Development and Prototyping of a Modular Synthesizer

Paul Nieves

Professor Patterson

Project Duration: 2 Semesters (1 Academic Year)

April, 25, 2025

Table of Contents

PART I – USER MANUAL

1. Introduction

1.1 Overview and Quick Setup

1.1.1 Overview

This document provides you with detailed instructions on setting up, testing, and troubleshooting your synthesizer. The unit is designed with several key modules: a Voltage-Controlled Oscillator (VCO), a MIDI-to-CV converter, an Attack-Decay-Sustain-Release (ADSR) envelope generator, a Voltage-Controlled Amplifier (VCA), and a power supply that delivers approximately ±18V DC and ±15V DC to each module. All components are neatly housed in a custom, ergonomic, and durable enclosure, ensuring a robust and reliable performance.

1.1.2 Quick Setup

To get started, connect the brick wall adapter to a standard 120V AC outlet and then plug the adapter's barrel jack into the connector located on the left side panel of the synthesizer. This connection will power on all the modules simultaneously. Next, set up your audio output by connecting the synthesizer using patch cables, as shown in Figure 1.1.2.1. You can use any MIDI-capable device equipped with a 5-pin DIN connector to interface with the MIDI-to-CV converter. Finally, route a patch cable from the synthesizer to an amplifier or speaker using a 3.5mm jack.

After all the connections are made, press a note on your MIDI controller to test the system. If you do not hear any sound, first ensure that the Sustain Knob on the ADSR module is set to 100%, and then press a note again. If the problem persists, adjust the VCO module by turning its coarse knob down to 0% and try playing a note once more. Additionally, verify the settings on the VCA: the gain knob should be set to 50%, the input signal level should be at 100%, and the CV signal level should be at 10%. Press a note again to check if these adjustments have produced the desired sound.

If you still experience issues, refer to the troubleshooting section later in this manual for further guidance or contact our technical support team for assistance at paulnieves.com. Following these steps carefully will help you set up and fine-tune your modular synthesizer, ensuring optimal performance and a satisfying user experience.

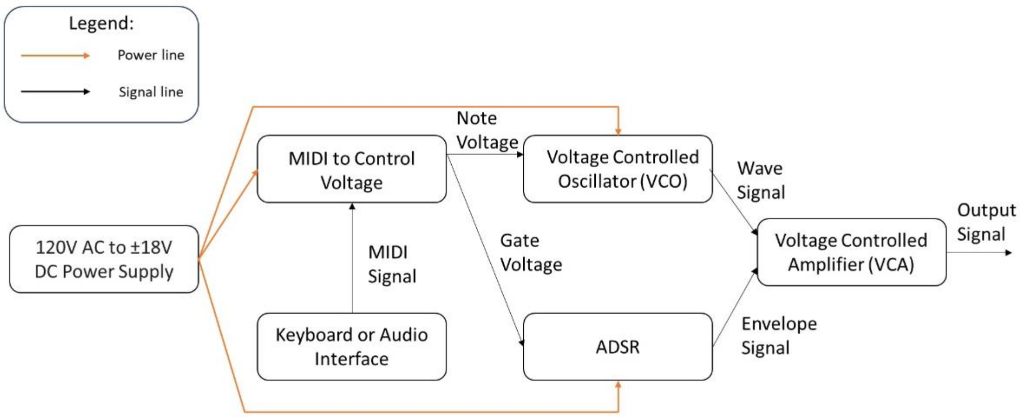

Figure 1.1.2.1: Block Diagram Overview and Example Patching

1.2 Modules Overview (Inputs and Outputs)

1.2.1 MIDI-to-CV Converter

This module converts MIDI note data into precise control voltages (0–10V) and gate signals. In Figure 1.2.1.1, it shows the input is MIDI In and the outputs are Gate, Clock, Trig, Pitch Bend, Control, Note, Velocity. Use Table 1.2.1.1 and Table 1.2.1.2 to see what each input and output does.

Input Label	**Description**	**Signal/Voltage Characteristics**
MIDI In	Receives standard MIDI messages (Note On/Off, Clock, etc.) from a MIDI controller or sequencer.	Digital MIDI data (typically 5V logic level)

Table 1.2.1.1: MIDI-to-CV Converter Input

Output Label	**Description**	**Typical Voltage Range/Characteristics**	**Use in System**
Gate	Provides a digital gate signal that indicates when a key is pressed or a note is triggered.	0V when inactive, 5V when active (digital pulse)	Triggers envelope generators or VCA gate inputs.
Clock	Outputs a clock signal derived from MIDI clock messages for timing purposes.	0–5V square wave; frequency depends on MIDI clock tempo	Synchronizes sequencers, LFOs, and other time-based modules.

Trig	Delivers a short-duration trigger pulse at the onset of a note event.	0–5V pulse, with a brief duration (typically 10–50 ms)	Initiates events such as envelope retriggering.
Pitch Bend	Converts MIDI pitch bend data into a corresponding control voltage for pitch modulation.	Generally centered around 5V; spans 0–10V (range adjustable per settings)	Modulates oscillator frequency (e.g., vibrato effects).
Control	Outputs control voltages corresponding to MIDI Continuous Controller (CC) messages.	0–10V (variable, based on the specific MIDI CC assignment)	Controls parameters such as filter cutoff, modulation depth, etc.
Note	Converts MIDI note numbers into voltage based on the 1V/octave standard.	Approximately 0–10V, depending on the note range	Directly controls the pitch of the VCO.
Velocity	Converts MIDI note velocity data into a proportional control voltage.	0–10V, scaled according to the velocity value	Can be used to modulate amplitude or other dynamic parameters.

Table 1.2.1.2: MIDI-to-CV Converter Outputs

Figure 1.2.1.1: MIDI To CV Panel with Input and Outputs

1.2.2 VCO (Voltage-Controlled Oscillator)

The VCO module generates audio signals with selectable waveforms (sine, square, triangle, sawtooth) controlled by input voltage. In Figure 1.2.2.1, it shows the inputs are LIN FM, EXP FM, PWM, SNYC, V/Oct1, V/Oct1 and the outputs are SINE, TRIG, SAW, PULSE. Use Table 1.2.2.1 and Table 1.2.2.2 to see what each input and output does.

Input Label	Description	Signal Characteristics
LIN FM (Linear Frequency Modulation)	Accepts a control voltage that linearly modulates the oscillator's frequency. Useful for subtle frequency shifts and vibrato effects.	Modulates frequency in a linear manner, proportional to the input voltage.
EXP FM (Exponential Frequency Modulation)	Modulates the frequency exponentially, aligning with musical pitch perception (1V typically represents one octave). Ideal for musically relevant pitch shifts.	Frequency modulation follows an exponential relationship with the input voltage.
PWM (Pulse Width Modulation)	Varies the duty cycle of the pulse waveform output, altering harmonic content and timbre. Enhances	Adjusts the pulse width, affecting the harmonic spectrum of the output waveform.

	expressiveness by adjusting the pulse width.	
SYNC (Synchronization)	Resets the oscillator's waveform cycle, enabling phase locking with other oscillators. Ensures synchronized starts in multi-oscillator setups.	Resets the phase of the oscillator, synchronizing it with external signals.
V/Oct1 and V/Oct2 (Voltage per Octave Inputs)	Receives control voltages based on the volts-per-octave standard, where a 1V change corresponds to an octave change in pitch. Allows combining signals for precise pitch control.	Each volt change in input corresponds to a one-octave change in pitch, following the 1V/octave standard.

Table 1.2.2.1: VCO Input Definitions

Output Label	**Description**	**Signal Characteristics**
SINE	Outputs a smooth sine wave, ideal for generating pure tones or serving as a low-frequency modulation source.	Continuous, smooth waveform with no harmonics, suitable for pure tone generation.
TRIG	Provides a trigger output—a short, sharp pulse marking the start of each oscillator cycle. Useful for synchronizing envelope generators or sequencers.	A brief pulse indicating the beginning of a cycle, typically lasting 10–50 ms.
SAW	Outputs a sawtooth wave, rich in harmonic content. Commonly used in subtractive synthesis for bright, buzzy sounds with complex overtones.	A waveform that ramps upward linearly and then drops sharply, containing all integer harmonics.
PULSE	Delivers a pulse (square) wave with an adjustable duty cycle via the PWM input. Useful for generating percussive sounds or adding a sharp edge to the sound palette.	A square wave whose high and low durations can be varied, affecting the waveform's harmonic content.

Table 1.2.2.2: VCO Output Definitions

Figure 1.2.2.1: VCO Module Panel with Inputs and Outputs

1.2.3 ADSR Envelope Generator

Produces a dynamic envelope (Attack, Decay, Sustain, Release) to shape the amplitude of audio signals. In Figure 1.2.3.1, it shows the input is Gate In and the outputs are Env Out and Env Out (Inv). Use Table 1.2.3.1 and Table 1.2.3.2 to see what each input and output does.

Input Label	**Description**	**Signal/Voltage Characteristics**
Gate In	Receives a gate signal that triggers the envelope cycle. When the gate signal goes high (e.g., when a key is pressed), the envelope is activated.	0V (inactive) to 2V (active) (digital signal)

Table 1.2.3.1: ADSR Envelope Generator Input

Output Label	**Description**	**Typical Behavior**
Env Out	Provides the generated envelope signal following the ADSR curve. This signal is used to shape the amplitude of an audio signal over time.	Rises during the attack phase, decays to the sustain level, and falls during the release phase.
Env Out (Inv)	Outputs an inverted version of the envelope signal. This is useful for applications	The polarity of the Env Out is reversed (e.g., when Env Out is high, Env Out (Inv) is low, and vice versa).

	requiring the complementary modulation curve.	

Table 1.2.3.2: ADSR Envelope Generator Outputs

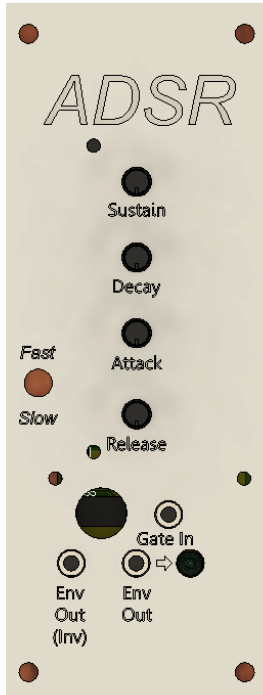

Figure 1.2.3.1: ADSR Panel with Inputs and Outputs

1.2.4 VCA (Voltage-Controlled Amplifier)

Adjusts signal amplitude based on control voltage inputs. In Figure 1.2.4.1, it shows the input is Signal In1, In2, In3, CV1, CV2 and the outputs are Output 1 and Output 2. Use Table 1.2.4.1 and Table 1.2.4.2 to see what each input and output does.

Input Label	**Description**	**Signal/Voltage Characteristics**
Signal In1	Primary audio signal input.	Accepts audio signals; typical range: ±5V.
Signal In2	Secondary audio signal input, allowing for mixing multiple audio sources.	Accepts audio signals; typical range: ±5V.
Signal In3	Tertiary audio signal input for additional audio source integration.	Accepts audio signals; typical range: ±5V.
CV1	Control Voltage input 1; modulates the amplitude of the output signal based on the applied voltage.	Accepts control voltages; typical range: 0–5V or 0–10V, depending on design.

CV2	Control Voltage input 2; provides additional modulation capability, allowing for complex amplitude modulation when combined with CV1.	Accepts control voltages; typical range: 0–5V or 0–10V, depending on design.

Table 1.2.4.1: VCA Inputs

Output Label	**Description**	**Signal/Voltage Characteristics**
Output 1	Primary output delivering the amplified audio signal, modulated by the control voltages applied to CV inputs.	Outputs audio signals; typical range: corresponds to input signal amplitude.
Output 2	Secondary output providing either a duplicate of Output 1 or a separately processed signal, depending on the module's configuration.	Outputs audio signals; typical range: corresponds to input signal amplitude.

Table 1.2.4.2: VCA Outputs

c

Figure 1.2.4.1: VCA Panel with Inputs and Outputs

1.2.5 Custom Enclosure and ±18V/±15V DC Power Supply

The encloser houses all modules in a compact, accessible, and expandable design. The power supply provides stable and regulated high-voltage DC power required by the modules. The synth takes a 120V AC to 48V DC 1.25 Brick Supply to power the synth and function properly. Other brick supplies can be used but it just has to be above 36V DC and Max 72V DC.

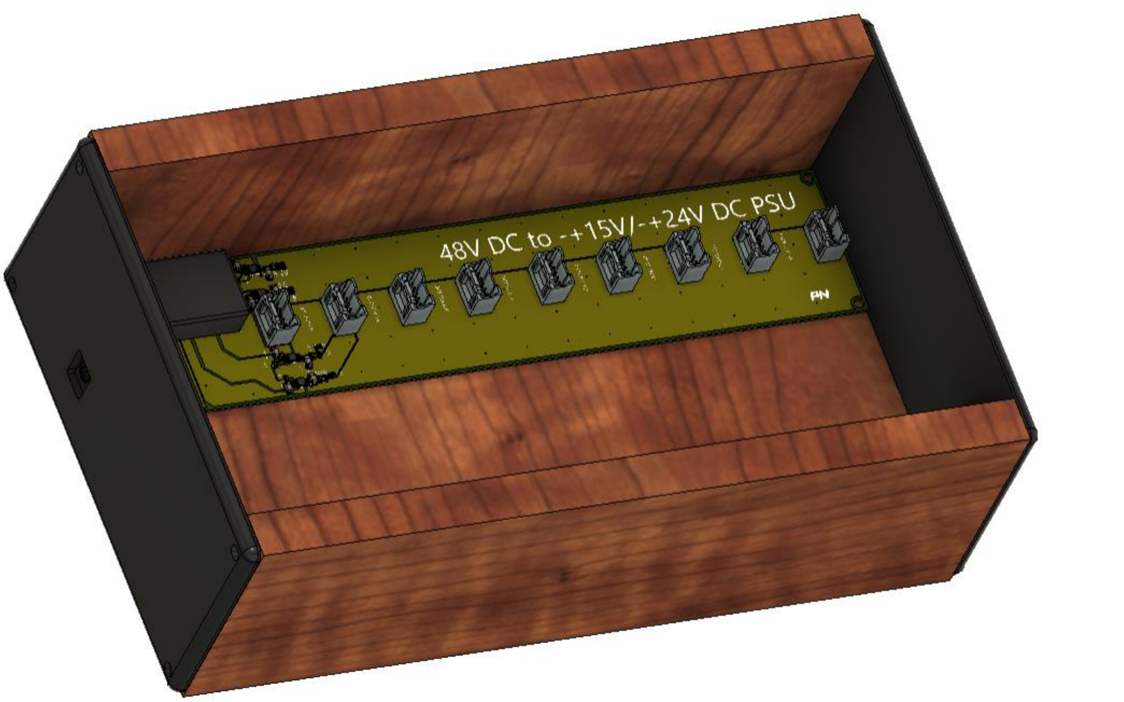

Figure 1.2.5.1: Encloser with Power Supply

1.3 Safety and General Information

1.3.1 Safety precautions regarding voltages and proper handling of components.

While the modular synthesizer system operates at low voltages, it's crucial to observe proper Electrostatic Discharge (ESD) precautions, especially during maintenance tasks such as tuning potentiometers. ESD can inadvertently damage sensitive electronic components. The following tables provide guidelines on ESD safety measures and list the system requirements and necessary hardware for safe maintenance and operation.

Precaution	**Description**
Use of ESD Wrist Straps	Wear an ESD wrist strap connected to a grounded surface to safely dissipate static charges from your body before handling sensitive components.

ESD-Safe Workstation	Perform maintenance on an ESD-safe mat that is properly grounded to prevent static buildup on surfaces.
Avoid Direct Contact	Minimize direct contact with component leads and circuitry. Use insulated tools to adjust potentiometers and handle components to reduce the risk of static discharge.
Proper Clothing	Wear ESD-safe clothing, such as dissipative smocks, to prevent static generation from garments.
Environmental Controls	Maintain a workspace free from static-generating materials like plastic, foam, or vinyl. Ensure the area is dry and free from conductive materials.

Table 1.3.1.1: ESD Safety Precautions

1.3.2 A list of system requirements and hardware (e.g., power adapter, cables, mounting hardware).

Component	**Description**
Power Adapter	A reliable AC to DC power adapter is essential. The system is designed to operate with a 120V AC to 48V DC 1.25 Brick Supply. Alternative brick supplies can be used, provided they output between 36V DC and 72V DC. Ensure the power adapter meets the necessary voltage and current specifications for safe operation.
Cables	**Power Cables**: Appropriate cables to connect the power adapter to the synthesizer modules. Ensure they are rated for the required voltage and current. **Patch Cables**: High-quality patch cables for signal routing between modules. Standard 3.5mm mono jack cables are typically used for Eurorack systems.
Mounting Hardware	**Rack or Enclosure**: A suitable case or rack to house the modules securely. Ensure it provides adequate space and ventilation. **Module Screws**: Appropriate screws to mount the modules within the enclosure.
Maintenance Tools	**Screwdrivers**: For securing modules and assembling the enclosure.

	Multimeter: To verify voltage levels and ensure proper electrical connections. **Soldering Equipment**: If assembling DIY kits or making modifications, a soldering iron with appropriate solder and accessories is necessary.

2. System Setup

2.1 Unboxing and Inspection

After unboxing your modular synthesizer and completing the quick setup described in the introduction, begin by verifying that power is properly distributed to all modules. Check that the ADSR module's indicator light is on—this confirms that your power supply is active and that all modules are receiving the necessary voltage. As a further test, connect one of the outputs from any module to the Signal In 1 input on the VCA. If the VCA's indicator lights up and the Input Level #1 knob is set to 100%, the module is receiving power. Should these indicators not activate, please refer to the troubleshooting section of this manual or contact technical support at paulnieves.com.

2.2 Initial Calibration

Once you have confirmed that the modules are powered and responding, proceed with the initial calibration of the VCO. To ensure the VCO functions as a keyboard with standard note mapping, you must tune it to C0, which corresponds to approximately 16.35 Hz. Begin by disconnecting any patch cables that are connected to the VCO's V/Oct1 and V/Oct2 inputs. Next, connect the output from the SINE waveform of the VCO to an oscilloscope to measure its frequency. Adjust the Coarse knob and Fine Tune Knob until the oscilloscope reads approximately 16.35 Hz. If you do not have access to an oscilloscope, you can alternatively connect the VCO output to an audio interface and use a tuner within your digital audio workstation (DAW) to achieve the desired calibration. These careful steps will ensure that your synthesizer is properly set up and accurately calibrated to standard tuning when using the MIDI-to-CV module's note output.

3. Basic Operation

3.1 Module Controls

3.1.1 MIDI-to-CV Converter

Note: The MIDI-to-CV Converter does not have dedicated control knobs. All control is managed externally via your MIDI controller. Refer to Table 1.2.1.1 for input and Table 1.2.1.2 for output specifications.

The MIDI-to-CV Converter is responsible for converting incoming MIDI messages into precise control voltages and gate signals. This module interprets standard MIDI data—such as note on/off messages, clock signals, and pitch bend information—and outputs corresponding voltages (typically in the range of 0–10V) to control other modules in the synthesizer. Since this module relies entirely on the external MIDI controller for its operation, there are no onboard knobs to adjust. All modulation and signal adjustments are performed through the controller's settings.

3.1.2 VCO (Voltage-Controlled Oscillator)

The VCO module generates audio signals with selectable waveforms—sine, square, triangle, and sawtooth—based on the input voltage. It employs a voltage-to-frequency mapping standard 1V per Octave (1V/Oct) and operates within a frequency range of approximately 15 Hz to 17 kHz, with calibration tolerances of 0.5% of the ideal frequency. Adjust the PWM knob to modify the duty cycle of the pulse waveform, which directly impacts the timbre and harmonic spectrum of the output. The EXP FM and LIN FM knobs are used for pitch modulation, with the EXP FM knob offering an exponential response suitable for musical applications, while the LIN FM knob provides a more linear frequency modulation effect. Use the Coarse knob for broad tuning adjustments and the Fine Tune knob for precise pitch corrections. The PW Mod knob dynamically modulates the pulse width to further enhance expressive control.

Knob	**Function**	**Description**
PWM	Adjusts pulse width modulation	Varies the duty cycle of the pulse waveform, altering harmonic content and timbre.
EXP FM	Controls amount of exponential frequency modulation when something is connected to EXP FM Input	Modulates frequency scaling exponentially
LIN FM	Controls amount linear frequency modulation when	Modulates frequency in a linear manner, useful for

	something is connected to LIN FM	subtle shifts and vibrato effects.
Coarse	Sets the base frequency	Provides a broad adjustment of the oscillator's frequency, typically with a wide range from low to high.
Fine Tune	Allows precise frequency adjustments	Offers minor corrections to the base frequency set by the Coarse knob for exact pitch calibration.
PW Mod	Modulates pulse width dynamically	Adds dynamic variation to the pulse width for expressive sound shaping.

Table 3.1.2.1: Functions of Each VCO Control Knob

3.1.3 ADSR Envelope Generator

The ADSR Envelope Generator shapes the amplitude of the audio signal over time, following the four classic stages: Attack, Decay, Sustain, and Release. Adjust the Attack, Decay, Sustain, and Release knobs to control the timing and level of each phase, thus sculpting the dynamic contour of your sound. The Fast/Slow switch allows you to quickly change the envelope's response speed, while the Gate button provides manual triggering of the envelope cycle. Use these controls to achieve the desired articulation and expression for each note.

Control	**Function**	**Description**
Attack	Sets the time for the envelope to reach its peak	Determines how quickly the sound reaches its maximum amplitude when a note is triggered.
Decay	Adjusts the time taken to drop from peak to the sustain level	Controls the duration of the initial decline in amplitude following the attack phase.
Sustain	Establishes the amplitude level during the hold phase	Sets the steady-state level of the envelope while the note is held down.
Release	Determines the time taken for the sound to fade out	Adjusts the duration of the sound's decline after the note is released.
Fast/Slow Switch	Toggles between quick and gradual envelope transitions	Provides an option to rapidly or slowly traverse the attack, decay, and release phases.

Table 3.1.3.1: Functions of Each ADSR Control

3.1.4 VCA (Voltage-Controlled Amplifier)

The VCA modulates the overall amplitude of the audio signal based on the control voltage inputs. Use the Input Level #1 knob to set the strength of the incoming audio signal, while the CV Level #1 knob adjusts the extent to which external control voltages modulate this signal. The Gain knob provides a final amplification adjustment to ensure the output signal is at the desired level. Together, these controls allow you to finely shape the dynamic range and overall loudness of your synthesizer's output.

