determined dynamically based on the amplitude of input signal. The user can configure the threshold and expansion ratio to customize the expander's behavior. The system is designed to operate in real-time, ensuring minimal latency and seamless audio processing. It provides improved clarity and dynamic contrast, making it suitable for various audio applications, including music production, speech enhancement, and noise reduction.

Expander Parameters

- Threshold
  The input level at which the expander activates. It triggers upward expansion for signals crossing above the threshold.

- Gain
  The degree of amplification applied.

2 System Architecture

2.1 Functional Block Diagram

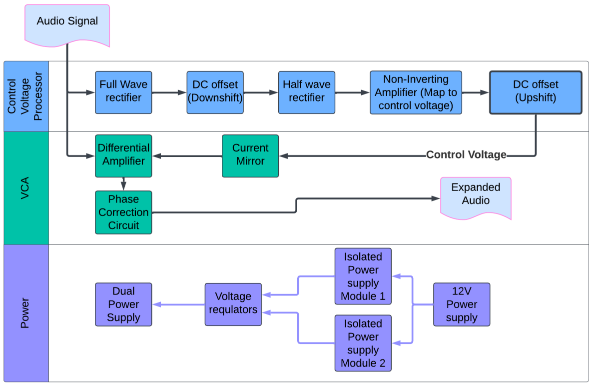


Figure 1: Functional Block Diagram

2.2 Control Voltage Processor

The Control Voltage Signal Processor is responsible for generating a control signal to dynamically adjust the gain of the audio signal using VCA. This processor includes several subsystems.

2.2.1 Full Wave Precision Rectifier

Converts the input audio signal to its absolute value, ensuring accurate amplitude detection. This component uses precision diodes and operational amplifiers to rectify both the positive and negative portions of the input signal without distortion.

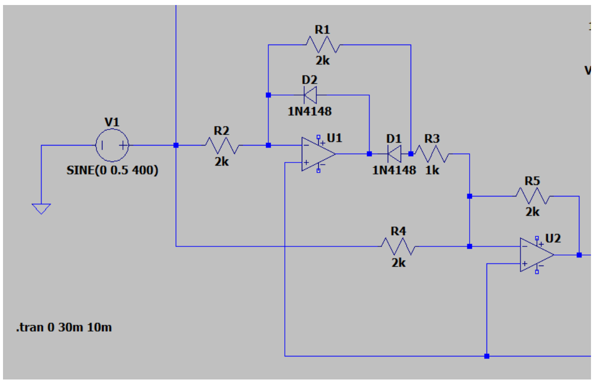


Figure 2: Full Wave Precision Rectifier Circuit

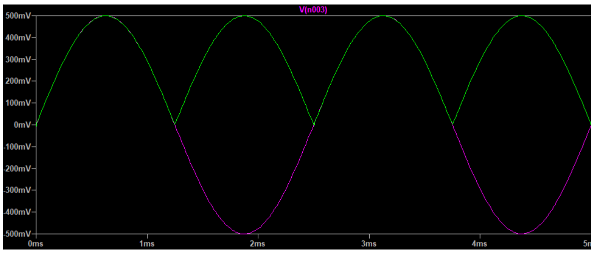


Figure 3: Full Wave Precision Rectifier Output

- ***Why Precision Rectifier?*** Standard diode rectifiers are unsuitable for low-amplitude signals due to forward voltage drops. Precision rectifiers eliminate this limitation, allowing accurate rectification of even millivolt-level signals.

2.2.2 DC offset(Downshift)

Adds a negative DC bias to the rectified signal to ensure that it operates within the appropriate voltage range for subsequent stages. Ideally adjusted to the unity gain voltage of the voltage controlled amplifier. This reference voltage depends on the threshold value that the user can control.

