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

# Analog Synthesizer Module

Analog Project Report

Group Members:



| | | |
|---|---|---|
| Member 1 | 220542J | Sadaruwan I.J.M.J |
| Member 2 | 220439B | Pahasara L.P.P |
| Member 3 | 220077L | Budvin M.P.L |
| Member 4 | 220468L | Perera M.D.R.N |



EN1190 Engineering Design Project

2024 December

# 1 Introduction and Functionality

## 1.1 Introduction

The analog synthesizer module we developed is designed to generate and manipulate sound waves using pure analog circuitry. This synthesizer combines traditional electronic components to produce and shape sound, offering musicians, sound designers, and enthusiasts a powerful tool for creating unique musical tones and effects. By integrating key components such as oscillators, filters, amplifiers, and envelope generators, the synthesizer achieves rich, organic sounds that are characteristic of classic analog synthesis.

The primary purpose of this module is to generate and shape basic waveforms—such as sine, square, and triangle waves into musical tones and complex audio textures. Through intuitive parameter control, users can manipulate sound characteristics like frequency, amplitude, and modulation to craft everything from smooth melodic tones to dynamic, evolving soundscapes. This module serves as both an educational tool for understanding analog electronics and a functional sound generator for musical applications, making it versatile for beginners and professionals alike.

## 1.2 Functionality

1. **Waveform Generation -** The module can generate **sine**, **square**, **triangle**, and **sawtooth waveforms** within a frequency range of **15 Hz to 300 Hz**. These fundamental waveforms serve as the building blocks for crafting musical tones and sound effects.

2. **Envelope Generation -** A basic **envelope generator** allows control over the amplitude dynamics of the sound, providing users with the ability to shape the *attack*, *sustain*, and *decay* of the audio signal.

3. **Low-Pass Filtering with Variable Cutoff and Resonance -** A **low-pass filter** is incorporated to shape the timbre of the generated waveforms by attenuating higher frequencies. Users can control the **cutoff frequency** to determine where the filter starts to reduce frequencies and adjust the **resonance** to emphasize specific tones near the cutoff point.

4. **Amplification -** The module includes an **amplifier stage** to ensure that the output audio signal is strong enough for further processing, external mixing, or playback through speakers or headphones.

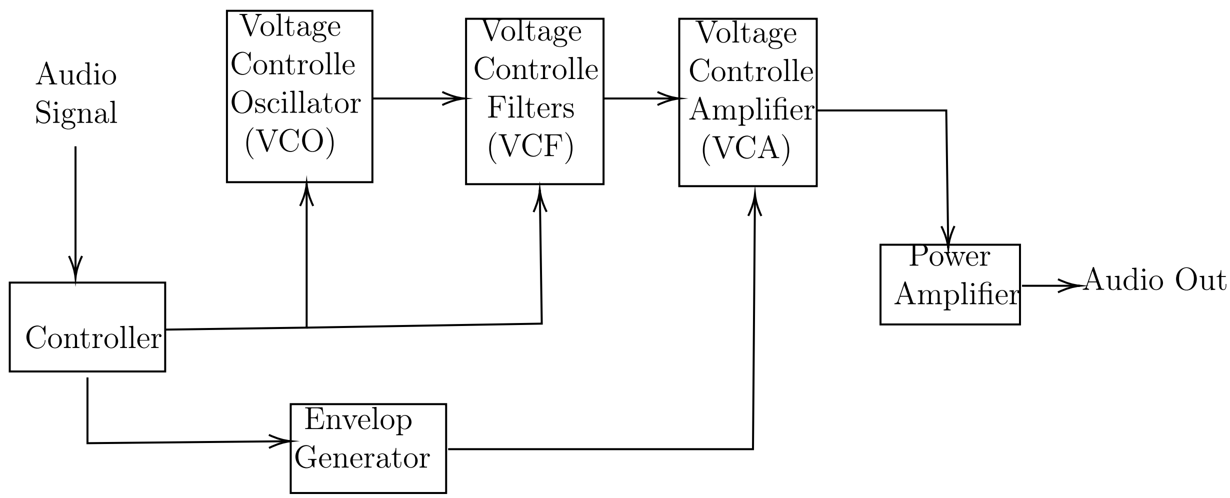
5. **Audio Mixing with External Input -** The synthesizer allows integration of **external audio inputs**, such as songs or pre-recorded music, which can be mixed with the generated waveforms. This feature expands the creative possibilities by combining natural and synthesized sounds.

6. **User-Configurable Parameters -** Users have access to **adjustable controls** for waveform selection, frequency tuning, filter cutoff, resonance, and envelope settings. These parameters allow real-time customization of the sound output, enabling the creation of a variety of tones and textures.

7. **Input and Output Integration -** The synthesizer supports **external audio input** for mixing and processes signals effectively. The final audio output can be connected to **speakers, headphones**, or **recording systems**, providing flexibility for live performances or recording applications.

# 2 System Architecture

## 2.1 The Block Diagram




## 2.2 Equations

- **RC Differentiator**

$$V_{\text{out1}} = RC \cdot \frac{d(V_{\text{in}})}{dt}$$

- **RC Integrator**

$$V_{\text{out2}} = \frac{1}{RC} \int V_{\text{in}} \, dt \Big|_0^t$$

- **Comparator**

$$V_{\text{out}} = \begin{cases} +V_{\text{cc}}, & \text{if } V_{\text{in}} > V_{\text{ref}} \\ -V_{\text{cc}}, & \text{if } V_{\text{in}} < V_{\text{ref}} \end{cases}$$

- **Oscillator (Non-Inverting Schmitt Trigger)**

$$\text{UTP} = \frac{R_f}{R} \cdot V_{\text{sat}}$$

$$\text{LTP} = -\frac{R_f}{R} \cdot V_{\text{sat}}$$

- **Op-Amp Integrator**

$$V_{\text{out}} = -\frac{1}{RC} \int V_{\text{in}} \, dt \Big|_0^t$$

- **Adder**

$$V_{\text{out}} = \left(1 + \frac{R_f}{R_a}\right)\left(\frac{R_2 V_1}{R_1 + R_2} + \frac{R_1 V_2}{R_1 + R_2}\right)$$