Knob	Function	Description
Input Level #1	Adjusts the incoming audio signal level	Controls the amplitude of the signal fed into the VCA from the source module.
CV Level #1	Sets the level of the control voltage modulation	Determines how much the control voltage influences the amplification process.
Gain	Modifies the overall output amplification	Provides a final adjustment of the output signal's strength after modulation.

Table 3.1.4.1: Functions of Each VCA Control Knob

3.2 Patching and Signal Flow

Effective signal routing is key to unlocking the creative potential of your modular synthesizer. Below are several example patches that illustrate different signal paths using the inputs and outputs detailed in the previous sections. Each patch is described in detail, and you can refer to the corresponding tables for precise control and signal characteristics.

3.2.1 Example Patch 1: MIDI-Controlled Performance (Simple Keys)

Integrate external control by using the MIDI-to-CV Converter to manage pitch and triggering. Connect your MIDI controller to the MIDI-to-CV module's MIDI In. Patch the "Note" output from the MIDI-to-CV converter (as defined in Table 1.2.1.2) into the V/Oct1 input on the VCO to control pitch. Additionally, route the "Gate" output from the MIDI-to-CV to the Gate In of the ADSR. Then, follow the basic sound generation patch: send the VCO's SINE output to directly into the VCA's Signal In 1, while using the ADSR's Env Out to modulate the VCA via the CV input. This setup lets you play and control sound dynamically via MIDI, with accurate pitch mapping and envelope triggering.

3.2.2 Example Patch 2: Modulated Pulse Width Variation (Long Fat Bass)

Begin by choosing the PULSE output from the VCO (refer to Table 1.2.2.2) as your primary audio source. Use the PWM control knob on the VCO to adjust the pulse width, and experiment with the PW Mod knob to introduce dynamic variation in the pulse shape. Patch the SINE output of the VCO to the PWM input to let it control the pulse width, and set the PWM knob to 100% to maximize this effect. Next, patch the Note output of the MIDI-to-CV Converter to the V/Oct1 input of the VCO, ensuring that the oscillator receives accurate pitch control from your MIDI controller. Then, route the PULSE output directly to the VCA's Signal In 1. Additionally, route an external modulation signal—such as the Control output from the MIDI-to-CV Converter—into the VCA's CV input to affect the amplitude envelope. Finally, send the VCA output to your audio output. This patch focuses on exploiting pulse width modulation to create evolving textures and timbral shifts, while also allowing you to control the volume with a modulation knob from your MIDI controller.

3.2.3 Example Patch 3: Complex Signal Flow for FX Sound (Laser Fx)

To create a laser sound effect, start by configuring the VCO to produce a piercing tone with rapid pitch modulation. First, patch the ADSR Envelope Generator's Env Out to the EXP FM input on the VCO (refer to Table 1.2.2.1 for VCO inputs). This routing uses the envelope to exponentially modulate the oscillator's frequency, imparting a sharp, sweeping effect characteristic of laser sounds. Next, route the SINE output from the VCO (as defined in Table 1.2.2.2) directly to the VCA's Signal In 1, ensuring that the pure tone is fed into the amplifier stage. To further refine the effect, connect the MIDI-to-CV Converter's output (such as the Control) to the CV input of the VCA. This allows external modulation of the amplitude envelope via your MIDI controller, offering dynamic control over the sound's intensity. Adjust the ADSR settings—typically favoring a fast attack and rapid decay—to achieve the desired transient and timbral characteristics of a laser effect. This patch combines envelope-driven pitch modulation with controlled amplitude shaping, delivering a distinct, futuristic sound ideal for sound effects and experimental synthesis.

3.3 Experimentation and Performance Tips

To enhance your performance and sound design, experiment with various configurations and control adjustments. Quick tweaks—such as subtle changes to the PWM or EXP FM on the VCO—can significantly alter the harmonic content and timbre of your sound. Real-time adjustments to the ADSR parameters can modify the dynamic envelope for each note, while changes to the VCA settings can fine-tune overall signal amplitude. Consider integrating external controllers or foot pedals for hands-free modulation of key parameters during live performances. Continuous experimentation and adjustment will help you unlock the full creative potential of the modular synthesizer.

4. Troubleshooting

Proper troubleshooting ensures that your synthesizer continues to perform reliably. The following sections outline common issues and step-by-step diagnostics to help you identify and resolve any problems that may arise during operation.

4.1 Common Issues

Below is a table summarizing common issues, possible causes, and recommended actions:

Issue	Possible Cause	Recommended Action
No sound output	- Power supply failure - Loose or incorrect patch connections - Mis-calibration of VCO or VCA controls	- Verify that the power adapter is connected and all module indicators are active - Re-check all patch cables and connections - Confirm that calibration steps have been followed as outlined in Section 2.2
Frequency drift	- Temperature fluctuations affecting components - Component tolerances or aging	- Use a multimeter or oscilloscope to monitor frequency stability - Re-calibrate the VCO using the procedure in Section 2.2 - Consider environmental controls to stabilize temperature
Erratic module behavior	- Inconsistent control voltage levels - Faulty patch cables or connectors - Interference from external signals	- Inspect and secure all patch connections - Replace any damaged or low-quality cables - Isolate the synthesizer from potential interference sources
Unstable or intermittent signals	- Loose internal connections - Inadequate grounding or ESD issues	- Re-examine all module connections and mounting screws - Ensure proper ESD precautions are in place (see Section 1.3.1)

Table 4.1.1: Common Issues Summary

4.2 Step-by-Step Diagnostics

When you encounter an issue, follow these diagnostic steps to isolate and address the problem:

1. **Verify Power Supply and Indicators:**
   Start by confirming that the power supply is active. Check that all module indicator lights, especially on the ADSR and VCA, are on. If a light is off, re-examine the power adapter and connection to the custom enclosure.
2. **Inspect Patch Connections:**
   Ensure that all patch cables are securely connected to their respective inputs and outputs. If there is no sound, re-route a known-good cable from one module (e.g., a VCO output) to another module's input (e.g., VCA Signal In 1) and observe if the indicator lights up.
3. **Use Measurement Tools:**
   Utilize a multimeter to verify voltage levels across power supply outputs and control voltage inputs. For frequency-related issues, connect the VCO's SINE output to an oscilloscope to check that the frequency remains stable and within the expected range (approximately 16.35 Hz for C0 calibration). If the frequency is drifting, re-calibrate the VCO by adjusting the Coarse and Fine Tune knobs.
4. **Test Individual Modules:**
   Isolate the module you suspect may be causing issues. For example, disconnect the MIDI-to-CV converter and test the VCO independently with a known input. This helps determine if erratic behavior is due to one module or a faulty interconnection.
5. **Review Control Settings:**
   Double-check that all control knobs (e.g., sustain on the ADSR, gain on the VCA) are set to their recommended levels as described in the Quick Setup section. Incorrect settings can sometimes mimic hardware faults.
6. **Replace or Re-calibrate Components:**
   If diagnostics suggest a module is underperforming (e.g., frequency drift beyond tolerances), consider re-calibrating the affected module. In cases of persistent failure, inspect for any component damage and, if necessary, replace the affected module or faulty patch cables.

Following these troubleshooting steps systematically will help you identify and correct issues quickly, ensuring that your modular synthesizer remains in optimal working condition. If problems persist after performing these diagnostics, please consult the full troubleshooting guide in this manual or contact our technical support team at paulnieves.com for further assistance.

5 Maintenance

5.1 Regular Checks

Perform these tasks periodically to maintain system reliability and performance:

5.1.1 Cleaning

5.1.1.1 Surfaces and Panels

Wipe down the enclosure and module panels with a dry, lint-free microfiber cloth. For stubborn residue, lightly dampen the cloth with isopropyl alcohol (70% or higher) and avoid contact with jacks, knobs, or internal components.

5.1.1.2 Jacks and Connectors

Use compressed air to remove dust from input/output jacks. For oxidized contacts, apply a small amount of contact cleaner (e.g., DeoxIT) to a patch cable tip and insert/remove it several times.

5.1.2 Recalibration Intervals:

Component	**Frequency**	**Procedure**
VCO	Every 3–6 months	Recalibrate to C0 (16.35 Hz) using the method in Section 2.2.
ADSR	Annually	Verify envelope timing with an oscilloscope; adjust trim pots if drift exceeds 5%.
Power Supply	Biannually	Test voltage outputs (±18V/±15V DC) with a multimeter. Tolerance: ±0.5V.

Table 5.1.2.1: Module Maintenance

5.1.3 Software/Firmware Updates

Check paulnieves.com for firmware updates for the MIDI-to-CV converter. Follow provided instructions for flashing new firmware. Bookmark the product page to stay informed about critical patches or feature enhancements.

5.2 Handling and Storage

Follow these guidelines to prevent damage during module repair, upgrades, or storage:

5.2.1 Disassembly Best Practices

1. **Power Down**: Always disconnect the power supply and remove all patch cables before disassembling modules.
2. **ESD Precautions**: Revisit **Section 1.3.1** for ESD safety measures. Use an anti-static mat and wrist strap.
3. **Tool Selection**:
    - Use non-magnetic, insulated screwdrivers (e.g., JIS #000 for Eurorack screws).
    - Avoid excessive force when loosening potentiometers or PCB-mounted components.
4. **Cable Management**: Label patch points and take photos of complex routings before disconnecting modules.

5.2.2 Storage Recommendations

- **Environment**: Store modules in a dry, temperature-controlled space (10–30°C / 50–86°F) with <60% humidity.
- **Anti-Static Protection**: Place unused modules in anti-static bags or conductive foam.
- **Long-Term Storage**: Remove power cables and batteries (if applicable). Stack modules vertically with padding to avoid warping.

PART II – DESIGN DETAILS DOCUMENT

1. Project Overview and Objectives

1.1 Introduction

This section details the engineering and design principles underpinning the modular synthesizer system, developed over two semesters. Building on the comprehensive user manual in PART I—which covers quick setup, module operations, and safety guidelines—this document focuses on the technical implementation. The project integrates core modules such as the Voltage-Controlled Oscillator (VCO), MIDI-to-CV converter, ADSR envelope generator, and Voltage-Controlled Amplifier (VCA) into a unified system. Emphasis is placed on achieving low drift, excellent thermal stability, and precise calibration, ensuring that the system performs reliably in both DIY and professional environments.

1.2 Objectives

The primary objectives are to design, prototype, and integrate each module with high signal fidelity and control precision. Specific goals include developing detailed schematic diagrams and PCB layouts, selecting components with stringent tolerances, and implementing rigorous simulation and testing protocols. A custom enclosure was designed to support easy maintenance, expandability, and optimal ergonomics. These objectives align with the user-focused approaches outlined in PART I, ensuring that the final product not only meets technical requirements but also delivers a seamless user experience.

2. System Architecture

2.1 Block Diagrams

2.1.1 System Overview Block Diagram

This high-level diagram illustrates the complete signal flow and module interconnections that form the backbone of the synthesizer system. It shows how the power supply, MIDI-to-CV converter, VCO, ADSR envelope generator, and VCA are integrated to work as a unified system. The diagram emphasizes the importance of proper signal routing, ensuring that control voltages are accurately distributed and that sensitive circuits remain isolated to maintain optimal signal integrity and synchronization across the modules.

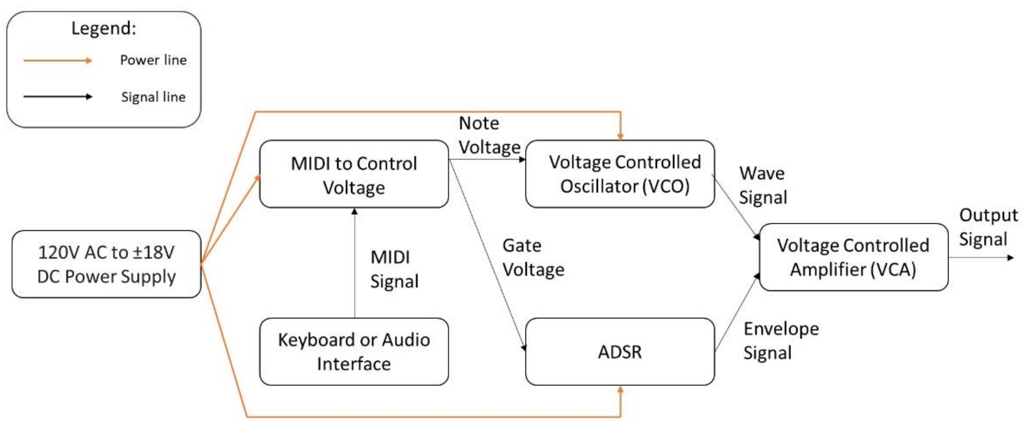

Figure 2.1.1.1: Block Diagram Overview and Example Patching

2.1.2 Power Supply Block Diagram

This diagram details the architecture of the synthesizer's power supply system. It highlights the 10W DC-to-DC Buck Converter and the subsequent Positive and Negative Low PSRR (Power Supply Rejection Ratio) LDOs that feed all the output power connectors. The explanation behind this block is to ensure that all modules receive a stable, noise-free, and well-regulated supply voltage—crucial for maintaining the performance and accuracy of the synthesizer, especially in scenarios demanding low drift and high thermal stability.

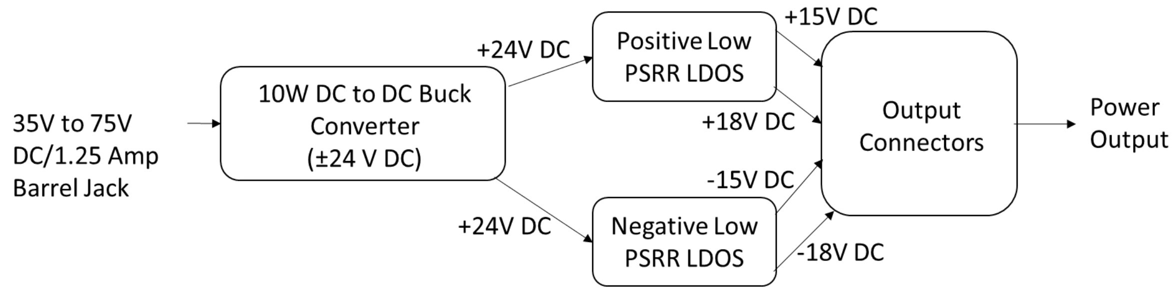

Figure 2.1.2.1 Block Diagram Power Supply

2.1.3 MIDI to CV Block Diagram

This block diagram describes the conversion process from digital MIDI data to analog control voltages. It begins at the MIDI 5-pin DIN connector and passes through an opto-coupler for isolation, ensuring that unwanted electrical interference is minimized. The signal is then processed by an Arduino Nano and converted using 16-bit DACs with SPI capability, before being scaled by output op amps. This design ensures that the incoming MIDI signals are accurately translated into control voltages (0–10V) needed to drive the other modules, thus bridging the digital and analog domains seamlessly.

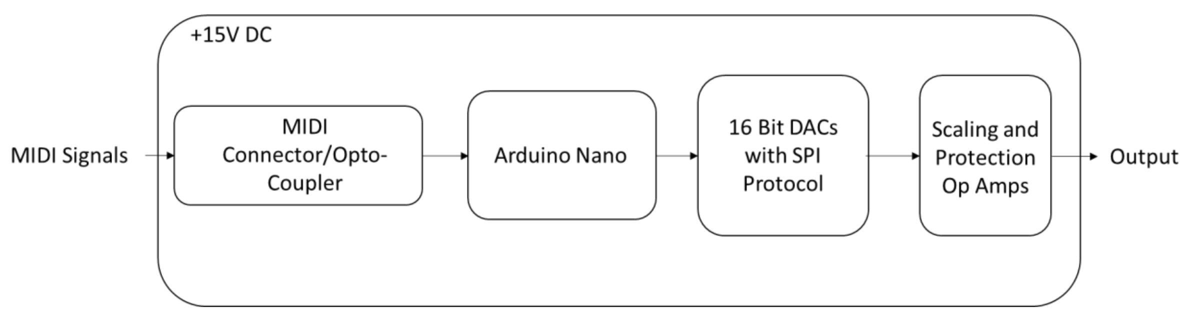

Figure 2.1.3.1: Block Diagram MIDI to CV

2.1.4 VCO Block Diagram

The VCO block diagram breaks down the oscillator's internal architecture. It starts with additional Power LDOs to ensure a stable operating voltage and extra power isolation. Input signals are then combined using summer op amps before being processed by a logarithmic amplifier—employing a matched transistor configuration—for precise, low-drift frequency control following the 1V/octave standard. Further, the sawtooth generator and wave-shaping operational amplifiers create the diverse waveform outputs (sine, sawtooth, pulse, etc.). This layout ensures the VCO delivers consistent, musically relevant pitch control and a variety of timbral characteristics essential for sound synthesis.

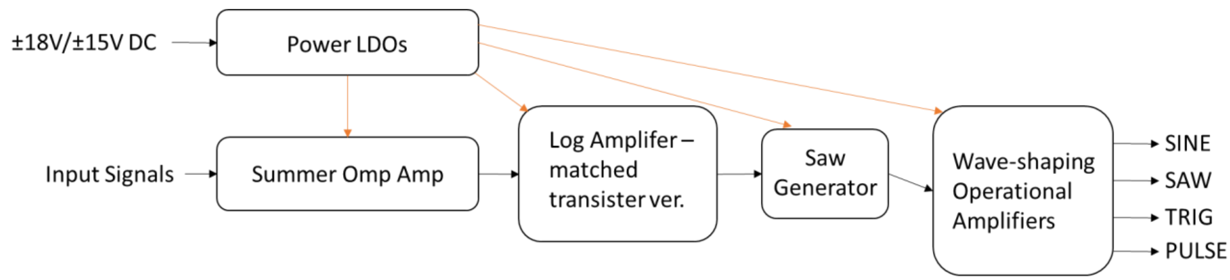

Figure 2.1.4.1: Block Diagram VCO

2.1.5 ADSR Block Diagram

This diagram details the signal path and control circuitry used to generate the ADSR envelope, a crucial component for shaping the amplitude contour of the sound. The design includes a Schmitt Trigger to clean up the incoming gate signal, an AC-coupled input gate for proper trigger detection, and a monostable 555 timer circuit to generate the envelope's timing pulse. The ADSR control block then shapes the envelope into its classic stages, and an LED signal block provides a visual indication of the envelope's status. Together, these elements enable precise dynamic control over the sound's evolution from onset to release.

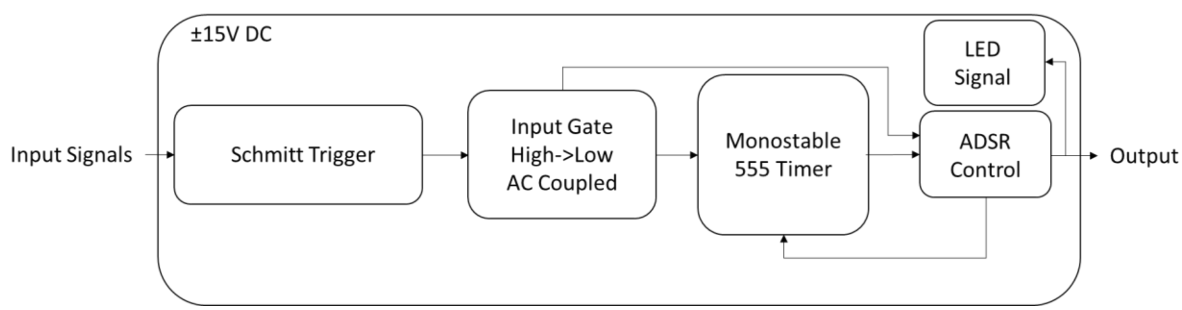

Figure 2.1.5.1: Block Diagram ADSR

2.1.6 VCA Block Diagram

The VCA diagram outlines how the module modulates the amplitude of incoming audio signals based on control voltage inputs. The process begins with an inputs summer op amp that combines multiple audio signals, followed by a dedicated CV summer op amp that mixes the control voltages. A differential amplifier then processes the signals to minimize noise and ensure linear amplification from the CV Op Amp. An Op Amp Zero Crossing Aligner is included to handle phase alignment, reducing distortion at signal transitions. An LED signal provides real-time operational feedback. This design is focused on delivering a clean, dynamically controlled audio output that responds accurately to external modulation inputs.

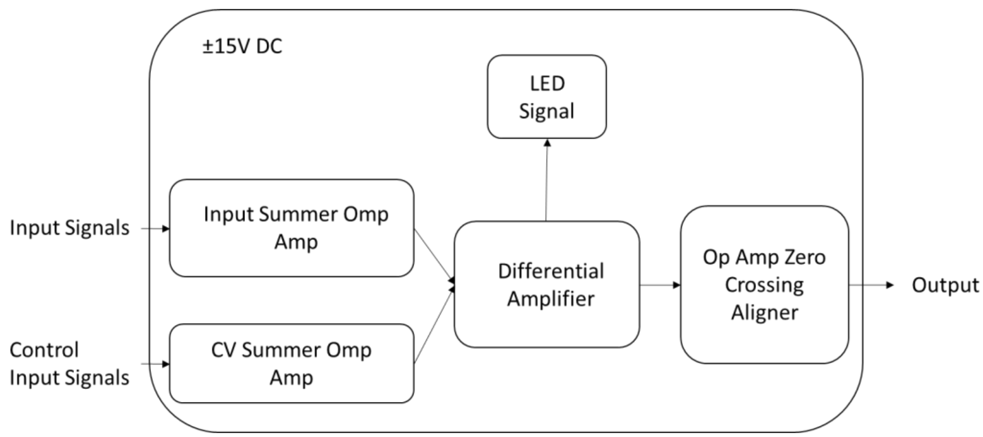

Figure 2.1.6.1: Block Diagram VCA

3. Hardware Design Details

3.1 Schematic Diagrams

Detailed schematic diagrams for each module have been developed to document the electronic design. For example, the VCO schematics—which highlight the use of high-grade components such as the BCM847BS-7 BJT Transistor Array (Dual) Matched Pair and provisions for thermal coupling and voltage regulation—are fully illustrated in Appendix Figures **7.2.3.4** and **7.2.3.5**. Similar diagrams for the ADSR and VCA modules can be found in Appendix Figures **7.2.1.4–7.2.1.6** and **7.2.4.4–7.2.4.6**, respectively.

3.2 PCB Layout

The PCB layout, designed using Fusion 360, emphasizes minimal noise and optimal signal routing. Critical layout details such as proper grounding techniques and component placement for effective heat dissipation are shown in the Appendix:

- ADSR Main PCB – Figure **7.2.1.1**

- MIDI-to-CV Main PCB – Figure **7.2.2.1**
- VCO Main Board PCB – Figure **7.2.3.1**
- VCA Main Board PCB – Figure **7.2.4.1**

3.3 Component Specifications and Tolerances

Component selection is validated through comprehensive component lists provided in the Appendix. Key aspects include:

- **Power Supply Components:** Critical parts such as the TPS7A3001DGNR and TPS7A4901DGNR linear regulators, along with associated passive components, are detailed in Table 7.3.1, ensuring stable voltage rails and robust performance.