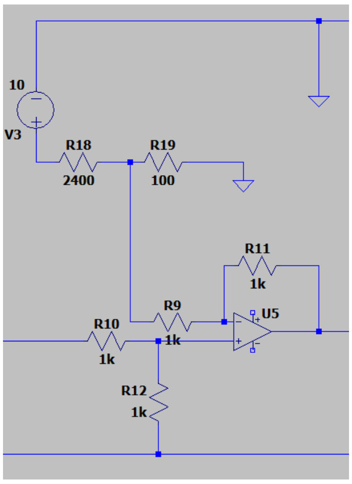


Figure 4: DC Downshift Circuit

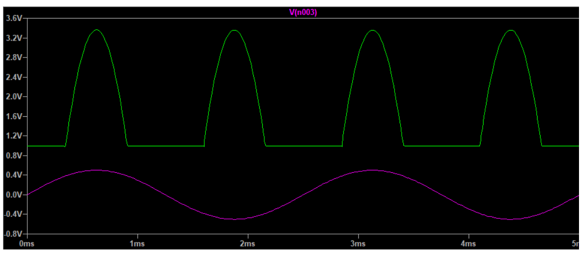


Figure 5: DC Downshift Output

2.2.3 Half Wave Precision Rectifier

Cutoff the signal that lies below the threshold level and extract accurate envelope of the audio signal. The resulting waveform represents the instantaneous amplitude of the signal above the threshold. A half wave precision rectifier is used to rectify signals with amplitudes as low as a few millivolts.

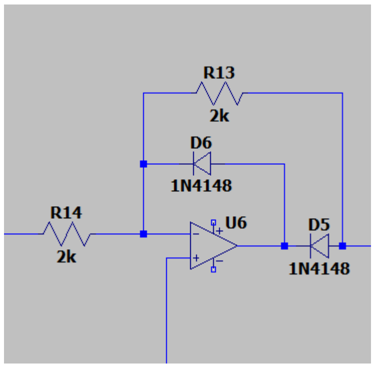


Figure 6: Half Wave Precision Rectifier Circuit

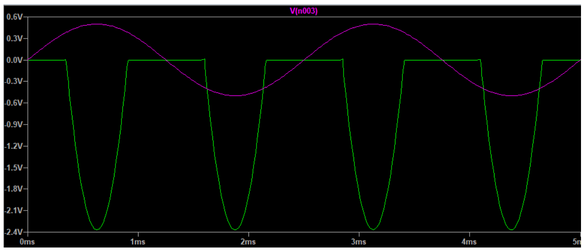


Figure 7: Half Wave Precision Rectifier Output

2.2.4 Non Inverting Amplifier

Amplifies the processed signal without inverting its phase. The gain of this amplifier is adjustable to scale the control voltage for effective operation of the Voltage Controlled Amplifier (VCA). A potentiometer in the feedback loop allows user-configurable gain.

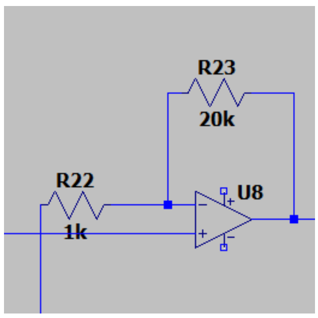


Figure 8: Non Inverting Amplifier Circuit

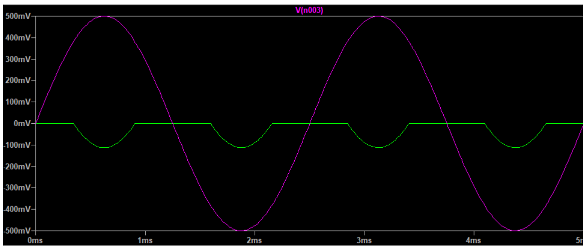


Figure 9: Non Inverting Amplifier Output

2.2.5 DC offset(Up-shift)

Reintroduces a positive DC bias to the signal after processing, ensuring DC offset aligns with the unity gain voltage of the voltage controlled amplifire. The unity gain control voltage of the VCA is 1 V. This output is used as control voltage of the voltage controlled amplifier.

2.3 Voltage Controlled Amplifier

The Voltage Controlled Amplifier (VCA) dynamically adjusts the gain of the input audio signal based on the control voltage generated by the processor. It operates at the center of the expander, providing real-time modulation of the signal's amplitude.

