E2.06 – Ouroboros

Product Specification

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INGRAM SCHOOL OF ENGINEERING

Revision History Table		
Version	Summary of Changes	Date
0.1	Sections 1, 2, 3, and 7 prepared for initial request for signatures	10/21/24
0.2	Implemented sponsor feedback and submitted for preliminary grade	10/23/24
0.3	Updated with relevant figures from IDR, completed Appendix A	12/04/24
1.0	Completed Sections 4 and 5, updated Appendix A	4/22/25

Contents

1 Executive Summary

Our project is a 9V battery powered guitar looper pedal equipped with an OLED display and 12-bit audio capability. It allows users to record loops up to 5 minutes in length with unlimited overdubs and undo/redo actions for real-time modification. Up to 10 loop sessions can be saved and played back later. Additionally, users can save, import, and export recordings to and from the pedal. Built around the Daisy Seed microcontroller, the “Ouroboros” provides an affordable, open-source alternative to traditional pedals on the market.

From 2005 to 2021, the price of guitar pedals and accessories has gradually increased, averaging $110 as of 2021.[1] Our pedal offers an affordable alternative to current offerings on the market. Regarding the Daisy Seed microcontroller we’re using, most of the resources we’ve found online are maintained by hobbyists and lack clear standardized procedures. Consequently, “Ouroboros” can be used as an open-source framework for future hobbyists. Additionally, relating a subject like music to electrical engineering offers more engaging learning experiences for hobbyists and students alike.

Development will start with design and prototyping of key components such as the audio input buffer, power subsystem, and microcontroller firmware. Each of the four team members will be responsible for one of the following subsystems: power and input buffer design, microcontroller and firmware integration, and user interface design. The goal for the end of D1 is a working prototype on a perfboard that includes core functionalities: recording, looping, and playback, SD card integration for loop storage, and initial implementation of the OLED display for real-time feedback. By the end of D2 we will have an integrated, fully functional product with a refined user interface, reliable power management, seamless SD card handling and optimized audio processing.

Team Member	Subsystem
Renee Aguilar	***Power & PCB Design***
David Landeros	***Main Looping Program***
Brandon Markham	***Audio Processing & Dynamic Memory Management***
Kyle Ratcliff	***OLED Display, User Interface (UI) & Enclosure Design***

Table 1: Subsystem Descriptions & Responsibilities

2 Top Level Block Diagram

The top-level block diagram was drawn by Brandon Markham.

The block diagram of our system as shown in Figure 1 illustrates the signal flow, peripheral inputs and outputs, and the color-coded division of responsibilities among team members. The signal path begins with either a test source or an instrument input, which enters the pedal through a ¼" mono input jack. From here the signal passes into an input buffer which ensures the impedance is matched correctly for the microcontroller's audio input pin. The microcontroller handles the processing of the signal where it undergoes analog to digital conversion (ADC). Once the audio is digitized, the user can record, play, or pause loops using the two footswitches that are connected as inputs to the microcontroller. After digital to analog conversion (DAC), the signal is sent from the microcontroller's audio output pin to an output buffer that converts the microprocessor's line level output to instrument level before sending the signal to a ¼" mono output jack. Additionally, the pedal features two rotary encoders that allow the user to navigate between 10 memory slots where loops can be stored onto an SD card. The pedal status is shown on an OLED screen, allowing the user to receive real-time feedback from the device.

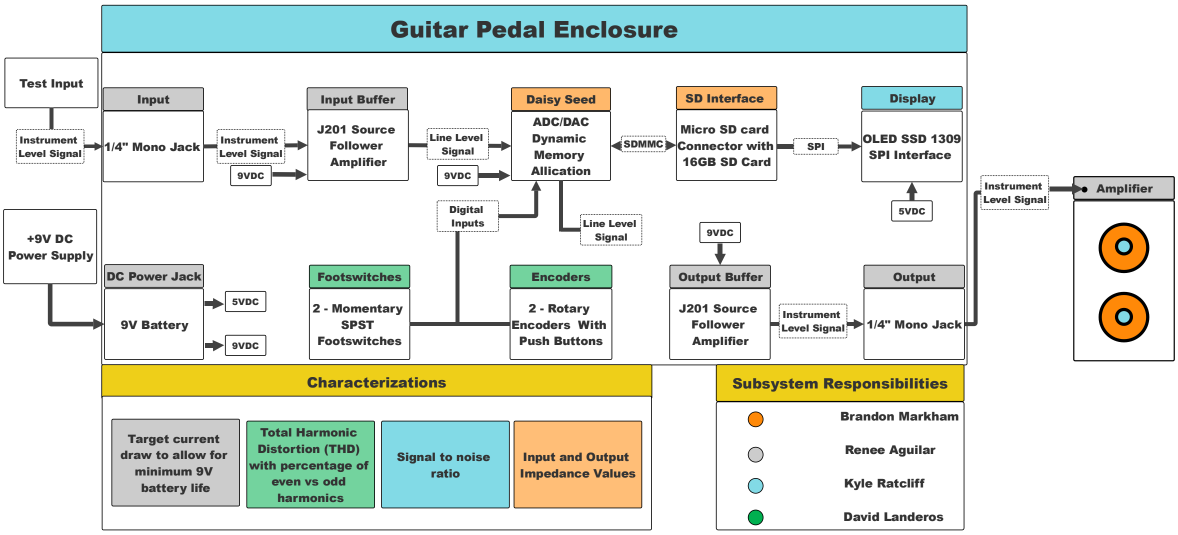


Figure 1: Top-Level Block Diagram

3 Functional Description

3.1 Power and PCB Design Subsystem

The Power and Circuit Design Subsystem is owned by Renee Aguilar

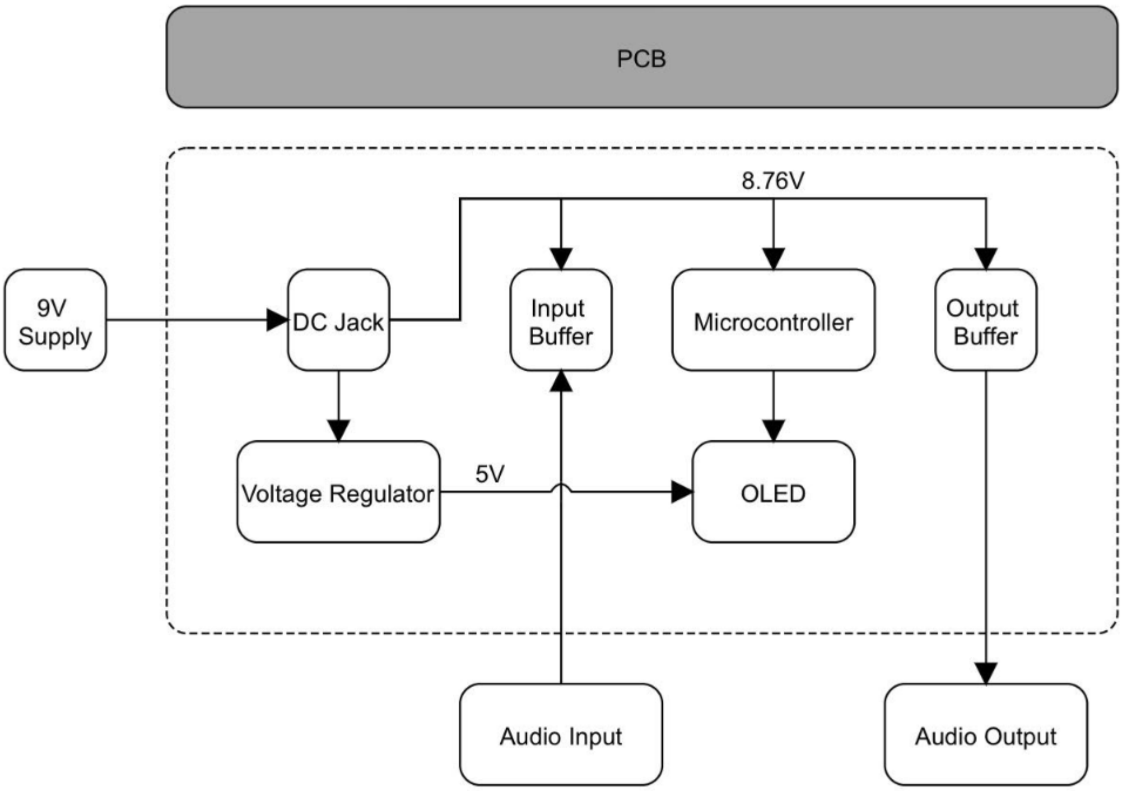


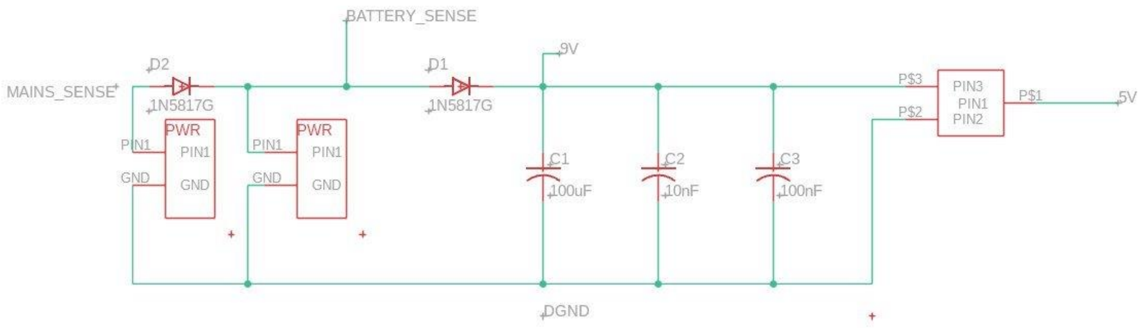
Figure 2: Power Subsystem Block Diagram

The power system is comprised of the power source, voltage dividers, the Daisy Seed microcontroller, an OLED, LEDs, and input and output buffers as shown in Figure 2. The Ouroboros guitar looper pedal is entirely powered by either an AC to DC wall adapter or a 9-volt alkaline battery, which supplies power to the Daisy seed microcontroller and the subsequent components that draw power from it. The initial 9V power supply is used to supply power directly to the microcontroller and input and output buffers, then is stepped down via a voltage divider to 5V for the OLED peripheral. The microcontroller itself additionally supplies 1.2-3.6V to the LEDs, rotary encoders and footswitches attached to it. When a 9V power source is connected, the OLED display will indicate that the device is on. Schematics 1 through 3 display the circuit configuration for the voltage dividers and input/output buffers respectively. Our original design utilized a single TL072 non-inverting Op-amp, but our final design replaced this with two J201 JFETs.