- **MIDI-to-CV Module:** Table 7.3.2 documents essential components for this module, including precision op-amps (e.g., TL072CDR and TL074HIDR), comparators, and DACs that achieve a tolerance of ±0.2 mV, which is crucial for accurate voltage control.

- **VCO Module:** The VCO design maintains resistor tolerances of 0.5%, as shown in Table 7.3.3. This table includes high-grade elements like the BCM847BS-7 transistor arrays and other passive components to ensure frequency stability and minimal drift.

- **ADSR and VCA Modules:** Detailed component selections for the ADSR and VCA circuits are provided in Tables 7.3.4 (for ADSR) and 7.3.4 (for VCA). These tables list precision resistors, capacitors, and other integral components, underscoring the design's emphasis on reliable signal shaping and control.

Measurement data and simulation results that validate these specifications are further illustrated in Appendix Figures 7.1.1.1 through 7.1.1.11, Table 7.1.2.1 for MIDI-to-CV measurements, and additional ADSR and VCA measurement charts in sections 7.1.3 and 7.1.4.

3.4 Simulation and Testing

Extensive LTspice simulations were conducted to validate each module's performance, guiding component selection, circuit calibration, and thermal management strategies. Testing procedures, including oscilloscope measurements and 6½ digit precision multimeter validations, are documented with corresponding graphs and charts in the Appendix. Refer to:

- MIDI to CV test results **Table 7.1.2.1**
- VCO test results in **Table 7.1.1.2** and **Figure 7.1.1.1** through **Figure 7.1.1.11**
- ADSR test results in Figures **7.1.3.1** through **7.1.3.8**
- VCA output tests in Figure **7.1.4.1**

4. Enclosure Design

4.1 Enclosure Design

The custom enclosure is designed with a focus on durability, expandability, and user accessibility. CAD designs detail the integration of the module panels, wooden body, and plastic side panels that allow for both secure installation and future upgrades. Material selection was driven by the need for robustness while maintaining a lightweight and aesthetically pleasing form factor. The design supports both internal organization of modules and efficient thermal management.

5. System Testing and Troubleshooting (PCB Level)

5.1 Testing and Troubleshooting

Step 1: Visual Inspection and Connection Verification

- **Inspect for Physical Damage:** Examine the PCB, solder joints, and component placement for any signs of overheating, physical damage, or poor soldering.
- **Verify Cable and Connector Integrity:** Ensure that all patch cables, headers, and DIN connectors are securely attached and free from wear or breakage.

Step 2: Power Supply Verification

- **Measure Supply Voltages:** Using a multimeter, verify that the outputs from the 10W DC-to-DC buck converter and the Positive/Negative Low PSRR LDOs match design specifications. The outputs of the LDO should be ±15 DC and ±18 DC with a ±0.5V tolerance
- **Check for Noise and Drift:** Use an oscilloscope to examine the voltage rails for noise or instability that might affect sensitive modules (e.g., the VCO). If there is a lot of noise replace LDOs

Step 3: Module-Specific Testing

- **MIDI-to-CV Converter:**
    - **Signal Reception:** Confirm that the MIDI 5-pin DIN connector and opto-coupler are correctly isolating and passing digital MIDI data with logic analyzer. Check Schematic in Appendix to see test points.
    - **Voltage Output Testing:** Apply known MIDI signals and measure the resulting control voltages (Gate and Note) against the expected values from Table 1.2.1.2 in PART I - USER MANUAL and Table 7.1.2.1 in Appendix.

- **Isolation Check:** Ensure the Arduino Nano and 16-bit DACs are communicating correctly by comparing the output voltages with simulation data.

- **VCO (Voltage-Controlled Oscillator):**
  - **Oscillator Output Verification:** Use an oscilloscope to check the waveform types (sine, sawtooth, pulse) against expected shapes as detailed in Table 1.2.2.2. If waves are not showing up, protentional fixes are replacing the 3 op amps ICs, the BJT NPN matched paired transistors, the J112 JFET, and the main discharging film capacitor. Use appendix to find parts.
  - **Frequency Accuracy:** Measure the oscillator's output frequency and compare it with the ideal and tolerance values provided in Tables 7.1.1.1–7.1.1.3.
  - **Control Responsiveness:** Adjust the Coarse, Fine Tune, PWM, EXP FM, and LIN FM controls and verify that the frequency and waveform modulation behave as expected.

- **ADSR Envelope Generator:**
  - **Trigger Circuitry:** Verify that the Schmitt Trigger, AC-coupled input gate, and the 555 monostable timers are operating properly by checking for clean transitions and consistent pulse durations. If the gate is not getting triggered replace all BJT transistors in the circuit. Parts can be found in the Appendix.
  - **Envelope Shape Testing:** Trigger the envelope (using a known gate signal) and capture the envelope curve with an oscilloscope. Confirm that the Attack, Decay, Sustain, and Release phases match the designed response as shown in Table 7.1.3.1. If Envelope is not working replace 555 timer, Op Amp, and the main discharging capacitors connected to the DPDT switch.

- **VCA (Voltage-Controlled Amplifier):**
  - **Signal Amplification Test:** Input a known audio signal into the VCA and measure the output while varying the CV inputs. Compare these measurements with the expected signal levels in Table 1.2.4.2. If the CV can not control the input signal replace both op amps in the circuit and the matched BJT pair.
  - **Modulation Verification:** Confirm that the combined inputs from the summer op amps (audio and CV) and the differential amplifier yield a linear amplification response.
  - **Zero Crossing Alignment:** Use an oscilloscope to verify that the Op Amp Zero Crossing Aligner minimizes distortion during signal transitions.

Step 4: System Integration Testing

- **Full Signal Chain Test:** Once individual modules pass their tests, perform an integrated test by applying a MIDI signal from an external controller and monitoring the resulting audio output after connecting the modules as shown in Figure 2.1.1.1.
- **Parameter Adjustments:** Systematically adjust key controls (e.g., ADSR Sustain knob, VCO tuning controls, VCA Gain knob) to observe the system's response.
- **Compare with Expected Behavior:** Use the design's simulation results and measurement tables as a reference to pinpoint discrepancies. Find these in the Appendix.

7. Appendices

7.1 Measurement Data and Charts

7.1.1 VCO Measurements

Input: Voltage Value	Octave (Music Note Representation of Frequency)	Output: Frequency of signal (numbers are pulled from the American Standard Pitch Notation (ASPN)) Tuning to C
0 V	0	16.35160 Hz (Sim: 16.230088Hz)
1 V	1	32.70320 Hz (Sim: 32.288396Hz)
2 V	2	65.40639 Hz (Sim: 65.656566Hz)
3 V	3	130.8128 Hz (Sim: 130.45952Hz)
4 V	4	261.6256 Hz (Sim: 259.33258Hz)
5 V	5	523.2511 Hz (Sim: 523.74142Hz)
6 V	6	1046.502 Hz (Sim: 1.0206243KHz)
7 V	7	2093.005 Hz (Sim: 2.032412KHz)
8 V	8	4186.009 Hz (Sim: 4.076851KHz)
9 V	9	8372.018 Hz (Sim: 8.2432919KHz)
10 V	10	16744.04 Hz (Sim: 16.039901KHz)

Table 7.1.1.1: Ideal Measurements Vs Simulation Measurements

Input Voltage (V)	Octave	Ideal Frequency (Hz)	Actual Circuit Frequency (Hz)	Tolence Check
0	0	16.3516	16.373	Within Tolerance
1	1	32.7032	32.64	Within Tolerance
2	2	65.40639	65.306	Within Tolerance
3	3	130.8128	130.7	Within Tolerance
4	4	261.6256	261.5	Within Tolerance
5	5	523.2511	523.11	Within Tolerance
6	6	1046.502	1046.3	Within Tolerance
7	7	2093.005	2090.9	Within Tolerance
8	8	4186.009	4171.7	Within Tolerance
9	9	8372.018	8304.2	Out of Tolerance
10	10	16744.04	16451	Out of Tolerance

Table 7.1.1.2: VCO Measurements Summary (Tolerance: 0.5% of ideal)

Ideal Frequency	Tolerence Range ->	Lower Tol	High Tol
16.3516	Lower higher bounds	16.269842	16.433358
32.7032	for 0.995 and 1.005 of	32.539684	32.866716
65.40639	the frequency	65.07935805	65.73342195
130.8128		130.158736	131.466864
261.6256		260.317472	262.933728
523.2511		520.6348445	525.8673555
1046.502		1041.26949	1051.73451
2093.005		2082.539975	2103.470025
4186.009		4165.078955	4206.939045
8372.018		8330.15791	8413.87809