The gain of the VCA is proportional to the emitter current of the differential amplifier,

$$G = \frac{I_e \times R_{\text{load}}}{V_T}$$

Emitter current I_e is generated by the control voltage (V_{CV}) through resistor R_{CV}:

$$I_E = \frac{V_{CV} - V_{BE}}{R_{CV}}$$

Thus, the gain G can be expressed as:

$$G = \frac{(V_{CV} - V_{BE}) \times R_{\text{load}}}{R_{CV} \times V_T}$$

Simplifying further:

$$G = \frac{(V_{CV} - 0.7) \times 1 \times 10^3}{10 \times 10^3 \times 25 \times 10^{-3}}$$

$$G = (V_{CV} - 0.7) \times 4$$

- **Maximum gain possible:** 9 to 10 dB
- **Required gain according to criterion:** 3 to 4 dB

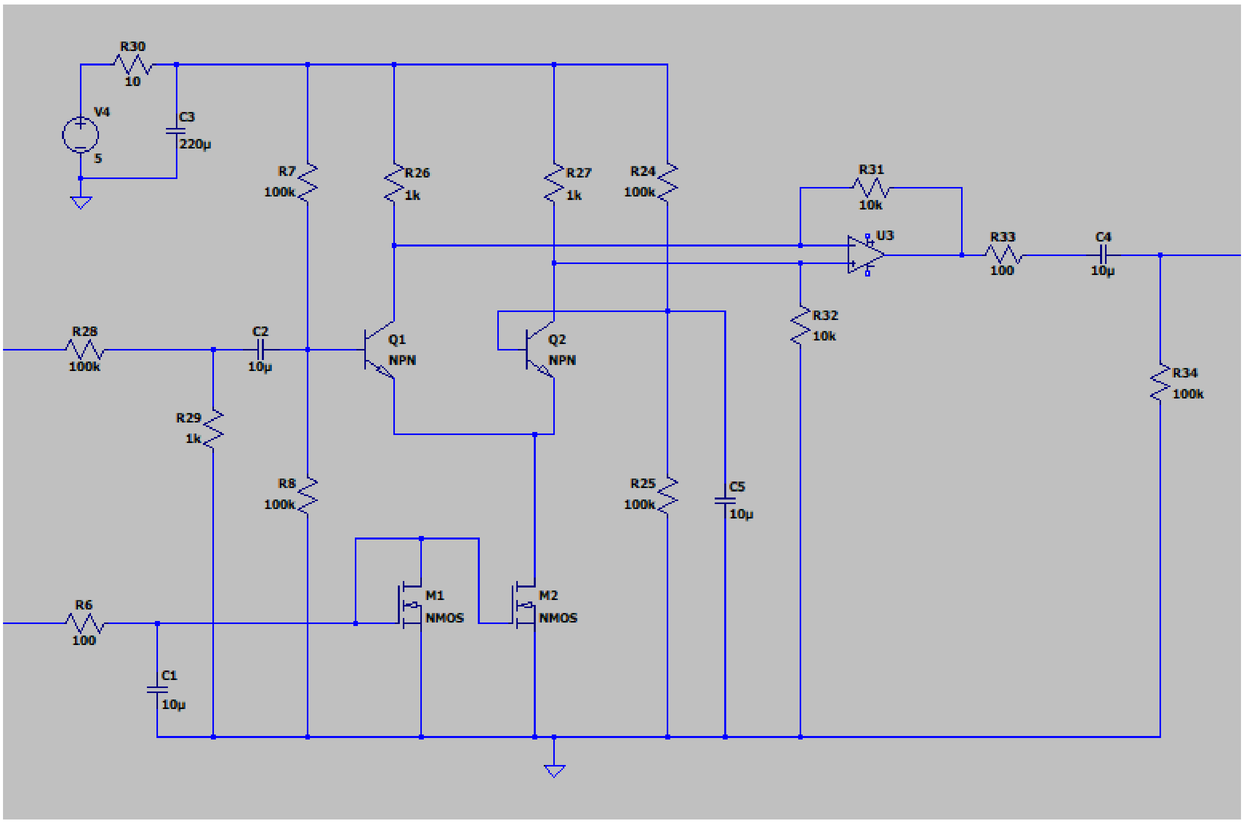


Figure 10: Voltage Controlled Amplifier (VCA)

