1.06 Ouroboros

Final Design Review

The Ouroboros looper pedal will provide an attractive, user-friendly way for musicians to play over pre-recorded or newly recorded loops. The device will be reproduceable by hobbyists using open-source hardware and software.

- Runs off 9-V battery or mains power
- 128 x 64 OLED Display
- 12-bit audio
- Undo/Redo functionality
- Sessions can be saved and recalled

Fig. 1: Photograph of Ouroboros looper pedal user menu

Kyle Ratcliff, Project Manager; Display, UI & Enclosure Design

Renee Aguilar, Power & PCB Design

David Landeros, Main Looping Program

Brandon Markham, Audio Processing & Dynamic Memory Mgmt.

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Original Requirements

Guitar Looper

Sponsor: TXSTATE

Description

Design and construct a battery powered guitar looper pedal. The looper can record the guitar input then loop it back to be played on its output.

- Store and recall up to 10 of your favorite loop sessions
- 5-minute recording time means you'll never run out of space for loops
- Import and export loop sessions and backing tracks via USB
- Unlimited overdubs and undo/ redo for total creative freedom
- Display provides detailed real-time looping information
- 16-bit uncompressed audio for ultimate sound quality

Potential subsystems:

- Power system
- A/D – D/A
- Microprocessor/memory
- UI

Performance Criteria Phases
EE4390 (D1)Requirements: • Functioning A/D subsection (possibly ADS1115, see link below) • Functioning D/A Subsection (possibly AD5693R, see link below) • Processor section prototyped (Possibly an ESP32 processor) • User interfaces and PC interfaces (USB) prototyped
EE4391 (D2) Requirements: • Unit must be fully functional according to the above specifications. • Full characterization of input vs output completed. • Prove how much noise the system interjects. • Full supporting subsystem validation details on poster or printed documents.

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Image from: TC Electronic | Product | DITTO+ LOOPER

