SDP23 Team 24: L.O.O.P.S.

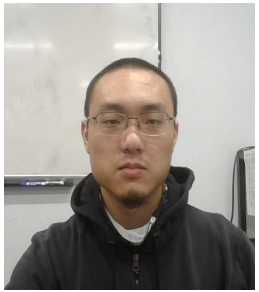
LOOPS Open Orchestrator Production System

University of Massachusetts Amherst

Advisor: Prof. Baird Soules
Evaluators: Prof. Christopher V. Hollot, Prof. Dennis L. Goeckel
Partners: Buzhuo Chen, John Folliard, Ben Rotker, Yunrui Yu

Team Responsibilities

John Folliard
(CompE)
PCB Lead
Instrument Lead



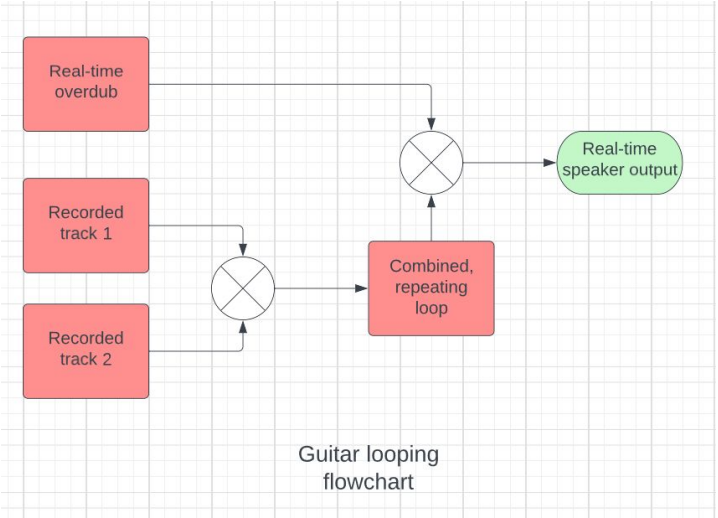
Buzhuo Chen
(CompE)
Software Lead

Yunrui Yu
(EE)
Hardware Lead

Ben Rotker
(CompE)
Logistics Lead
Signal Proc. Lead

Background

- What are guitar effects?
- How are these effects integrated in a performance?
- What is looping?



Problem Statement

- There is a lack of open source and extensible gear for performing musicians.
- Different effects need different pedals
- Some projects exist that combine the benefits of looper pedals and effects pedals into one singular user interface. (But not open source).
- This makes it nearly impossible to add or remove various effects as desired.

Our Solution

Provide user with one system that loops audio, adds effects to that audio, and adjusts the audio altogether instead of purchasing effects pedals like a looper pedal, distortion pedal, and tremolo pedal separately. We wish to make this an open source project so users can both modify the implementation of the effects we have and add new effects as desired.

Specification	Quantities
HiFi, monaural Audio	16 bits/sample 44,100 Hz sampling rate
2 looping tracks	5,292 kB/min (individually) 10.584 MB/min (concurrently)
Visual indicators	Visible from 8 ft
Power	DC and/or 9V battery
Sound latency	Imperceptible within 10-12 milliseconds [1]
Total harmonic distortion	<1%
Signal-to-noise ratio	>70 dB

Source: [1]https://ask.audio/articles/monitoring-latency-how-low-can-you-go

Specification	**Quantities**
I/O connections	Unbalanced ¼ inch hi-Z instrument cable
Memoryless Effects	Overdrive (full, warm tone) Modulation (Underwater-like sound)
Effects w/ memory	Delay (design goal) Chorus (design goal)

Testing Plan

Specification	Test plan
2 tracks	Listener describes the difference between two looping guitar tracks, compare to known difference
44.1 kHz sampling rate 16-bit samples	Based on file size and file length calculate the sampling rate and sample bit
THD less than 1%	Tektronics DPO4032 Digital Phospor Oscilloscope MATLAB
SNR greater than 70 dB	
Visual indicators	Viewer stands between 6-8 feet away, describes what they see on visual indicators, compare to known display