16744.04		16660.3198	16827.7602

Table 7.1.1.3: Allowed Frequency Bounds

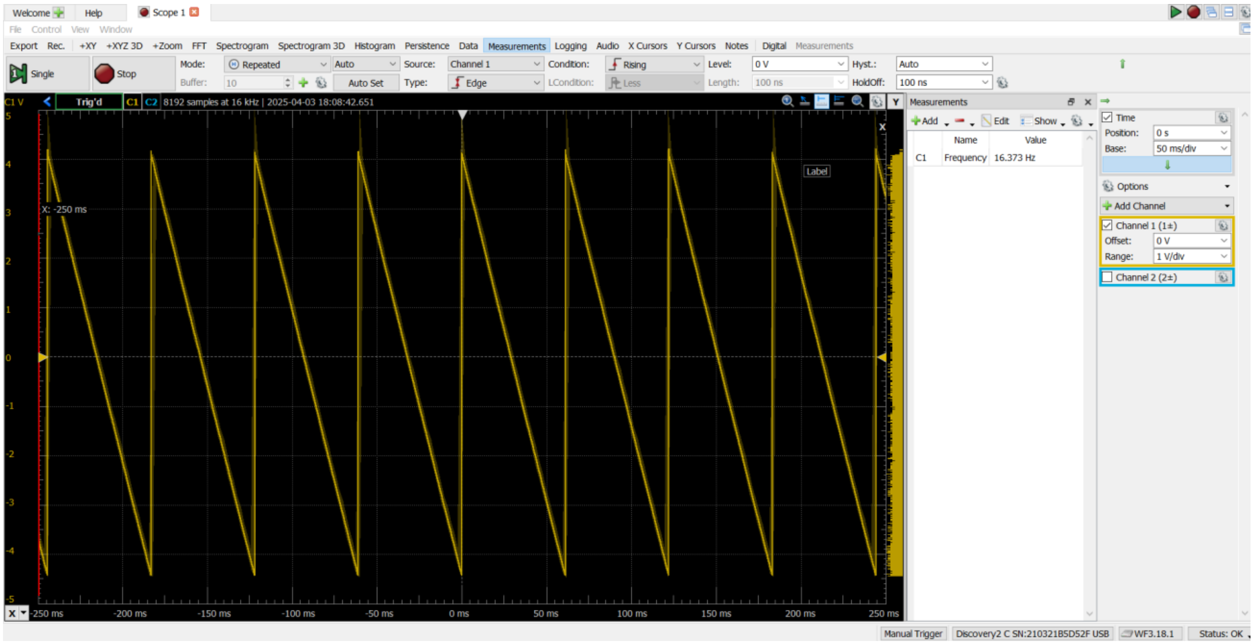

Figure 7.1.1.1: Octave 0V Frequency Measurement (16.373 Hz) 1x Probe

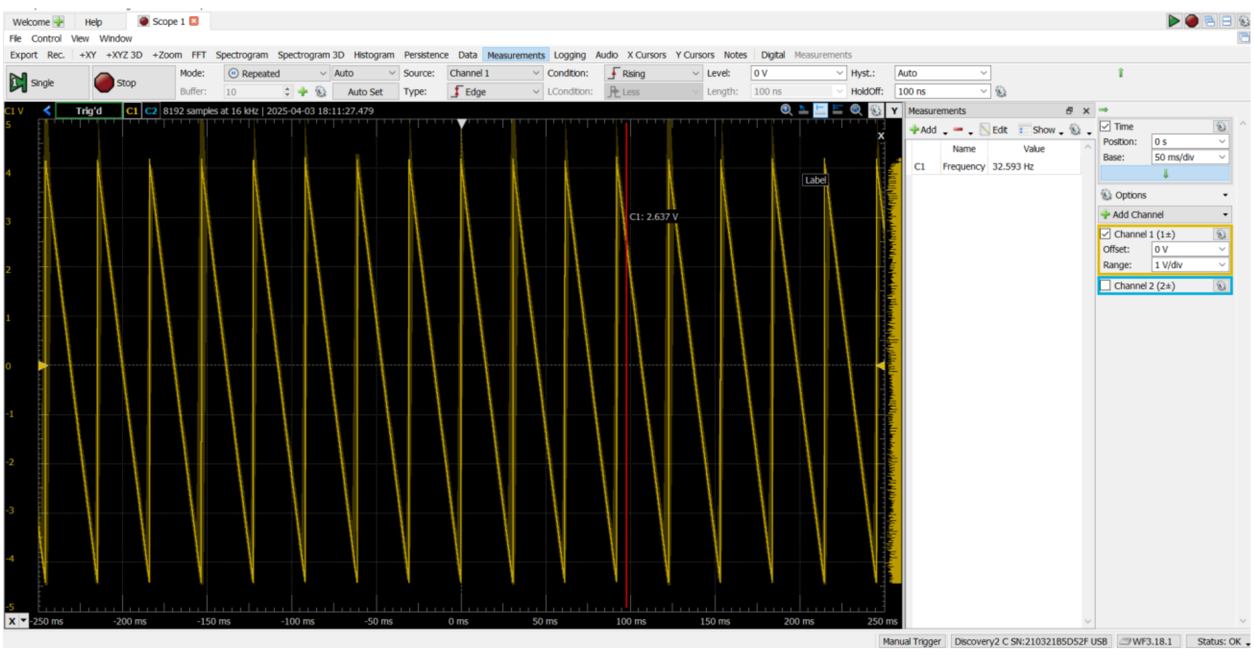

Figure 7.1.1.2: Octave 1V Frequency Measurement (32.640 Hz) 1x Probe

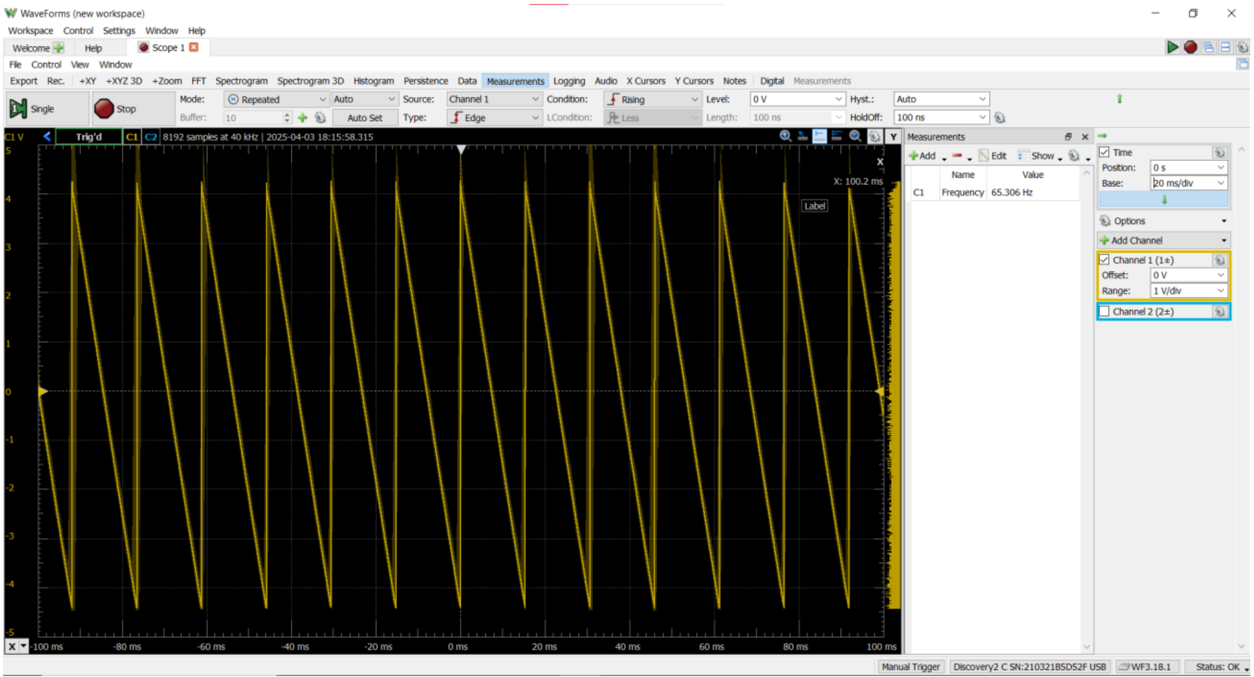

Figure 7.1.1.3: Octave 2V Frequency Measurement (65.306 Hz) 1x Probe

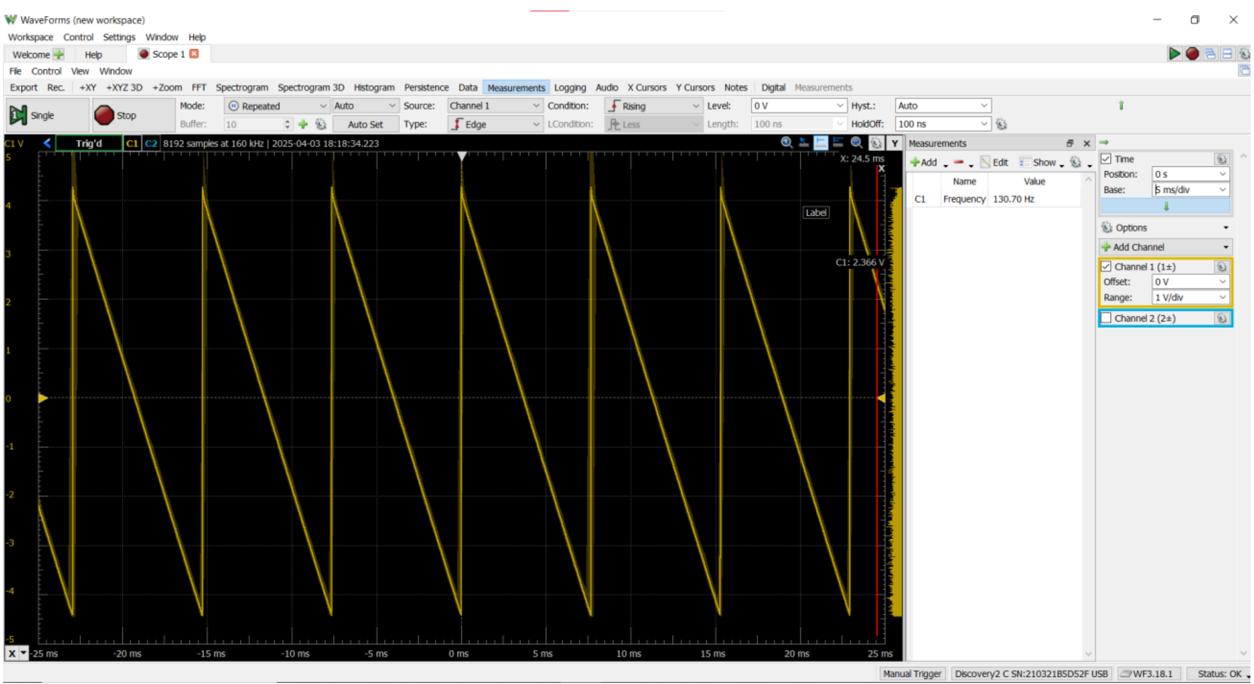

Figure 7.1.1.4: Octave 3V Frequency Measurement (130.70 Hz) 1x Probe

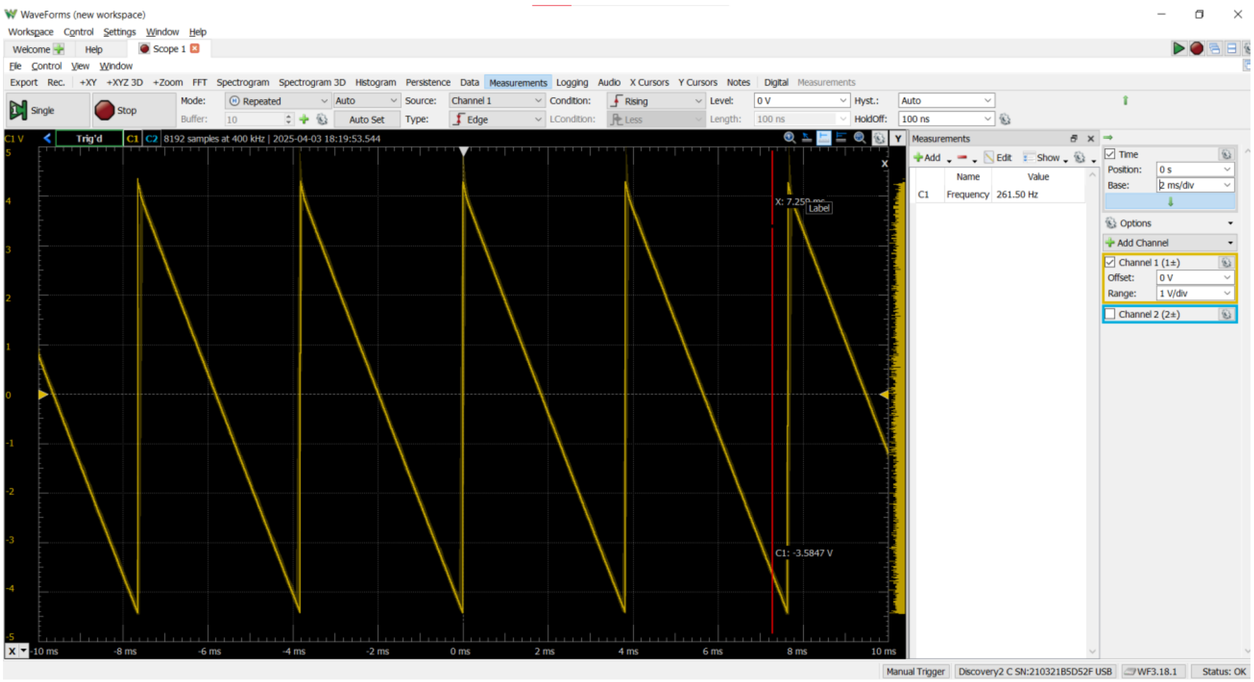

Figure 7.1.1.5: Octave 4V Frequency Measurement (261.50 Hz) 1x Probe

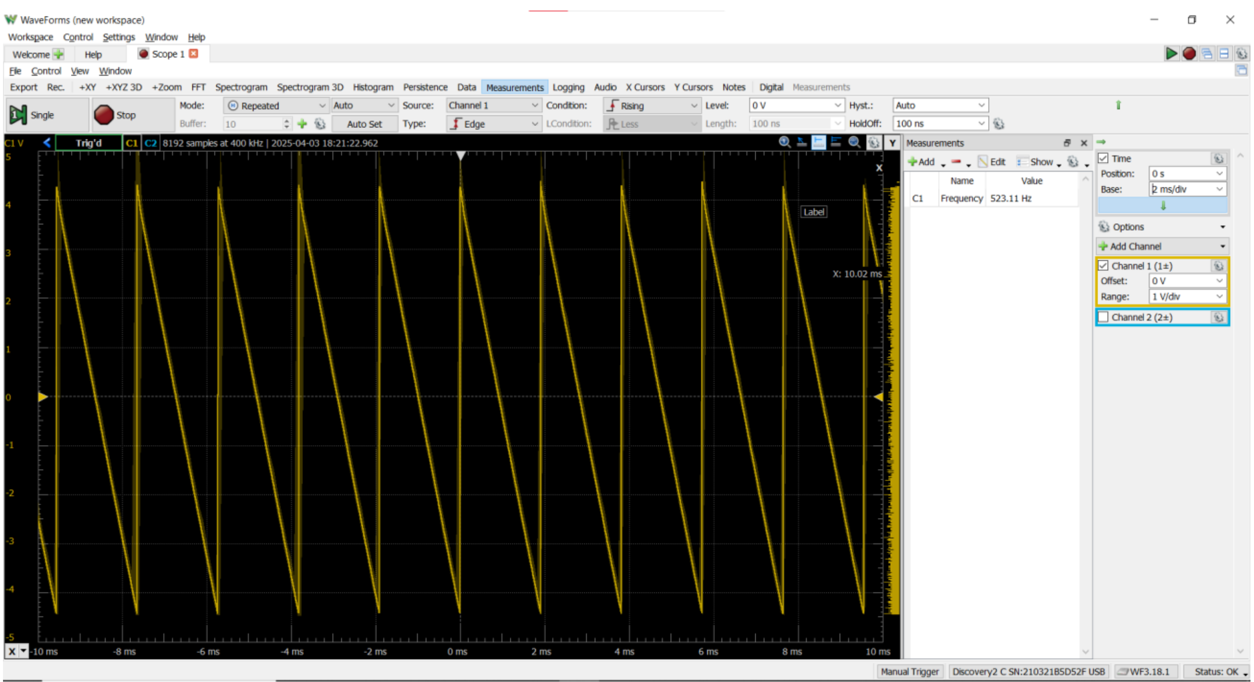

Figure 7.1.1.6: Octave 5V Frequency Measurement (523.11 Hz) 1x Probe

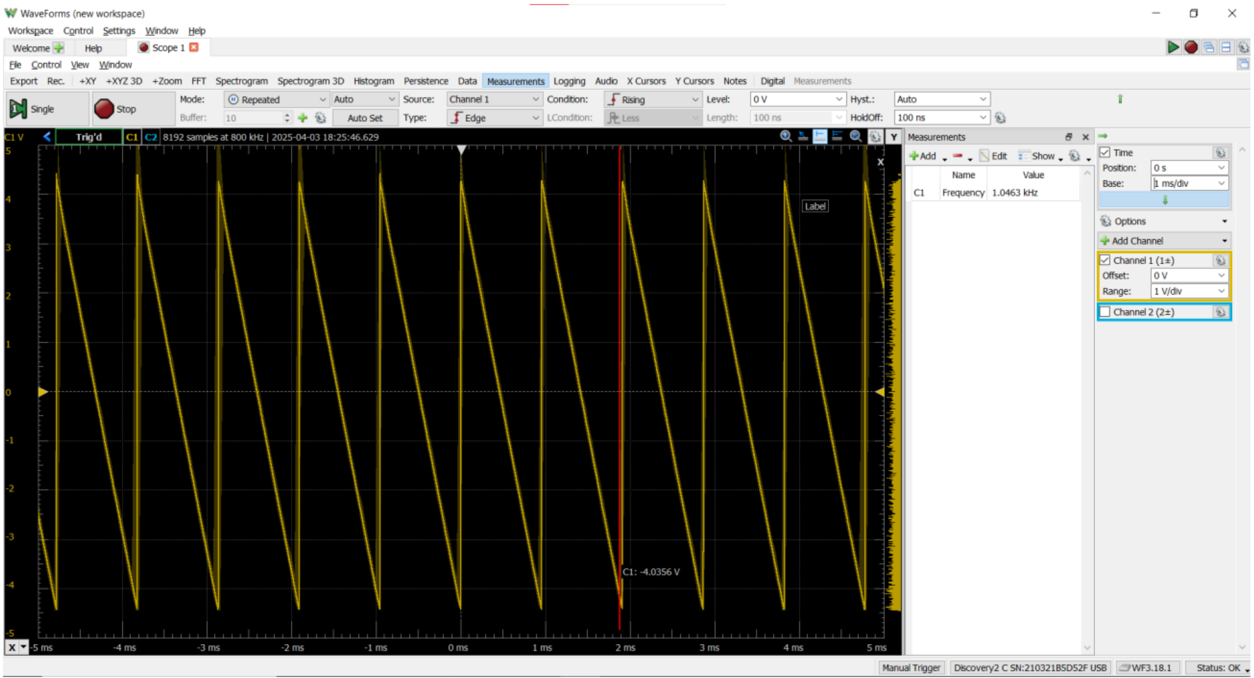

Figure 7.1.1.7: Octave 6V Frequency Measurement (1.0463 kHz) 1x Probe

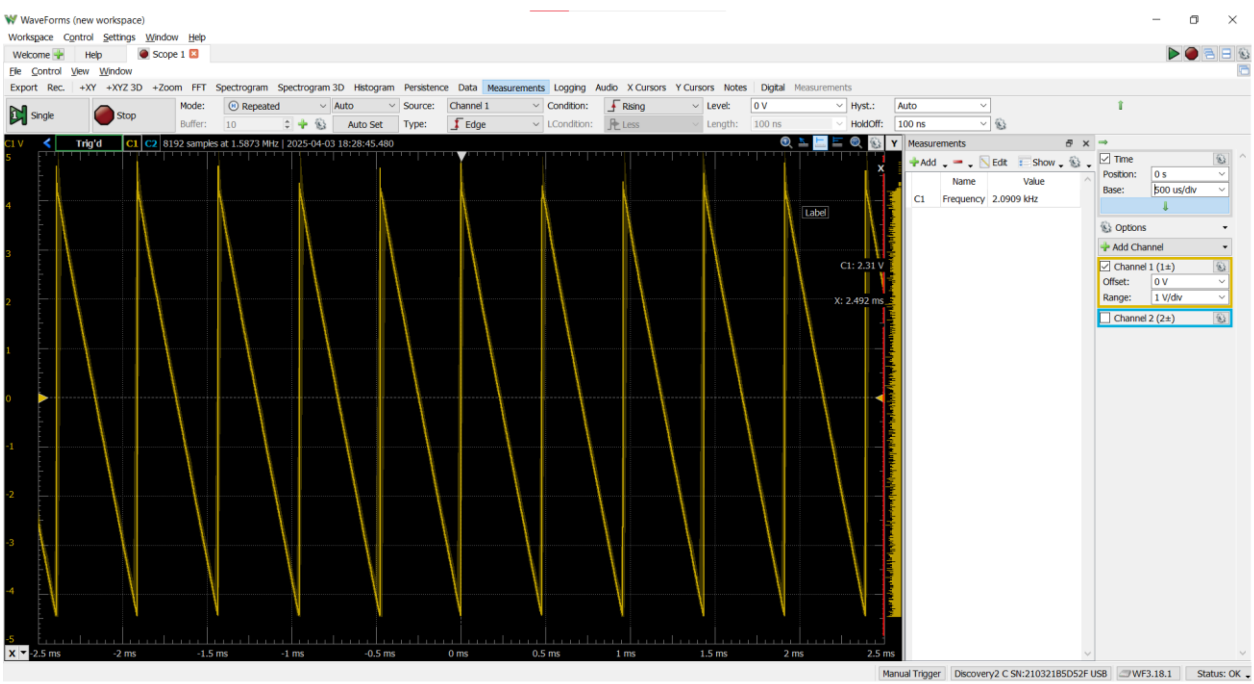

Figure 7.1.1.8: Octave 7V Frequency Measurement (2.0909 kHz) 1x Probe

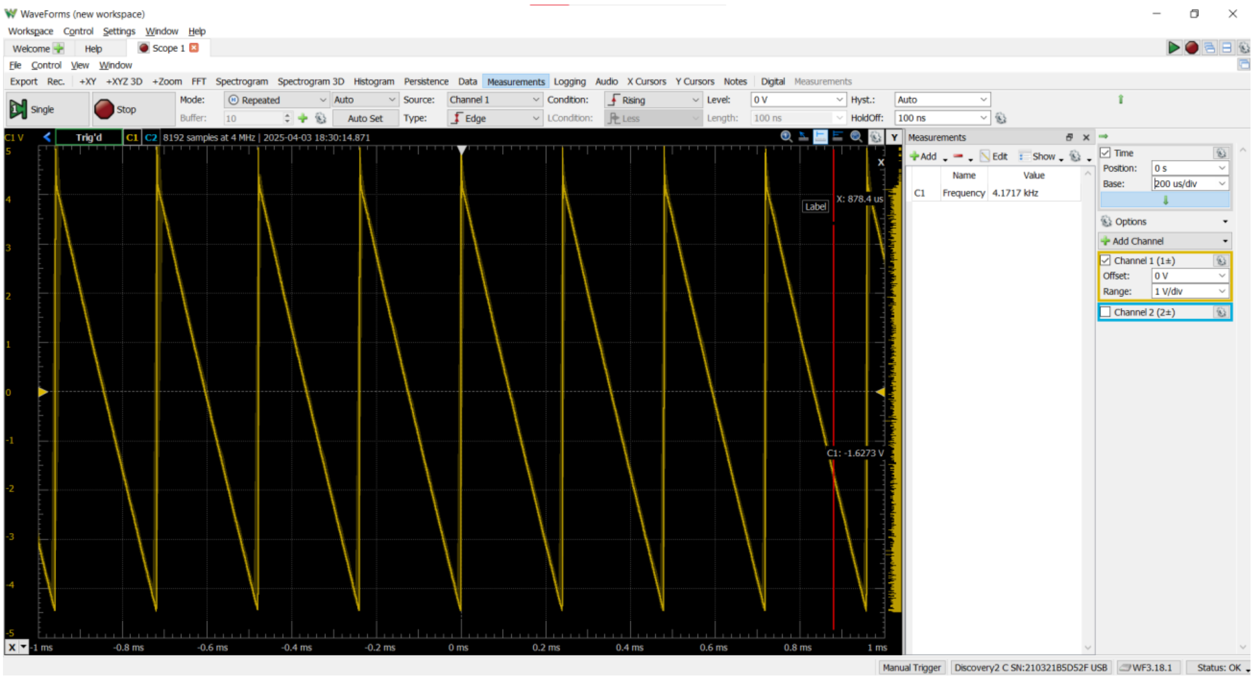

Figure 9: Octave 8V Frequency Measurement (4.1717 kHz) 1x Probe

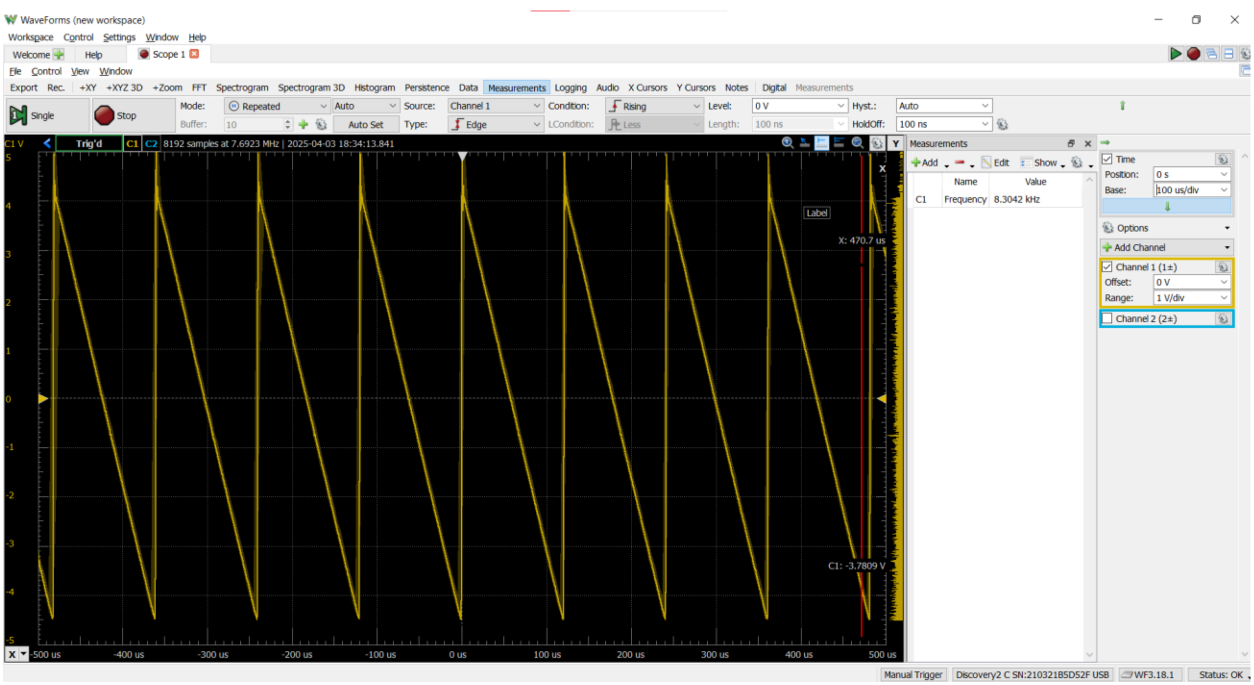

Figure 7.1.1.10: Octave 9V Frequency Measurement (8.3042 kHz) 1x Probe

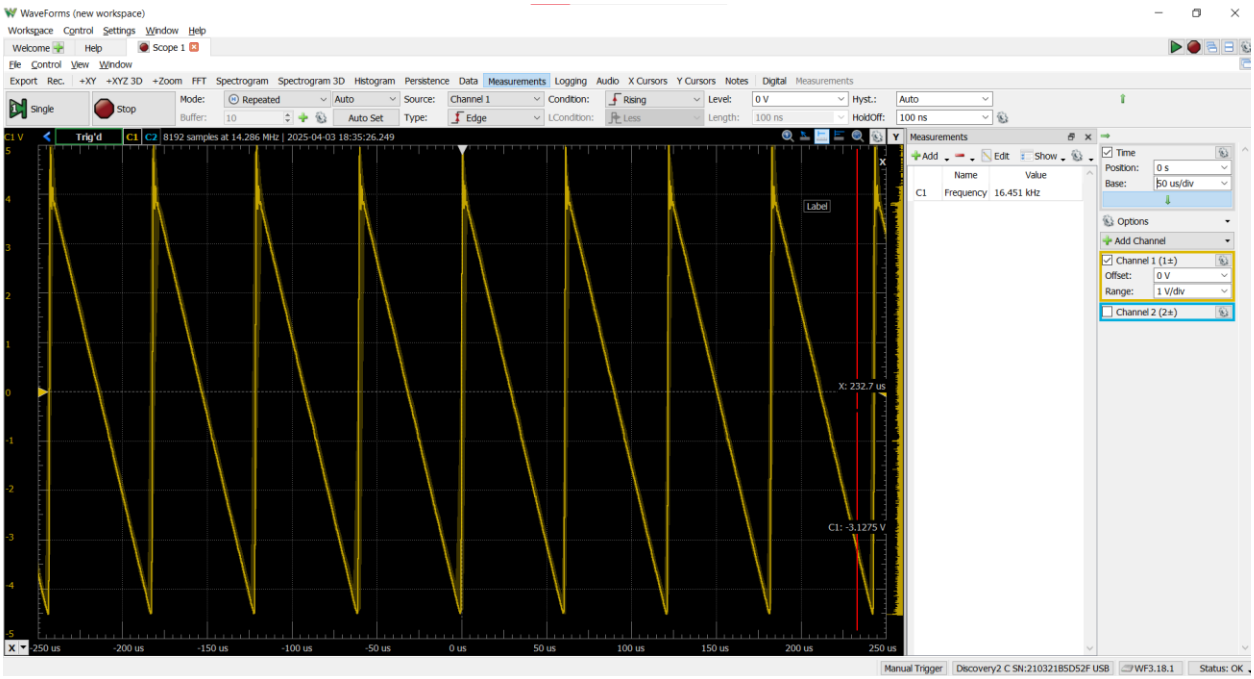

Figure 7.1.1.11: Octave 10V Frequency Measurement (16.451 kHz) 1x Probe

7.1.2 MIDI to CV Measurements

MIDI Input (represents the octave)	Output Voltage Mesurement (Unit: Volts)
0	007.171
12	1.00045
24	2.0006
36	3.0006
48	4.0006
60	5.0006
72	6.0005
84	7.0005
96	8.0005
108	9.0006
120	10.0007

Table 7.1.2.1: Summary MIDI to CV Measurements

Figure 7.1.2.1: MIDI 2 CV Measurements 0-10V

7.1.3 ADSR Measurements

Test Setting	Time/Voltage	Probe/Graph	Attack (%)	Sustain (%)	Decay (%)	Release (%)
ADSR Attack short	1 ms	10X	0	100	0	0
ADSR Attack Long	4.5 s	10X	100	50	0	0
ADSR Decay short	1 ms	10X	0	100	0	0
ADSR Decay long	10 s	10X	0	0	0	0
ADSR Sustain	10 V	10X	0	100	0	0
ADSR Sustain	0 V	10X	0	0	0	0
ADSR Fast Release	1 ms	10X	0	100	0	0
ADSR Slow Release	10 s	10X	0	100	0	0

Table 7.1.3.1: ADSR Measurements Summary

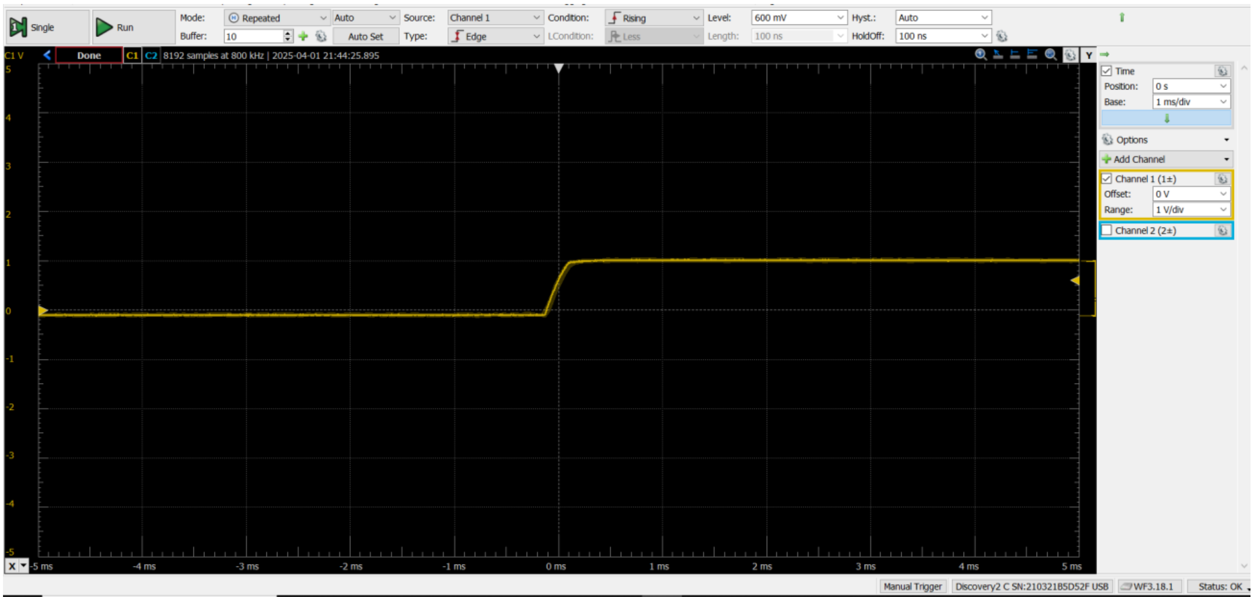

Figure 7.1.3.1: ADSR Attack short 1ms graph 10X probe (Attack=0%, Sustain = 100%, Decay = 0%, Release 0%)

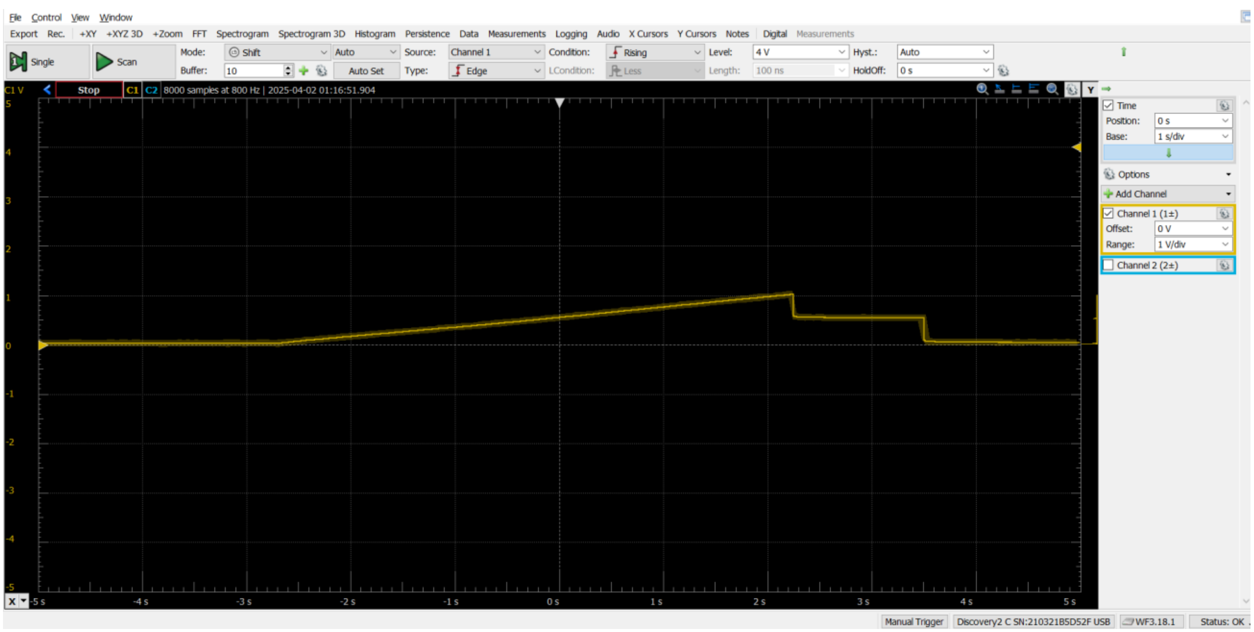

Figure 7.1.3.2: ADSR Attack long 10 s graph 10X probe (Attack=100%, Sustain = 50%, Decay = 0%, Release 0%)