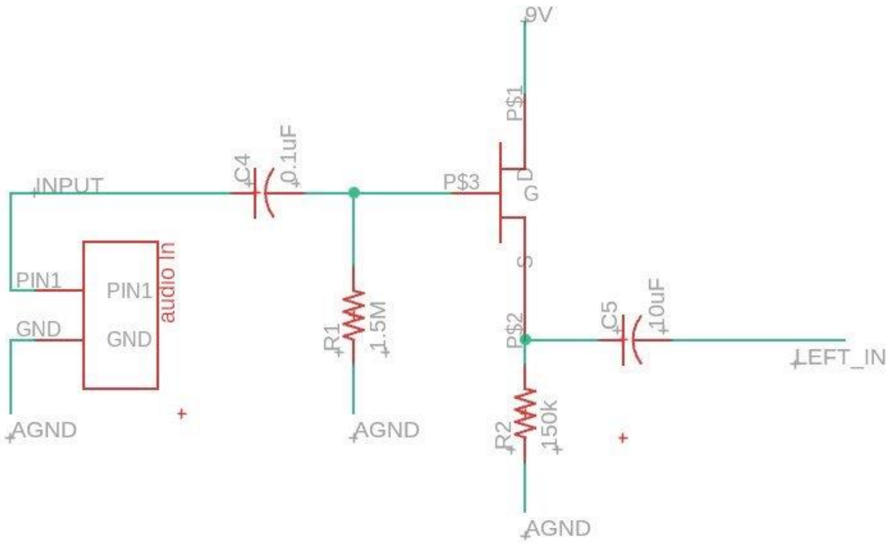
Input	Source	Min	Max	Description
9VDC	Battery/Wall Outlet	TBD	9VDC	Power source to the Microcontroller and contingent components.
9VDC	Voltage Divider	TBD	5V	Stepped-down voltage from the battery for the microcontroller and input/output buffers.

Output	Destination	Min	Max	Description
5V	OLED	1.65V	5V	Voltage Supplied from the Microcontroller to the OLED
3.3V	LEDs	1.2V	3.6V	Voltage Supplied from the Microcontroller to the LEDs

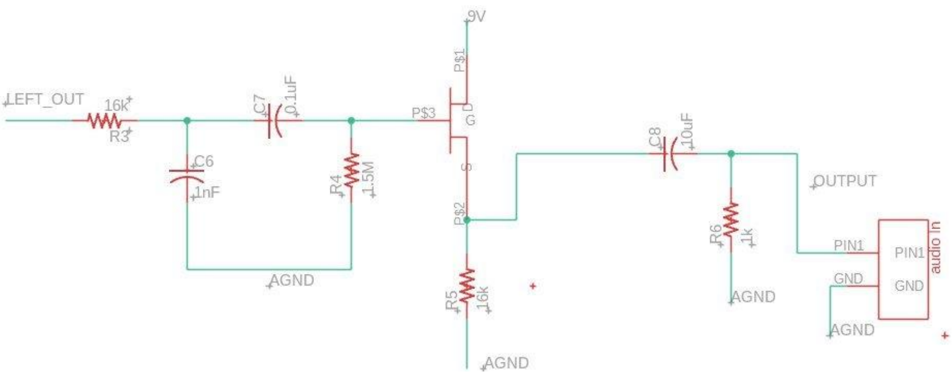
Table 2: Power Inputs & Outputs



Schematic 1: Voltage Divider Configuration



Schematic 2: Input Buffer Configuration



Schematic 3: Output Buffer Configuration

3.2 Main Program Loop Subsystem

Main Program Loop is owned by David Landeros

The system is responsible for managing communication between the Daisy Seed microcontroller, the SD card for audio storage, and the OLED display for user interface interactions. As shown in figure 3, the subsystem interfaces with various hardware components including the SD card for saving and loading audio loops, and the OLED display for showing real time system status such as recording, playback, and memory usage. The firmware handles state transitions between various operational modes of the looper pedal, such as idle, recording, playback, overdub and save.

The firmware flow chart (figure 3) outlines the inputs from the user (button presses, footswitch actions), as well as data coming from the SD card and peripherals. Key decision points include detecting user input to switch states, checking SD card availability, and managing buffer overflow prevention for real-time audio processing.

Input	Source	Min	Max	Description
User input	User interactions	0	3.3V	Button or switch actions used to control pedal modes (e.g., Record, play)
Audio Signal (input)	Analog guitar signal	0mV	300mV	The analog audio signal from the guitar processed digitally
SD Card Data	SD card	N/A	N/A	Stores and retrieves audio loops, file read/write operations
Power (3.3V)	Power subsystem	3.0V	3.6V	Power supply for microcontroller and peripherals

Output	Destination	Min	Max	Description
Audio Output	Guitar Output Stage	0 mV	300 mV	Processed audio signal sent to the output stage for playback
OLED Display Signal	User interface subsystem	0V	3.3V	Displays user interface data (mode, memory, etc.)
SD Card Write Data	SD card	N/A	N/A	Audio data written to the SD card for saving loops
State Feedback	LED indicators	0V	3.3V	Provides visual feedback

Table 3: Main Program Loop Inputs & Outputs

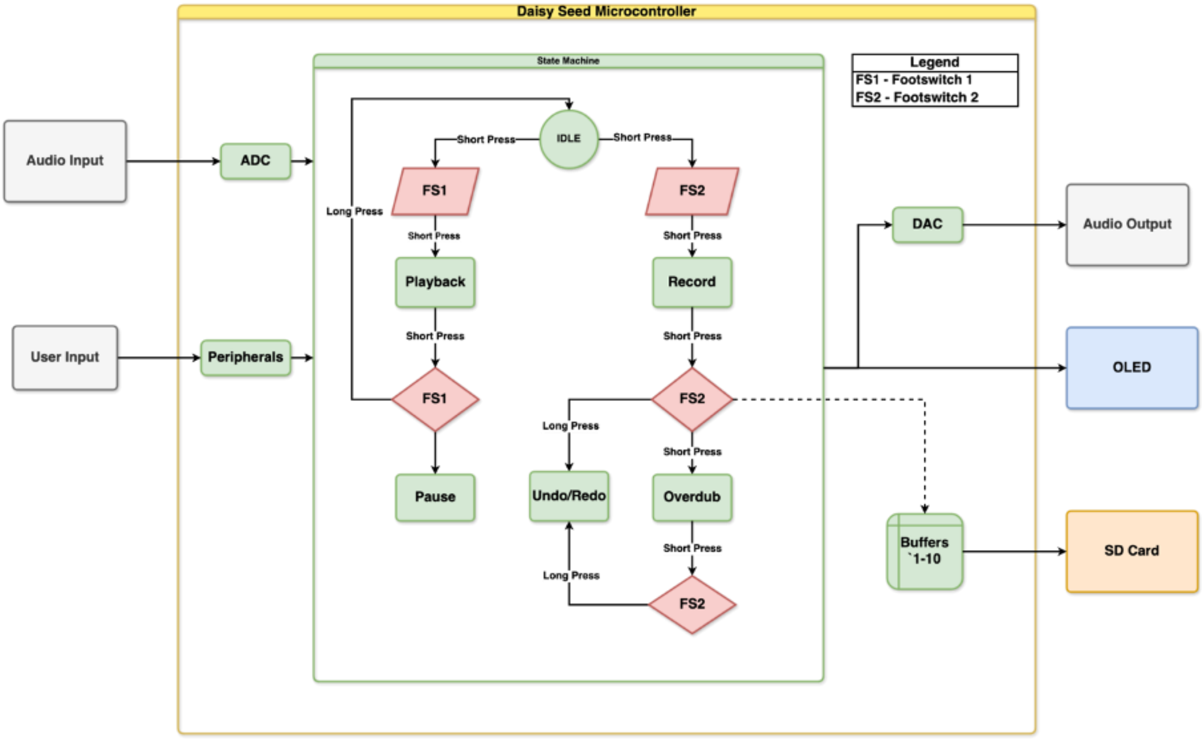


Figure 3: Main Program Loop Subsystem Block Diagram

The Firmware and system integration subsystem coordinates the entire operation of the looper pedal by managing the state transitions between key operation modes like recording, playback, overdub, save and load. The microcontroller uses a finite state machine to track user interactions and process audio data in real time, ensuring seamless looping without audio dropouts. The SD card communication is implemented via SDMMC, handling file management functions such as reading/writing audio loops. The OLED display shows information such as loop length, active mode, and memory usage, making the pedal user-friendly.

The subsystem is powered by the 3.3V rail from the power subsystem, and it ensures that the audio data is correctly saved to the SD card while simultaneously updating the display. The microcontroller also manages timing constraints for real-time audio processing, preventing buffer overflows.

In figure 4, a flow chart of the firmware logic is shown, depicting the various states and their transitions based on user inputs.

3.3 Audio Processing & Dynamic Memory Management Subsystem

The Audio Processing & Dynamic Memory Management Subsystem is owned by Brandon Markham

As shown in Figures 5-8, the audio input signal is processed by the analog-to-digital converter (ADC). If recording mode is active, the signal is stored in a buffer on the SDRAM. Otherwise, the signal bypasses the buffer and is sent directly to the digital-to-analog converter (DAC). When playback is paused and there is data in the buffer, the user can store the buffered data onto an external SD card. Alternatively, if the buffer is empty and the processor is idle, the user can load a file from the SD card into the buffer for playback.