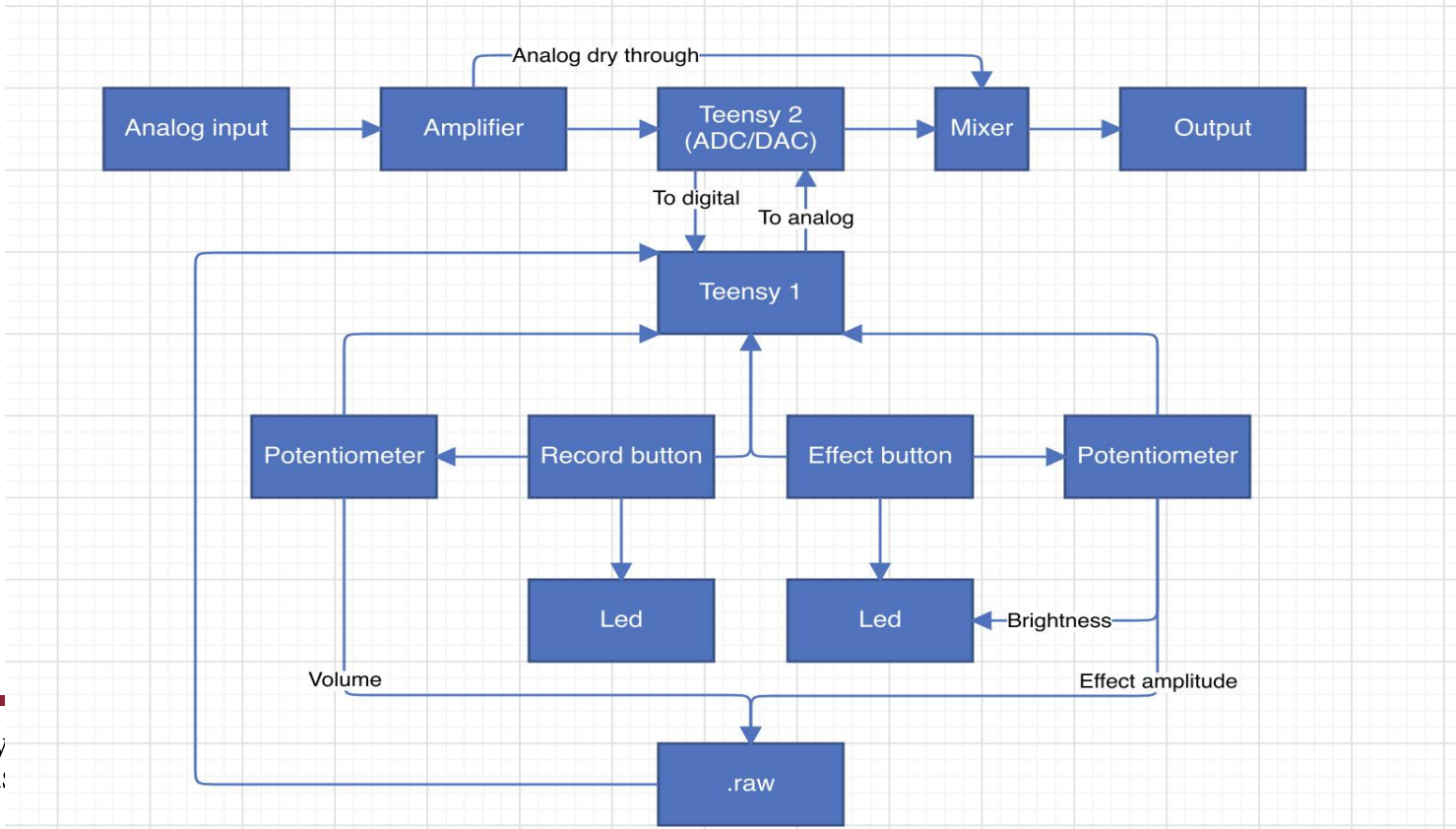
Testing Plan

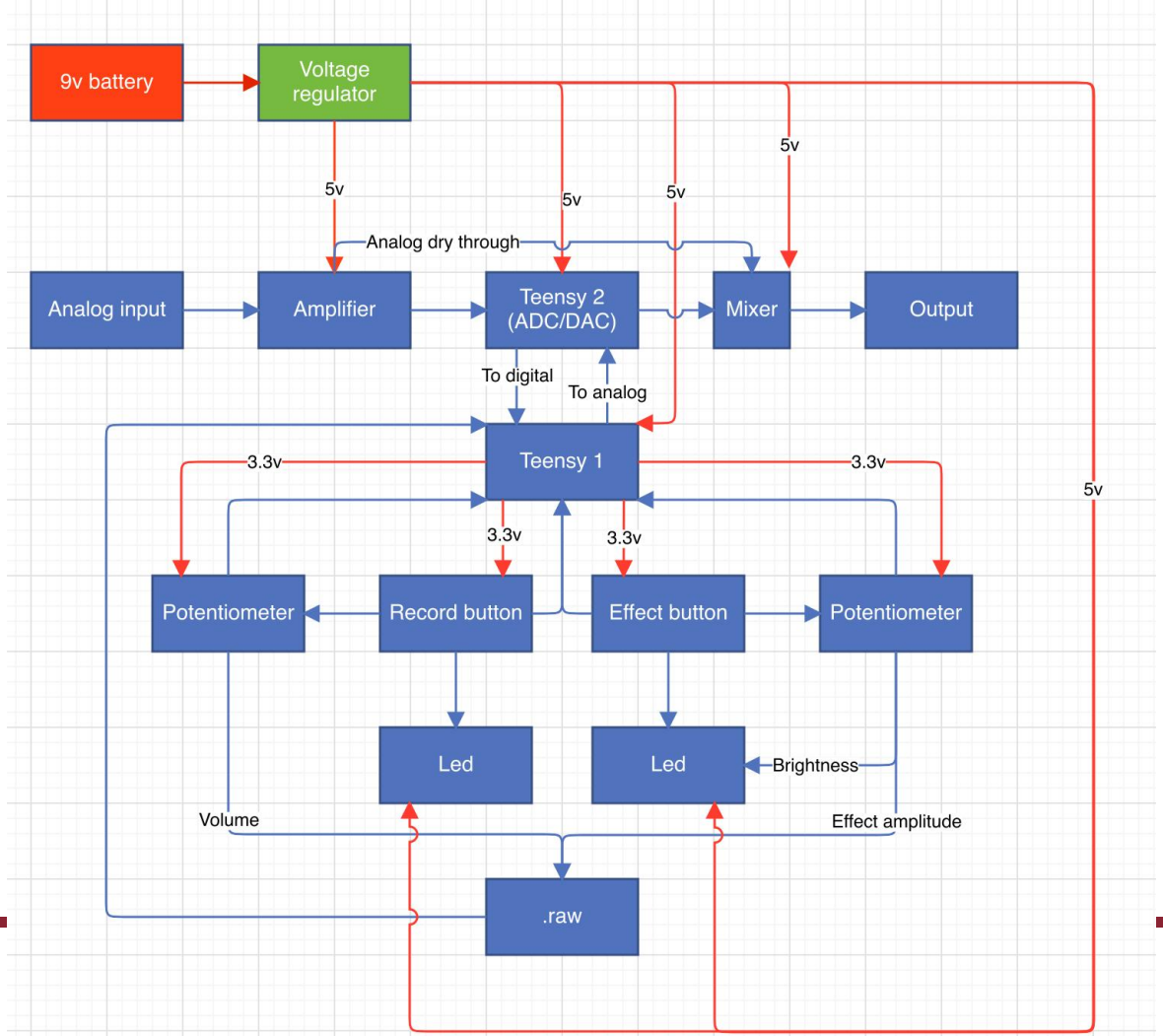
Specification	Test plan
Feet or hand control	Ensure all controls can be manipulated with hand/feet (no smartphone/PC)
Sound latency	Measure the time between feedback