- **Attenuator**

$$V_{\text{out}} = \frac{R_f}{R_a} V_{\text{in}}, \quad R_f < 1$$

- **Non-Inverting Amplifier**

$$V_{\text{out}} = \left(1 + \frac{R_f}{R_a}\right) V_{\text{in}}$$

- **Subtractor**

$$V_{\text{out}} = \frac{R_2}{R_1}(V_2 - V_1)$$

- **Single Input Balanced Output BJT Differential Amplifier**

$$V_{\text{out}} = \frac{R_c}{r_e} V_{\text{in1}}, \quad \text{where } V_{\text{out}} = V_{\text{out2}} - V_{\text{out1}}, \quad r_e = \frac{0.026}{|I_e|}$$

## 2.3 Guidelines for References

- `https://www.youtube.com/watch?v=kBT4ycltfBE`
- `http://web.mit.edu/6.101/www/s2017/projects/dominikm_Project_Final_Report.pdf`
- `https://web.mit.edu/6.101/www/s2014/projects/lgresko_Project_Design_Presentation.pdf`
- `https://www.youtube.com/watch?v=GsTGu2V7tcU`
- `https://musicfromouterspace.com/analogsynth_new/THE_CAVE/KBD%20Controller%20Old%20Design%20I/Analog%20Synth%20Keyboard%20Schematic.htm`

# 3 Component Selection

## 3.1 Oscillators

- We used **LM358 op-amps** for waveform generation due to their low noise and high slew rate, ensuring clean and stable waveforms.
- Resistors and capacitors were chosen to set the frequency range from **15 Hz to 300 Hz**.

## 3.2 Waveform Selection

- We used **SPDT switches** to allow the user to select between sine, square, triangle, and sawtooth waveforms.

## 3.3 Filters

- We used **LM358 op-amps** for implementing the low-pass filter due to their low offset voltage and suitability for audio applications.
- **Potentiometers (100 kΩ)** were used to allow real-time adjustment of the cutoff frequency and resonance.
- Capacitors and resistors with **1% tolerance** were chosen for precise filtering performance.

## 3.4 Amplifier Stage

- We used an **LM386 amplifier** to boost the audio signal for driving headphones or small speakers.
- Resistors and capacitors were selected based on the gain and frequency response requirements.

## 3.5 Input and Output

- We used **3.5mm audio jacks** for external input and output connections to ensure compatibility with common audio devices.
- **Potentiometers (100 kΩ, 1 MΩ)** were used to allow real-time parameter adjustments, such as waveform tuning and volume control.