2.4 Notch Filter

The notch filter is designed to eliminate power line interference, which typically occurs at 50 Hz. A Twin-T Notch Filter with feedback is implemented, with a calculated notch frequency of 50 Hz,

$$f_n = \frac{1}{2\pi RC} = \frac{10^3}{2\pi \times 6.8 \times 0.47} = 50Hz \quad (1)$$

2.5 Power Supply

Dual power supply using isolated power modules. This provides stable power to operational amplifiers and the VCA, ensuring reliable performance. **Module:** B1212S-2W

- Maximum Power: 2W
- Maximum Current: 244 mA
- Required Current: 130 mA – 150 mA

3 Component Selection

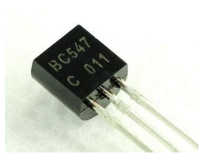
3.1 TL072CP opamp

We selected the TL072CP as our operational amplifier due to several key advantages. It offers a high slew rate of 13 V/µs, which helps prevent signal distortion, with a low power consumption of 1.4 mA, making it energy efficient. In addition, it provides high input impedance and low output impedance, ensuring effective signal amplification, and its low noise characteristics make it suitable for sensitive applications. As alternatives, the OPA2134 can be used due to its ultra-low noise performance, and NE5532 can be used due to its low noise and higher drive capability. But they come at a higher cost.

3.2 UF4007 diode

We used the UF4007 diode due to several reasons. It has a consistent forward voltage drop of approximately 0.7V over a range of currents and an ultra-fast reverse recovery time of around 75ns, making it highly suitable for audio frequency signals. As alternatives, Schottky diodes can be considered because they have an ultra-low forward voltage drop of around 0.2V, which reduces power losses. Another option is the 1N4148 diode, which is a low-cost solution suitable for low-current circuits, though it is less robust compared to the UF4007.

3.3 BC547 transistor



We used the BC547 transistor for the differential amplifier and current mirror in the voltage-controlled amplifier. The BC547 was chosen due to its low noise characteristics and good low-frequency response. Also it is a very cheap and widely available option, making it ideal for cost-effective designs.

3.4 Hilink B1212S 2WR3 isolated power supply module

We used the B1212S-2WR3 module to get +12V and -12V isolated outputs for our power supply circuit. This module is small, efficient (up to 90%), and has low power consumption. It also provides short circuit protection and works well in a wide temperature range (-40°C to +85°C). It is ideal for stable and isolated power needs.

4 PCB Design

We have designed two PCBs for volume expander part and power supply using **Altium Designer** software and printed them via **JLCPCB**. The design followed the manufacturing constraints for manufacturing by JLCPCB. [4]

PCB Details

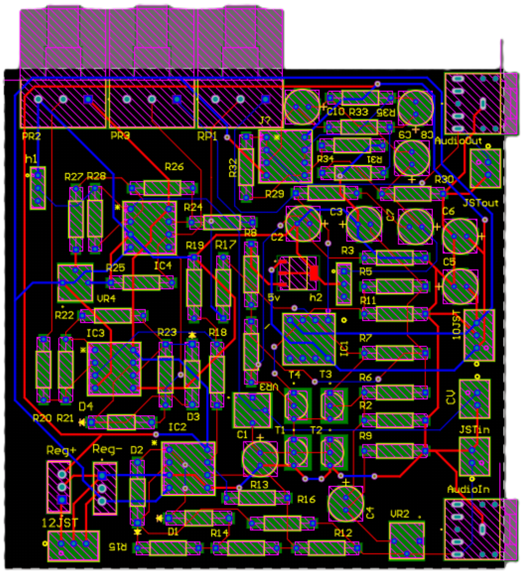
- **Volume Expander PCB:**
  Dimensions are 10 cm × 10 cm.
- **Power Supply PCB:**
  Dimensions are 10 cm × 4.75 cm.