Overall Block Diagram

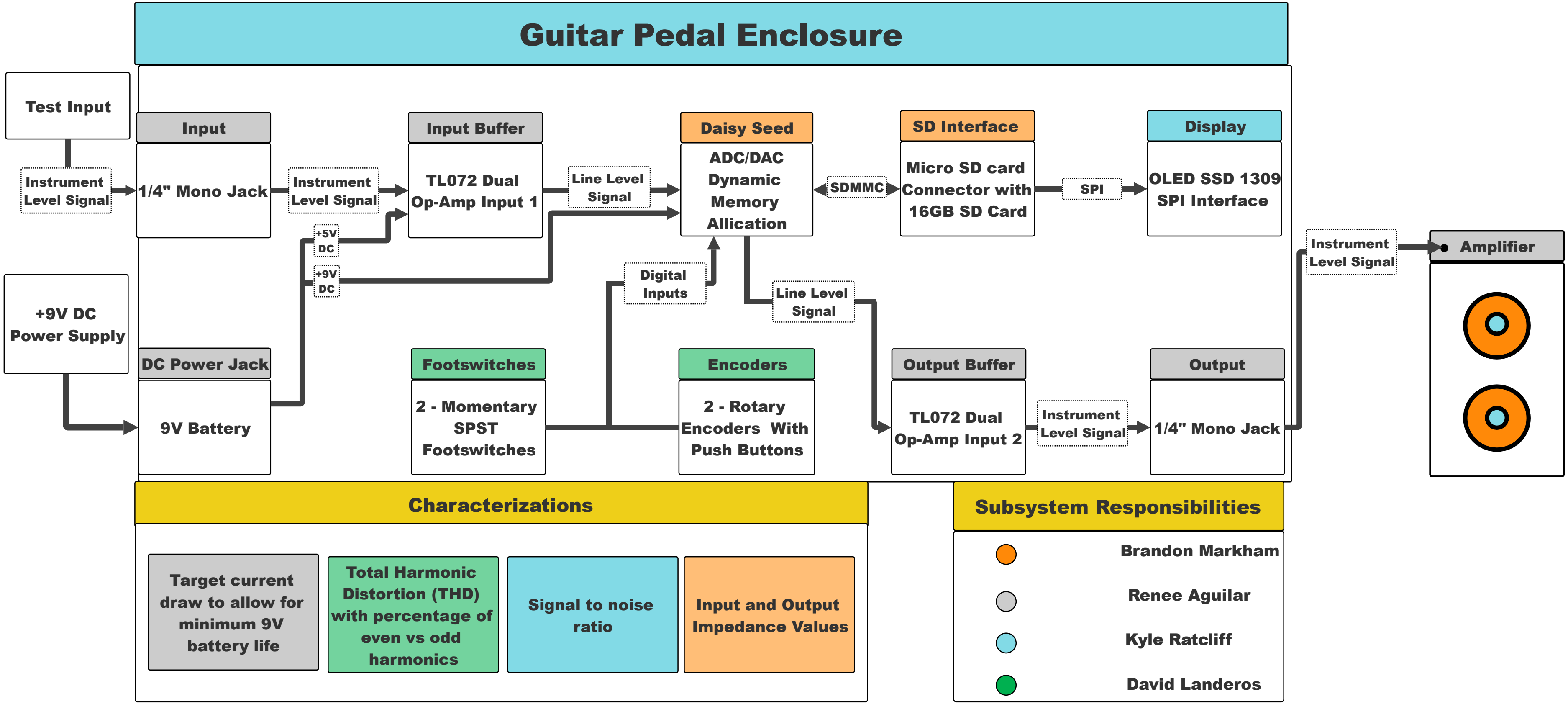

Fig. 2: Block Diagram of Entire System

Power & PCB Design : Renee Aguilar

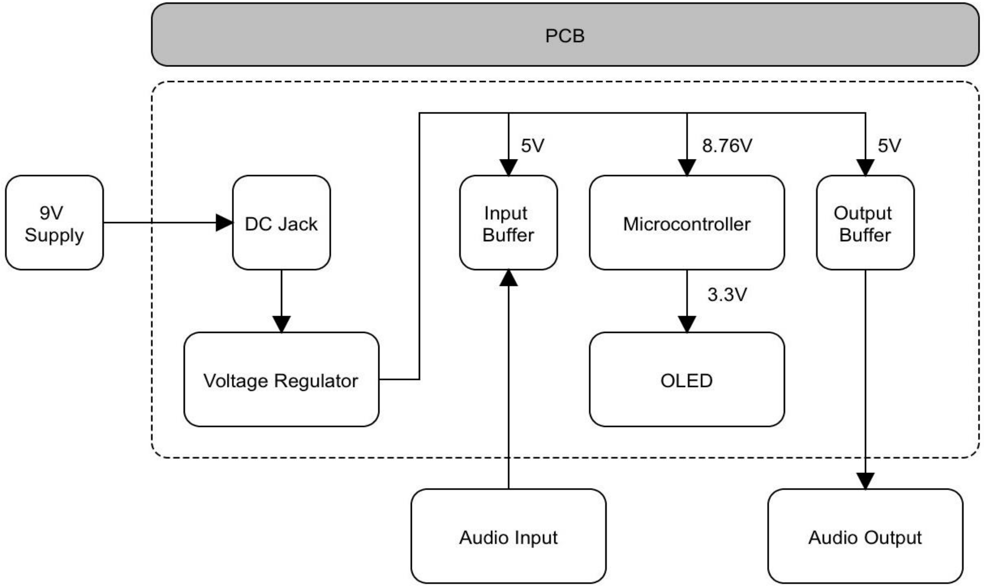

Fig. 3: Block Diagram of Power & PCB Design Subsystem

The **Power** subsystem provides power to the Microcontroller and contingent devices such as the Input/Output Buffers and OLED. A 9VDC Power Source (from either a wall adapter or battery) supplies power to the Microcontroller and is stepped down to 5V via a voltage regulator circuit.

Requirements:
- Operated by 9V Supply
- Sustain at least an hour of use with Battery

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Power Subsystem : Renee Aguilar

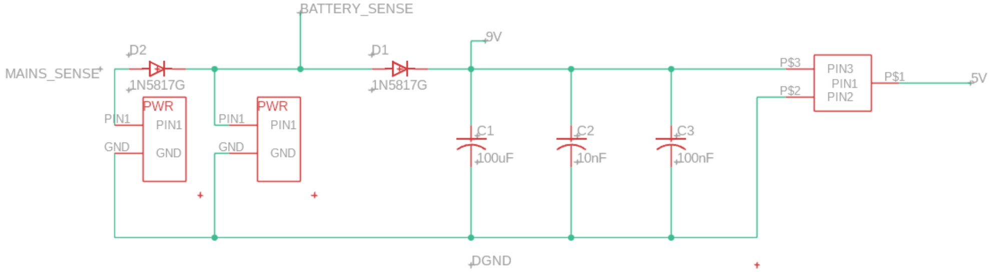

Fig. 4: Schematic of Voltage Regulator

Design Proposal:
-9 to 5V Voltage Regulator Circuit
-Input and Output Audio Buffer Circuit
-Updated design from unity gain amplifier to JFETT to reduce noise at the output buffer

Characterization Plan:
- LTSpice simulation and verification
- Perfboard/Breadboard assembly
- PCB design and assembly for further testing and verification

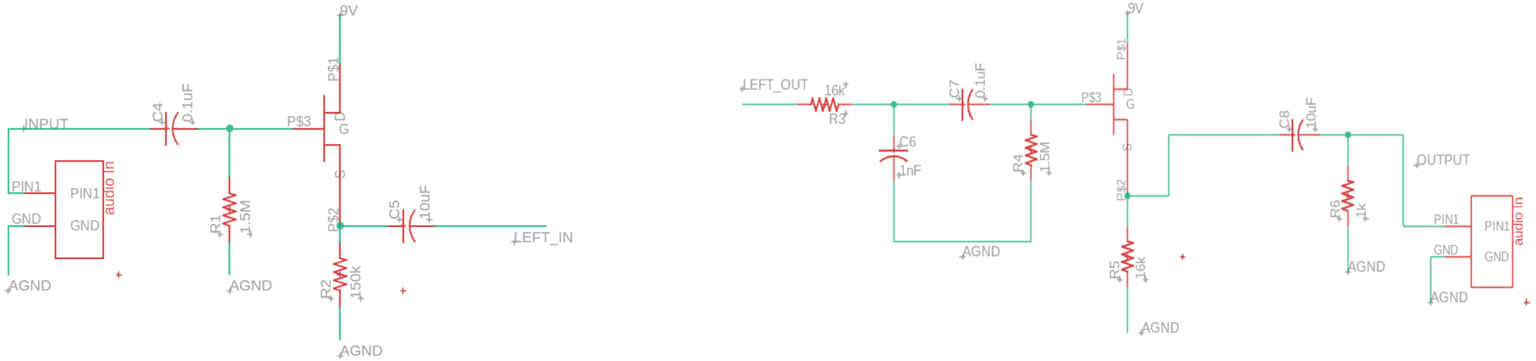

Fig. 5: Schematics of Input and Output Buffers

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Power and Battery Supply Characterization: Renee Aguilar