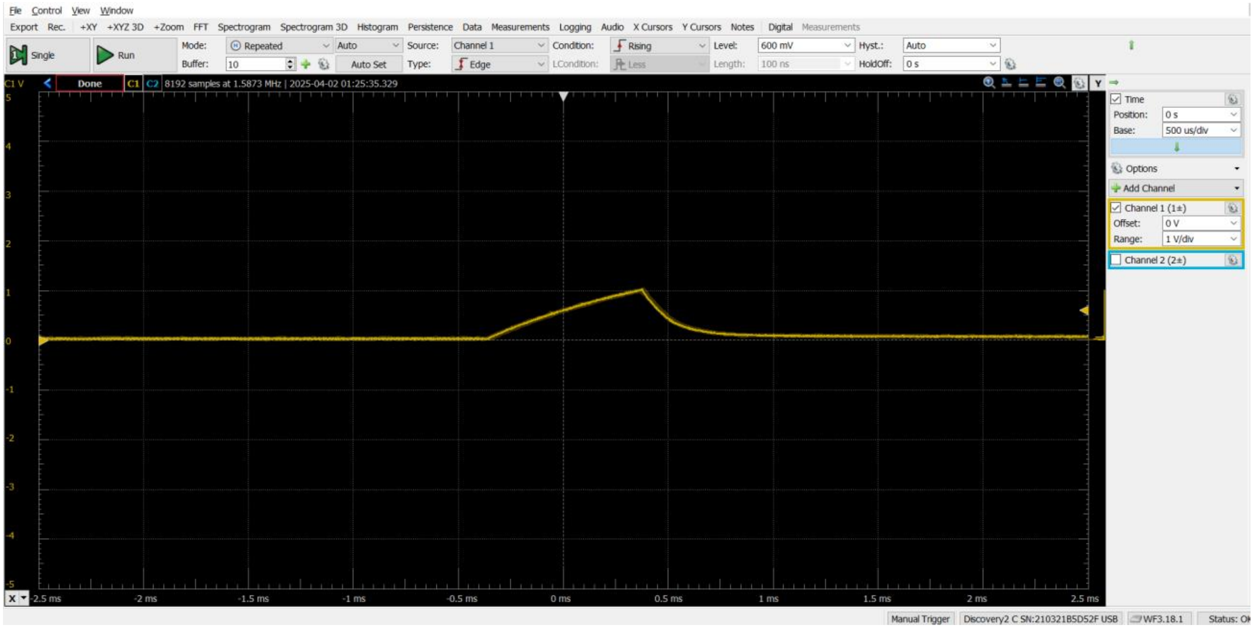

Figure 7.1.3.3: ADSR Decay short 1ms graph 10X probe (Attack=0%, Sustain = 100%, Decay = 0%, Release 0%)

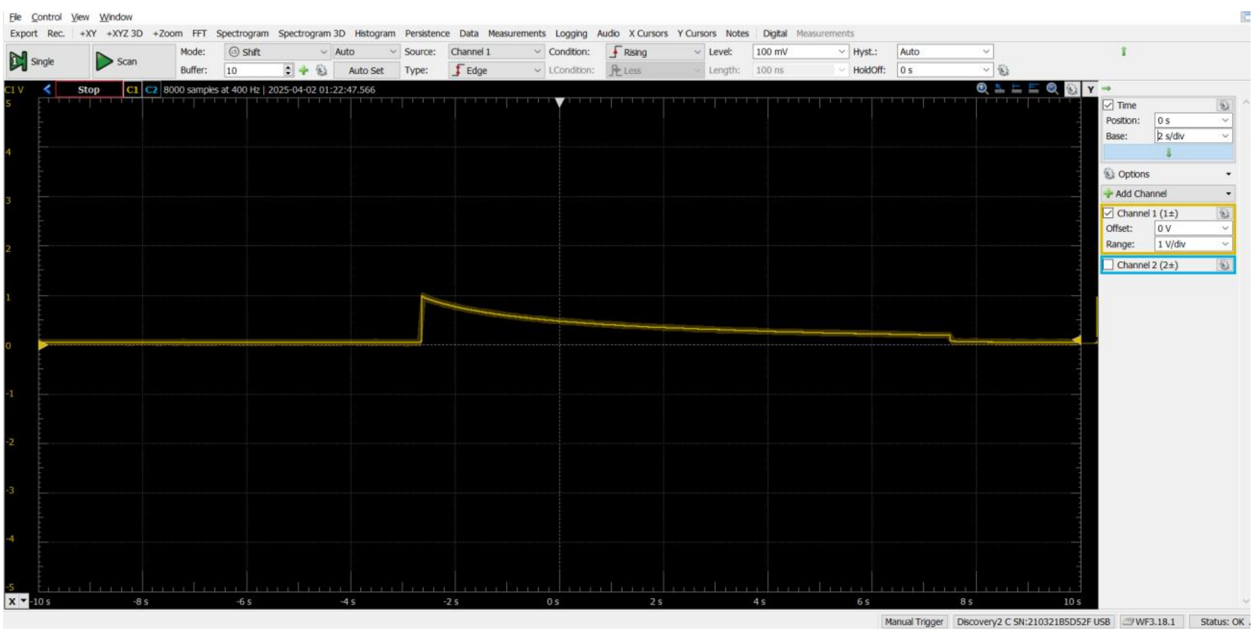

Figure 7.1.3.4: ADSR Decay long 10s graph 10x Probe (Attack=0%, Sustain = 0%, Decay = 0%, Release 0%)

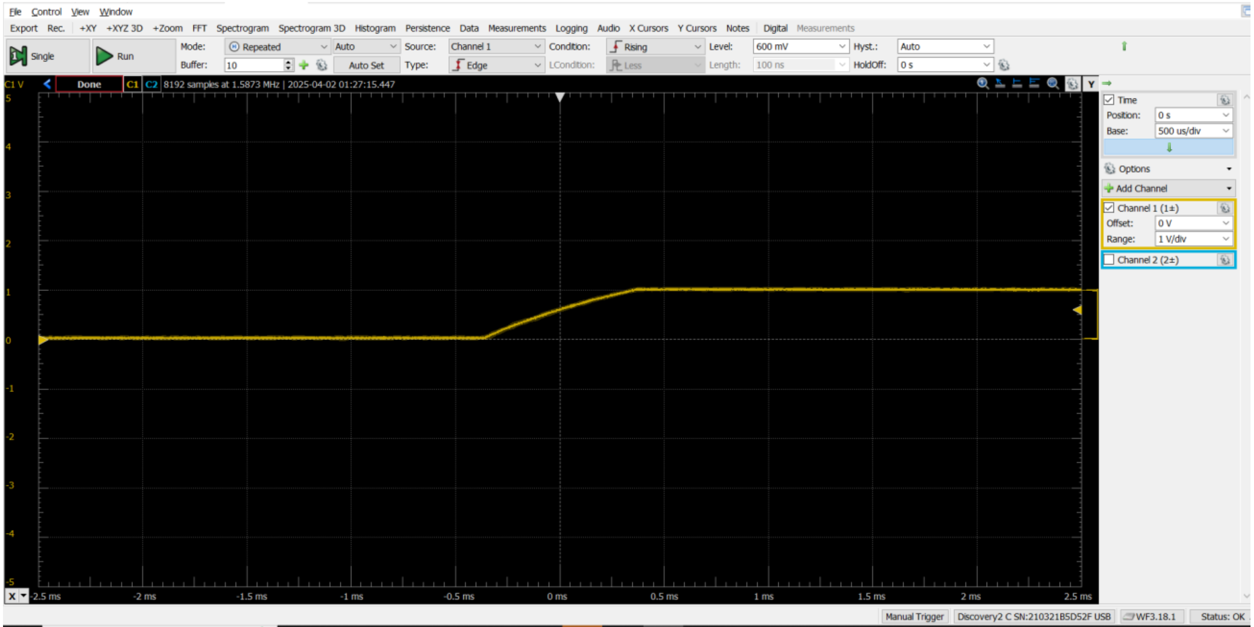

Figure 7.1.3.5: ADSR Sustain 10V Graph 10x Probe (Attack=0%, Sustain = 100%, Decay = 0%, Release 0%)

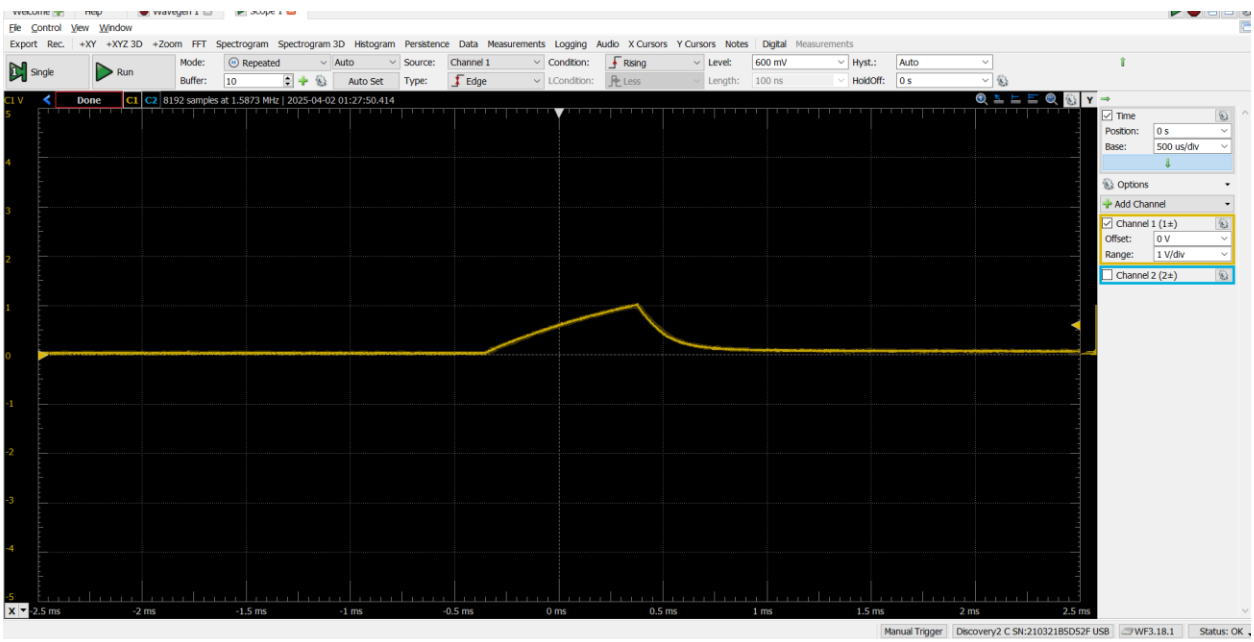

Figure 7.1.3.6: ADSR Sustain 0V Graph 10x Probe (Attack=0%, Sustain = 0%, Decay = 0%, Release 0%)

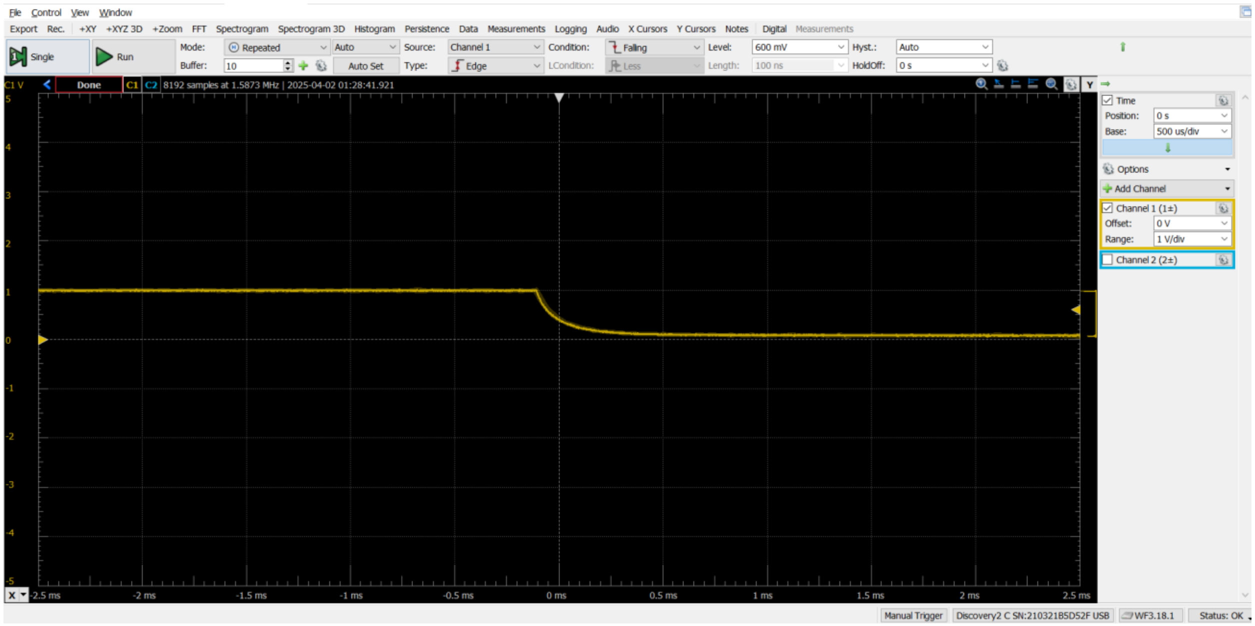

Figure 7.1.3.7: ADSR Fast Release 1ms Graph 10x Probe (Attack=0%, Sustain = 100%, Decay = 0%, Release 0%)

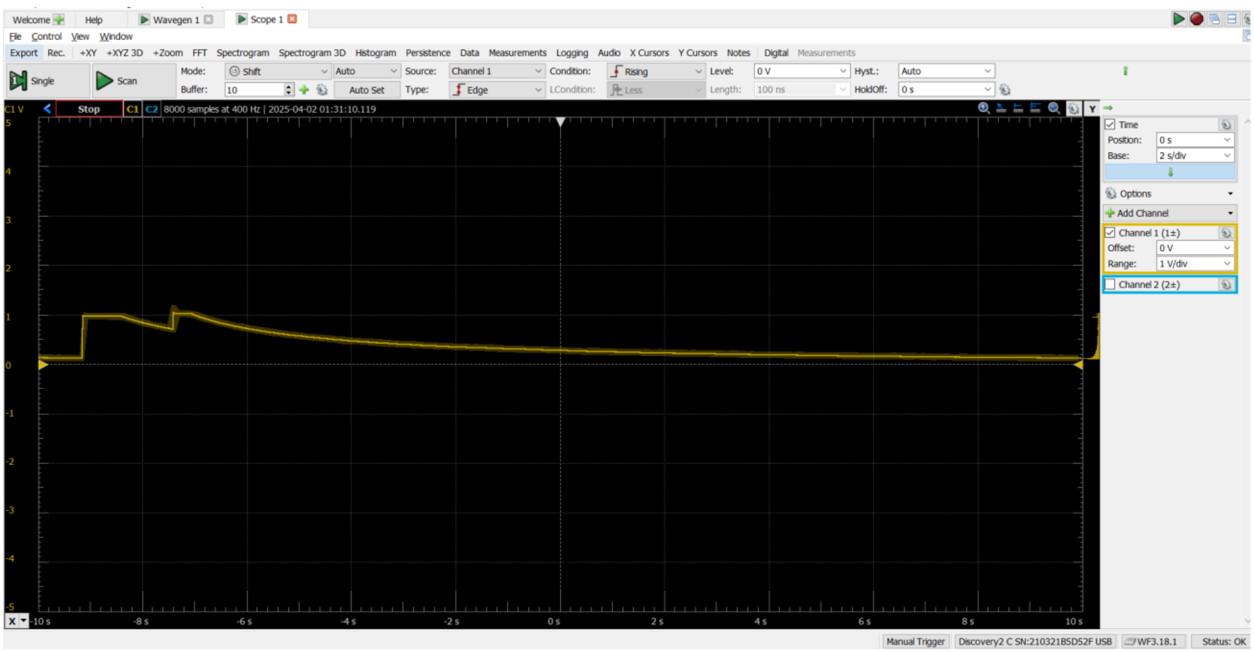

Figure 7.1.3.8: ADSR Slow Release 10s Graph 10x Probe (Attack=0%, Sustain = 100%, Decay = 0%, Release 0%)

7.1.4 VCA Measurement

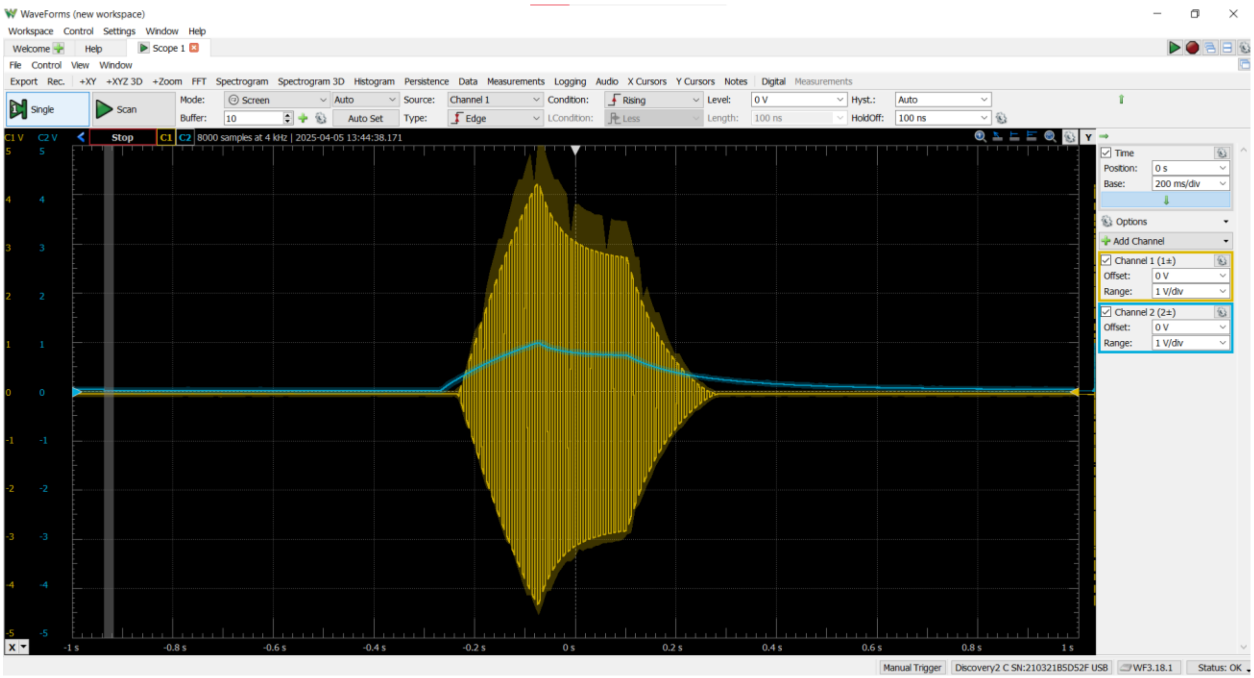

Figure 7.1.4.1: VCA Output Test Measurement (Orange 1X Probe), CV1 Input (Blue 10X Probe) (e.g ADSR Env Out), Sig In 1 (not shown, e.g PULSE Output of VCO), VCA Knob Settings (Gain 5%, CV Level #1 95%, Input Level #1 100%)