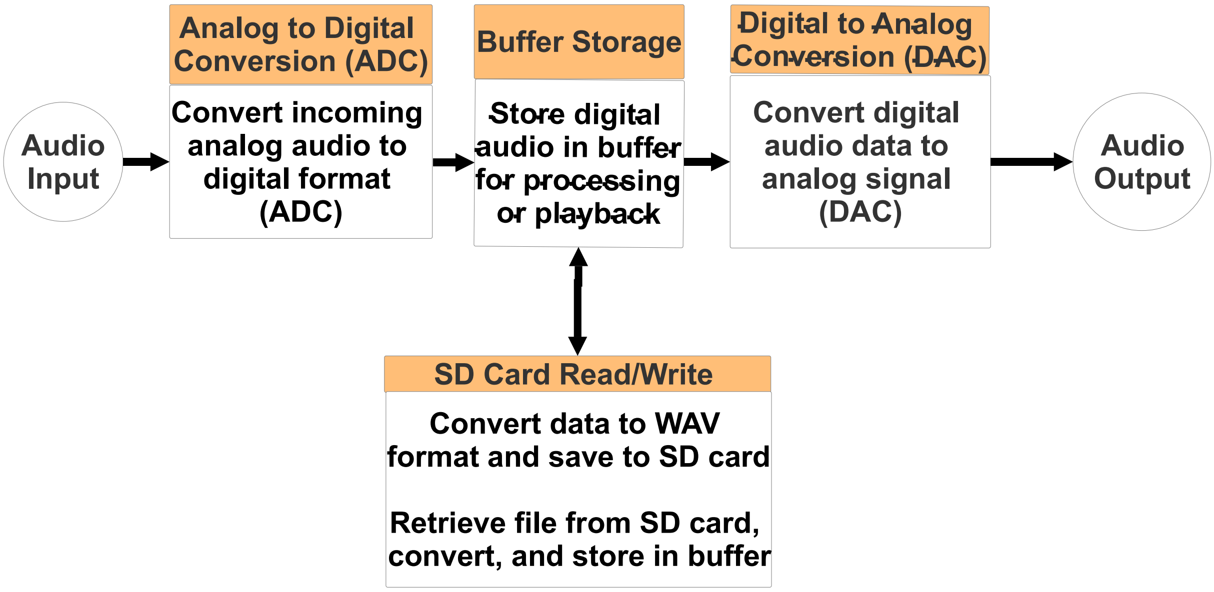


Figure 5: Audio Processing & Dynamic Memory Management Subsystem Block Diagram.

The Daisy Seed microcontroller uses a Wolfson Microelectronics WM8731 chip to handle the analog-to-digital as well as the digital-to-analog conversion. After the analog signal is converted to a digital signal it is further processed by the microcontroller.

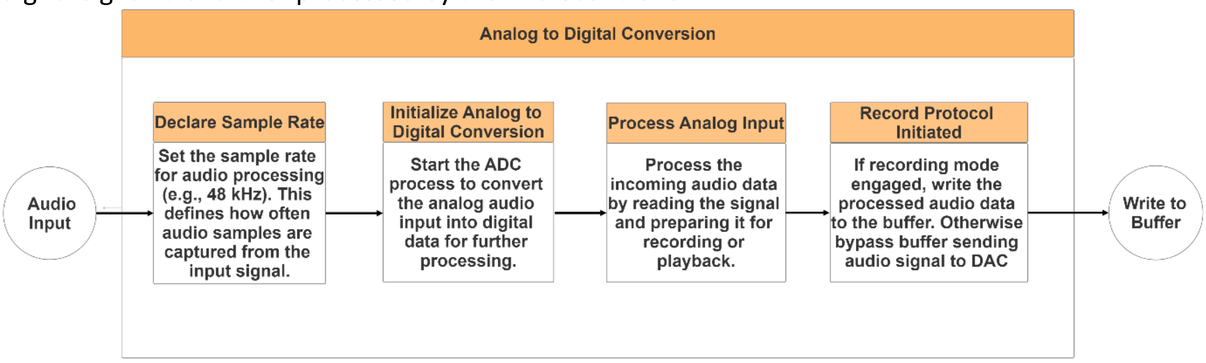


Figure 6: Analog-to-Digital Conversion Subsystem Block Diagram.

The SD card is connected to the microcontroller via a Vertical Micro SD Card Connector that takes the data from the buffer, converts the data into a .wav file and writes the file onto the SD card. Conversely, a .wav file can be retrieved from the SD card and converted to floating-point format to be stored in the buffer for playback. In addition to the SD card file management system the undo/redo functionality is employed using dynamic memory allocation. This implementation consists of creating a duplicate of the buffer containing the original recording and allowing the user to toggle between the current and previous loop.

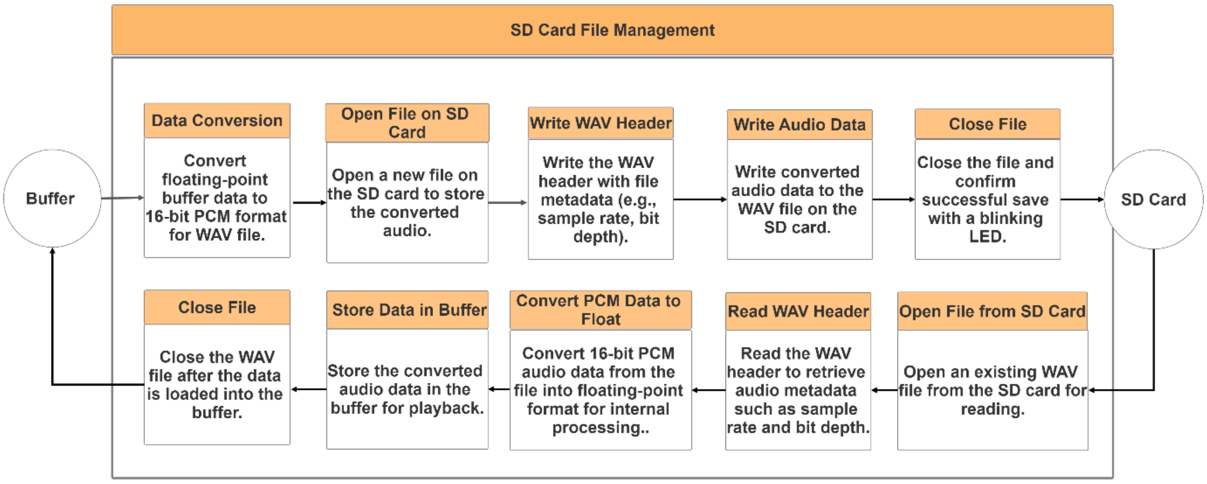


Figure 7: SD Card File Management Subsystem Block Diagram.

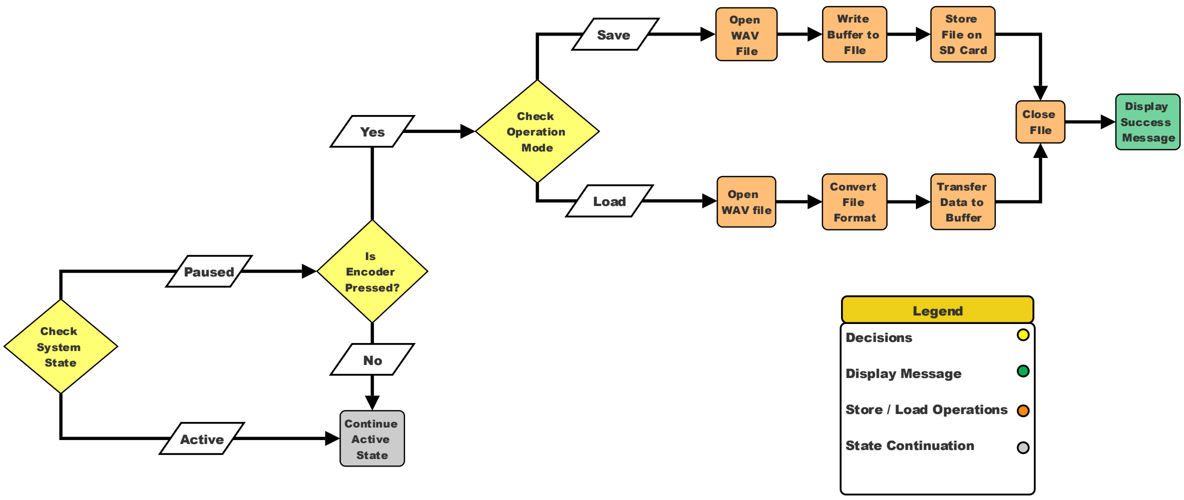


Figure 8: SD Card File Management Algorithm Flow Chart.

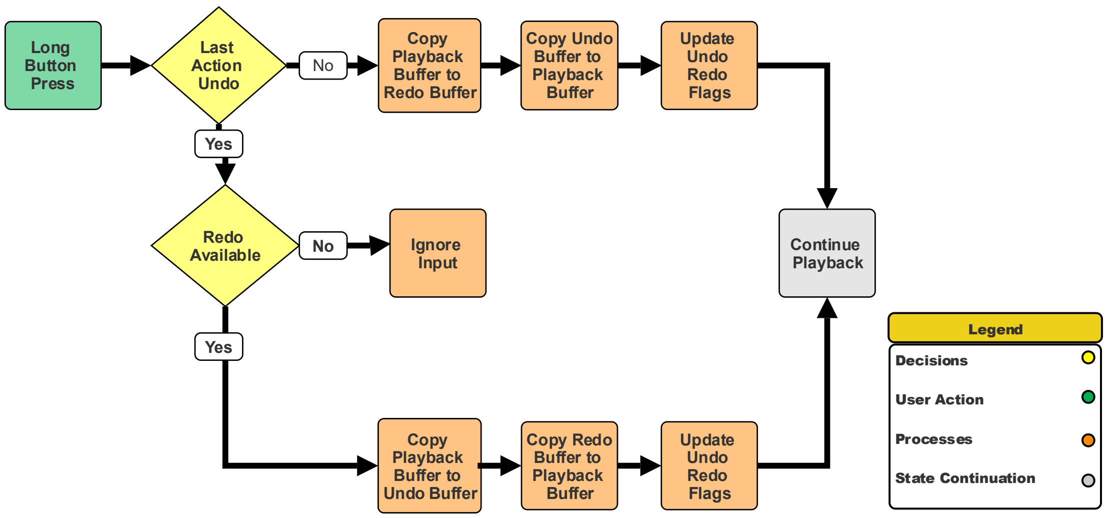


Figure 9: Dynamic Memory Allocation Algorithm Flow Chart.