Procedure	Expected Results	Actual Results	Pass/Fail
Connect the Power Supply to Voltage Regulator at 9V	9 V	8.97 V	PASS
Set Power Supply to 9V and measure voltage supplied to Microcontroller	8.76 V	8.53 V	PASS
Measure load of Voltage Regulator supplying power to OLED peripheral	5 V	4.87 V	PASS
Measure voltage of test Battery	9 V	8.49 V	PASS
Set timer and monitor voltage supplied to the Microcontroller until output drops to 5 V	1 hr runtime	Approx 18 minutes runtime	FAIL At the 17-minute mark, the battery caused increasingly loud noise which interfered with recording/playback. The battery may have supplied the looper longer, but it would have been unusable past 18 minutes due to the level of noise.

Main Looping Program : David Landeros

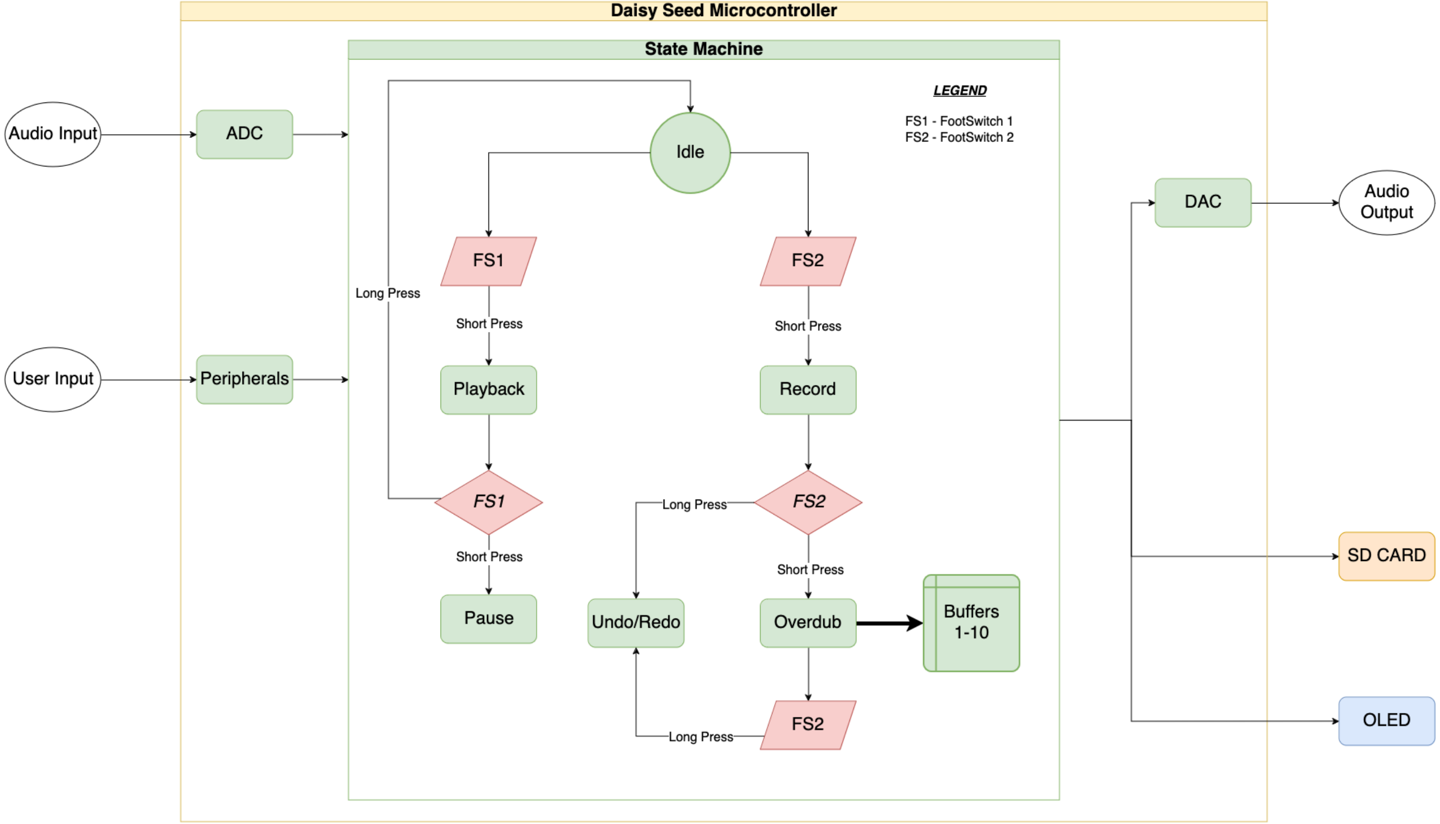

Fig. 6: Main looping Program Subsystem Diagram

- Audio input (ADC)
- Peripheral inputs
- State Machine
- Audio output (bypass sound)
- SD Card / OLED output

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Main Looping Program : David Landeros

Requirements:

State Transition Test:

- Playback (FS1)
- Pause (FS1)
- Record (FS2)
- Overdub (FS2)
- Undo/Redo (FS1/FS2)

Audio Loopback Test:

- < 5ms delay
- 32kHz Sample rate
- 12 Bit Audio Rate

Procedures:

The **State Transition Test** evaluates the correctness and responsiveness of the looper pedal's state machine by verifying transitions based on user inputs. A **serial output from the Daisy Seed will be monitored using PuTTY** to capture debug messages and confirm state changes in real time. The test procedure involves simulating short and long presses on **footswitches FS1 and FS2** to transition through key states: **IDLE, RECORD, PLAYBACK, OVERDUB, UNDO/REDO, SAVE, and LOAD**. Each transition will be validated by checking system outputs, including **LED indicators, serial logs in PuTTY, and waveform playback on the oscilloscope**.