# 4 PCB

## 4.1 Schematics

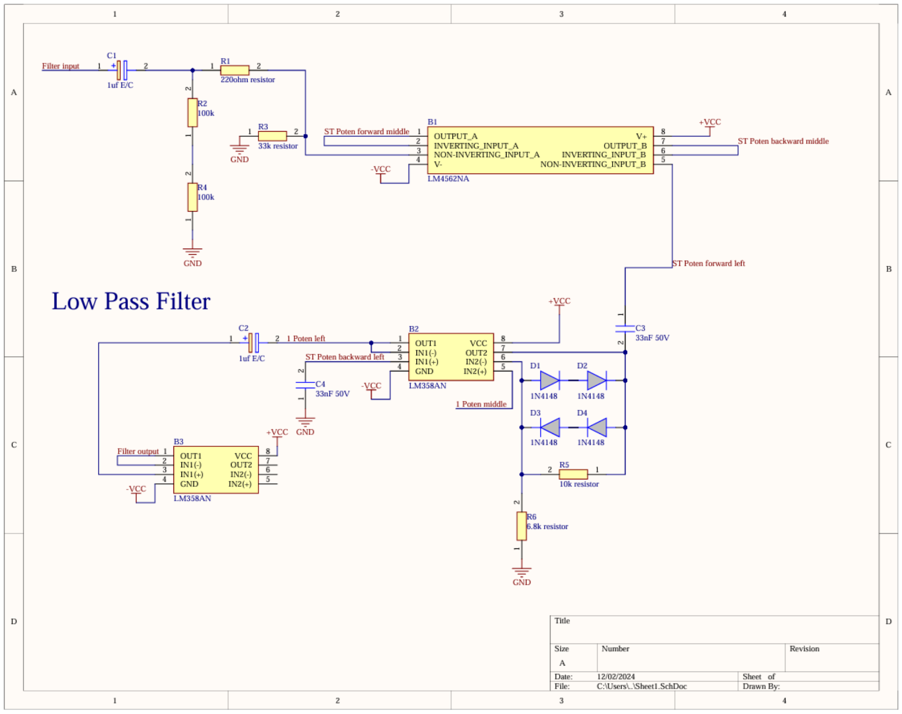



Figure 1: Sheet 1

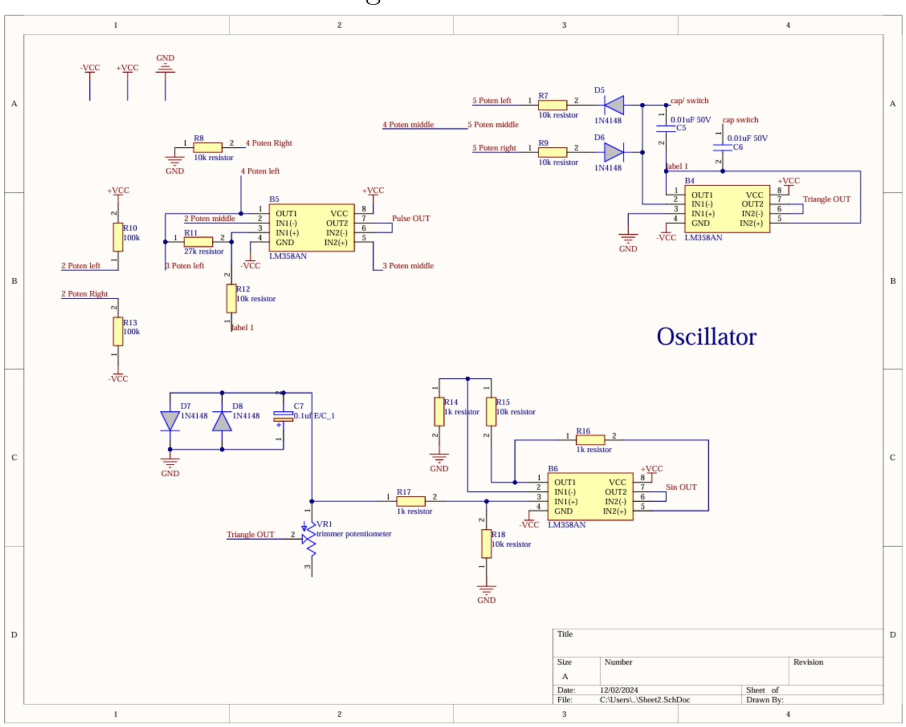



Figure 2: sheet 2

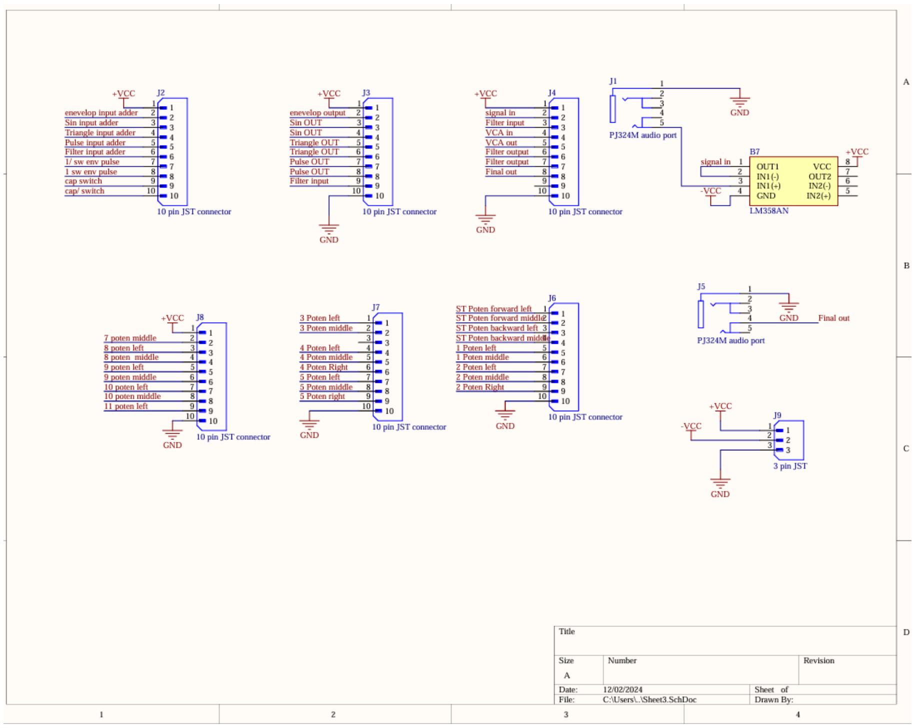


Figure 3: Sheet 3

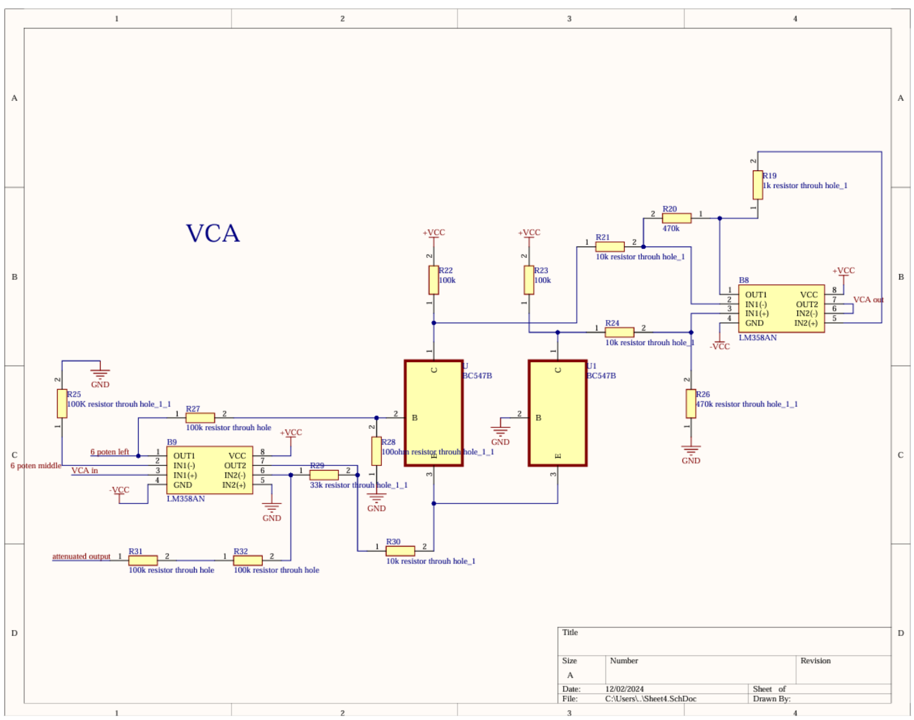