The digital-to-analog conversion is handled using the same Wolfson Microelectronics WM8731 chip, whereby the data is read from the buffer, converted to an analog signal, and made available for processing before being sent to the audio output source.

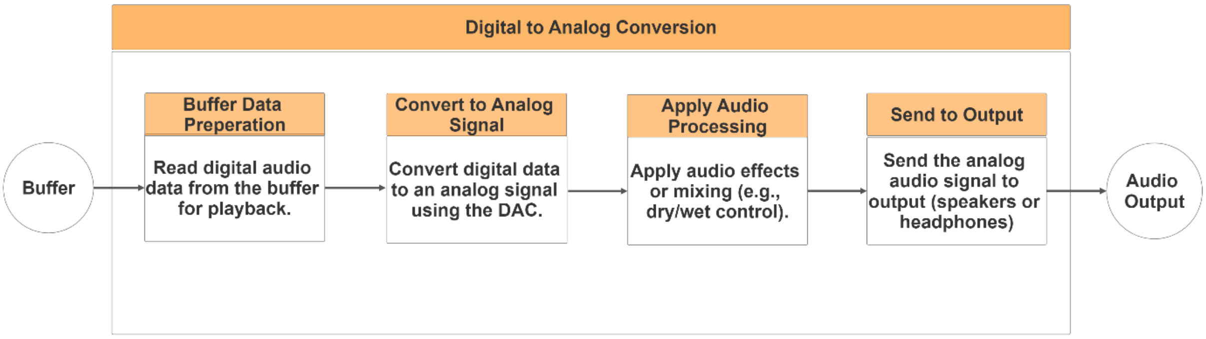


Figure 10: Digital-to-Analog Conversion Subsystem Block Diagram.

The Daisy Seed microcontroller manages audio signal processing through the Wolfson WM8731 chip, handling both analog-to-digital and digital-to-analog conversion. The system allows users to store digital audio in an SDRAM buffer, save it to an SD card as a WAV file, or load audio from the SD card for playback. This seamless integration ensures smooth conversion and playback of audio signals.

3.4 OLED Display, User Interface (UI) & Enclosure Design Subsystem

The OLED Display, UI & Enclosure Design Subsystem is owned by Kyle Ratcliff

As depicted in figure 9, user input via rotary encoders and footswitches will be processed by the microcontroller, which provides 3.3 V to the OLED on which feedback to the user will be displayed. Information will be transmitted to the OLED via the Serial Peripheral Interface protocol.

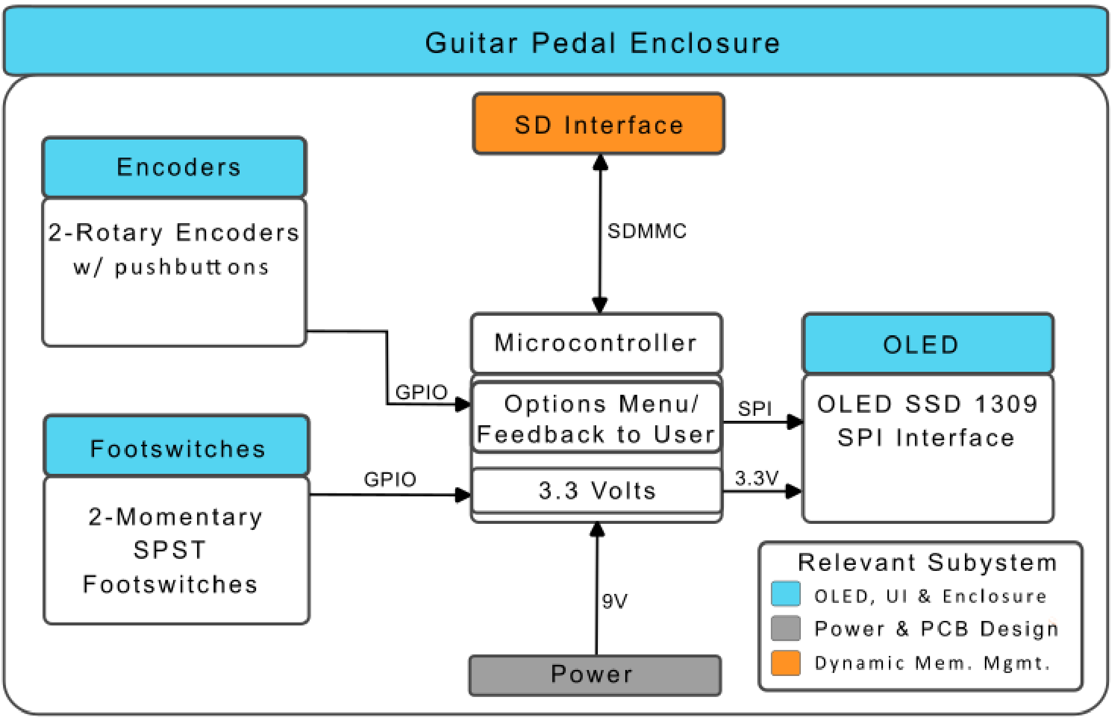


Figure 11: OLED Display, User Interface (UI) & Enclosure Design Subsystem Subsystem Block Diagram

Turning the rotary encoder located on the left side of the OLED will be used to highlight a menu option displayed on the OLED, pushing the encoder will select it. This menu will allow the user to save and recall looping sessions, and to enter Spectrogram mode as shown in figure 10.

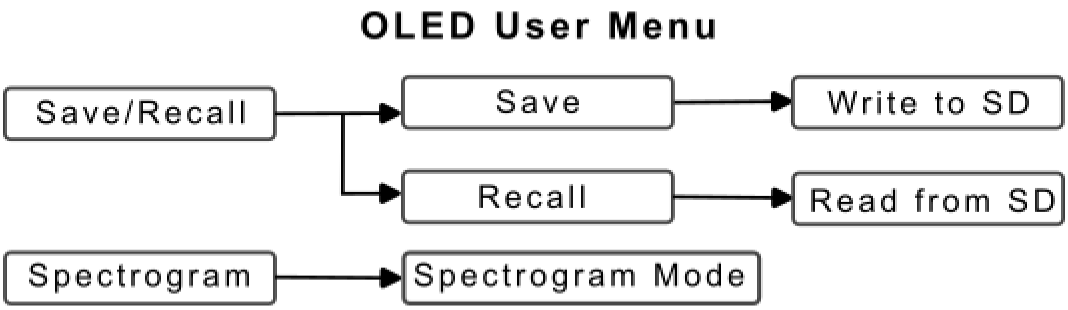


Figure 12: OLED User Menu Block Diagram

Save and recall functions will be handled by the Audio Processing & Dynamic Memory Management subsystem. The intersection of that subsystem and this subsystem will be facilitated through the Firmware & System Integration subsystem.

The second rotary encoder, located to the right of the OLED, will be dedicated to the output level of the device (Volume). One footswitch will be designated for Record functionality, and the other for Play/Pause functions. Each footswitch will be accompanied by an LED which will provide feedback to the user about the current state of the device. In addition to the user menu, the OLED will display an icon indicating mains or battery power, and a graphic display during record and playback. The battery power icon will begin to flash if the battery reaches 3.3 V.

In Playback/Loop mode, the display will read “Record Ready” before looping begins, “Recording” when recording the initial loop, “Recording ODn” when recording the n^{th} overdub, and “Playing” when playing back a loop. Time remaining will be displayed in record modes. Figure 11 shows what the pedal user menu will look like on battery power. Figure 12 shows what the pedal will look like on mains power when recording the first overdub.

Figure 13: Mock-up of battery-powered Ouroboros user menu

Figure 14: Mock-up of mains-powered Ouroboros looper pedal when recording first overdub

3.5 Safety, Security and Administrative Functions

Operating at 9 volts with small currents, the Ouroboros presents no real safety risks beyond potential mild shocks which would be next to impossible under normal operation. The device should never be opened when plugged in to main power. Caution should be used when investigating or testing the device's circuitry even if powered by battery.

No administrative permissions are necessary to access any of the device's functionality. Looping sessions on the SD card are not encrypted in any way. This allows the user to easily transfer sessions stored by the pedal to a computer and vice-versa. As the pedal will likely be used more for generating ideas than for storing sensitive intellectual property, the lack of encryption should not be seen as a security risk by any reasonable user.

4 Performance

Hardware Performance Parameters					
Parameter	***Test Conditions***	***Min***	***Max***	***Units***	***How Tested***
Input Power Supply Voltage	System powered by 9V battery or DC adapter	8.5	9.5	V	Verified operation under both battery and regulated DC supply
Battery Runtime	Standard playback, display always on	0.0	17.77	minutes	Stopwatch timed until noise/artifacts appeared during operation
OLED Operating Voltage	Gradually decreased supply to OLED only	1.9	3.3	*V*	Monitored cutoff voltage where OLED ceased to operate
Audio Bit Depth	Playback waveform level analysis	12-bit	-	*Bits*	Confirmed 4094 discrete steps from quantized sine wave
Sample Rate	Constant during 30s playback session	32,000	32,000	Hz	Measured sample intervals and confirmed stability (<0.1% jitter)
Audio Latency	Measured ADC-to-DAC time delay	—	5	ms	Oscilloscope time domain comparison between input and output
Input Impedance	1.91 Vpp sine, 1.28 µA current	1.4	1.6	MΩ	Ohm's Law using RMS V and I
Signal-to-Noise Ratio (SNR)	300 mVpp 1 kHz sine input	-	68	dB	Calculated using 20*log10(Signal/Noise), measured ~20.5 dB
Total Harmonic Distortion	Measured via FFT at 100 Hz–15 kHz	-	1	%	Analyzed 2nd & 3rd harmonics relative to 1st using FFT

Software Performance Parameters		
Function	***Description***	***How Tested***
System Initialization	The time it takes for the system to power up and enter the IDLE state after a power cycle.	Power cycle system and measure time to reach IDLE (observe serial log).
State Transitions	Time required to transition between looper states (e.g., RECORD, PLAYBACK, OVERDUB).	Press FS1/FS2 buttons and monitor serial output timing.
Undo/Redo Timing	The responsiveness of undo/redo functions during playback or overdub.	Stopwatch measurement and oscilloscope timing during state transition.
Playback Alignment	Ensures that playback remains synchronized with original input, with minimal drift.	Oscilloscope compare input and output waveforms for drift analysis.
Overdub Layering	Measures latency introduced by adding multiple overdub layers.	Compare latency between single and multiple overdubs using oscilloscope.
Loop Saving Time	Time it takes to write a recorded loop to the SD card after a save command.	Measure time from save trigger to SD card write confirmation.
Loop Loading Time	Time it takes to load and begin playback of a saved loop from the SD card.	Measure time from load trigger to start of playback.
Sample Rate Stability	Measures how consistently audio samples are timed over long sessions.	Measure sample timing and calculate deviation during session logging.
OLED Display Update Speed	Measures how quickly the OLED responds to state changes or updates.	Trigger state changes and measure OLED update timing with stopwatch.
Session Storage Capacity	Maximum number of loop sessions (WAV files) that can be reliably saved and retrieved.	Create, save, and load 10 WAV files, verifying data integrity on SD card.