In addition, the **Audio Loopback Test** is essential to ensure that the system's audio performance meets quality standards. This includes verifying that the system introduces less than **5ms of delay** during audio processing, ensuring real-time interaction with the loops. The system should operate at a **32kHz sample rate**. Lastly, the system should maintain a **12-bit audio rate**, providing sufficient resolution to ensure high-quality sound reproduction without noticeable distortion.

Characterization Plan:

Total Harmonic Distortion, even and odd harmonics validated and verified with an oscilloscope

State Transition Test : David Landeros

Procedure	Expected Results	Actual Results	Pass/Fail
Power on Daisy Seed	Enter Idle state	Serial logs: System Initialized → [STATE] IDLE	PASS
Short press FS2 (from IDLE)	Transition to RECORD; audio input starts	Serial logs: [INPUT] FS2 Press Detected → [STATE] RECORD	PASS
Short press FS1 (from RECORD)	Transition to PLAYBACK; loop plays back	Serial logs: [INPUT] FS1 Press Detected → [STATE] PLAYBACK	PASS
Short press FS1 (from PLAYBACK)	Transition to PAUSE; playback halts	Serial logs: [INPUT] FS1 Press Detected → [STATE] PAUSE	PASS
Short press FS1 (from PAUSE)	Transition back to PLAYBACK; resumes loop	Serial logs: [INPUT] FS1 Press Detected → [STATE] PLAYBACK	PASS
Short press FS2 (from PLAYBACK)	Transition to OVERDUB; overdub recording starts	Serial logs: [INPUT] FS1 Press Detected → [STATE] PLAYBACK	PASS
Long press FS2 (from OVERDUB)	Transition to UNDO; last overdub removed, returns to IDLE	Serial logs: [INPUT] FS2 Long Press Detected → [STATE] UNDO	PASS
Long press ENC 2 (from PLAYBACK or OVERDUB)	Transition to IDLE; all activity stops	Serial logs: [INPUT] FS2 Long Press Detected → [STATE] UNDO	PASS
Issue Save Command (in IDLE)	Loop saved to SD card buffer (1–10)	Serial logs: Saving loop buffer to SD card... → [DEBUG] Writing complete! Total bytes written: XXXX	PASS
Issue Load Command (in IDLE)	Loop retrieved from SD and transitions to PLAYBACK	System retrieves loop and enters PLAYBACK state.	PASS

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Audio Loopback Test : David Landeros

Procedure	Expected Results	Actual Results	Pass/Fail
Play 1kHz sine wave into input and record loop for 5 seconds	Clean loop playback with < 5ms latency	Latency measured ≈ 2.1 ms	PASS
Overdub a synchronized 2nd layer of 1 kHz pulses at known intervals	Overdub is phase-aligned, delay < 5 ms	Delay ≈ 1.9 ms, waveform aligned with original	PASS
Record and overdub 3+ layers of audio, each 1 second apart	Overdub is phase-aligned, delay < 5 ms	Delay stable across layers (<2.5 ms)	PASS
Analyze sample timestamps in recorded buffers over 30s session	Sample intervals remain consistent with 32 kHz sample rate	Sample rate constant at 32,000 ±0.1 Hz (jitter < 0.3%)	PASS
Feed in stepped amplitude signal to cover 12-bit resolution	Output waveform shows ~4096 discrete steps	4094 unique levels detected from waveform analysis, Step size ≈ 0.0244% of full scale (1 / 4096)	PASS
Save recorded loop to SD, reload and compare playback	Playback matches original loop waveform	RMS error < 0.1%, waveform aligned on reload	PASS
Add and remove overdubs repeatedly under playback	Undo/Redo timing is immediate and accurate	Undo/Redo time < 2ms, no delay in state transition	PASS

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Total Harmonic Distortion : David Landeros