Design Specifications

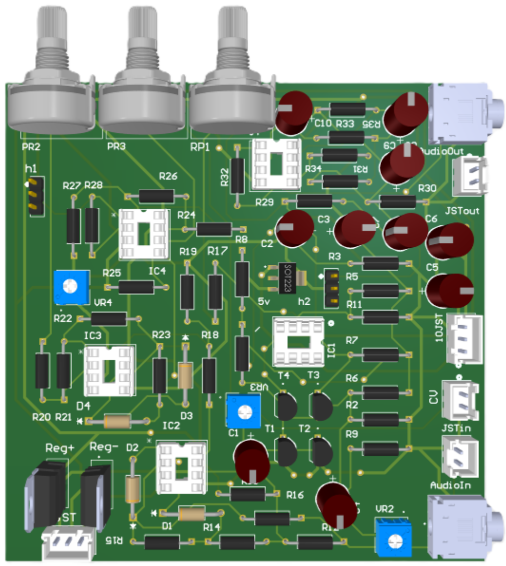
- **Layer Count:**
  Both PCBs are two-layered.
- **Via Sizes:** 1.27 mm.
- **Trace Sizes:**
  - **Power Lines:** 0.635 mm.
  - **Other Traces:** 0.381 mm.

Design Considerations

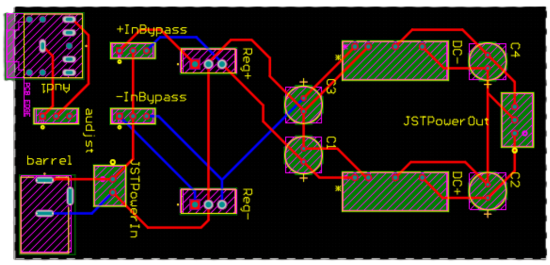
- The PCBs are designed to minimize the use of wires, ensuring an efficient layout.
- Proper separation between power and signal traces is maintained to reduce interference and improve reliability.
- The use of two-layers balances out cost-effectiveness with design complexity



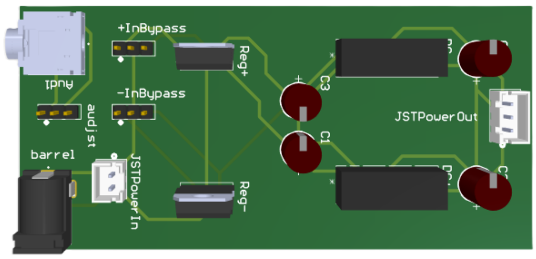
Volume Expander Circuit



Volume Expander Circuit 3D view



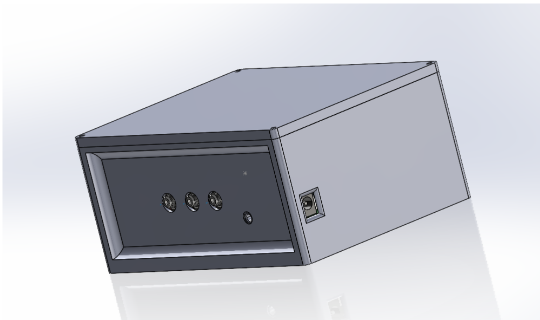
Power Supply Circuit

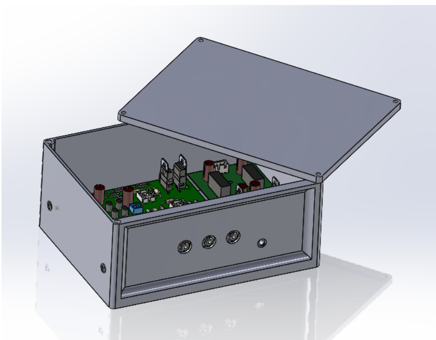


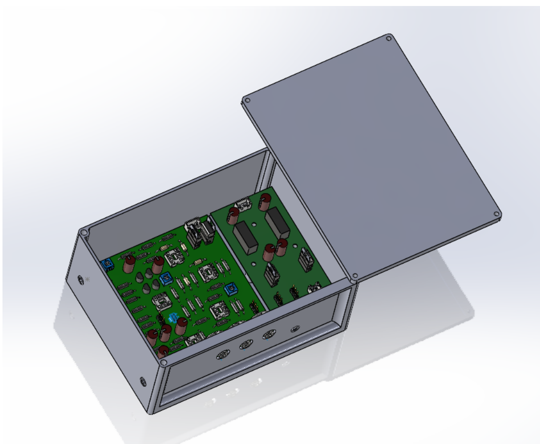
Power Supply Circuit 3D view

5 Enclosure Design

- **Structure:**
  The enclosure features a simple design consisting of a box and a detachable lid for easy access to internal components.
- **Software:**
  The design was created using **SolidWorks**.
- **Material:**
  3D printed using **PLA+**, a durable and slightly flexible material, ideal for creating robust and lightweight enclosures.
- **Dimensions:**
  154 mm × 116 mm × 70 mm