pulses to get the sum of the output latency, input latency, and application overhead.
Effects	Listen to each effect and make sure it sounds as desired

System Design

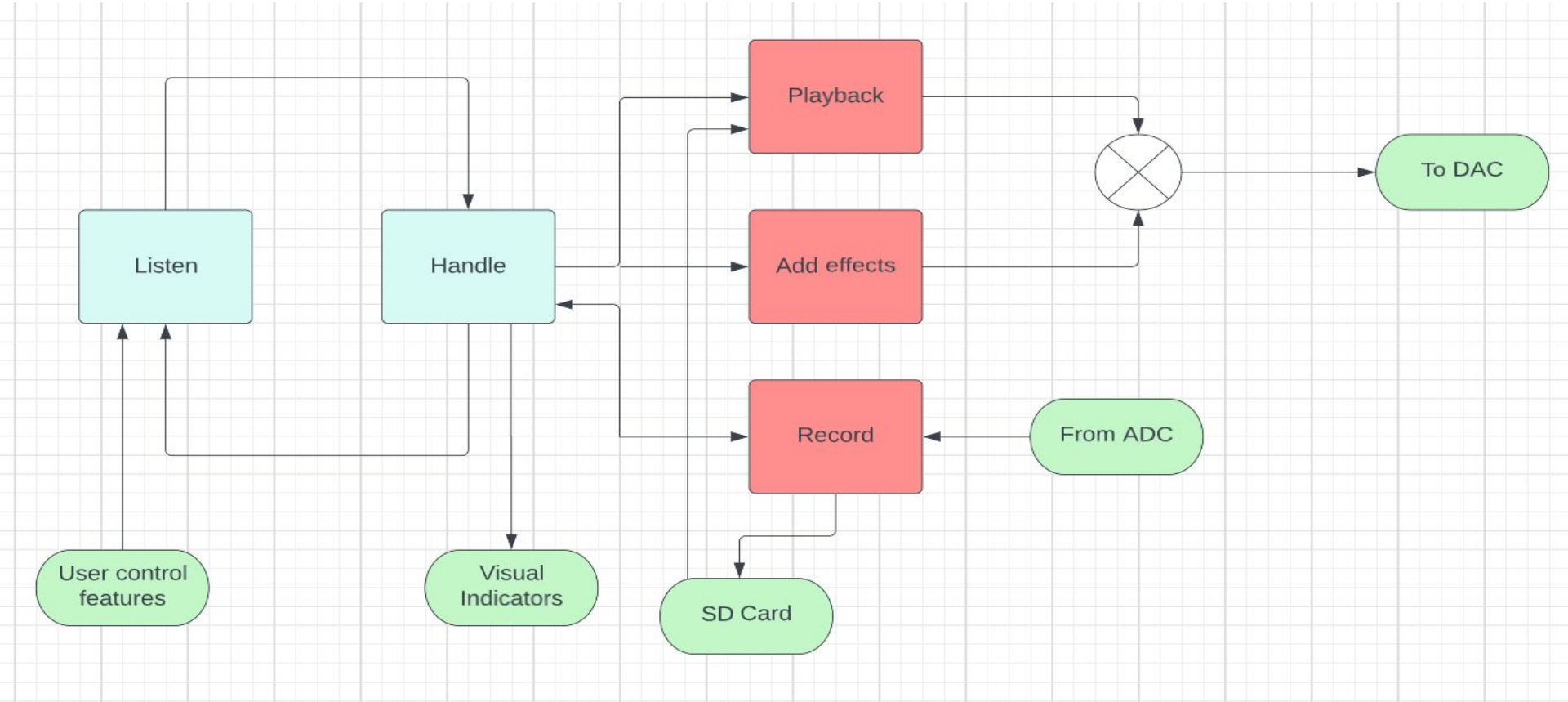
Block and other diagrams on following slides