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%

Audio Processing & Memory Mgmt. Subsystem: Brandon K Markham

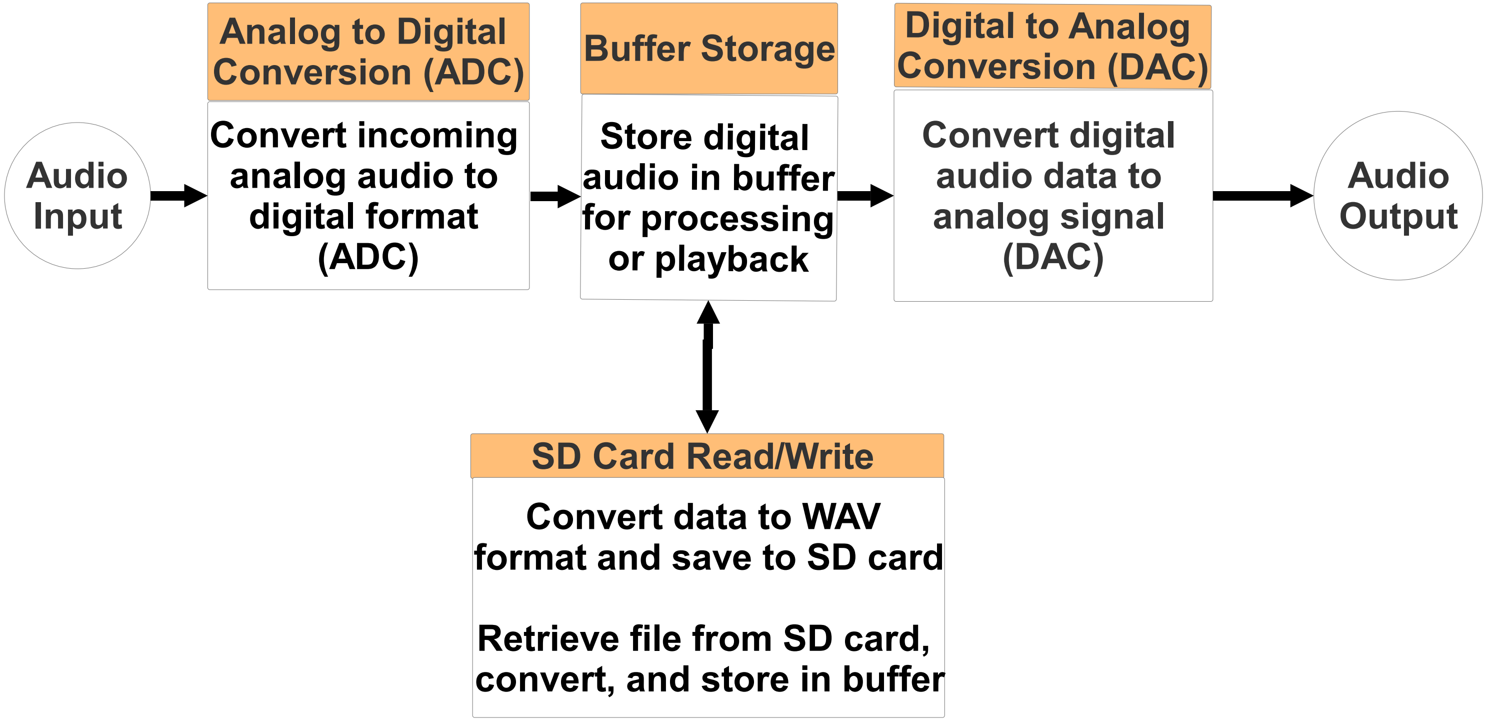

Fig. 7: Generalized top level diagram for the Audio Processing and Memory Mgmt. subsystem

Audio Processing & Memory Mgmt. Subsystem: Brandon K Markham

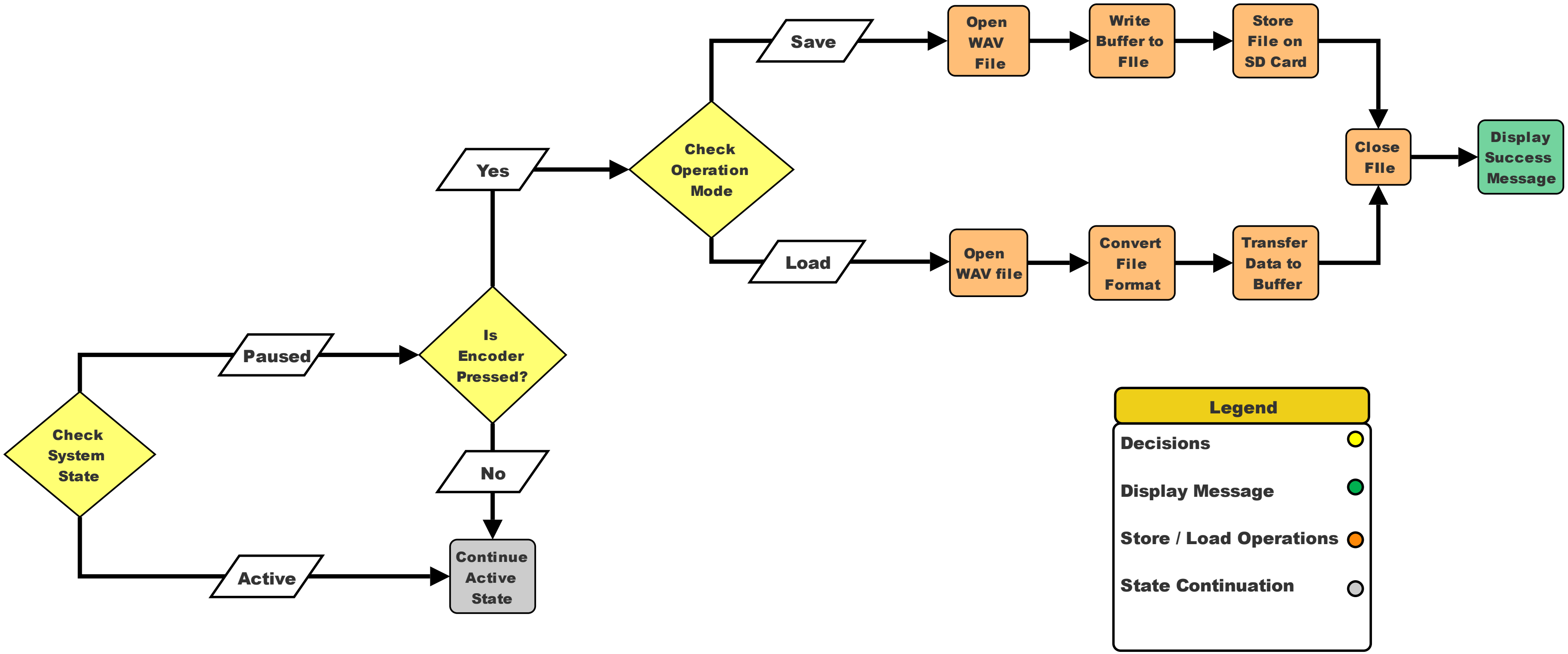

Fig. 8.1: Dynamic Memory Allocation Protocol

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Audio Processing & Memory Mgmt. Subsystem: Brandon K Markham