6 Final Product

Figure 11: Volume Expander

Figure 12: Volume Expander internal view

7 Software Simulation and Hardware Testing

7.1 Software Simulations

We used LT spice software for the simulation of the circuit which is very accurate, flexible, and capable of handling complex circuit simulations efficiently.

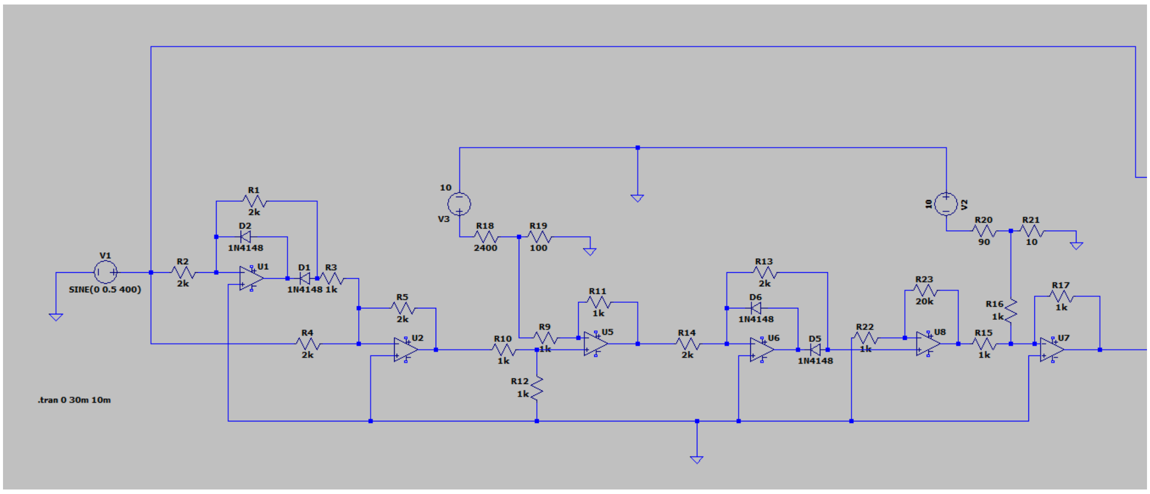


Figure 13: Control Voltage Processor simulation

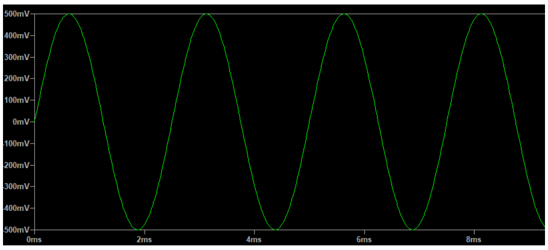


Figure 14: Input for Control Voltage Processor

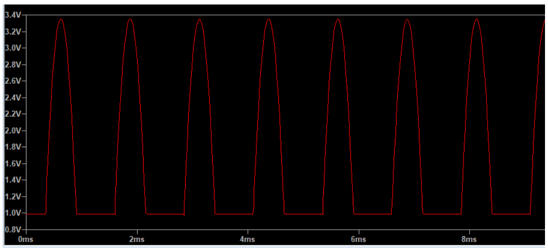


Figure 15: Control Voltage Signal

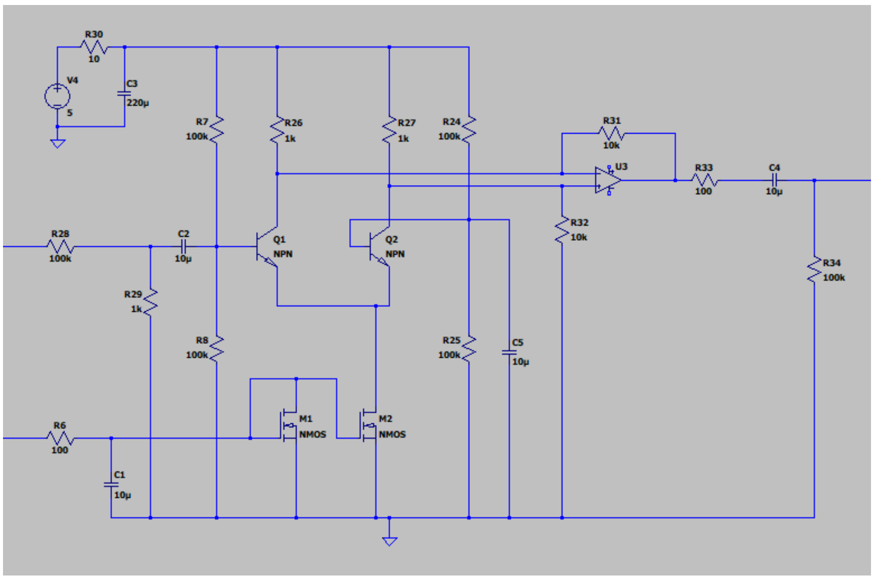


Figure 16: Voltage Controlled Amplifier

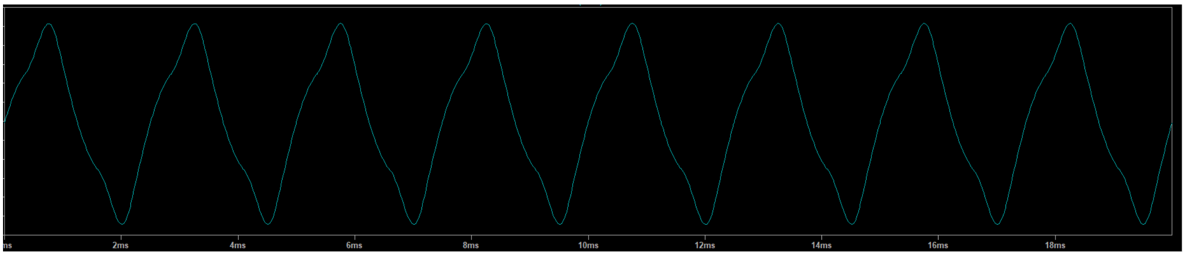


Figure 17: Voltage Controlled Amplifier Output

7.2 Hardware Testing

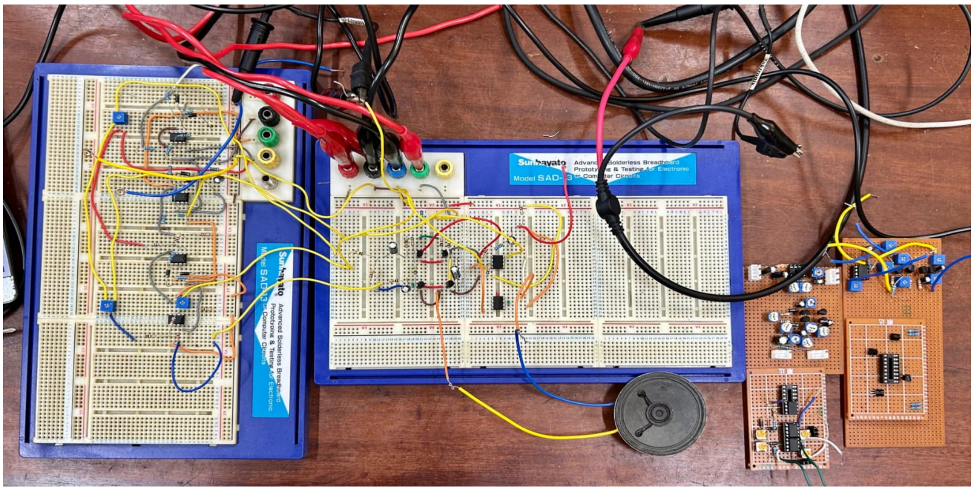


Figure 18: Breadboard Implementation

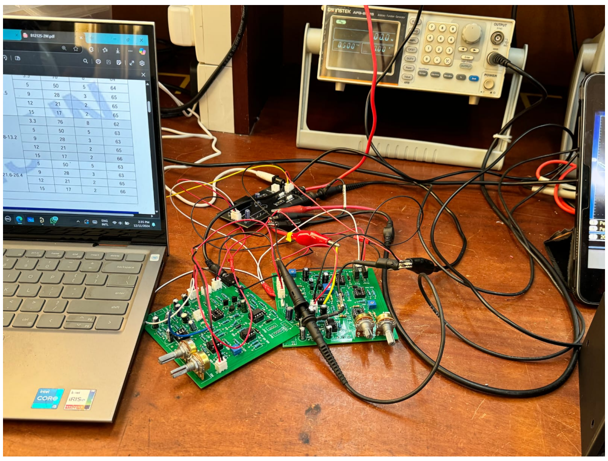


Figure 19: PCB testing

8 Conclusion & Future Works

In this project, we successfully designed and implemented an upward volume expander. The upward expander amplifies signals above a set threshold, enhancing the clarity and depth of audio signals. Despite the challenges, our team was able to build this system from scratch, which significantly broadened our understanding of analog electronics.