System Design - Hardware Block Diagram

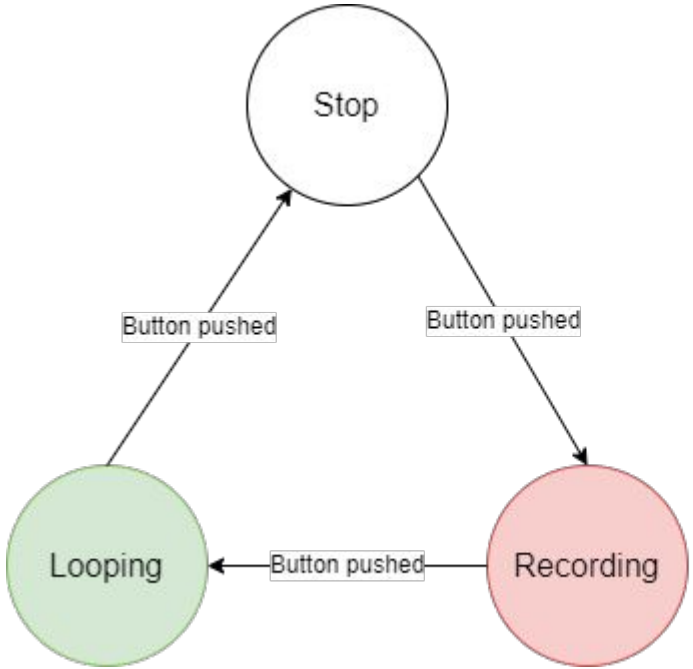


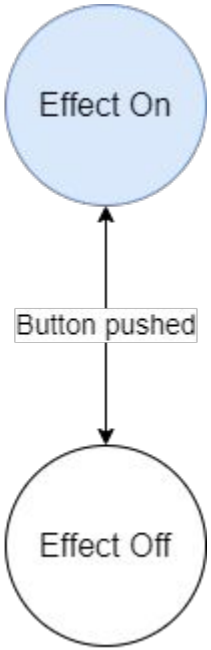

9v battery
Voltage regulator
5v
5v
5v
5v
Analog dry through
Analog input
Amplifier
Teensy 2 (ADC/DAC)
Mixer
Output
To digital
To analog
Teensy 1
3.3v
3.3v
3.3v
3.3v
5v
Potentiometer
Record button
Effect button
Potentiometer
Led
Led
Brightness
Volume
Effect amplitude
.raw

System Design - Software Block Diagram



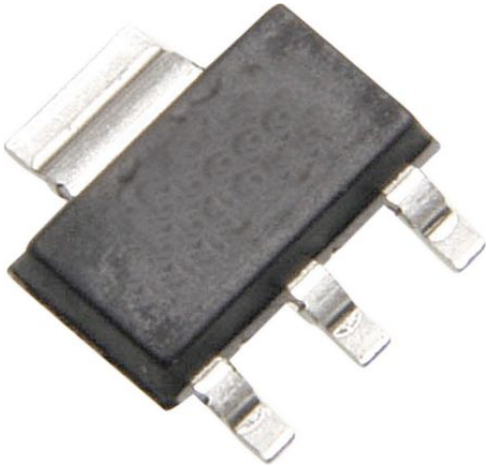
System Design - Pushbutton Control Flow





Hardware components: LDO Voltage Regulators

Microchip MCP1755ST



From the datasheet:

- Maximum output current: 300mA
- Input operating voltage: 3.6 to 16.0 V
- 150 C Typical thermal shutdown temperature

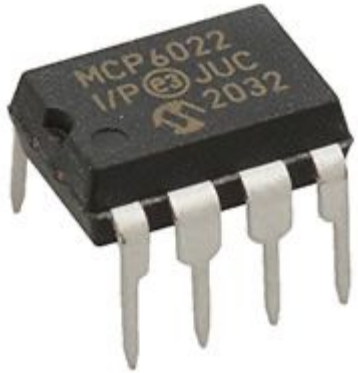
In our system:

- Separate regulators for analog and digital power
- At this time, digital power supply regulator only supplies ~1.5 V
- When using a tabletop power supply with a maximum 1 A current draw, we see the digital section draw well over 300 mA (typ. 330 - 420 mA)
- Heat dissipation tab was never soldered, could have exceeded 150 C (Typ. thermal shutdown temperature)

Source: MCP1755ST datasheet

Hardware components: OpAmps

Microchip MCP6022

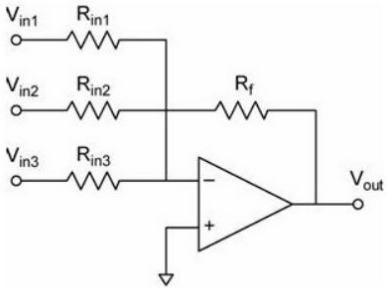


From the datasheet:

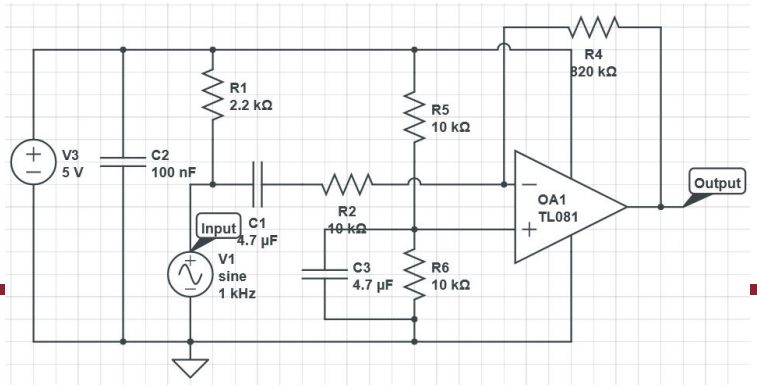
- Recommended supply voltages:
  - V_{DD} = 2.5 – 5.5 V
  - V_{SS} = GND

In our system:

- Preamp and Mixing OpAmps currently only receive 3.3 - 3.5 V from power rail
- We set Vcc^+ to (ideally) 5 V and Vcc^- to GND (0V)
- Currently using 220kΩ for feedback and 5kΩ for each mixer input line



The Summing Amplifier Circuit Diagram



Source: TI NE5532P datasheet
Summing amplifiers

AD/DAC Components

CS4272

- Complete stereo codec
- 24-bit conversion
- System sampling rates up to 192 kHz
- -100 dB THD+N
- Differential analog architecture

AD/DAC Components

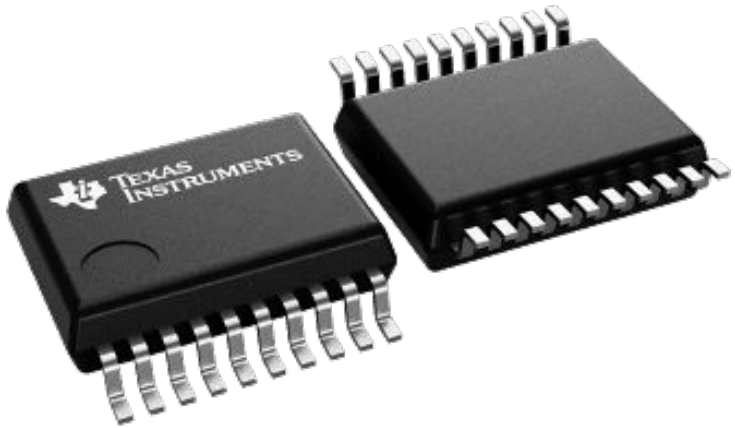
SGTL5000

- Complete stereo codec
- 24-bit conversion
- System sampling rates up to 96 kHz
- 93 dB SNR and -73 dB THD+N (VDDA = 3.3 V) for ADC
- 100 dB SNR and -85 dB THD+N (VDDA=3.3 V) for DAC