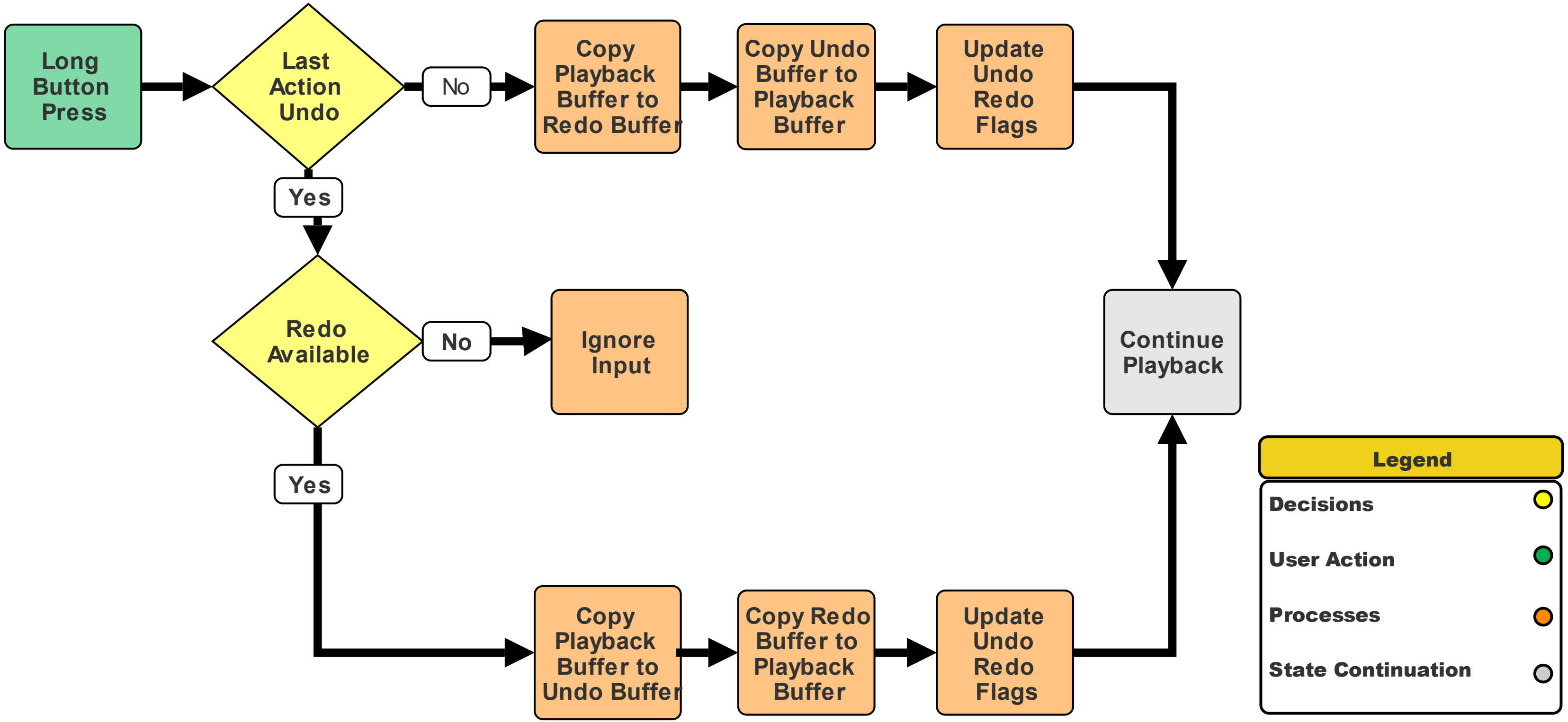

Fig. 8.2: Undo/Redo Protocol

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Audio Processing & Memory Mgmt. Subsystem: Brandon K Markham

Design Requirements:

- **SD Card Save Load Functionality:**
  - Store WAV on SD CARD
  - Convert Buffer Data to WAV
  - Load File Into Buffer
  - Convert WAV to Buffer Data
- **Undo/Redo Functionality:**
  - Save Playback to Undo/Redo Buffers as Needed
  - Toggle Between Playback and Secondary Buffer

Input and Output Impedance Characterizations

- Input impedance of 1.5 MΩ at 1.9 Vpp
- Output impedance of 10 KΩ at 2.3 Vpp

Characterization protocol:
Input and output impedances will be calculated and measured. The percent difference between the theoretical and measured values will be used to determine how far each measurement is with respect to our target values for an input impedance of 1.5M ohm @ 1.9 V and an Output impedance of 10 K ohm @ 2.3 V.