Figure 4: Sheet 4

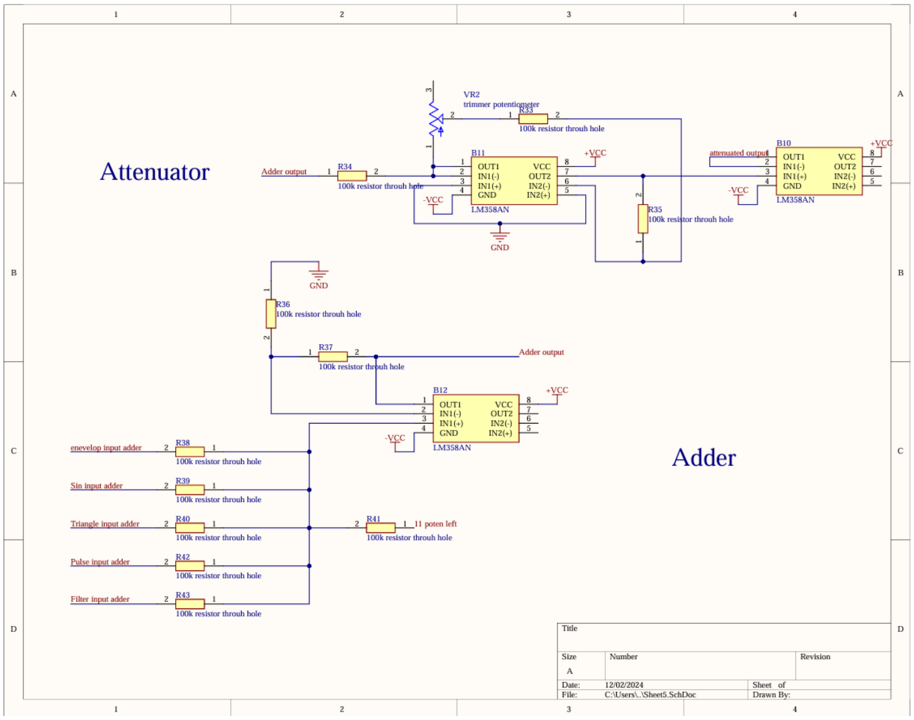



Figure 5: Sheet 5

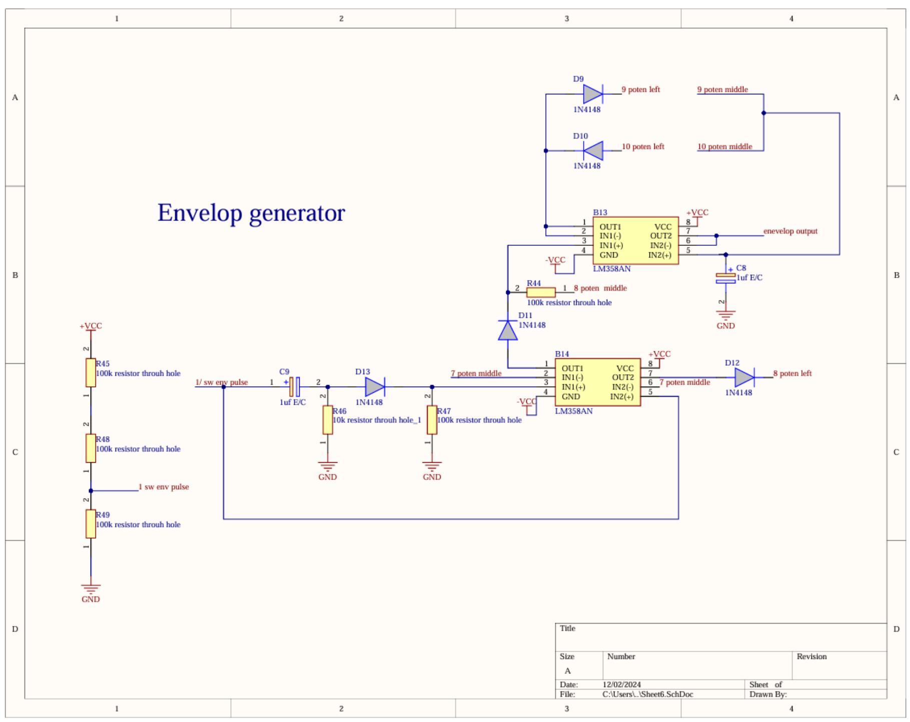



Figure 6: Sheet 6

## 4.2 PCB

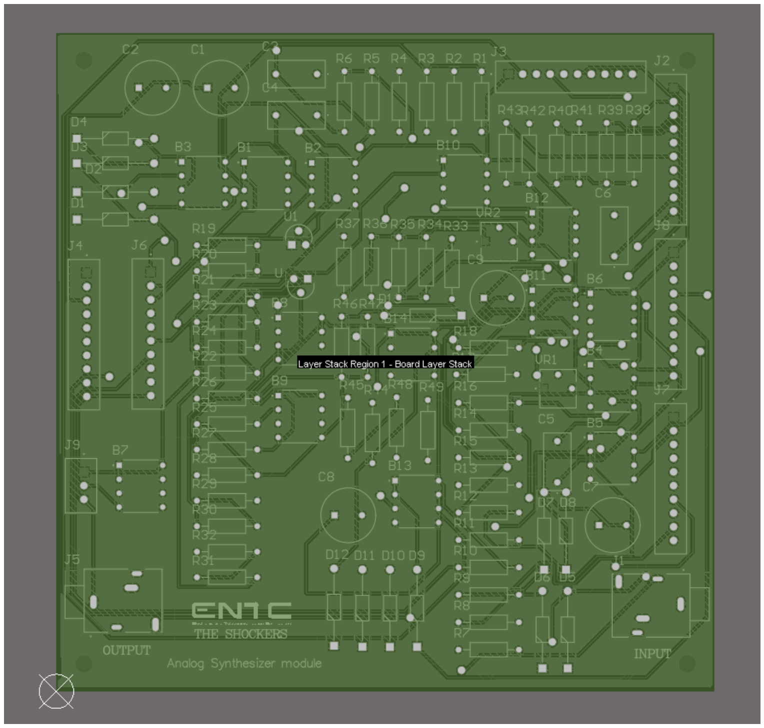



Figure 7: **2D Layout Mode**