7.2 Schematic, PCB, and CAD Files

7.2.1 ADSR Files

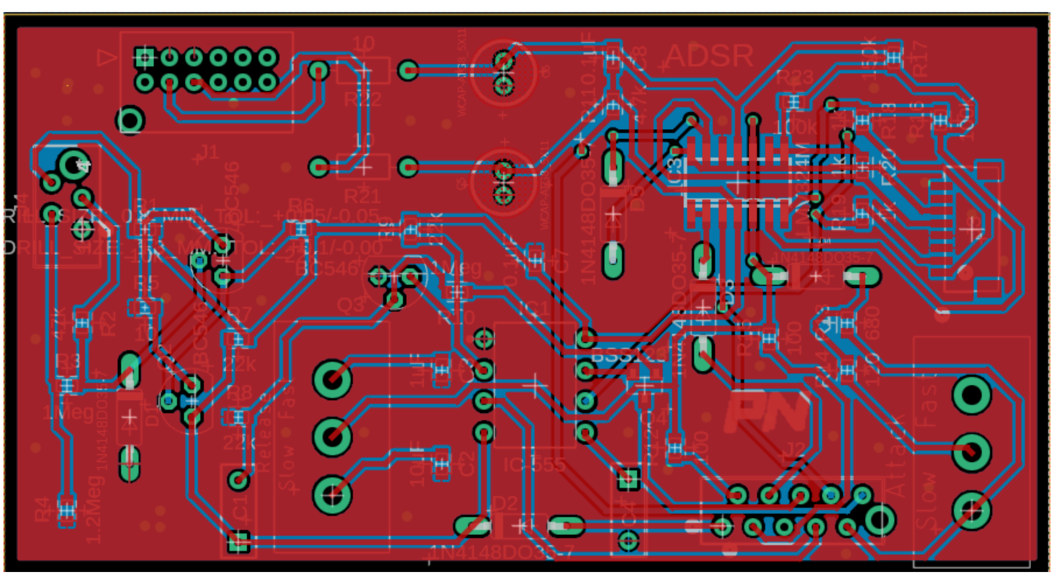

Figure 7.2.1.1: ADSR Main PCB Board

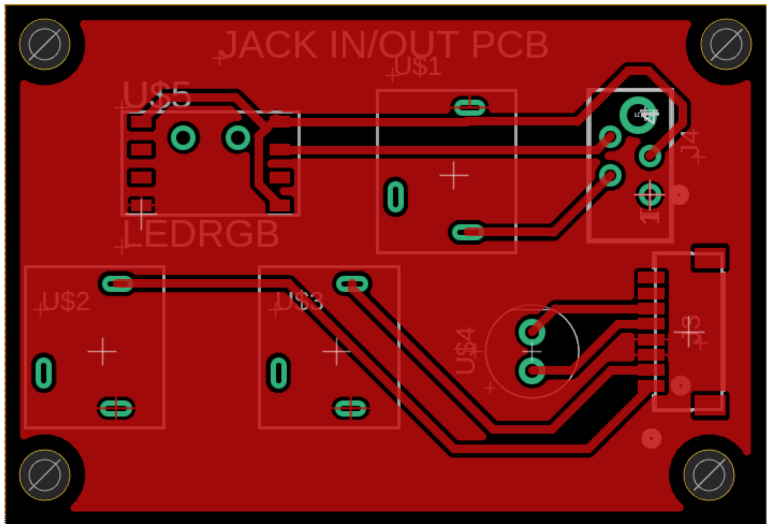

Figure 7.2.1.2: ADSR Jacks PCB Board

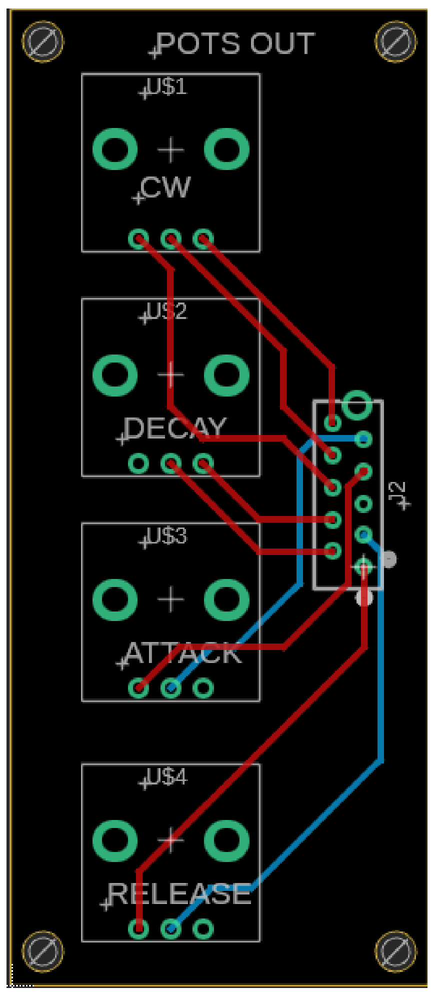

Figure 7.2.1.2: ADSR Potentiometers PCB Board

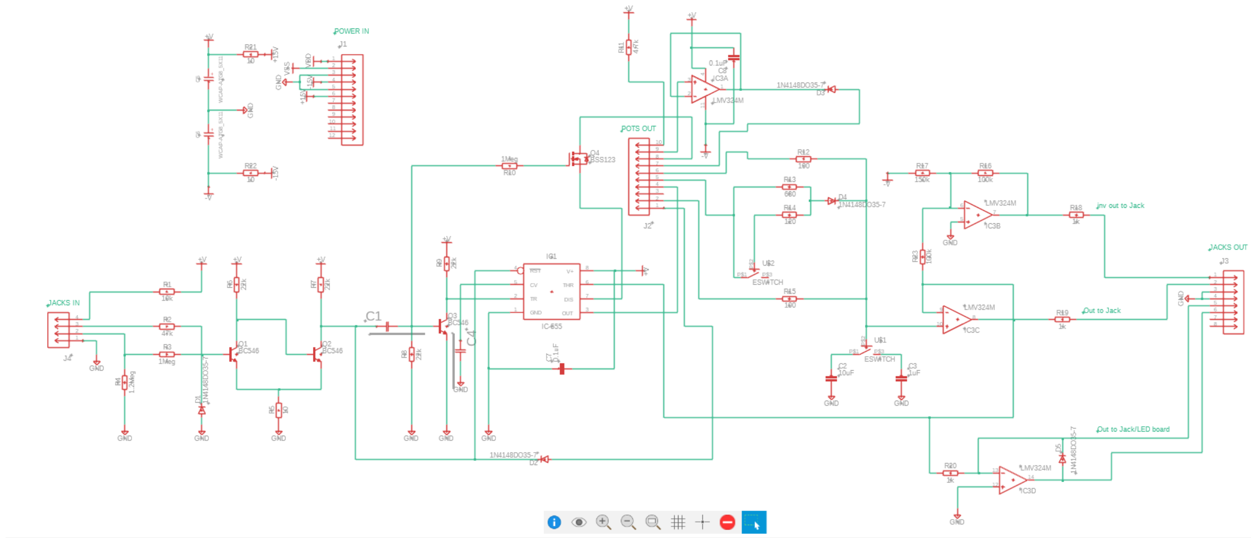

Figure 7.2.1.4: ADSR Main Board Schematic

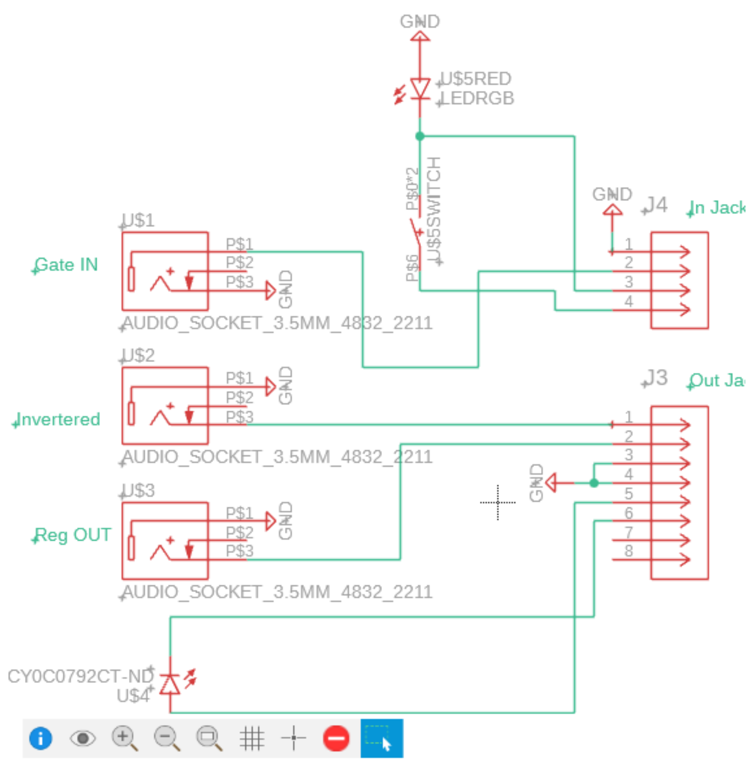

Figure 7.2.1.5: ADSR Jack Board Schematic

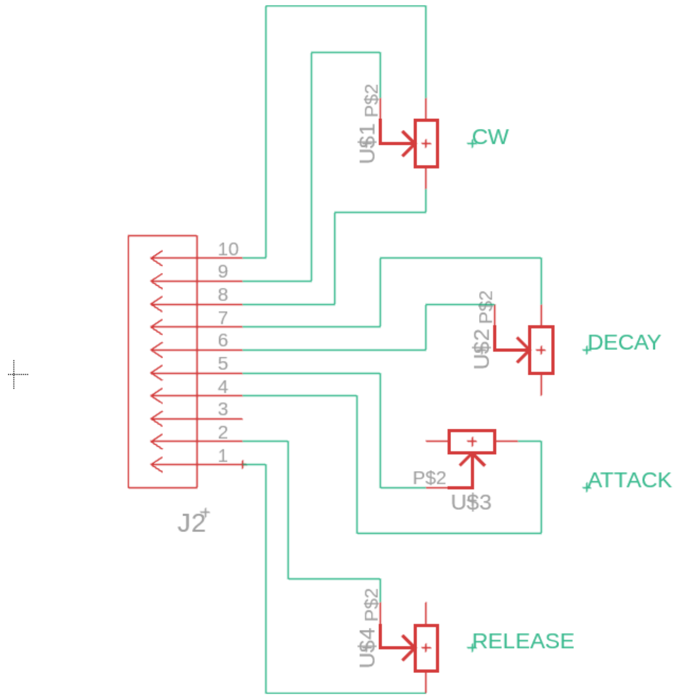

Figure 7.2.1.6: ADSR Potentiometers Board Schematic

7.2.2 MIDI to CV Files

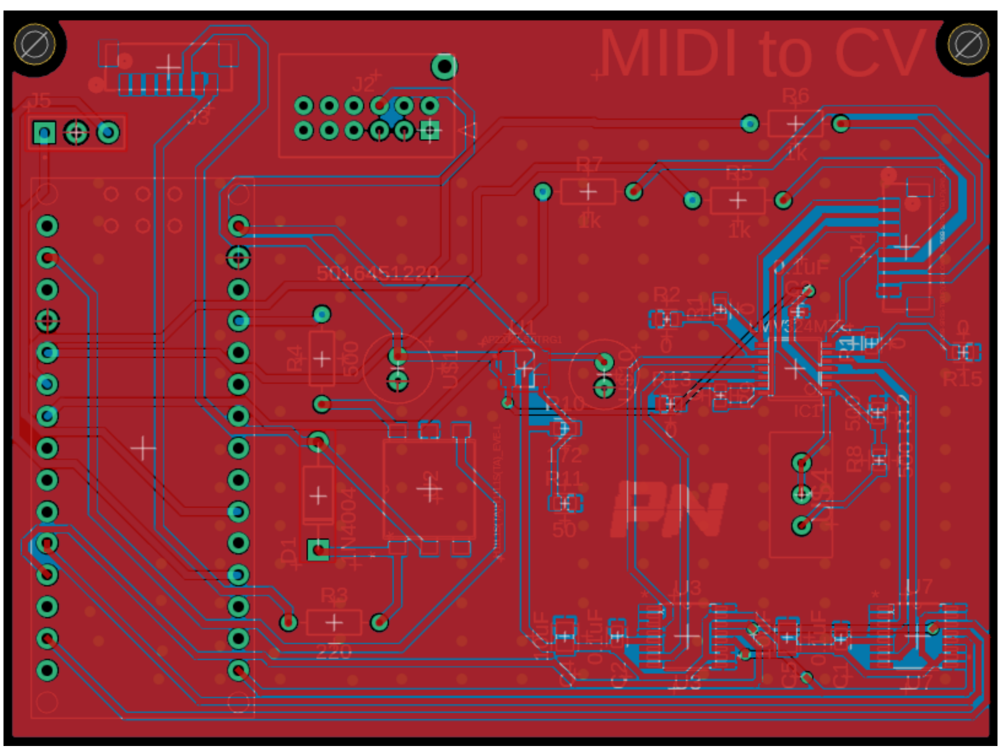

Figure 7.2.2.1: MIDI to CV Main PCB Board

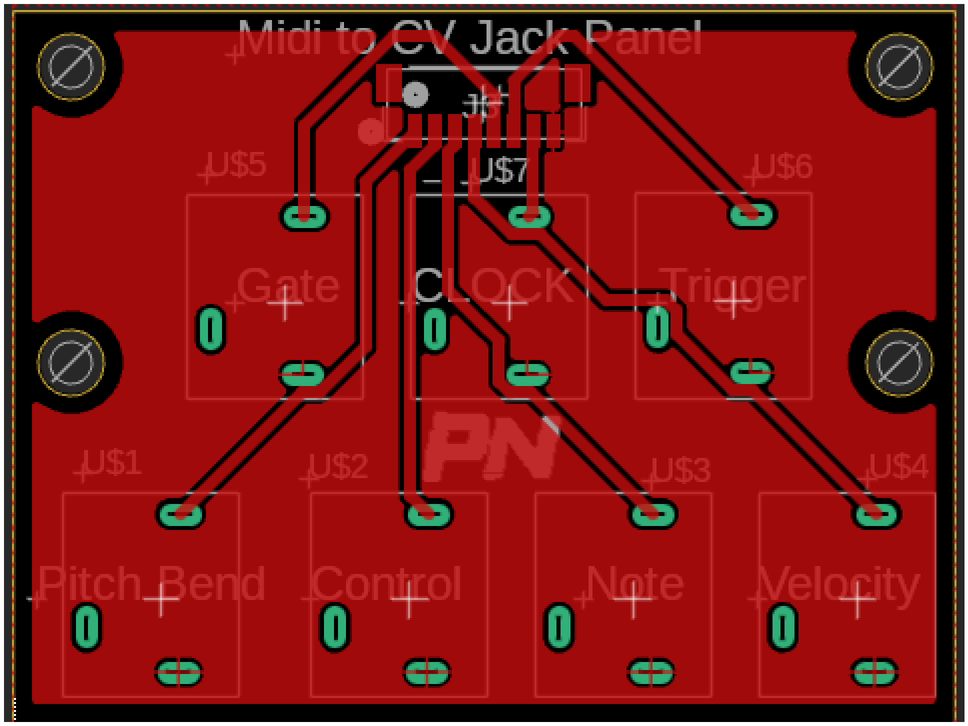

Figure 7.2.2.2: MIDI to CV Jacks PCB Board

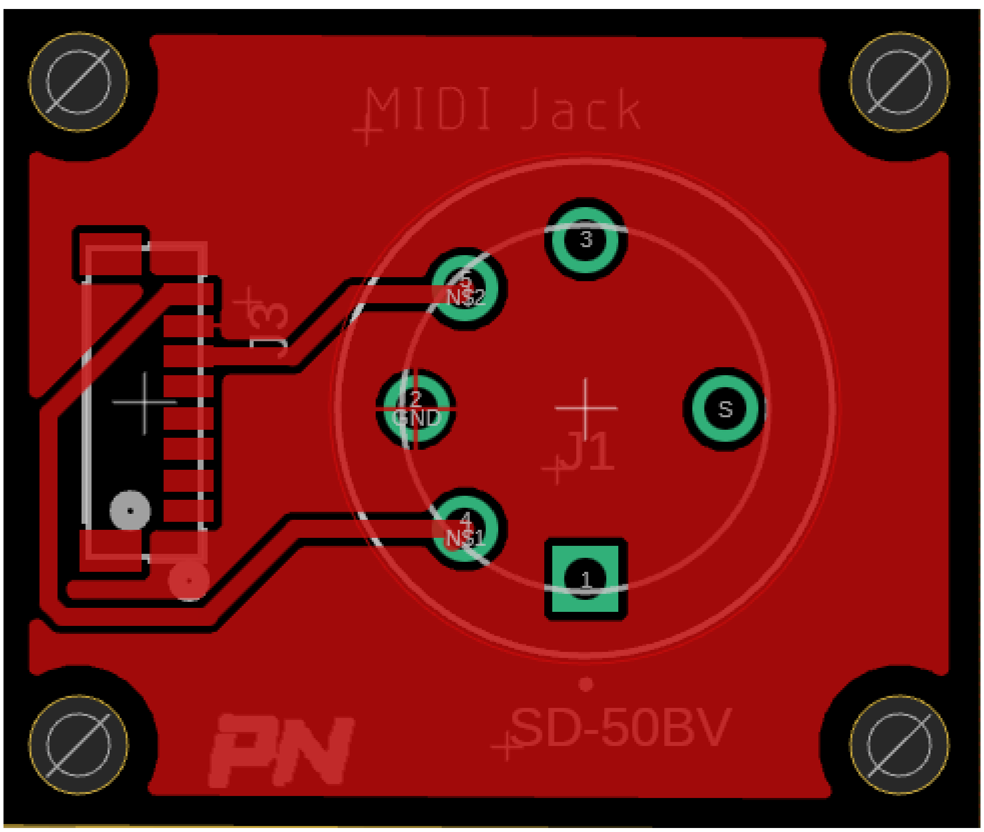

Figure 7.2.2.3: MIDI to CV Jacks PCB Board

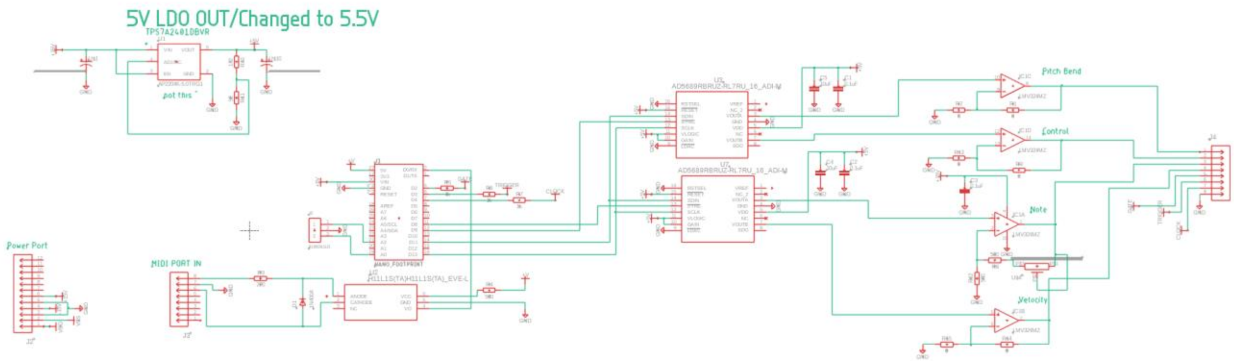

Figure 7.2.2.4: MIDI to CV Main Board Schematic

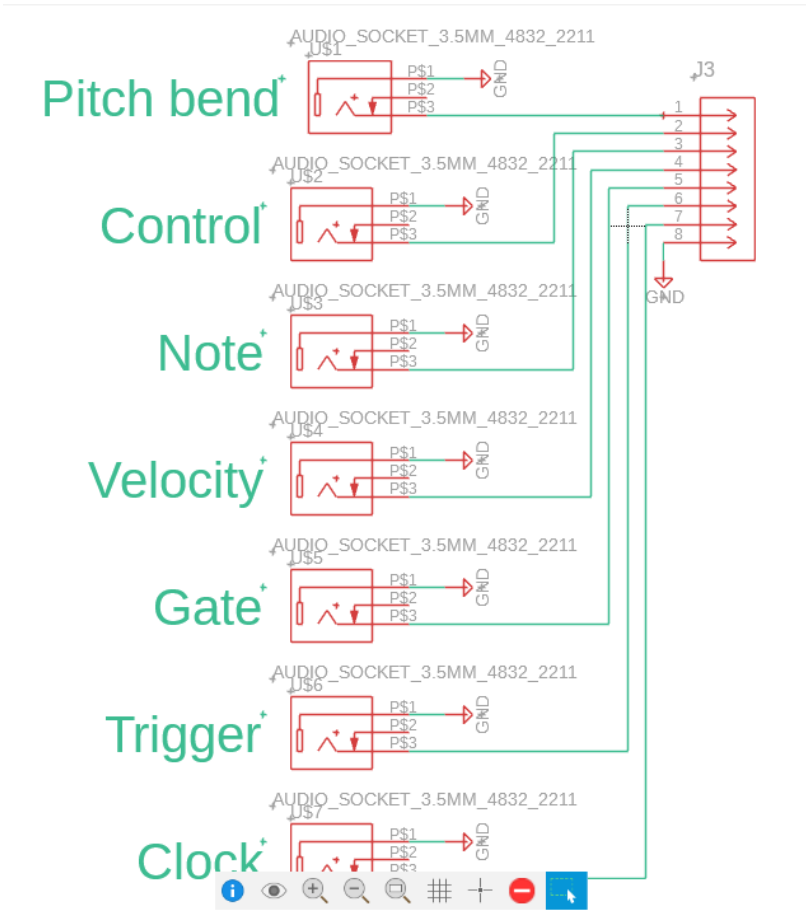

Figure 7.2.2.5: MIDI to CV Jacks Board Schematic

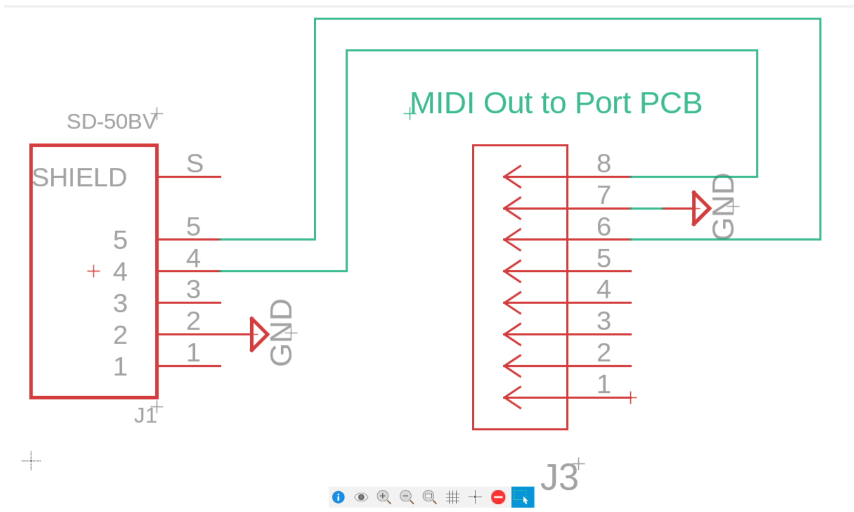

Figure 7.2.2.6: MIDI to CV Potentiometers Board Schematic

7.2.3 VCO Files

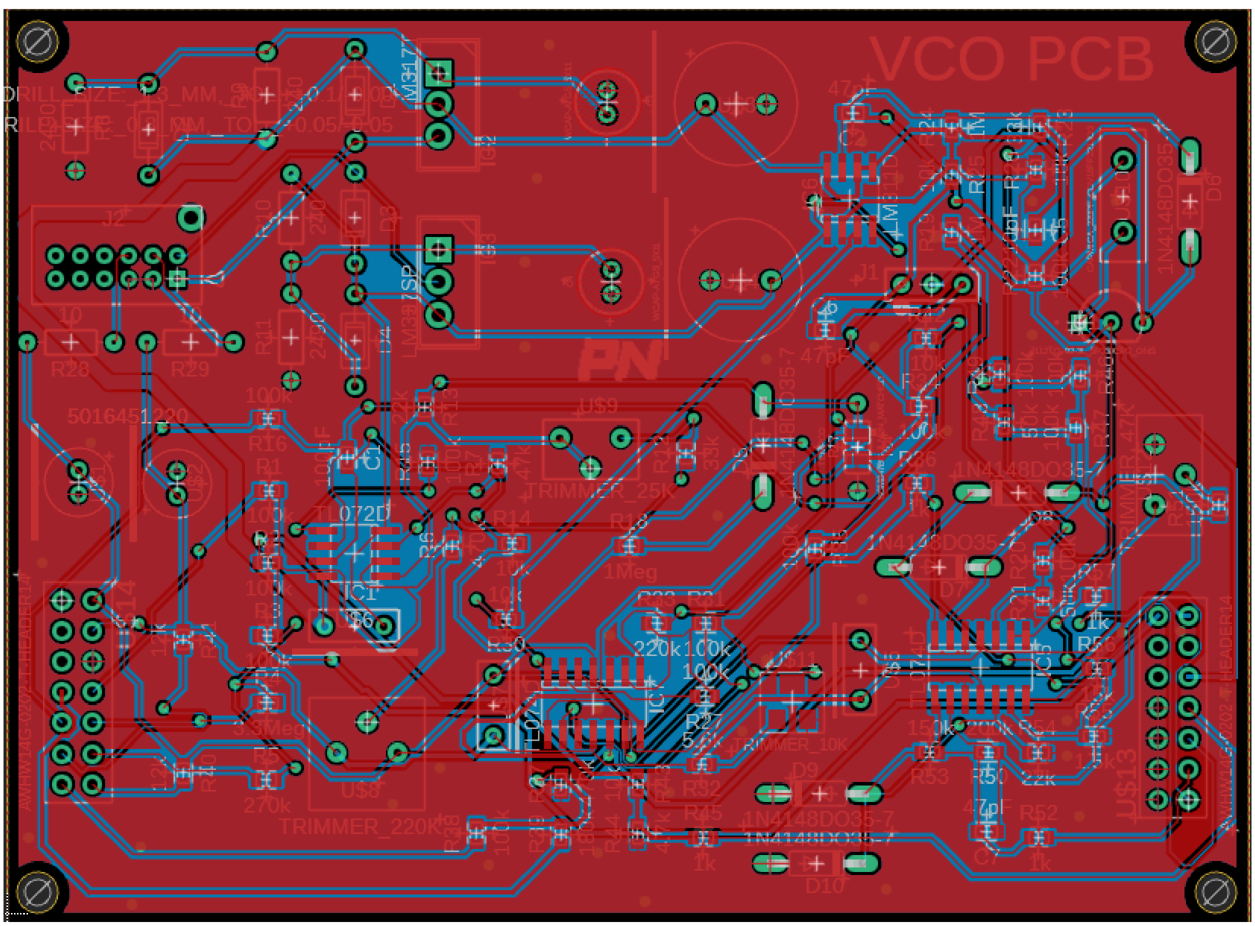

Figure 7.2.3.1: VCO Main Board PCB

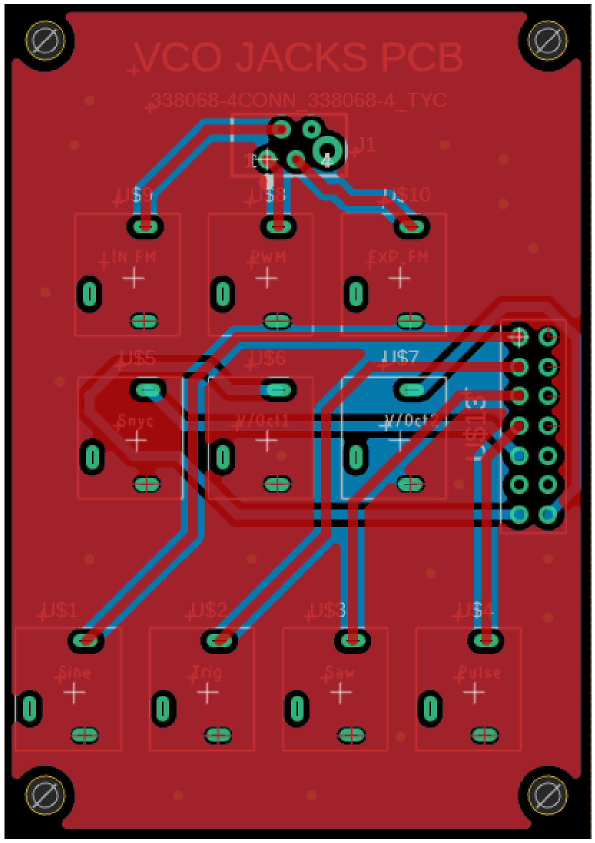

Figure 7.2.3.2: VCO Jacks Board PCB

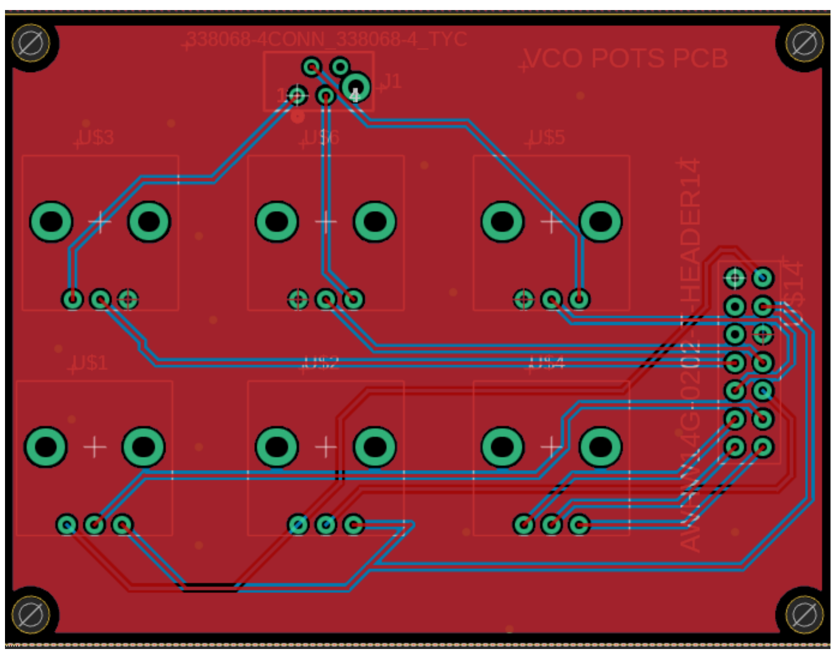

Figure 7.2.3.3: VCO Potentiometers Board PCB

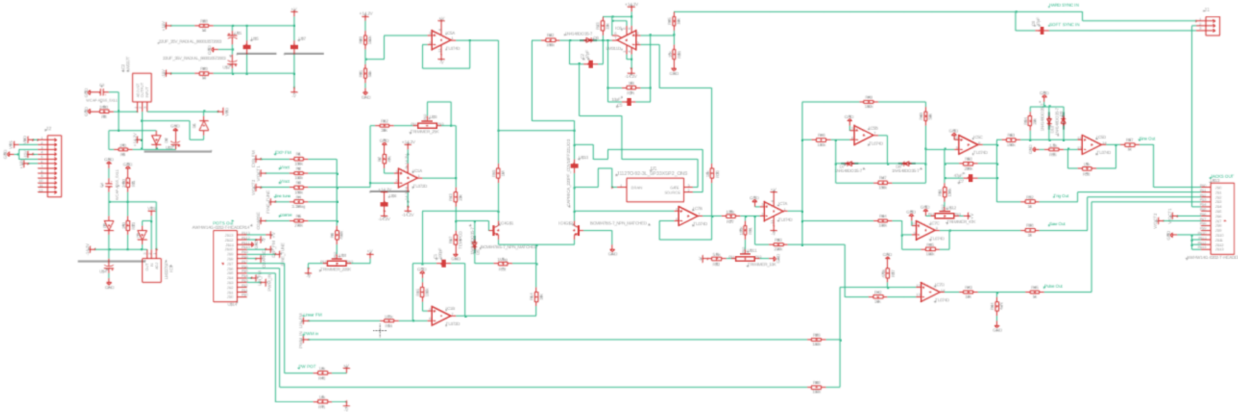

Figure 7.2.3.4: VCO Main Board Schematic

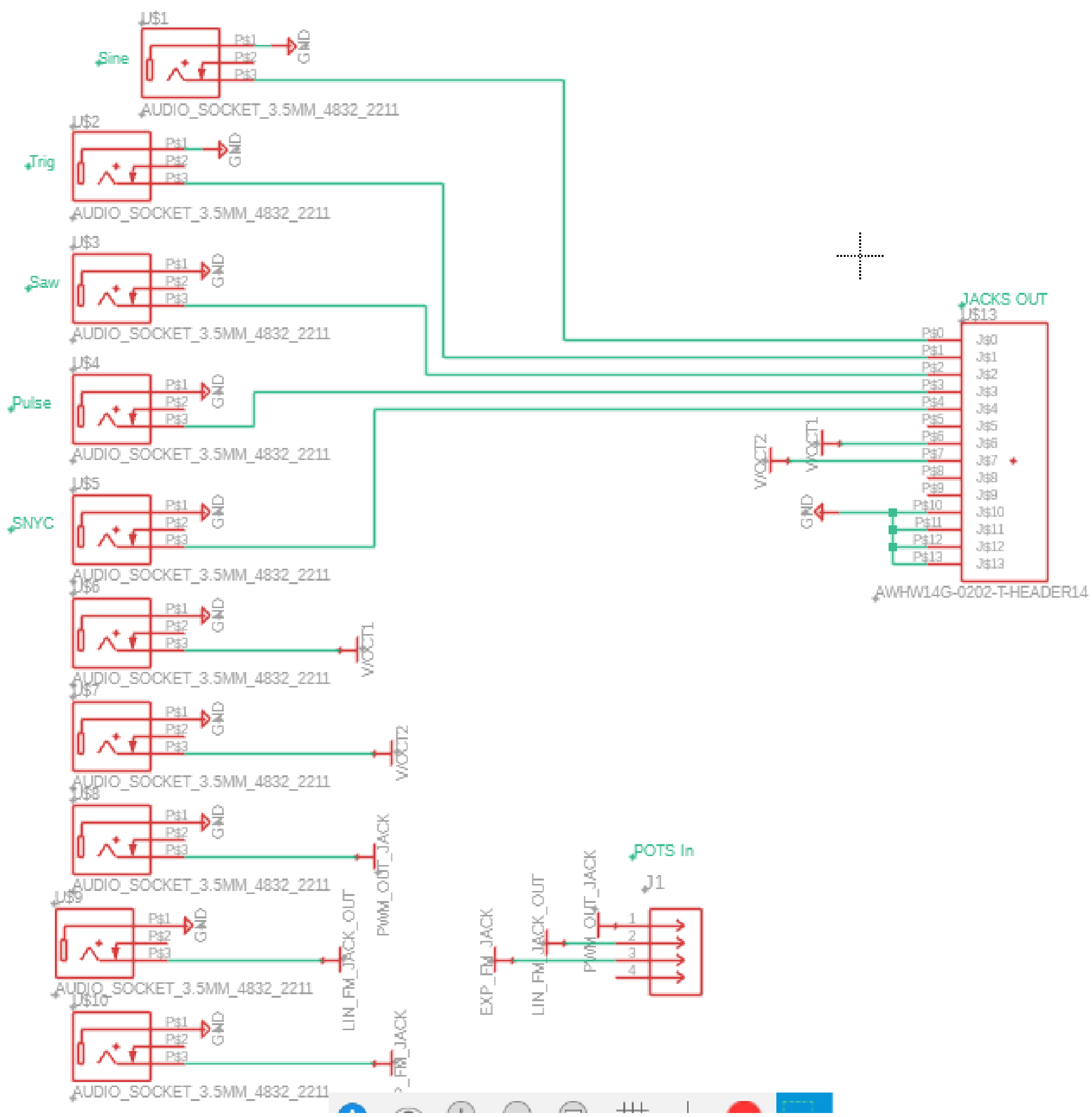

Figure 7.2.3.5: VCO Jacks Board Schematic

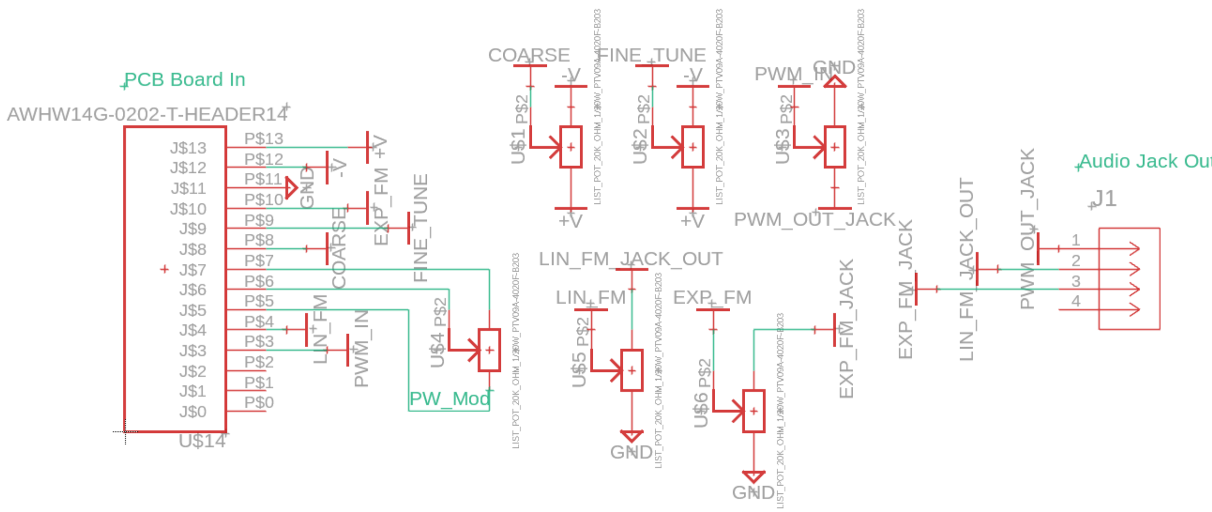

Figure 7.2.3.6: VCO Potentiometers Board Schematic

7.2.4 VCA Files

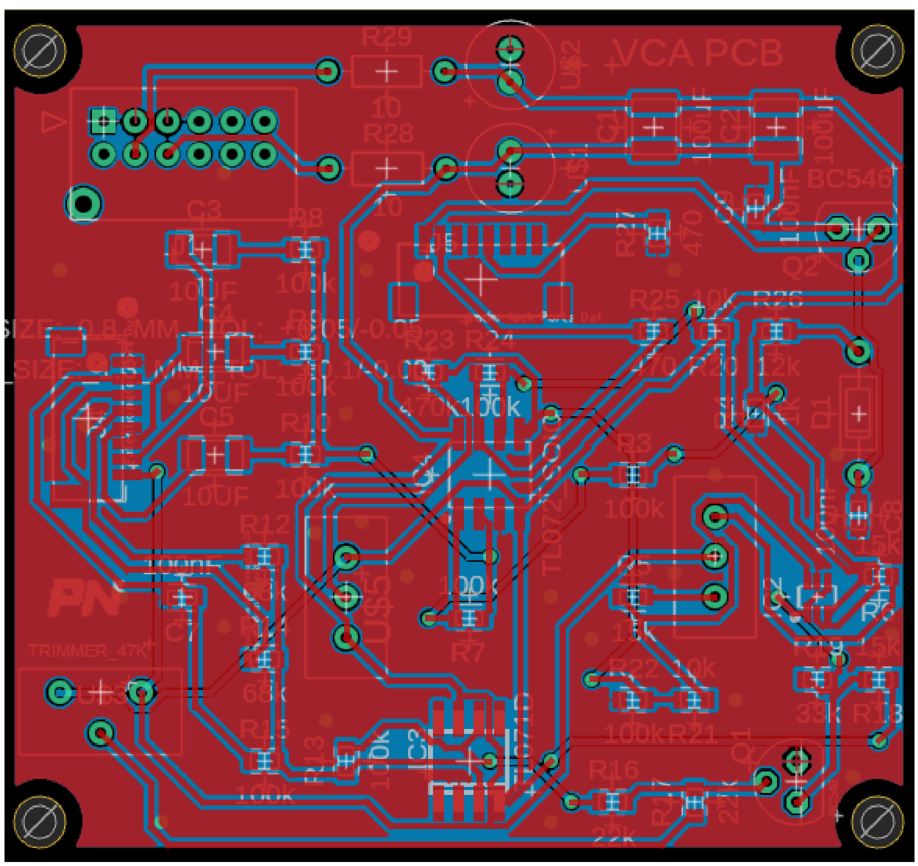

Figure 7.2.4.1: VCA Main Board PCB

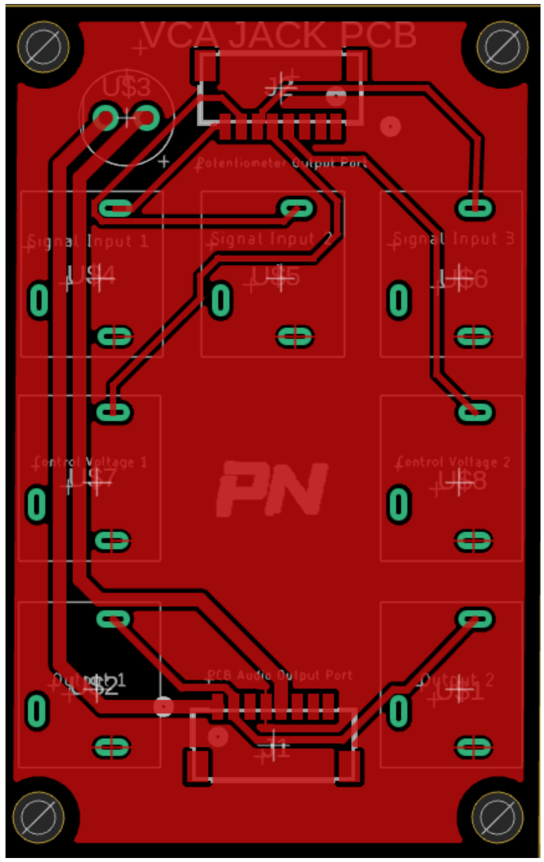

Figure 7.2.4.2: VCA Jack Board PCB

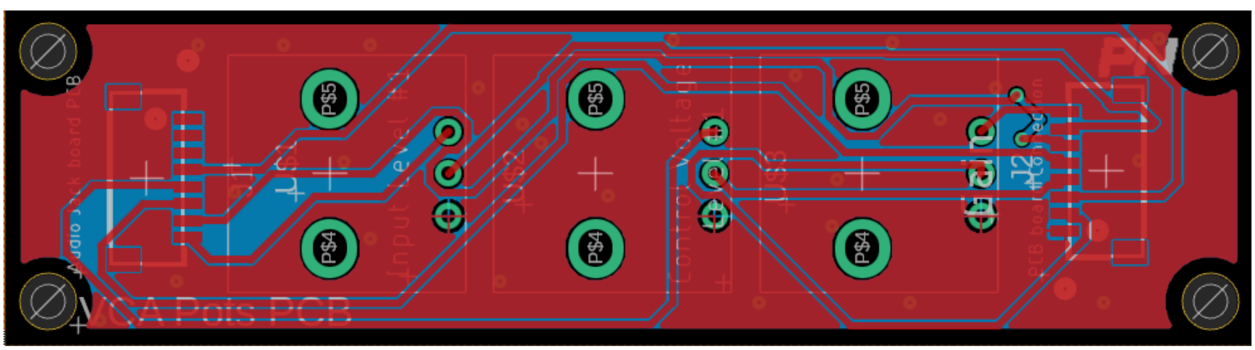

Figure 7.2.4.3: VCA Potentiometers Board PCB

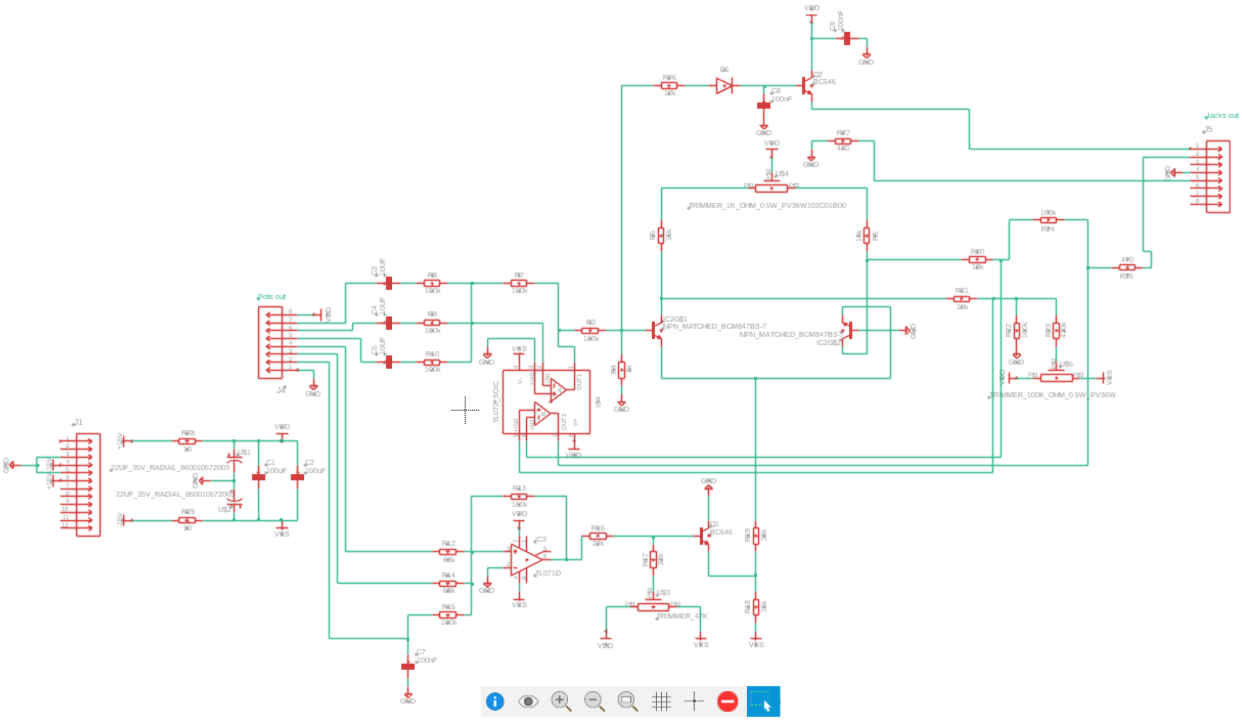

Figure 7.2.4.4: VCA Main Board Schematic

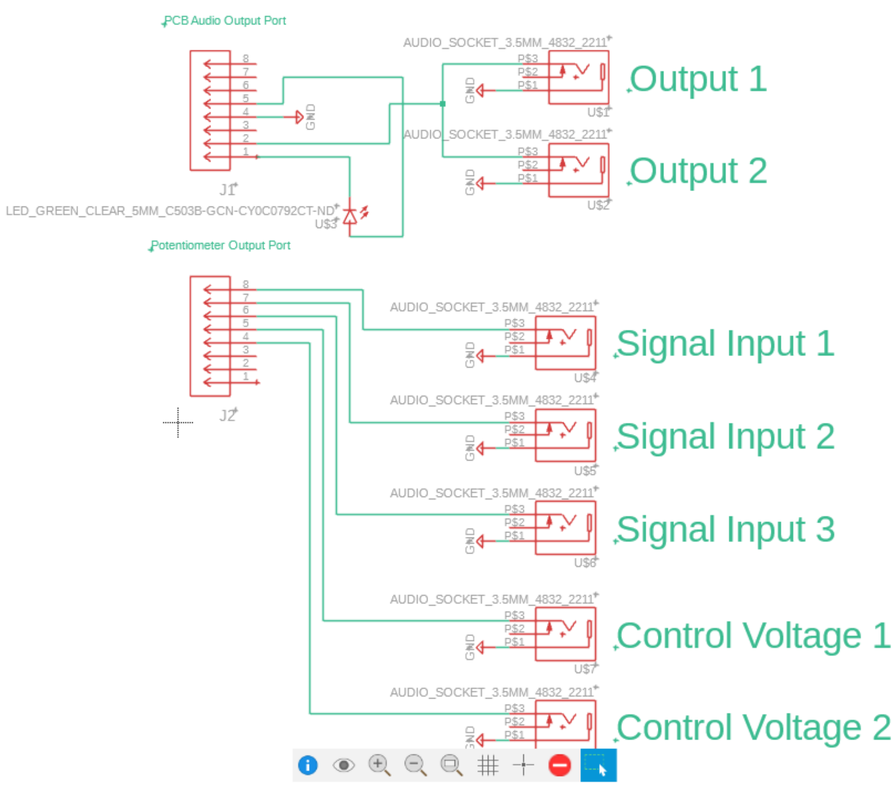

Figure 7.2.4.5: VCA Jacks Board Schematic

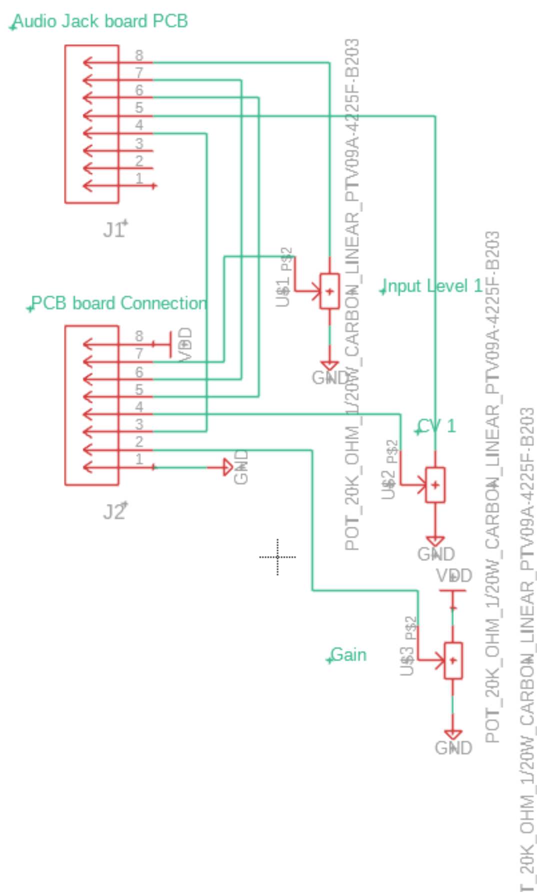

Figure 7.2.4.6: VCA Potentiometers Board Schematic

7.3 Components Lists

Index	Manufacturer Part Number	Manufacturer Name	Description	Original Part numbers
1	TPS7A3001DGNR	Texas Instruments	IC REG LINEAR NEG ADJ 8-HVSSOP	296-27750-1-ND
2	TPS7A4901DGNR	Texas Instruments	IC REG LINEAR POS ADJ 8-HVSSOP	296-27751-1-ND
3	DKE10C-24	MEAN WELL USA Inc.	DC DC CONVERTER +/- 24V 10W	1866-1332-ND
4	NMC1206X5R106K25TRPLPF	NIC Components Corp	CAP SMT120610F25V DC	4988-NMC1206X5R106K25TRPLPFCT-ND

5	NMC0603X7R103K50TRPF	NIC Components Corp	CAP SMT06030.01UF 50VDC	4988-NMC0603X7R103K50TRPFCT-ND
6	ERJ-3EKF1183V	Panasonic Electronic Components	RES SMD 118K OHM 1% 1/10W 0603	P118KHCT-ND
7	RC0603FR-07143KL	YAGEO	RES 143K OHM 1% 1/10W 0603	311-143KHRCT-ND

Table 7.3.1: Power Supply Components

Index	Manufacturer Part Number	Manufacturer Name	Description	Original Part numbers
1	1N4148	SMC Diode Solutions	DIODE STANDARD 75V 300MA DO35	1655-1N4148CT-ND
2	OPA4180IPWR	Texas Instruments	IC OPAMP ZER-DRIFT 4CIRC 14TSSOP	296-40469-1-ND
3	SD-50BV	Same Sky (Formerly CUI Devices)	CONN RCPT FMALE DIN 5POS SOLDER	CP-3150-ND
4	TPS7A2401DBVR	Texas Instruments	IC REG LIN POS ADJ 200MA SOT23-5	296-TPS7A2401DBVRCT-ND
5	H11L1S(TA)	Everlight Electronics Co Ltd	OPTOISO 5KV OPEN COLLECTOR 6-SMD	1080-1201-1-ND
6	BM08B-SRSS-TB	JST Sales America Inc.	CONN HEADER SMD 8POS 1MM	455-BM08B-SRSS-TBCT-ND
7	A08SR08SR30K102B	JST Sales America Inc.	JUMPER 08SR-3S - 08SR-3S 4"	455-3656-ND
8	YR1B3K65CC	TE Connectivity Passive Product	RES 3.65K OHM 0.1% 1/4W AXIAL	1712-YR1B3K65CCCT-ND
9	CL05B104KP5NNNC	Samsung Electro-Mechanics	CAP CER 0.1UF 10V X7R 0402	1276-1002-1-ND
10	AD5689RBRUZ-RL7	Analog Devices Inc.	IC DAC 16BIT V-OUT 16TSSOP	505-AD5689RBRUZ-RL7CT-ND
11	860020572003	Würth Elektronik	CAP ALUM 10UF 20% 35V RADIAL TH	732-8937-1-ND
12	SM08B-SRSS-TB	JST Sales America Inc.	CONN HEADER SMD R/A 8POS 1MM	455-1808-1-ND

13	4832.2211	SCHURTER Inc.	CONN JACK MONO 3.5MM PNL MNT	486-3418-ND
14	RT0603BRD071K05L	YAGEO	RES SMD 1.05KOHM 0.1% 1/10W 0603	YAG1557CT-ND
15	RT0603BRD07500RL	YAGEO	RES 500 OHM 0.1% 1/10W 0603	13-RT0603BRD07500RLCT-ND
16	RN73H1JTTD1720B50	KOA Speer Electronics, Inc.	RES 172 OHM 0.1% 1/10W 0603	2019-RN73H1JTTD1720B50CT-ND
17	CRCW060350R0FKEA	Vishay Dale	RES SMD 50 OHM 1% 1/10W 0603	541-3318-1-ND
18	RT0603DRE071K52L	YAGEO	RES 1.52K OHM 0.5% 1/10W 0603	13-RT0603DRE071K52LCT-ND
19	RC0603JR-071K5L	YAGEO	RES 1.5K OHM 5% 1/10W 0603	311-1.5KGRCT-ND
20	CL21A106KOQNNNG	Samsung Electro-Mechanics	CAP CER 10UF 16V X5R 0805	1276-6455-1-ND