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Input Impedance Characterization: Brandon K Markham

Procedure	Expected Results	Actual Results	Pass/Fail
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
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.	1.9 Vpp	Vin = 1.91 Vpp	PASS Input signal measured at 0.675 V RMS and then calculated to 1.91 Vpp
Using the digital multimeter, measure the input RMS current of the system then multiply the value by 2√2.	Input current = 1.26 μA	Input current = 1.28 μA	PASS Input current measured at 0.452 μA RMS and then calculated to 1.28 μA
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 Vpp	Input impedance = 1.49 MΩ	PASS Simulated values yielded calculation of 1.503MΩ Real world measurement of 1.49MΩ
Compare measured values with calculated and simulated values.	Percent difference of less than 1%	Measured % difference = 0.87%	PASS

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Output Impedance Characterization: Brandon K Markham

Procedure	Expected Results	Actual Results	Pass/Fail
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
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
Measure open circuit voltage between audio output and ground	1.83 Vpp	Open Circuit Voltage = 1.864 Vpp	PASS Open circuit voltage measured at 659 mV RMS and multiplied by 2√2 for 1.863 Vpp
Place 1kΩ teste resistor between audio output and ground and measure voltage across test resistor. Apply Ohms law to derive the current across the test resistor and then again to derive output 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
Compare measured values with calculated and simulated values.	Percent difference of less than 1%	Measured % difference = 1.76 %	TBD

LTSPICE Simulation Results: Brandon K Markham

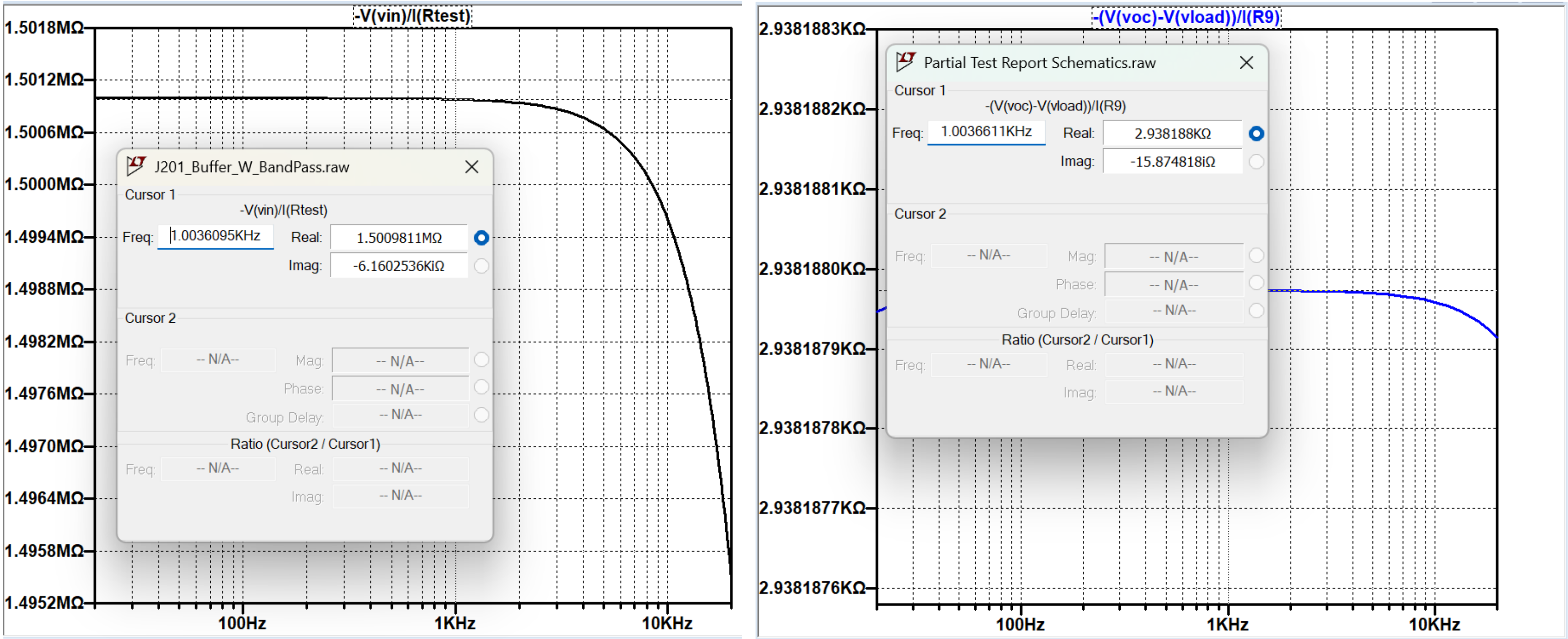

Fig. 8.3: LTSPICE Impedance Simulation Results

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Display, UI & Enclosure Design : Kyle Ratcliff