AD/DAC Components

PCM1802

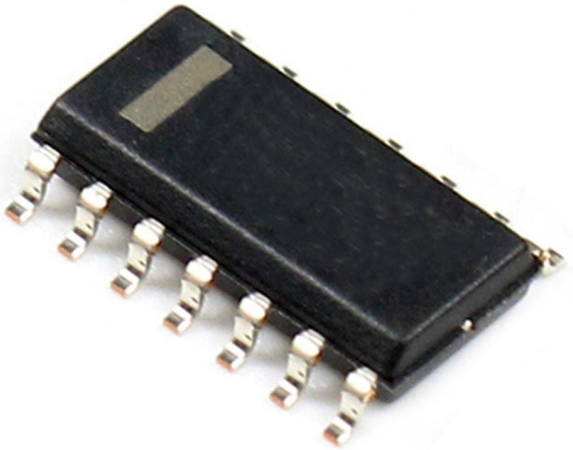
- Stereo 24 bits ADC
- Sampling Rate: 16 kHz to 96 kHz
- THD+N: 96 dB, SNR: 105 dB
- Single-Ended Voltage Input



AD/DAC Components

PCM1801

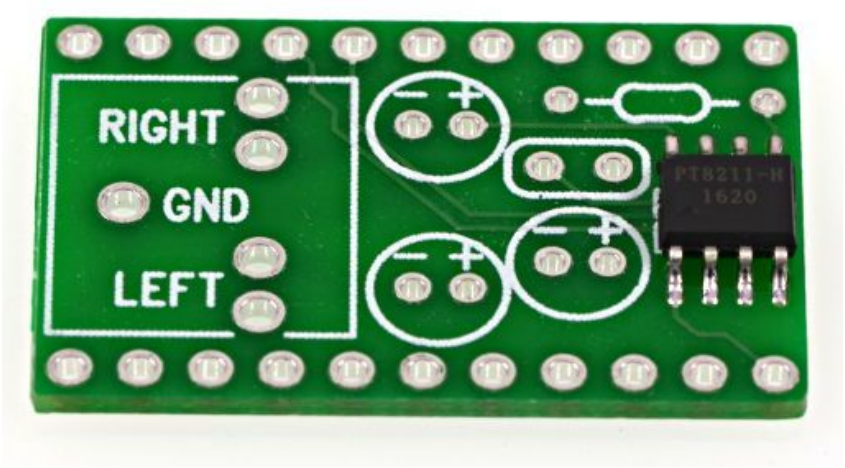
- Stereo 16 bits ADC
- Sampling Rate: 4 kHz to 48 kHz
- THD+N: –88 dB, SNR: 93 dB
- Single-Ended Voltage Input



AD/DAC Components

PT8211

- Dual channel, 16 bit DAC
- Up to 384 kHz sampling rate
- THD: 0.1% with 1KHz
- SNR: 93 dB
- Single-Ended Voltage Input



Video Demo 0

Video Demo 1

Challenges and Performance

SD card problem

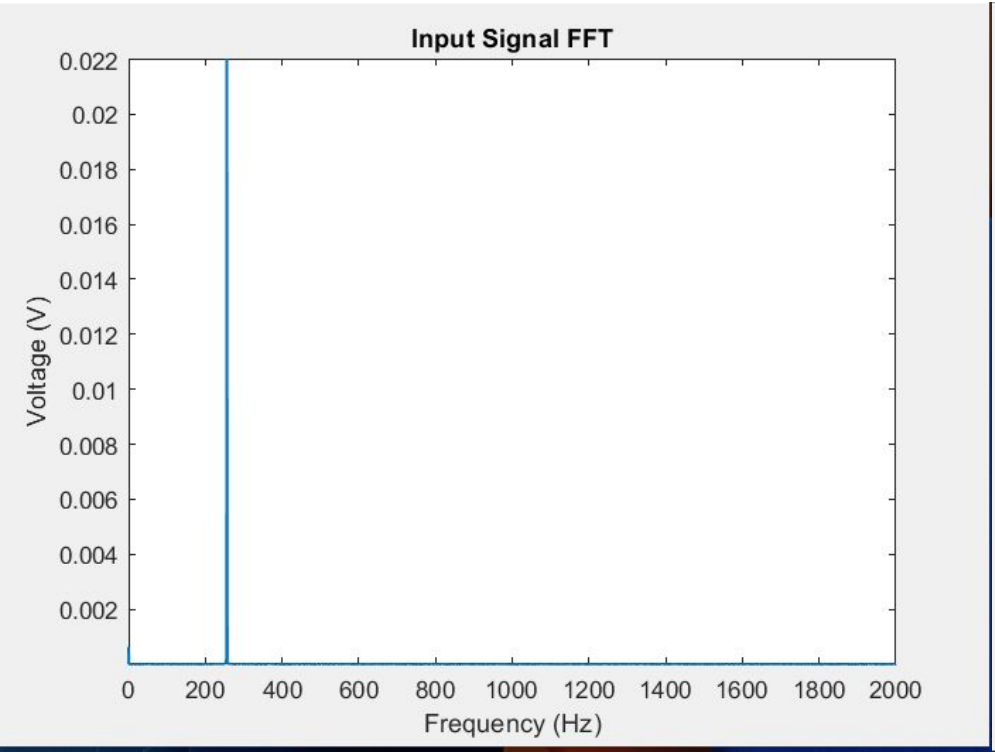
- **Occasional Micro SD card problem**
- **Unable to read and write file with a certain filename properly**
  - Perhaps cannot close file correctly
- **Solution: Use other SD cards, formatting, or simply read and write file with another filename**