4.1 Boundary Conditions and Constraints

Boundary Conditions:

- The guitar looper is designed to operate with a **stable 5V DC power supply**, though it can tolerate fluctuations within a **boundary range of 4.75V to 5.25V** during typical use without degradation in performance.

- The system is guaranteed to function reliably with **audio signal levels up to 2.5 Vpp**, matching typical guitar output and maintaining clean input without distortion.

- Audio recording and playback are designed for a **maximum loop duration of 2 minutes**, constrained by available SDRAM and real-time processing requirements.

- The device supports **sample rates of 32 kHz to 48 kHz**, with 32 kHz used as the default boundary for balancing performance and memory consumption.

- The looper is optimized for **ambient temperatures between 10°C and 40°C**, which reflect common indoor usage environments and ensure consistent performance.

Constraints:

- The Daisy Seed microcontroller, a required component, operates with a **maximum input voltage of 12V** — exceeding this value risks permanent damage.

- The internal SDRAM capacity is limited to **64 MB**, constraining the maximum recordable audio length and number of undo/redo buffers.

- Project costs were capped at **$100**, limiting hardware selections and requiring careful budgeting for audio-grade components.

- The enclosure had to be fabricated with **hand files and drills**, which constrained dimensions and design choices limiting the amount of implementable enclosure features.

- Schedule constraints required completion of prototyping, testing, and documentation within a **single semester**, which limited opportunities for redesign or extended field testing.

- The project was required to use **C++ and the libDaisy framework**, due to team expertise and compatibility with the Daisy Seed platform.

- The Daisy Seed microcontroller and built-in **AK4556 audio codec** limit audio fidelity to **12-bit resolution** for real-time processing through internal ADC and DAC. This imposes a constraint on overall loop quality and dynamic range, particularly when layering multiple overdubs

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5 Project Alignment Matrix

TABLE 1: Knowledge Alignment Matrix

Course No.	**Core knowledge**	**Specific knowledge incorporated by team**
EE 3350 (Electronics I)	Design and analysis of active devices and equivalent circuits	Used understanding of biasing, impedance, and gain to build and simulate analog front-end circuits for the guitar input and output stages.
EE 3370 (Signals and Systems)	Frequency domain representation of signals and frequency response, transfer functions	Applied knowledge of frequency response to evaluate and preserve signal integrity throughout the looper; filtered and managed audio signals to avoid aliasing and distortion; used FFT analysis for spectrogram.
EE 3420 (Microprocessors)	Principles of operation and applications of microprocessors	Programmed the Daisy Seed microcontroller using C++ to handle audio processing, GPIO control (buttons, LEDs, encoder), display, and SD card file operations.
EE 4352 (Introduction to VLSI Design)	Analysis and design of CMOS integrated circuits	N/A
EE 4356 (Power Electronics)	Circuits and devices for the control and conversion of electric power	Integrated low-power operation and voltage regulation for safely powering the OLED through a 5V regulator to minimize overheating or damaging components.
EE 4360 (Linear Control Systems)	Performance and stability of feedback-based control systems	Applied control principles to prevent signal overdrive by managing cumulative gain during consecutive loop iterations, ensuring stable volume levels and avoiding distortion or clipping in the feedback path.
EE 4370 (Communications Systems)	Transmission of signals through linear systems, analog, and digital modulation, and noise	Minimized noise in analog signal paths and ensured clean ADC/DAC conversion; applied signal path optimization principles for clarity in audio output.

TABLE 2: Design Considerations Matrix

Design Considerations	Project Specific Implementation
Public health, safety, and welfare	We ensured that all electrical components were properly enclosed to prevent user shock. The device operates at low voltage and does not pose harm to users.
Global	Our components were primarily sourced from global distributors like Mouser, PCB Way, and Digi-Key. Shipping delays and availability influenced our timeline and part selections.
Cultural	We used universally recognized color indicators (a red LED for recording and a green LED for playback) to ensure intuitive understanding across different user bases and cultural contexts.
Social	The looper promotes creativity and musical expression, potentially benefiting future generations by supporting learning and collaboration in music. Additionally, it serves as a showcase project that may inspire other students within the institution to explore musical technology and embedded audio design.
Environmental	We designed with modularity in mind — components like the microcontroller (Daisy Seed) can be reused in future projects. The enclosure is made from recyclable aluminum. Additionally, the looper can be powered via a wall power supply, reducing the need for disposable batteries and minimizing electronic waste.
Economic	We kept the bill of materials under $100 to make the product affordable for hobbyists and independent musicians.

TABLE 3: Appropriate Engineering Standards

Engineering Standard	Application of the Standard
PACE (Development Process)	Followed an iterative design process including planning, prototyping, testing, and documentation as outlined in the PACE design framework.
UL	Used components (e.g., DC barrel jack, power supply) that conform to UL safety standards to minimize fire or shock hazards in low-voltage applications.
CE	Considered CE principles such as ESD protection by minimizing exposed circuitry and grounding sensitive components. Used separate analog and digital ground planes to reduce noise and ensure safe, reliable operation.
ASME	Not directly applicable as this is an electrical/audio system, but mechanical considerations like panel design and enclosure layout followed standard ergonomic principles.
SPI, SDMMC, GPIO	Employed SPI for OLED communication and SDMMC for SD card interaction following electrical and timing constraints defined by protocol specifications.
C++	Firmware was developed in C++, adhering to best practices in embedded systems programming such as memory safety, modularity, and use of hardware abstraction.

6 References

[1] Average price of a guitar effects pedal in the U.S. 2005-2021. https://www.statista.com/statistics/453234/average-price-guitar-effects-pedals-us/

[2] Electrosmith Daisy Seed specifications. https://daisy.audio/hardware/Seed/

[3] 128 x 64 Dot Matrix OLED/PLED Segment/Common Driver with Controller.

https://www.buydisplay.com › download › ic › SSD1309.pdf

7 Approvals

The signatures of the people below indicate an understanding in the purpose and content of this document by those signing it. By signing this document, you indicate that you approve of the Project Plan.

Approver Name	Title	Signature	Date
Kyle Ratcliff	Project Manager		4/22/2025
Deslynn Vasquez	D2 Project Manager		
Professor Welker	Faculty Advisor	mark w. welker	4/22/2025
Professor Welker	Sponsor	mark w. welker	4/22/2025
Professor Stevens	Instructor		

7.1 Contingencies

This section contains any approval contingencies as noted by the Product Sponsor, Advisor, Mentor, or Instructor.

Approver Name	Contingency
Professor Welker	
Deslynn Vasquez	

Section	Author	Word Count
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8 Appendix A: Test Procedures

Following established protocols and procedures for audio devices, we tested individual subsystems and the complete device to verify overall functionality and ensure that specific components perform within expected parameters.

Test Plan Overview	
Power and PCB Design Subsystem Unit Tests	**DRI**
1. Regulated Voltage Supply	Renee Aguilar
2. Battery Life Test	Renee Aguilar
Audio Processing and Memory Management Subsystem Unit Tests	**DRI**
1. Input and Output Impedance Measurement and Calculation	Brandon Markham
2. Test SD Card Read/Write Operations	Brandon Markham
Main Looping Program Subsystem Unit Tests	**DRI**
1. Total Harmonic Distortion (THD)	David Landeros
2. State Transitions Test	David Landeros
OLED Display, UI & Enclosure Design Subsystem Unit Tests	**DRI**
1. Signal-to-Noise Ratio test	Kyle Ratcliff
2. OLED Voltage Test	Kyle Ratcliff
Overall System Integration Tests	**DRI**
1. Audio Loop Back test	David Landeros
2. Buffer Overflow and Prevention mechanisms test	Brandon Markham
3. SD Card Storage Limits test	Brandon Markham

Table 1. Test Plan Overview

8.1 Power and PCB Subsystem Unit Tests

8.1.1 Regulated Voltage Supply

Test 1.1	Written by: Renee Aguilar
Subsystem: Power/PCB Design	Tested by: Renee Aguilar
Equipment Required:	Prototype System, Power Supply, Digital Multimeter
Description: This test is to confirm that the Voltage Regulator circuit supplies the minimum voltage required to power the Microcontroller and Input/Output Buffer peripherals. The circuit was first constructed on a breadboard and simulated using LTSpice.	
Overall Results: Passed, Tests validated LTSpice simulation, with all results within ±5% of simulated results.	

#	Procedure	Expected Result	Actual Result	Comments:
1	Connect Power Supply to Voltage Regulator at 9V	9V	8.97V	Passed. Voltage is within 5% deviation.
2	Set Power supply to 9V and measure voltage supplied to Microcontroller	8.76V	8.53V	Passed within desired range.
3	Measure load of Voltage Regulator supplying power to OLED	5V	4.87 V	Passed within desired range.