One of the primary challenges was the limited availability of resources, both online and from other sources, on the design and implementation of such systems. As a result, we relied heavily on theoretical concepts and iterative experimentation to develop functional circuit components. This process deepened our practical knowledge of operational amplifiers, rectifiers, voltage-controlled amplifiers, and filters, while strengthening our problem solving skills.

For future work, we aim to extend this project by incorporating a downward expander. The downward expander will attenuate signals below a set threshold, further improving the dynamic range control of the system. This addition will make the system more versatile and applicable for a wider range of audio processing needs.

This project provided invaluable hands-on experience and enhanced our understanding of dynamic range processing in audio systems. We are confident that the skills and knowledge gained will serve as a strong foundation for future endeavors in analog and digital electronics.

Acknowledgments

We extend our heartfelt gratitude to everyone who contributed to the successful completion of our volume expander project. First and foremost, we express our sincere appreciation to our project supervisor, Mr. S. Rukshanth, Mr.Thilanka Udana, Ms.Dinithi Fernando, Mr.Sandun Ranasinghe for their invaluable guidance, insights, and unwavering support throughout the development process.

We also acknowledge the dedication, hard work, and collaborative efforts of every team member, which were instrumental in achieving the project objectives. Our special thanks go to Dr. Sampath Perera, Dr. Jayathu Samarawickrama, Dr. Chamira Edirisooriya, and Dr. Wageesha Manamperi for their constructive feedback during project reviews, which greatly contributed to refining and enhancing our design.