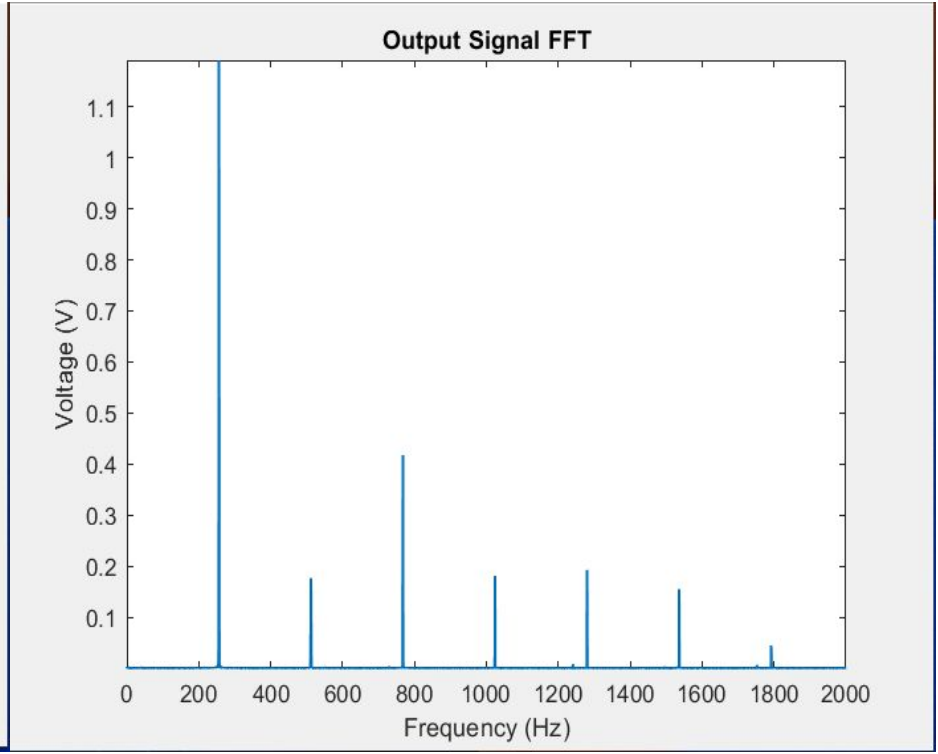
Signal to Noise Ratio (SNR) and Total Harmonic Distortion (THD)

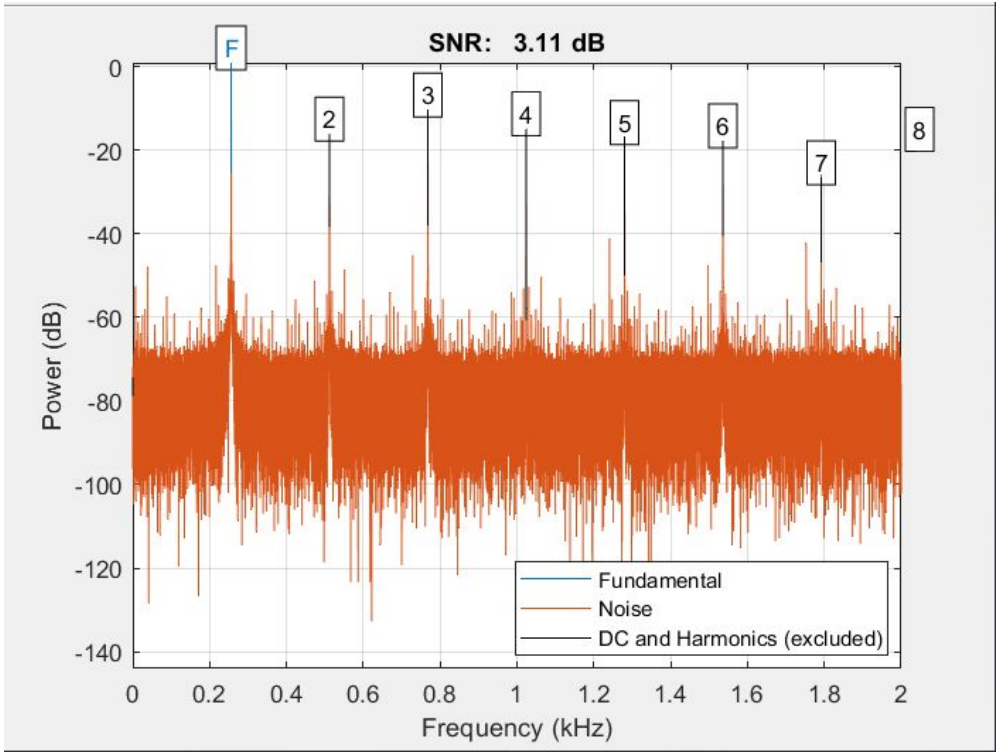
256 Hz sine wave (middle C) from Keysight 33220A Function/Arbitrary Waveform Generator as measured with Tektronix TDS 2002B Oscilloscope