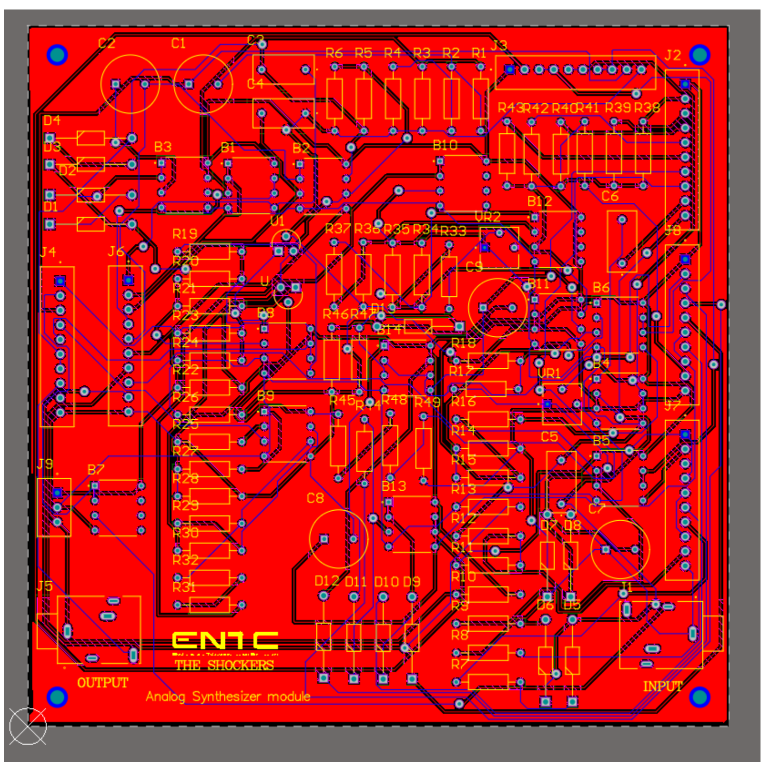



Figure 8: **2D Layout Mode with Multi-Layer View**

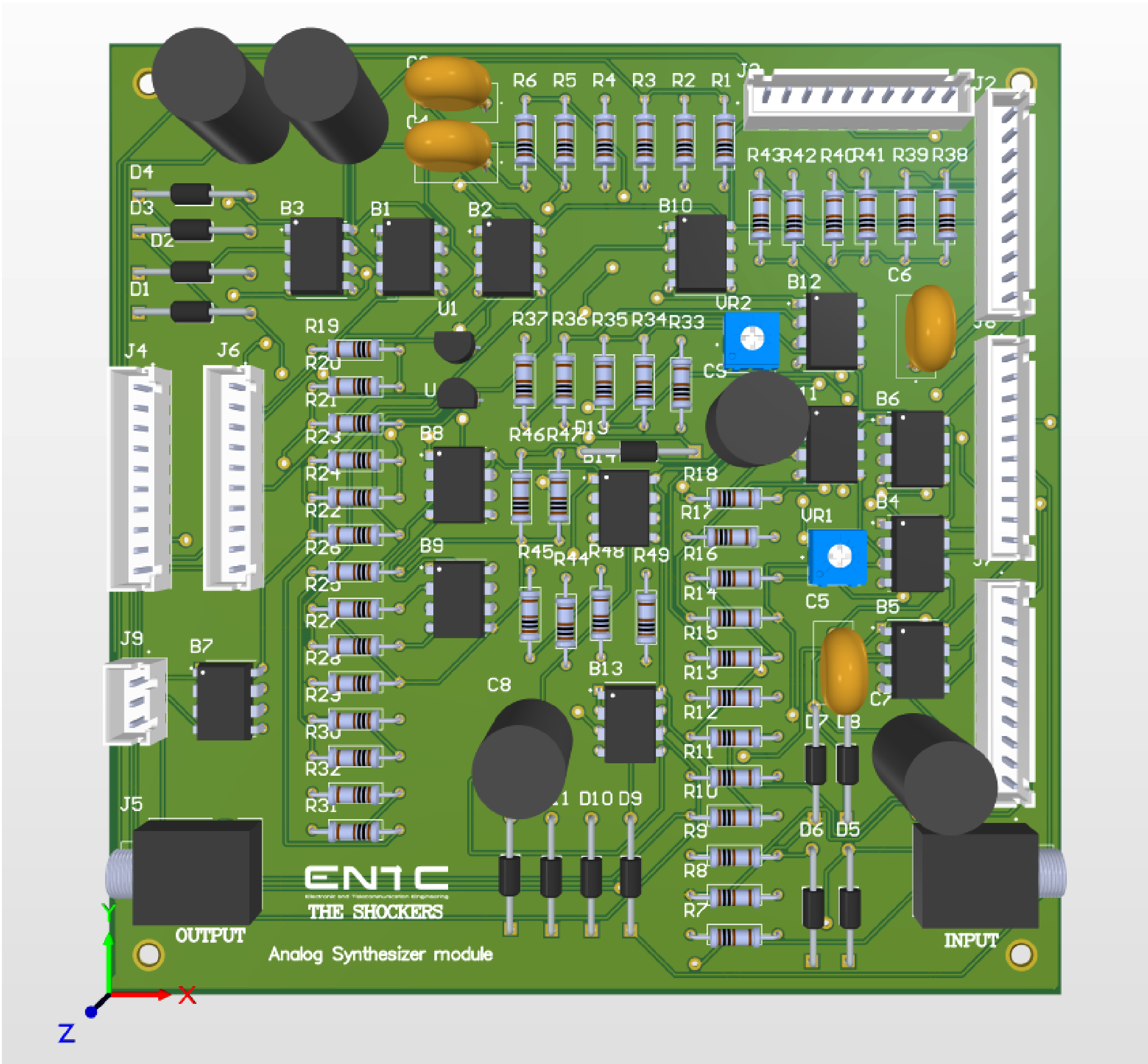



Figure 9: **3D Layout Mode**

# 5 Enclosure Design

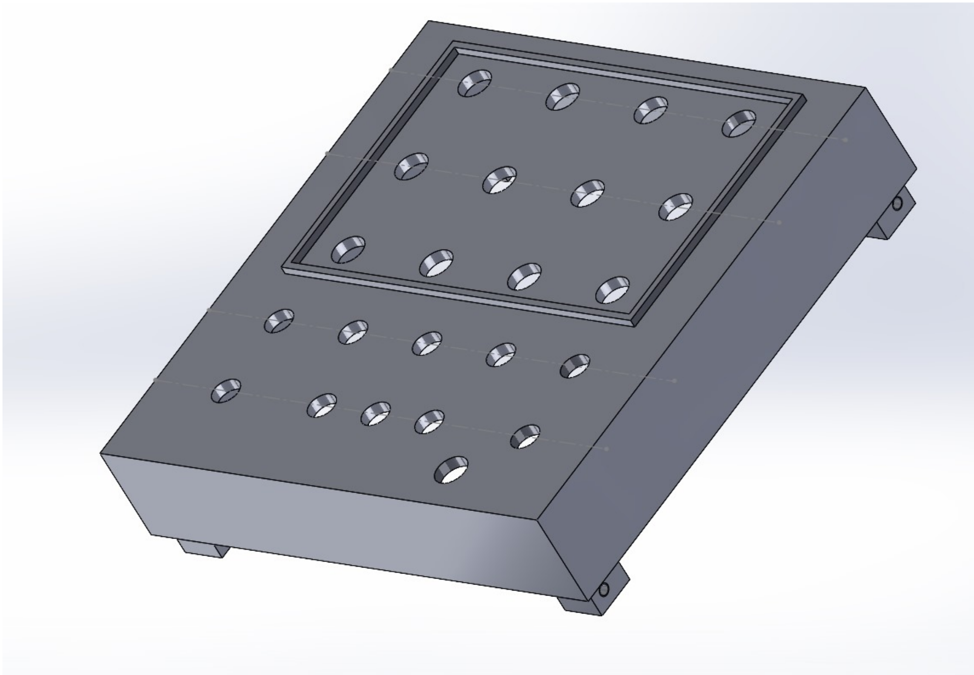