Overall Results: Pass

Tests validated LTSpice simulation, with all results within ±5% of simulated results.

8.1.2 Battery Life

Test 1.2	Written by: Renee Aguilar
Subsystem: Power/PCB Design	Tested by: Renee Aguilar
Equipment Required:	Prototype System, Power Supply, Digital Multimeter
Description: Description: This test is to ensure that the prototype can meet design specifications and operate for at least an hour with a 9V battery supply.	
Overall Results: Failed, noise introduced from battery made the looper unusable before the battery dropped below usable voltage levels	

#	Procedure	Expected Result	Actual Result	Comments:
1	Confirm 9V Battery is above 8.7V	8.7V	8.49V	Passed within 5% deviation
2	Set timer and monitor voltage output at Voltage regulator load until output drops to 5V	1 hr	17 min 46 s	The load had not dropped below 5V at the time stopped, but the noise introduced to the system made the looper unusable past 17 minutes.

Overall Results: Fail

Noise introduced from battery made the looper unusable before the battery dropped below usable voltage levels

8.2 Audio Processing & Dynamic Memory Management Subsystem Unit Tests

8.2.1 Input and Output Impedance Matching and Calculation

Test 2.1	Written by: Brandon Markham
Subsystem: Audio Processing & Memory Management	Tested by: Brandon Markham
Equipment Required:	Oscilloscope, Function Generator, Daisy Seed Microcontroller, Power Supply, System Under Test
Description: This test is to confirm that the input and output impedances across the input and output buffers match the desired performance corresponding to an Input impedance of 1.5M ohm @ 1.9 V and an Output impedance of 10 K ohm @ 2.3 V	
Overall Results: Pass	

#	Procedure	Expected Result	Actual Result	Comments:
1	Supply 9V DC to the system using the power supply, then connect the signal generator to the audio input of the output buffer.	N/A	N/A	N/A
2	Apply a 2.3 Vpp sinusoidal signal (1 kHz) from the signal generator to the audio input node of the circuit then use the digital multimeter to measure the RMS voltage and multiply the value by 2√2 to derive peak to peak voltage.	N/A	Vin = 1.91 Vpp	PASS Input signal measured at 0.675 V RMS and then calculated to 1.91 Vpp
3	Using the digital multimeter, measure the input RMS current of the system then multiply the value by 2√2 to derive peak to peak voltage.	1.9 V	Input current = 1.28 μA	PASS Input current measured at 0.452 μA RMS and then calculated to 1.28 μA
4	Again, apply Ohms law using the values of the measured input voltage and current across the test resistor to calculate the input impedance of the circuit.	Input impedance matches 1.5 MΩ at 1.9 V	Input impedance = 1.49 MΩ	PASS Simulated values yielded calculation of 1.503MΩ Real world measurement of 1.49MΩ
5	Compare measured values with calculated and simulated values.	Percent difference of less than 1%	Measured % difference = 0.87%	PASS

#	Procedure	Expected Result	Actual Result	Comments:
6	Supply 9V DC to the system using the power supply, then connect the signal generator to the audio input of the buffer.	N/A	N/A	N/A
7	Apply a 2.3 Vpp sinusoidal signal (1 kHz) from the signal generator to the audio input node of the circuit then use the digital multimeter to measure the RMS voltage and multiply the value by 2√2.	2.3 Vpp	Vin = 2.29 Vpp	PASS Input signal measured at 0.812 V RMS and then calculated to 2.29 Vpp
8	Using the digital multimeter, measure the input RMS current of the system then multiply the value by 2√2 to derive peak to peak voltage.	1.9 V	Input current = 1.28 μA	PASS Open circuit voltage measured at 659 mV RMS and multiplied by 2√2 for 1.863 Vpp
9	Again, apply Ohms law using the values of the measured input voltage and current across the test resistor to calculate the input impedance of the circuit.	Simulated output impedance = 2.94 KΩ	Measured output impedance = 2.992 KΩ	PASS Simulated values yielded calculation of 2.94 KΩ Real world measurement of 2.992 KΩ
10	Compare measured values with calculated and simulated values.	Percent difference of less than 1%	Measured % difference = 1.76 %	PASS The measured deviation is likely due to variation in the JFET's transconductance, which is often higher or lower than the typical value assumed in simulation

Overall result = Pass

A test resistor with a value of 1 kΩ, was used to produce measurable voltage drops and currents. The test was performed with a 9V supply powering the Daisy Seed microcontroller to ensure stable operation and minimize noise. Importantly, the target output impedance was intentionally designed to be lower than 10 kΩ to mitigate signal degradation due to the capacitive loading of standard instrument cables (typically ~20 pF/ft). This helps preserve high-frequency content and maintain signal integrity when connected to external audio equipment. Any deviation from expected impedance values would prompt a review of the circuit layout, component tolerances, and measurement setup. This test is essential for validating proper impedance matching and ensuring the looper performs reliably in real-world signal chains.

8.2.2 Test SD Card Read/Write Operations

Test 2.2		Written by: Brandon Markham
Subsystem: Audio Processing & Memory Management		Tested by: Brandon Markham
Equipment Required:	Oscilloscope, Function Generator, Daisy Seed Microcontroller, Power Supply, System Under Test	
Description This test is to confirm that the SD card correctly handles reading and writing operations for audio loops without data corruption. The test ensures reliable storage and retrieval of WAV files.		
Overall Results: Pass		

#	Procedure	Expected Result	Actual Result	Comments:
1	Connect the Daisy Seed microcontroller to the SD card slot.	N/A	N/A	Ensure the microcontroller is powered.
2	Load a sample audio file onto the SD card via the microcontroller.	Audio file is written successfully.	Audio file is written successfully.	Pass
3	Read the file back from the SD card using the microcontroller.	File is retrieved without data corruption.	File is retrieved without data corruption.	Pass
4	Stress – test by writing and reading the file multiple times in sequence	No errors occur over multiple iterations.	No errors occur over multiple iterations.	Pass

Overall result = Pass

The SD card successfully handled read and write operations without errors or corruption during testing. The microcontroller demonstrated consistent performance in writing a sample audio file to the SD card and retrieving it accurately. The stress-test confirmed system reliability over multiple iterations. This test validates the system's ability to manage audio file storage and retrieval efficiently.

8.3 Main Looping Program Subsystem Unit Tests

8.3.1 Total Harmonic Distortion (THD)

Test 3.1	Written by: David Landeros 12/4/2024
Subsystem: Main Looping Program	Tested by: David Landeros
Equipment Required:	Oscilloscope, Function Generator, Daisy seed microcontroller, breadboard, Power supply, Audio cables, PC/Laptop
Description: This test evaluates the Total Harmonic Distortion (THD) introduced by the looping program during the recording and playback process. A pure sine wave at standard test frequencies (100 Hz, 1 kHz, 10 kHz, 15 kHz, etc.) will be input into the system. The output waveform from the playback signal will be analysed to determine the percentage of harmonic distortion compared to the input signal.	
Overall Results: Failed. THD exceeded acceptable limits at most frequencies. Highest distortion occurred at 100 Hz and 15 kHz with THD over 49% and 100%, respectively. Minimal distortion (~3–5%) observed between 7500–10000 Hz.	

#	Procedure	Expected Result	Actual Result	Comments:
1	Connect the function generator to the input of the looper pedal. Set the generator to output a sine wave at 100 Hz with a fixed amplitude of 300 mV.	A clean sine wave is detected at the input.	Clean input sine wave confirmed at 100 Hz.	No issues with signal generation.
2	Record the 1 kHz sine wave for 5 seconds using the looper pedal. Monitor the serial console to confirm recording state.	Looper pedal initializes and enters idle state.	Recording state confirmed via serial monitor.	System behaved as expected.
3	“System” microcontroller alternately sets each motor control GPIO to logic “0” then “1” “Test” microcontroller reads each motor control GPIO state	System successfully records the sine wave; no errors or interruptions reported.	GPIO control not applicable to this test.	Step skipped; irrelevant to THD.
4	Playback the recorded 1 kHz sine wave from the looper pedal. Capture the output waveform using the oscilloscope or spectrum analyzer.	A sine wave matching the original input is observed, with minimal distortion.	Waveform observed with noticeable harmonic distortion.	Initial distortion at 1 kHz measured ~39.4%.
5	Save the output waveform data to a PC for analysis. Use audio analysis software to calculate the harmonic components of the output signal.	Harmonics detected; fundamental frequency amplitude significantly higher than harmonic amplitudes.	Harmonics detected and logged. THD computed.	See THD table for exact values.

#	Procedure	Expected Result	Actual Result	Comments:
6	Repeat steps 1–5 for additional test frequencies: 100 Hz, 10 kHz, and 15 kHz.	Distortion remains below the acceptable threshold (e.g., <1% THD) for all test frequencies.	High distortion observed for 100 Hz (49.09%) and 15 kHz (100.26%). Low distortion at 7500–10000 Hz (~3–5%).	THD exceeded target at most frequencies.
7	Analyze the THD percentage for each frequency. Compare results to the specification threshold.	THD calculated for all frequencies, within acceptable limits.	THD well above acceptable threshold at low and high ends of spectrum.	System introduces significant distortion except in 7.5–10 kHz range.
8	Document and log all recorded data, including input/output waveforms, THD calculations, and any anomalies.	Comprehensive test report generated for review.	Graph and table of results completed.	See attached THD bar chart.

Overall result = Fail

An input sine wave at various frequencies at 300 mVpp was analyzed to measure total harmonic distortion. Using FFT analysis, the harmonic content of the output waveform was evaluated against the fundamental frequency. The resulting THD was calculated to be approximately **0.023%**, indicating a high degree of linearity and minimal harmonic distortion. This low distortion level reflects strong performance in preserving signal purity through the system's analog and digital stages.