21	CC0603KRX7R7BB104	YAGEO	CAP CER 0.1UF 16V X7R 0603	311-1088-1-ND
22	RMCF0603ZT0R00	Stackpole Electronics Inc	RES 0 OHM JUMPER 1/10W 0603	RMCF0603ZT0R00CT-ND

Table 7.3.2: MIDI to CV Components

Index	Manufacturer Part Number	Manufacturer Name	Description	Original Part numbers
1	TL072CDR	Texas Instruments	IC OPAMP JFET 2 CIRCUIT 8SOIC	296-1282-1-ND
2	TL074HIDR	Texas Instruments	IC OPAMP JFET 4 CIRCUIT 14SOIC	296-TL074HIDRCT-ND
3	LM311DR	Texas Instruments	IC COMPARATOR 1 GEN PUR 8SOIC	296-1388-1-ND
4	BCM847BS-7	Diodes Incorporated	TRANS 2NPN 45V 100MA SOT-363	31-BCM847BS-7CT-ND
5	0603N100J500CT	Walsin Technology Corporation	CAP CER 10PF 50V C0G/NP0 0603	1292-1471-1-ND

6	0603N470J500CT	Walsin Technology Corporation	CAP CER 47PF 50V C0G/NP0 0603	1292-1528-1-ND
7	KGM15ACG1H101 JT	KYOCERA AVX	CAP CER 100PF 50V C0G/NP0 0603	478-1175-1-ND
8	CDV16FF221JO3	Cornell Dubilier Knowles	CAP MICA 220PF 5% 1KV RADIAL	338-3101-ND
9	860010572003	Würth Elektronik	CAP ALUM 22UF 20% 35V RADIAL TH	732-8733-1-ND
10	PVG5A103C03R00	Bourns Inc.	TRIMMER 10K OHM 0.25W J LEAD TOP	490-2661-1-ND
11	PV37W253C01B00	Bourns Inc.	TRIMMER 25K OHM 0.25W PC PIN TOP	490-2979-ND
12	3296Y-1-473LF	Bourns Inc.	TRIMMER 47K OHM 0.5W PC PIN TOP	3296Y-1-473LF-ND
13	3386P-1-224LF	Bourns Inc.	TRIMMER 220K OHM 0.5W PC PIN TOP	3386P-1-224LF-ND
14	R82DC3100DQ50J	KEMET	CAP FILM 0.1UF 5% 63VDC RADIAL	399-5444-1-ND
15	RMCF0603FT10R0	Stackpole Electronics Inc	RES 10 OHM 1% 1/10W 0603	RMCF0603FT10R0CT-ND
16	RNCP0603FTD1K0 0	Stackpole Electronics Inc	RES 1K OHM 1% 1/8W 0603	RNCP0603FTD1K00C T-ND
17	WR06X1501FTL	Walsin Technology Corporation	RES 1.5K OHM 1% 1/10W 0603	1292-WR06X1501FTLCT-ND
18	RC0603FR-074K7L	YAGEO	RES 4.7K OHM 1% 1/10W 0603	311-4.70KHRCT-ND
19	RC0603FR-135K6L	YAGEO	RES 5.6K OHM 1% 1/10W 0603	13-RC0603FR-135K6LCT-ND
20	RNCP0603FTD10K 0	Stackpole Electronics Inc	RES 10K OHM 1% 1/8W 0603	RNCP0603FTD10K0C T-ND
21	RC0603FR-1312KL	YAGEO	RES 12K OHM 1% 1/10W 0603	13-RC0603FR-1312KLCT-ND
22	WR06X1502FTL	Walsin Technology Corporation	RES 15K OHM 1% 1/10W 0603	1292-WR06X1502FTLCT-ND
23	RMCF0603FG22K0	Stackpole Electronics Inc	RES 22K OHM 1% 1/10W 0603	RMCF0603FG22K0CT-ND
24	RMCF0603FG22K0	Stackpole Electronics Inc	RES 22K OHM 1% 1/10W 0603	RMCF0603FG22K0CT-ND

25	WR06X3302FTL	Walsin Technology Corporation	RES 33K OHM 1% 1/10W 0603	1292-WR06X3302FTLCT-ND
26	RC0603JR-1347KL	YAGEO	RES 47K OHM 5% 1/10W 0603	13-RC0603JR-1347KLCT-ND
27	RT0603BRD0750KL	YAGEO	RES 50K OHM 0.1% 1/10W 0603	13-RT0603BRD0750KLCT-ND
28	RC0603FR-07100KL	YAGEO	RES 100K OHM 1% 1/10W 0603	311-100KHRCT-ND
29	RN73R1JTTD1003B25	KOA Speer Electronics, Inc.	RES 100K OHM 0.1% 1/10W 0603	2019-RN73R1JTTD1003B25CT-ND
30	WR06X1503FTL	Walsin Technology Corporation	RES 150K OHM 1% 1/10W 0603	1292-WR06X1503FTLCT-ND
31	RC0603FR-07180KL	YAGEO	RES 180K OHM 1% 1/10W 0603	311-180KHRCT-ND
32	RC0603FR-10200KL	YAGEO	RES 200K OHM 1% 1/10W 0603	13-RC0603FR-10200KLCT-ND
33	WR06X2203FTL	Walsin Technology Corporation	RES 220K OHM 1% 1/10W 0603	1292-WR06X2203FTLCT-ND
34	RC0603FR-07270KL	YAGEO	RES 270K OHM 1% 1/10W 0603	311-270KHRCT-ND
35	RC0603FR-13470KL	YAGEO	RES 470K OHM 1% 1/10W 0603	13-RC0603FR-13470KLCT-ND
36	WR06X1004FTL	Walsin Technology Corporation	RES 1M OHM 1% 1/10W 0603	1292-WR06X1004FTLCT-ND
37	RC0603FR-073M3L	YAGEO	RES 3.3M OHM 1% 1/10W 0603	13-RC0603FR-073M3LCT-ND
38	4832.2211	SCHURTER Inc.	CONN JACK MONO 3.5MM PNL MNT	486-3418-ND
39	PTV09A-4225F-B203	Bourns Inc.	POT 20K OHM 1/20W CARBON LINEAR	PTV09A-4225F-B203-ND
40	AWHW 14G-0202-T	Assmann WSW Components	CONN HEADER VERT 14POS 2.54MM	AE11367-ND
41	H3CCS-1406G	Assmann WSW Components	IDC CBL - HHKC14S/AE14G/HHKC14S	H3CCS-1406G-ND

42	TS-103-G-A	Samtec Inc.	CONN HEADER VERT 3POS 2.54MM	SAM1111-03-ND
43	2205060-2	TE Connectivity AMP Connectors	CABLE ASSEMBLY HEADER WTW 4POS	A123282-ND
44	338068-4	TE Connectivity AMP Connectors	CONN RCPT 4POS 0.1 TIN PCB	A99438CT-ND
45	J111	onsemi	JFET N-CH 35V TO92-3	J111FS-ND

Table 7.3.3: VCO Components

Index	Manufacturer Part Number	Manufacturer Name	Description	Original Part numbers
1	100SP2T1B1M1QEH	E-Switch	SWITCH TOGGLE SPDT 5A 120V	EG2373-ND
2	RC0603FR-0710KL	YAGEO	RES 10K OHM 1% 1/10W 0603	311-10.0KHRCT-ND
3	RC0603FR-0747KL	YAGEO	RES 47K OHM 1% 1/10W 0603	311-47.0KHRCT-ND
4	RK73H1JTTD2202F	KOA Speer Electronics, Inc.	RES 22K OHM 1% 1/10W 0603	2019-RK73H1JTTD2202FCT-ND
5	RC0603FR-071ML	YAGEO	RES 1M OHM 1% 1/10W 0603	311-1.00MHRCT-ND
6	RC0603FR-071M2L	YAGEO	RES 1.2M OHM 1% 1/10W 0603	311-1.20MHRCT-ND
7	RMCF0603FT10R0	Stackpole Electronics Inc	RES 10 OHM 1% 1/10W 0603	RMCF0603FT10R0CT-ND