Additionally, we are grateful for the encouragement and assistance provided by our peers and colleagues, whose support further motivated us during this journey. This project has been a collective effort, and the collaborative environment enabled us to explore, innovate, and overcome challenges effectively.

The invaluable experience gained from this project will undoubtedly serve as a foundation for our future endeavors.

9 Contribution of Group Members

Index Number	Tasks
220054N	Circuit design ,PCB design, Documentation
220112R	Circuit design, Enclosure design, PCB testing
220128V	Circuit design, Enclosure design, Documentation
220143L	Circuit design, PCB design, PCB testing

References

[1] R. HD-Audio. Audio dynamics processing: Compression, expansion, limiting, and gating. [Online]. Available: https://www.realhd-audio.com/?p=3318

[2] iZotope. Audio dynamics 101: Compressors, limiters, expanders, and gates. [Online]. Available: https://www.izotope.com/en/learn/audio-dynamics-101-compressors-limiters-expanders-and-gates.html?srsltid=AfmBOoruOm2PhKe4r2WJ2IwvQ9CTKq4

[3] MathWorks. Expander system object. [Online]. Available: https://www.mathworks.com/help/audio/ref/expander-system-object.html

[4] Pcb capabilities and limitations. Available: https://jlcpcb.com. JLCPCB. Accessed: Dec. 23, 2024.