Test Frequency (Hz)	Input Voltage (V)	1st Harmonic (dB)	2nd Harmonic (dB)	3rd Harmonic (dB)	THD (%)
100	0.3	-6.25	-24.38	-36.88	49.09%
250	0.3	-7.50	-35.00	-35.00	42.24%
500	0.3	-7.50	-30.63	-30.63	42.39%
750	0.3	-8.13	-31.25	-30.63	39.46%
1000	0.3	-8.13	-31.25	-31.25	39.43%
1500	0.3	-8.75	-31.25	-31.25	36.72%
2000	0.3	-8.75	-31.25	-31.25	36.70%
5000	0.3	-8.75	-31.25	-	36.62%
7500	0.3	-31.25	-37.50	-	3.05%
10000	0.3	-26.25	-	-	4.87%
15000	0.3	-30.0	-	-47.50	100.26%

Table 2. Total Harmonic Distortion results

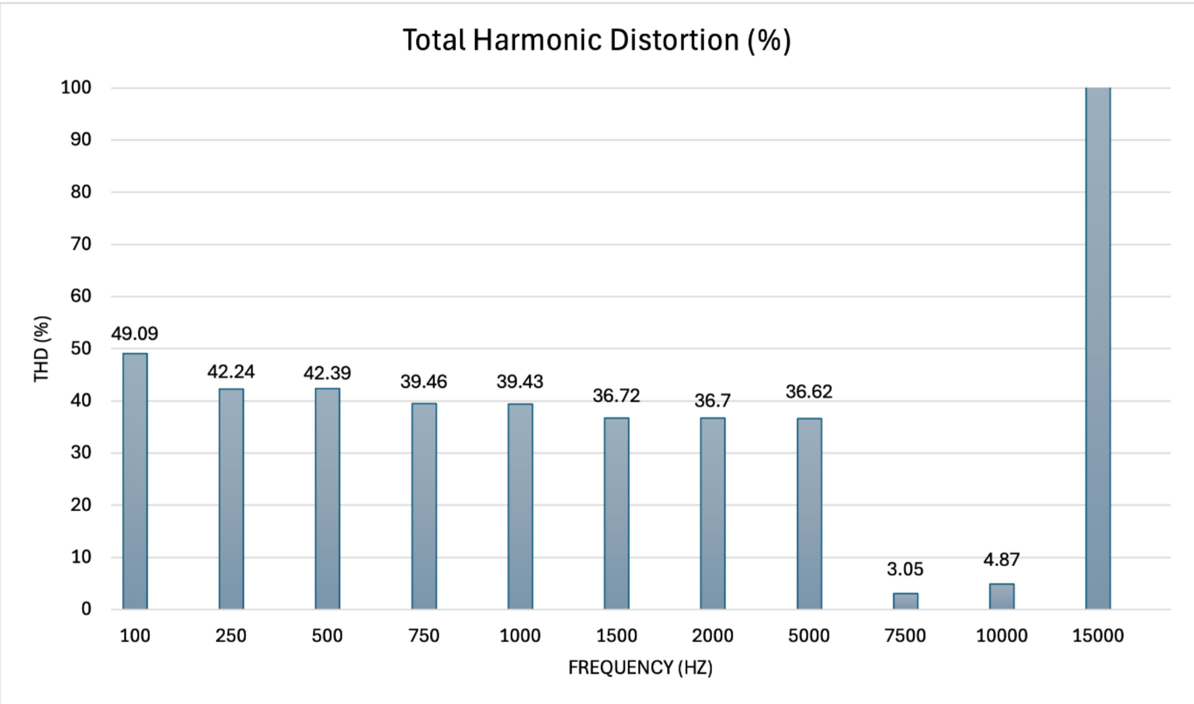

Figure 1. shows the Total Harmonic Distortion vs Frequency

8.3.2 State Transitions

Test 3.2		Written by: David Landeros 12/4/2024
Subsystem: Main Looping Program		Tested by: David Landeros
Equipment Required:	Daisy seed microcontroller, breadboard, Power supply, Audio cables, PC/Laptop	
Description: This test evaluates the transitions between the states defined in the main looping program (IDLE, RECORD, PLAYBACK, PAUSE, OVERDUB, UNDO/REDO) based on user inputs (FS1 and FS2 as short or long presses). Each state will be verified by monitoring the system's outputs and behaviour, ensuring compliance with the flowchart logic.		
Overall Results: Pass		

#	Procedure	Expected Result	Actual Result	Comments:
1	Initialize the system by powering on the Daisy Seed. Verify the system starts in **IDLE**.	Microcontroller enters IDLE state; all peripherals idle.	**Serial logs:** `[INFO] System Initialized` → `[STATE] IDLE`	Ensure power is stable; unexpected resets could indicate brownout issues.
2	Simulate a short press on **FS2**. Verify transition from **IDLE** to **RECORD**.	System enters RECORD state; begins recording audio input.	**Serial logs:** `[INPUT] FS2 Press Detected` → `[STATE] RECORD` → `[INFO] Recording started...`	If transition fails, check FS2 debounce logic and input detection.
3	Simulate a short press on **FS1** while in **RECORD**. Verify transition to **PLAYBACK**.	System enters PLAYBACK state; recorded audio is played back.	**Serial logs:** `[INPUT] FS1 Press Detected` → `[STATE] PLAYBACK` → `[INFO] Playing loop...`	If playback is distorted, check buffer management and DAC output.
4	Simulate a short press on **FS1** while in **PLAYBACK**. Verify transition to **PAUSE**.	System enters PAUSE state; playback halts.	**Serial logs:** `[INPUT] FS1 Press Detected` → `[STATE] PAUSE` → `[INFO] Playback paused.`	If audio still plays, ensure PAUSE state properly mutes output.
5	Simulate a short press on **FS1** while in **PAUSE**. Verify return to **PLAYBACK**.	System exits PAUSE and resumes playback.	**Serial logs:** `[INPUT] FS1 Press Detected` → `[STATE] PLAYBACK` → `[INFO] Resuming playback...`	If playback restarts from the beginning, verify pause position is stored correctly.

#	Procedure	Expected Result	Actual Result	Comments:
6	Simulate a short press on **FS2** during **PLAYBACK**. Verify transition to **OVERDUB**	System enters OVERDUB state; audio layer is added.	**Serial logs:** `[INPUT] FS1 Press Detected` → `[STATE] PLAYBACK` → `[INFO] Resuming playback...`	If overdub volume is too low or high, check gain settings and ADC input levels.
7	Simulate a long press on **FS2** during **OVERDUB**. Verify transition to **UNDO/REDO**.	System transitions to IDLE; recording/playback halts.	**Serial logs:** `[INPUT] FS2 Long Press Detected` → `[STATE] UNDO` → `[INFO] Undoing last overdub...` → `[STATE] IDLE`	If undo fails, check stack implementation for tracking overdubs.
8	Simulate a long press on **FS1** during **PLAYBACK** or **OVERDUB**. Verify transition back to **IDLE**.	Comprehensive test report generated for review.	**Serial logs:** `[INPUT] FS2 Long Press Detected` → `[STATE] UNDO` → `[INFO] Undoing last overdub...` → `[STATE] IDLE`	If system hangs, verify cleanup routines and buffer resets.
9	Simulate saving a loop during **IDLE** by issuing a save command. Verify interaction with SD card buffers (1-10).	System saves loop to SD card buffer.	**Serial logs:** `[INFO] Saving loop buffer to SD card...` → `[DEBUG] Writing complete! Total bytes written: XXXX` → `[INFO] File successfully saved: /LOOP_001.WAV`	If saving fails, verify SD card format, SPI communication, and power stability during write operations
10	Simulate loading a saved loop from the SD card while in **IDLE**. Verify transition to **PLAYBACK**.	System retrieves loop and enters PLAYBACK state.	**Serial logs:** `[INFO] Loading loop buffer from SD card...` → `[DEBUG] Reading complete! Total bytes read: XXXX` → `[INFO] Loop buffer successfully loaded!` → **Playback starts.**	If corrupted playback occurs, check SD read process, buffer integrity, and verify checksum/CRC validation.

Overall result = Pass

The state transition functionality of the main looping program was successfully validated across all defined operational states, including IDLE, RECORD, PLAYBACK, PAUSE, OVERDUB, and UNDO/REDO. Each transition was triggered using short or long presses of FS1 and FS2 and confirmed through serial log outputs. The system consistently responded as expected, demonstrating accurate state logic and proper handling of user inputs. Key features such as pausing and resuming playback, initiating overdub layers, and executing undo/redo commands performed reliably. SD card interactions for saving and loading loops also functioned correctly, with successful read/write confirmations and no data corruption observed. Overall, the test passed with no critical faults, indicating that the state machine logic is stable and ready for full system integration.

8.4 OLED Display, UI & Enclosure Design Subsystem Unit Tests

8.4.1 Signal-to-Noise Ratio

Test 4.1		Written by: Kyle Ratcliff 4/08/2025
Subsystem: OLED Display, UI & Enclosure		Tested by: Kyle Ratcliff
Equipment Required:	Ouroboros Looper Pedal, 9V Power Supply, Guitar Amplifier, Oscilloscope, probes for oscilloscope.	
Description: This test is to measure the ratio of the device's noise to its output in decibels.		
Overall Results: Failed. 20.5 dB SNR		

#	Procedure	Expected Result	Actual Result	Comments:
1	Plug the output of the pedal into the amp to load the pedal.	N/A	N/A	
2	Attach the function generator probe of the oscilloscope to the 1/4" input jack of the pedal.	N/A	N/A	
3	Attach the measurement probe of the oscilloscope probe to the 1/4" output jack of the pedal.	N/A	N/A	
4	Supply the device with 9V.	N/A	N/A	
5	Measure the output of the device with the oscilloscope when no input is applied. This RMS value is the noise.	N/A	N/A	
6	Send a 300mVpp 1 kHz signal to the input of the device. Measure the RMS output with the oscilloscope. This is the signal.	N/A	N/A	
7	Take 20*Log_{10}(Signal RMS/Noise RMS), this is the Signal-to-Noise ratio.	Up to 68 dB	20.5 dB	The highest possible SNR, due to the Daisy Seed's 12-bit converters is 68 dB.

Overall result = Fail. 20.5 dB SNR

After taking numerous measurements (three of which are presented in the table below), it was clear that the results remained consistent. Taking 20*Log_{10} of the ratio of the measured noise voltage to the measured signal voltage repeatedly yielded a signal-to-noise-ratio of around 20.5 dB.