Figure 10: **Upper Part**

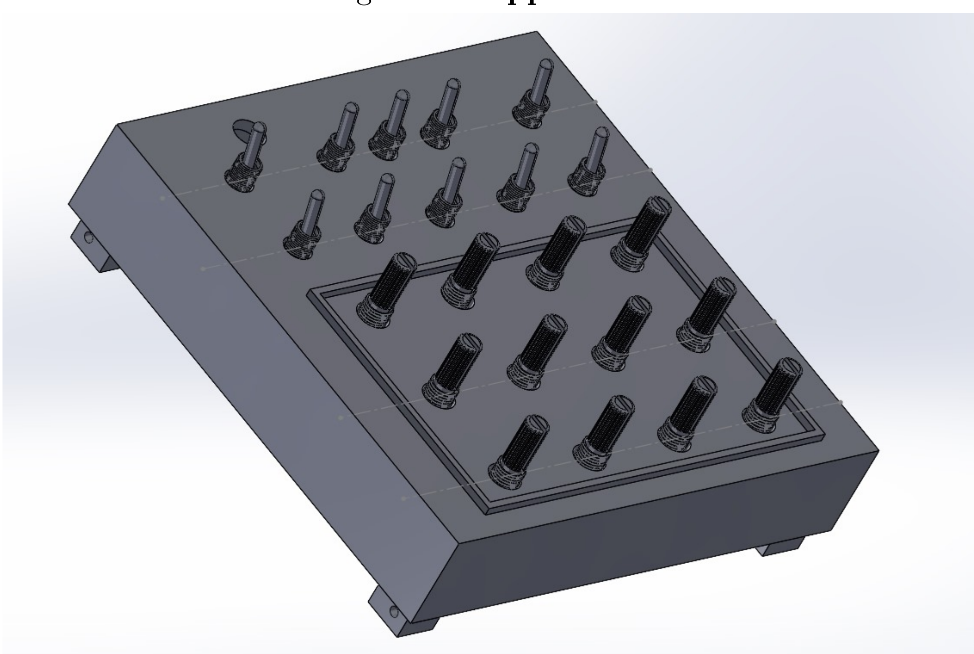


Figure 11: **Upper Part with assembly**

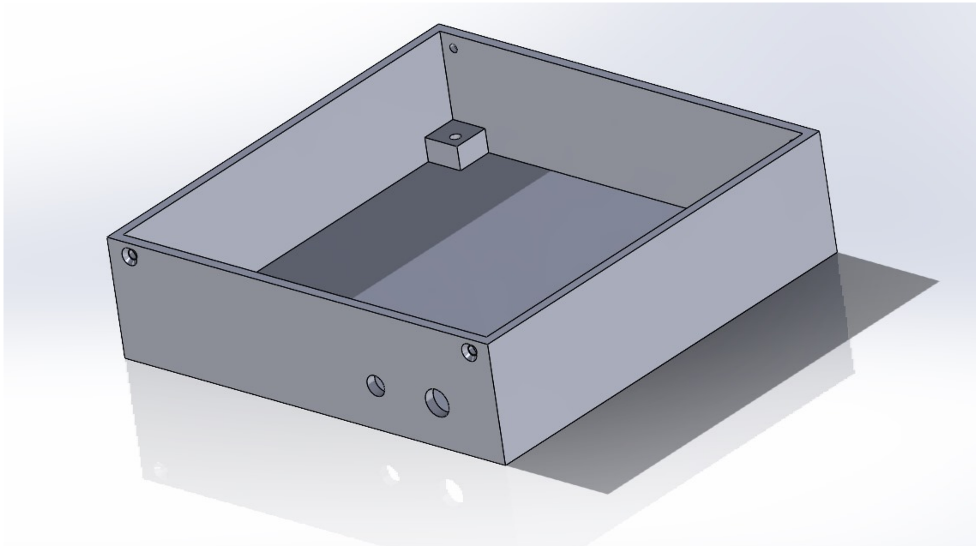


Figure 12: **Lower Part**

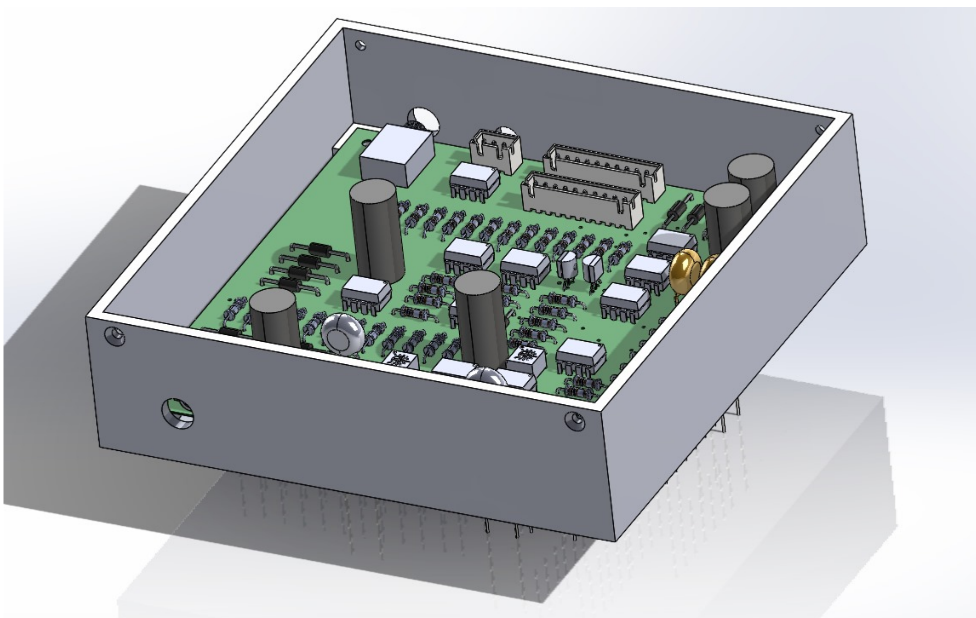


Figure 13: **Lower Part with assembly**

# 6 Final Product

Our product is designed with a focus on durability, safety, and aesthetics. Constructed from high-quality, fire-resistant materials, it ensures long-term reliability while promoting an enhanced user experience.