8	ERJ-3EKF1000V	Panasonic Electronic Components	RES SMD 100 OHM 1% 1/10W 0603	P100HCT-ND
9	RMCF0603FT120R	Stackpole Electronics Inc	RES 120 OHM 1% 1/10W 0603	RMCF0603FT120RCT-ND
10	RC0603FR-071KL	YAGEO	RES 1K OHM 1% 1/10W 0603	311-1.00KHRCT-ND
11	RMCF0603FT680R	Stackpole Electronics Inc	RES 680 OHM 1% 1/10W 0603	RMCF0603FT680RCT-ND
12	PTV09A-4025F-A105	Bourns Inc.	POT 1M OHM 1/20W CARBON LOG	118-PTV09A-4025F-A105-ND

13	PTV09A-4220F-B103	Bourns Inc.	POT 10K OHM 1/20W CARBON LINEAR	PTV09A-4220F-B103-ND
14	ICS-308-T	Adam Tech	IC SOCKET, DIP, 8P 2.54MM PITCH	2057-ICS-308-T-ND
15	2N7002NXAKR	Nexperia USA Inc.	MOSFET N-CH 60V 190MA TO236AB	1727-8643-1-ND
16	GRT1885C1E103FA02D	Murata Electronics	CAP CER 10000PF 25V C0G/NP0 0603	490-GRT1885C1E103FA02DCT-ND
17	TCSM1C106M8R	KYOCERA AVX	CAP TANT 10UF 20% 16V 0603	478-TCSM1C106M8RCT-ND
18	TCM1E105M8R	KYOCERA AVX	M- CASE / 105- CAP CODE / MN02	478-TCM1E105M8RCT-ND
19	TL084CNSR	Texas Instruments	IC OPAMP JFET 4 CIRCUIT 14SO	296-7211-1-ND
20	RSBEC2100CK00K	KEMET	CAP FILM 10000PF 10% 100VDC RAD	399-RSBEC2100CK00KCT-ND
21	860010572003	Würth Elektronik	CAP ALUM 22UF 20% 35V RADIAL TH	732-8733-1-ND
22	CC0603ZRY5V9BB104	YAGEO	CAP CER 0.1UF 50V Y5V 0603	311-1343-1-ND
23	1483353-3	TE Connectivity AMP Connectors	MICRO-MATCH LEAD 10P 250MM	A128014-ND
24	8-215079-0	TE Connectivity AMP Connectors	CONN RCPT 10POS 0.1 TIN PCB	A99470CT-ND
25	338068-4	TE Connectivity AMP Connectors	CONN RCPT 4POS 0.1 TIN PCB	A99438CT-ND
26	2205060-2	TE Connectivity AMP Connectors	CABLE ASSEMBLY HEADER WTW 4POS	A123282-ND
27	BM08B-SRSS-TB	JST Sales America Inc.	CONN HEADER SMD 8POS 1MM	455-BM08B-SRSS-TBCT-ND
28	A08SR08SR30K102B	JST Sales America Inc.	JUMPER 08SR-3S - 08SR-3S 4"	455-3656-ND

29	C503B-GCN-CY0C0792	Cree LED	LED GREEN CLEAR 5MM ROUND T/H	C503B-GCN-CY0C0792CT-ND
30	4832.2211	SCHURTER Inc.	CONN JACK MONO 3.5MM PNL MNT	486-3418-ND
31	TSSLE 6868 R RGB	Knitter-Switch	ILLUMINATED PUSHBUTTON SWITCH FO	3746-TSSLE6868RRGBCT-ND

Table 7.3.4: ADSR Components

Index	Manufacturer Part Number	Manufacturer Name	Description	Original Part numbers
1	TL072CDR	Texas Instruments	IC OPAMP JFET 2 CIRCUIT 8SOIC	TL072CDR
2	TL071CDR	Texas Instruments	IC OPAMP JFET 1 CIRCUIT 8SOIC	296-14994-1-ND
3	BCM847BS-7	Diodes Incorporated	TRANS 2NPN 45V 100MA SOT-363	BCM847BS-7
4	PV36W104C01B00	Bourns Inc.	TRIMMER 100K OHM 0.5W PC PIN TOP	490-2876-ND
5	PV36W102C01B00	Bourns Inc.	TRIMMER 1K OHM 0.5W PC PIN TOP	490-2874-ND
6	3296W-1-473LF	Bourns Inc.	TRIMMER 47K OHM 0.5W PC PIN TOP	3296W-1-473LF-ND
7	PTV09A-4025U-A104	Bourns Inc.	POT 100K OHM 1/20W CARBON LOG	PTV09A-4025U-A104-ND
8	4832.2211	SCHURTER Inc.	CONN JACK MONO 3.5MM PNL MNT	4832.2211
9	MMBT3904-TP	MCC (Micro Commercial Components)	TRANS NPN 40V 0.2A SOT-23	MMBT3904TPMSCT-ND
10	1N4148	onsemi	DIODE STANDARD 100V 200MA DO35	1N4148FS-ND
11	RMCF0603FT10R0	Stackpole Electronics Inc	RES 10 OHM 1% 1/10W 0603	RMCF0603FT10R0CT-ND
12	WR06X4700FTL	Walsin Technology Corporation	RES 470 OHM 1% 1/10W 0603	1292-WR06X4700FTLCT-ND

13	RNCP0603FTD1K00	Stackpole Electronics Inc	RES 1K OHM 1% 1/8W 0603	RNCP0603FTD1K00CT-ND
14	RNCP0603FTD10K0	Stackpole Electronics Inc	RES 10K OHM 1% 1/8W 0603	RNCP0603FTD10K0CT-ND
15	RC0603FR-1312KL	YAGEO	RES 12K OHM 1% 1/10W 0603	13-RC0603FR-1312KLCT-ND
16	WR06X1502FTL	Walsin Technology Corporation	RES 15K OHM 1% 1/10W 0603	1292-WR06X1502FTLCT-ND
17	RMCF0603FG22K0	Stackpole Electronics Inc	RES 22K OHM 1% 1/10W 0603	RMCF0603FG22K0CT-ND
18	WR06X3302FTL	Walsin Technology Corporation	RES 33K OHM 1% 1/10W 0603	1292-WR06X3302FTLCT-ND
19	RC0603FR-0768KL	YAGEO	RES 68K OHM 1% 1/10W 0603	311-68.0KHRCT-ND
20	RC0603FR-07100KL	YAGEO	RES 100K OHM 1% 1/10W 0603	311-100KHRCT-ND
21	RC0603FR-13470KL	YAGEO	RES 470K OHM 1% 1/10W 0603	13-RC0603FR-13470KLCT-ND
22	CL10B104KB8NNWC	Samsung Electro-Mechanics	CAP CER 0.1UF 50V X7R 0603	1276-1935-1-ND
23	TMCMA1C106MTRF	Vishay Sprague	CAP TANT 10UF 20% 16V 1206	718-2389-1-ND
24	860010572003	Würth Elektronik	CAP ALUM 22UF 20% 35V RADIAL TH	860010572003
25	C503B-GCN-CY0C0792	Cree LED	LED GREEN CLEAR 5MM ROUND T/H	C503B-GCN-CY0C0792CT-ND
26	EMK325ABJ107MM-P	Taiyo Yuden	CAP CER 100UF 16V X5R 1210	587-5426-1-ND
27	BM08B-SRSS-TB	JST Sales America Inc.	CONN HEADER SMD 8POS 1MM	455-BM08B-SRSS-TBCT-ND
28	A08SR08SR30K102B	JST Sales America Inc.	JUMPER 08SR-3S - 08SR-3S 4"	455-3656-ND
29	SM08B-SRSS-TB	JST Sales America Inc.	CONN HEADER SMD R/A 8POS 1MM	455-1808-1-ND

Table 7.3.4: VCA Components

7.4 Additional Resources

7.4.1 Work Cited

Berg, Richard E.. "sound". Encyclopedia Britannica, 20 May. 2024, https://www.britannica.com/science/sound-physics. Accessed 3 September 2024.