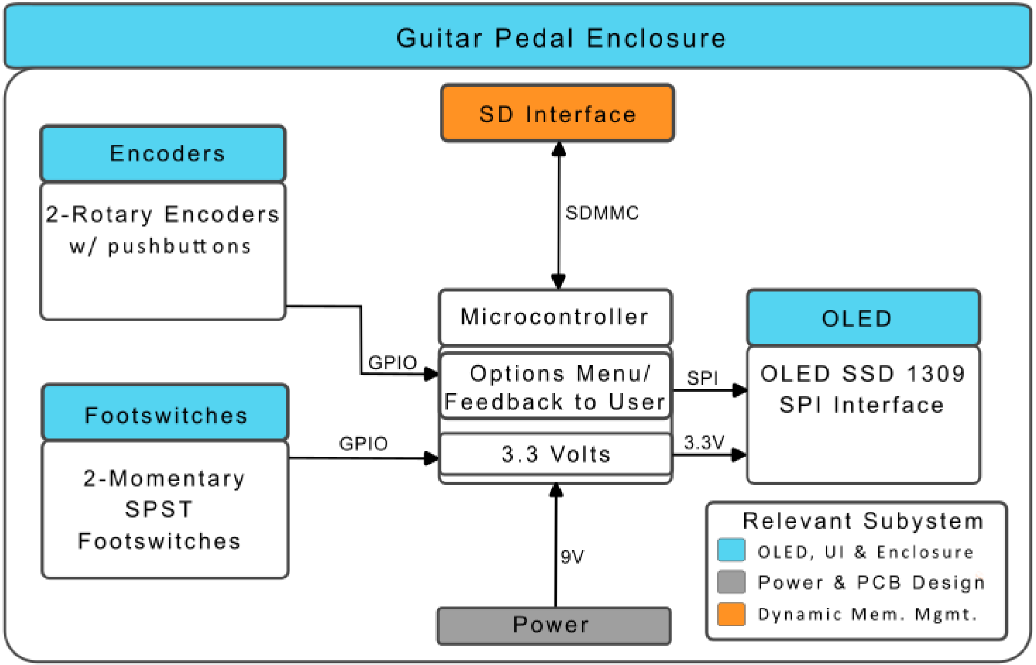

Fig. 9: Block diagram of Display, UI & Enclosure Design subsystem

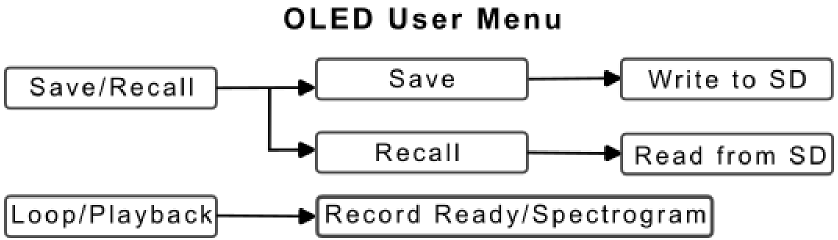

Fig. 10: OLED User Menu Flowchart

Design Changes

- Larger Enclosure
- No Settings Option

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Display, UI & Enclosure Design : Kyle Ratcliff

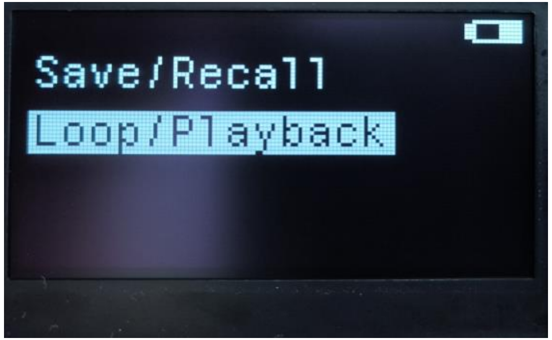

Fig. 11: Photo of OLED user menu and battery life indicator

Fig. 12: Photo of OLED spectrogram and mains power indicator

Fig. 13: Photo of enclosure

Features Implemented

- User Menu
- Spectrogram
- Power Indication
- State Indication
- Timer

Features Abandoned

- Brightness

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Display, UI & Enclosure Design : Kyle Ratcliff

Characterization 1: OLED Voltage Test

- Display normally receives 5V from voltage regulator
- Becomes unusable at 2.15V
- Ceased functioning 0.25V higher than manufacturer's stated specification of 1.65V

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

Table 4: OLED Voltage Test Results

Characterization 2: Signal-to-Noise Ratio

- Expected up to 68 dB with 12-bit converters
- AC RMS output measured
- SNR = $20 * \mathrm{Log}_{10}(\text{Signal/Noise})$
- Result of 20.5 dB far less than ideal

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 5: Signal-to-Noise Ratio Test Results

Overall Results

Requirement	Result	Description
Fully Functioning Looper	Completed	Looping pedal with A/D, D/A, user and PC interfaces
Input vs. Output Characterized	Completed	THD, SNR, Input and Output Impedances
Prove How Much Noise System Interjects	Completed	Noise of 1.31 mV, but low SNR of 20.5 dB
Store/ Recall up to 10 Sessions	Completed	Accomplished via microSD card
5-minute Record Time	Altered	Reduced to 2 minutes with sponsor approval
Display Provides Real-Time Looping info	Completed	State of device, spectrogram, and elapsed time
1 hour battery life	Failed	Device becomes too noisy to use after 17 minutes

Cost and Budget

Bill of Materials

Component	Quantity	Price Each	Subtotal Cost
Daisy Seed	1	$29.50	$29.50
OLED Display	1	$13.88	$13.88
SD Card Connector	1	$1.33	$1.33
Diodes, Integrated Circuits	1	$8.96	$8.96
Powder Coated Enclosure	1	$14.99	$14.99
Jacks, Switches, Etc.	1	$21.04	$21.04
		Total Cost	$89.70

Senior Design Day

Materials For Demonstration

- Ouroboros Guitar Looper
- 9VDC Power Supply
- Guitar
- Amplifier

Demonstration Process

- Connect the Looper to the power supply.
- Connect the guitar and amplifier to the looper
- Record a Loop and Overdub
- Demo Undo/Redo
- Demo Save/Recall For Recorded Loop

Questions & Comments!

Sponsor:

- Professor Welker

Faculty Advisor:

- Professor Welker

Additional Support:

- Dr. Compeau
- Professor Stevens

Note Taker:

- Paul Henson

Daisy Pod, a protoboard for the Daisy Seed
https://electro-smith.com/products/pod

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