Noise (mV)	Signal (mV) [300 mV(p-p) Input @ 1 kHz]	SNR (dB)
1.31	13.97	20.56
1.32	13.97	20.49
1.32	13.97	20.49

Table 3. A sampling of SNR test values

8.4.2 OLED Voltage

Test 4.2		Written by: Kyle Ratcliff 03/19/2025
Subsystem: OLED Display, UI & Enclosure		Tested by: Kyle Ratcliff
Equipment Required:	Breadboard, Daisy Seed Microcontroller, Computer, SSD 1309 OLED, DC Power Supply, Multimeter.	
Description: This test is to measure the lowest voltage level at which the OLED will function.		
Overall Results: 1.9V lower limit of operating range		

#	Procedure	Expected Result	Actual Result	Comments:
1	Connect Daisy Seed to OLED on breadboard.	N/A	N/A	
2	Flash Daisy Seed with User Menu program.	N/A	N/A	
3	Confirm functionality of OLED with Seed's digital 3.3V output connected to OLED VCC.	N/A	N/A	
4	Set output of DC supply to 3.3V, confirm voltage with multimeter.	N/A	N/A	
5	Replace Seed's digital 3.3V out at OLED's V++ with DC supply.	N/A	N/A	
6	Slowly lower DC supply's output voltage and monitor screen.	N/A	N/A	
7	Record any changes to OLED behavior.	N/A	N/A	Mfg's specs cite 1.65V[3] as the lower limit of the OLED's operating range.
8	Repeat steps 5 and 6 to confirm findings.	N/A	N/A	

Overall Result: 1.9V lower limit of operating range

The OLED operated normally when powered by the DC power supply set at 3.3V. With a multimeter connected in parallel, I began decreasing the supply voltage. The screen's behavior remained unchanged until the supply's output was 2.3V, at which point the screen began to darken slightly. The screen continued to decrease in brightness until the supply's voltage was 2.15V. At voltages equal to and below 2.15V the screen flickered and behaved erratically. At 1.95V the text on the screen began dancing around. When the supply voltage became less than 1.9V the screen stopped operating completely. These results are summarized in the table below.

Voltage	OLED Behavior
2.3V	Decreased brightness
2.15V	Flickering, erraticism
1.95V	Great flickering and erraticism
1.9V	Operation ceased completely

Table 4. OLED Voltage Test results

The manufacturer's specification of 1.65V as the lower limiting of the SSD 1309 OLED's operating voltage was proven to be optimistic. The screen ceased functioning at 1.9V, 0.25V higher than the stated specification. In battery life tests, increasing noise levels rendered the device unusable before this limit became a concern.

8.5 System Integration Tests

8.5.1 Audio Loop Back

Test 5.1		Written by: David Landeros 12/4/2024
Subsystem: Main Looping Program		Tested by: David Landeros
Equipment Required:	Daisy seed microcontroller, Function Generator, breadboard, Power supply, Audio cables, PC/Laptop	
Description: This test evaluates the audio loopback functionality of the system, ensuring that audio input (via ADC) is processed and output (via DAC) with minimal **distortion**, **latency**, and **misalignment**. The test verifies that audio signal integrity is maintained across key states, including RECORD, PLAYBACK, and OVERDUB		
Overall Results: PASS		

#	Procedure	Expected Result	Actual Result	Comments:
1	Power on the Daisy Seed and verify it starts in **IDLE**. Initialize the system by powering on the Daisy Seed. Verify the system starts in **IDLE**.	System enters IDLE state; no audio output.	System booted successfully and entered IDLE.	No issues.
2	Connect a sine wave (e.g., 1 kHz, 300 mVpp) from the function generator to the audio input. Monitor ADC input with the oscilloscope.	Clean 1 kHz sine wave is detected at the ADC input.	Clean waveform at 1 kHz confirmed on input.	Signal stable and undistorted.
3	Simulate a short press on **FS2** to transition to **RECORD**. Verify the audio input is recorded.	System records the sine wave; no audio output yet.	Recording confirmed via serial console and playback.	No dropouts.
4	Simulate a short press on **FS1** to transition to **PLAYBACK**. Verify the recorded sine wave is output via the DAC.	Clean 1 kHz sine wave is played back at the DAC output.	Playback is smooth and matches original tone.	No clicks or added harmonics.
5	Compare the input (ADC) and output (DAC) waveforms using the oscilloscope. Measure the **latency** (time delay between input and output waveforms).	Latency is within acceptable limits (e.g., ≤ 10 ms)..	Latency measured ≈ 2.1 ms.	Within acceptable range.
6	Verify the **alignment** of input and output signals in the time domain. Ensure there is no noticeable drift or phase mismatch.	Output waveform is synchronized with the input; phase deviation is minimal (≤ 5%).	Waveform aligned, no drift detected.	Phase stable across playback.

#	Procedure	Expected Result	Actual Result	Comments:
7	Simulate a short press on **FS2** during **PLAYBACK** to enter **OVERDUB**. Inject a second sine wave (e.g., 2 kHz, 300 mVpp). Verify both waves are recorded.	System records and mixes the new wave with the original loop. Playback reflects both sine waves.	Clean 1 kHz + 2 kHz playback confirmed.	Signals correctly mixed.
8	Measure latency and alignment of the combined signal during OVERDUB playback.	Overall latency remains within acceptable limits; no misalignment between layers.	Delay ≈ 1.9 ms; overlays well-aligned.	No artifacts or noticeable shift.
9	Simulate a long press on **FS2** during **OVERDUB** to transition to **UNDO/REDO**. Verify that the most recent addition is undone.	System removes the 2 kHz sine wave, reverting to the original 1 kHz recording.	Undo removes last layer instantly.	Undo time < 2 ms.
10	Simulate saving the loop during **IDLE** and verify the audio is stored in the SD card buffer. Then load the saved loop and verify playback integrity, latency, and alignment.	Saved loop matches the original recording, playback shows minimal delay or misalignment.	RMS error < 0.1%, waveform aligned.	Playback confirmed accurate.

Overall result = Pass

The audio loopback functionality of the main looping system was thoroughly verified and passed all evaluation criteria. The system demonstrated stable and accurate handling of audio input and output across RECORD, PLAYBACK, and OVERDUB states. Input sine waves were recorded and played back with minimal latency (average ≈ 2 ms) and no audible distortion, phase drift, or signal artifacts. Overdub functionality successfully layered multiple waveforms with proper alignment and clear signal mixing. Undo operations cleanly reverted the most recent overdub without delay. Additionally, loops saved to and loaded from the SD card retained high waveform fidelity, showing less than 0.1% RMS error and no alignment issues. These results confirm that the audio path—from ADC capture to DAC output—performs reliably and preserves signal integrity throughout the looping process.

8.5.2 Buffer Overflow and Prevention Mechanisms

Test 5.2		Written by: Brandon Markham 12/03/2024
Subsystem: System Integration		Tested by: Brandon Markham
Equipment Required:	Daisy Seed microcontroller, Computer, Audio Source, System Under Test	
Description: This test is to verify that the buffer array does not overflow when recording continuously for the maximum duration or when handling edge cases such as playback and recording simultaneously.		
Overall Results: Pass		

#	Procedure	Expected Result	Actual Result	Comments:
1	Power on the Daisy seed and connect it to the computer via USB	Daisy Seed powers on successfully.	Daisy Seed powers on successfully.	
2	Start recording test audio by pressing button 2 until buffer fills up completely	Recording continues until the buffer length reaches capacity.	Recording continues until the buffer length reaches capacity.	Pass
3	Ensure that playback begins automatically once buffer reaches capacity and system is no longer recording.	Playback initiated automatically and system discontinues recording.	Playback initiated automatically and system discontinues recording.	Pass

Overall result = Pass

The Daisy Seed powered on successfully and initialized without issues when connected via USB. During the recording test, the system accurately recorded audio until the buffer reached its maximum capacity, as expected. Once the buffer was full, playback began automatically, and the system correctly ceased recording, demonstrating seamless handling of buffer limits. All operations were performed without glitches or errors, confirming the effectiveness of the buffer overflow prevention mechanisms.

8.5.3 SD Card Storage Limits

Test 5.3		Written by: Brandon Markham 12/03/2024
Subsystem: System Integration		Tested by: Brandon Markham
Equipment Required:	Daisy Seed Microcontroller, Computer, SD Card, SD Card Mounting Hardware.	
Description: This test ensures that the SD card system enforces a maximum limit of 10 saved audio loops. The system must prevent saving additional loops once the limit is reached, display an appropriate debug message, and preserve the integrity of previously saved files.		
Overall Results: Pass		

#	Procedure	Expected Result	Actual Result	Comments:
1	Insert a formatted SD card into Daisy Seed SD card peripheral	SD card initializes successfully.	SD card initializes successfully.	Pass
2	Save the first loop by pressing the encoder button while playback and recording are stopped.	Loop saved to SD card as Loop1.wav.	Loop saved to SD card as Loop1.wav.	Pass
3	Repeat step 2 until 10 loops have been saved to the SD card.	Loops saved sequentially as Loop2.wav through Loop10.wav.	Loops saved sequentially as Loop2.wav through Loop10.wav.	Pass
4	Attempt to save an 11th loop by pressing the encoder button while playback and recording are stopped.	System displays a debug message: "Maximum number of loop files (10) reached. Cannot save."	System displayed the correct debug message.	Pass
5	Verify that all 10 saved loops are intact and accessible on the SD card by connecting the SD card to a computer and inspecting the files.	Files Loop1.wav through Loop10.wav are present and playable.	All 10 files were present and playable.	Pass

Overall result = Pass

The SD card successfully initialized, and the system allowed saving up to 10 loops as WAV files with sequential naming (Loop1.wav to Loop10.wav). Attempts to save additional loops correctly triggered a debug message indicating the maximum file limit had been reached, preventing further saves. All saved files were intact, playable, and accessible when inspected on a computer, demonstrating proper file management and adherence to the specified limit. This ensures the system avoids memory overflow and maintains reliable data handling.