Figure 14: **Top view**

sideview.jpg

Figure 15: **Side View**

# 7 Software Simulation and Hardware Testing

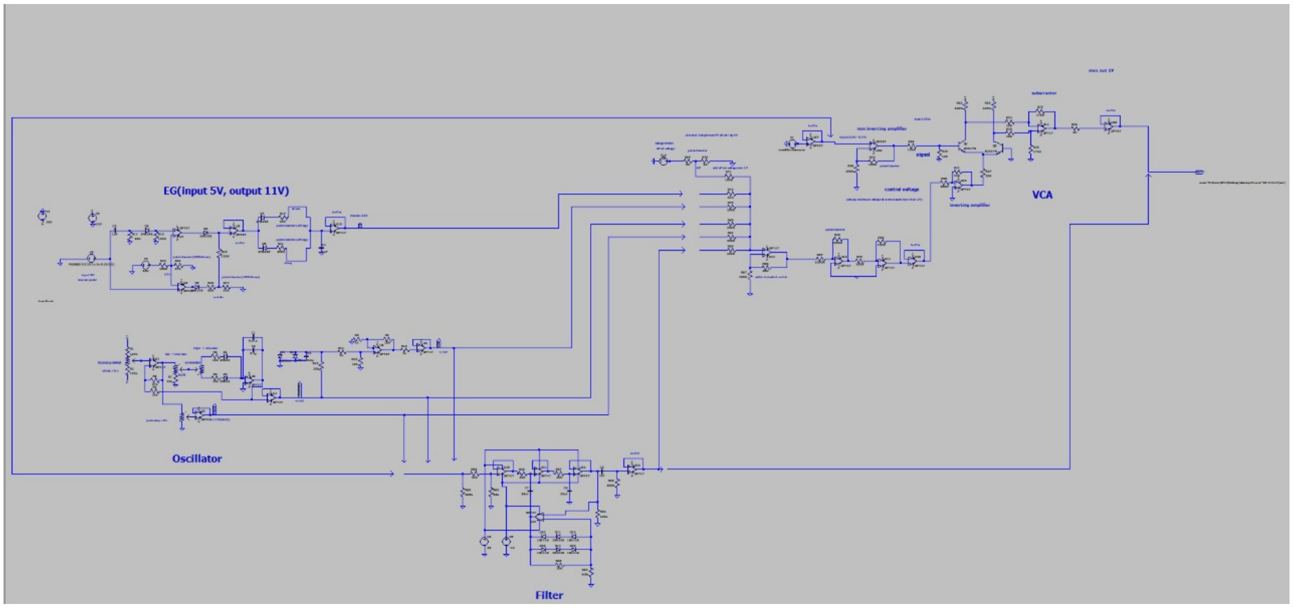



Figure 16: **Simulation in LTspice**

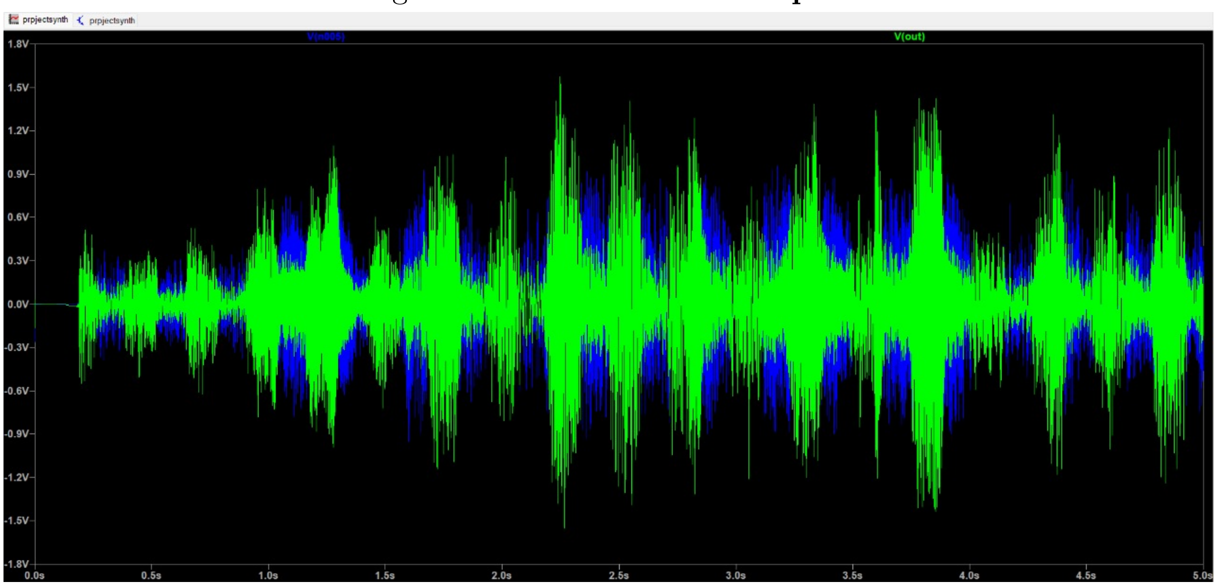



Figure 17: **song mixing with sin wave song - Blue waveform / output - Green Waveform**

# 8 Conclusion and Future Works

## 8.1 Conclusion

The analog synthesizer module we developed successfully demonstrates the generation and manipulation of sound through analog circuitry. By integrating key components such as waveform generators, envelope generators, low-pass filters with adjustable cutoff and resonance, amplifiers, and audio mixing capabilities, the module delivers a versatile platform for creating a wide range of tones and sound effects. The user-configurable parameters allow real-time control over the sound output, making the synthesizer suitable for musical performances, sound design, and experimental audio applications.

The project has provided valuable insights into analog signal processing, circuit design, and the implementation of audio systems. It serves as a strong foundation for further development and innovation in analog sound synthesis.

## 8.2 Future Works

While the current module achieves its intended functionality, there are several opportunities for improvement and expansion in future iterations:

1. **Advanced Waveform Control** Implementing features such as **pulse-width modulation (PWM)** for square waves and **waveform blending** to allow more complex sound generation.

2. **Additional Filters** Incorporating **high-pass** and **band-pass filters** alongside the existing low-pass filter to provide more versatility in sound shaping.

3. **Envelope Enhancements** Expanding the envelope generator to include more stages (e.g., **attack, decay, sustain, release - ADSR**) for finer control over sound dynamics.

4. **MIDI Integration** Incorporating a **MIDI input interface** to allow external control from digital devices and keyboards, bridging the gap between analog and digital synthesis.

5. **Improved Audio Mixing** Enhancing the mixing stage to include **multi-channel audio inputs** and **adjustable gain controls** for better signal integration.

6. **Compact and Modular Design** Redesigning the system for a more **compact form factor** or **modular format** to enable integration with existing analog synthesizer systems.

By incorporating these improvements, the analog synthesizer module can be transformed into a more sophisticated, versatile, and user-friendly tool, expanding its applications in **music production, education**, and **sound experimentation**.

# 9 Contribution of Group members

| Group Member | Task and Details |
|---|---|
| Sadaruwan I.J.M.J | As the team leader, Sadaruwan was responsible for overseeing the entire project.He took part in assembling and testing the first version of the circuit on a breadboard, making it easier to iterate quickly and resolve issues before moving on to the final design. He handled the main circuit and PCB design, simulating circuits using **Proteus** and **LTspice**, and designing the PCB with **Altium Designer**. Additionally, He collaborated closely with the team to finalize the report and managed all essential aspects, including team management. Sadaruwan was also actively involved in the component soldering process. |
| Pahasara L.P.P | Pahasara was responsible for designing oscillator and he tested the initial circuit models using simulation tools(**LTspice,Proteus**) to verify their functionality. He also built and tested the initial circuit on a breadboard, allowing for rapid iteration and troubleshooting before moving on to more permanent designs. He was also involved in creating and debugging PCB layouts in **Altium**. He soldered components onto the PCB and oversaw the assembly of the entire system. |
| Budvin M.P.L | Budvin contributed to this synthesizer project by designing the Envelope Generator (EG) and the Voltage-Controlled Amplifier (VCA). He played a key role in integrating the various parts developed by team members, including the filter, oscillator, EG, and VCA, to achieve the desired output. This involved simulating the interconnected components to ensure proper functionality. Additionally, he was responsible for soldering the components. |
| Perera M.D.R.N | Perera played a vital role in the project, contributing her expertise in designing the **low pass filter circuit**, conducting detailed circuit simulations on **LTspice**, and implementing the design on a breadboard with rigorous testing to ensure optimal performance. She also developed the product enclosure using **Solidworks** , balancing aesthetics and functionality. Furthermore, she prepared the project presentation, effectively showcasing the team's efforts and achievements. |

Table 1: Task Allocation for Group Project