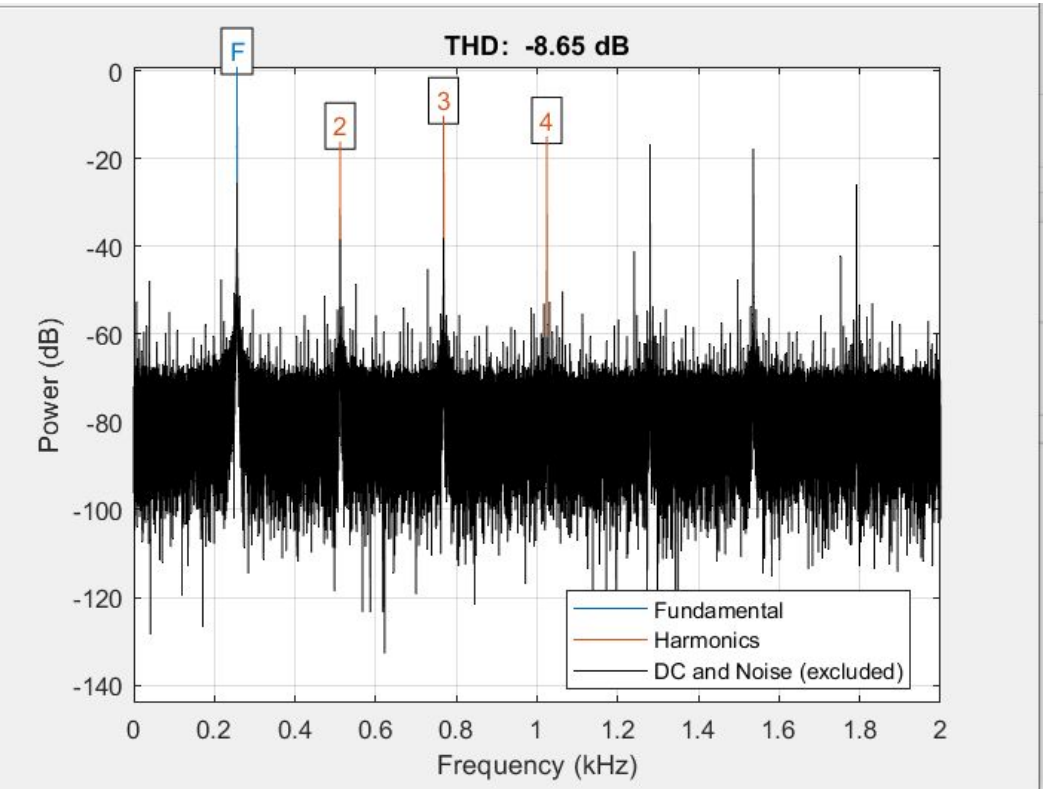
Magnitude of signal: -2.59 dB
Magnitude of noise floor: -59.4
SNR: 56.8 dB

harmonic	frequency	dB	dBc	power ratio
1	256	-2.9897	0	1
2	512	-60.5897	-57.6	0.000001737800829
3	768	-57.3897	-54.4	0.000003630780548
4	1024	-60.5897	-57.6	0.000001737800829
5	1280	-66.9897	-64	0.0000003981071706
			THD	0.002739432309


Input Signal FFT
Voltage (V)
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Frequency (Hz)


Output Signal FFT
Voltage (V)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Frequency (Hz)


SNR: 3.11 dB
F
2
3
4
5
6
7
8
0
-20
-40
-60
-80
-100
-120
-140
Power (dB)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Frequency (kHz)
Fundamental
Noise
DC and Harmonics (excluded)



Distortion attenuation *a* -8.65 dB

↓ calculate

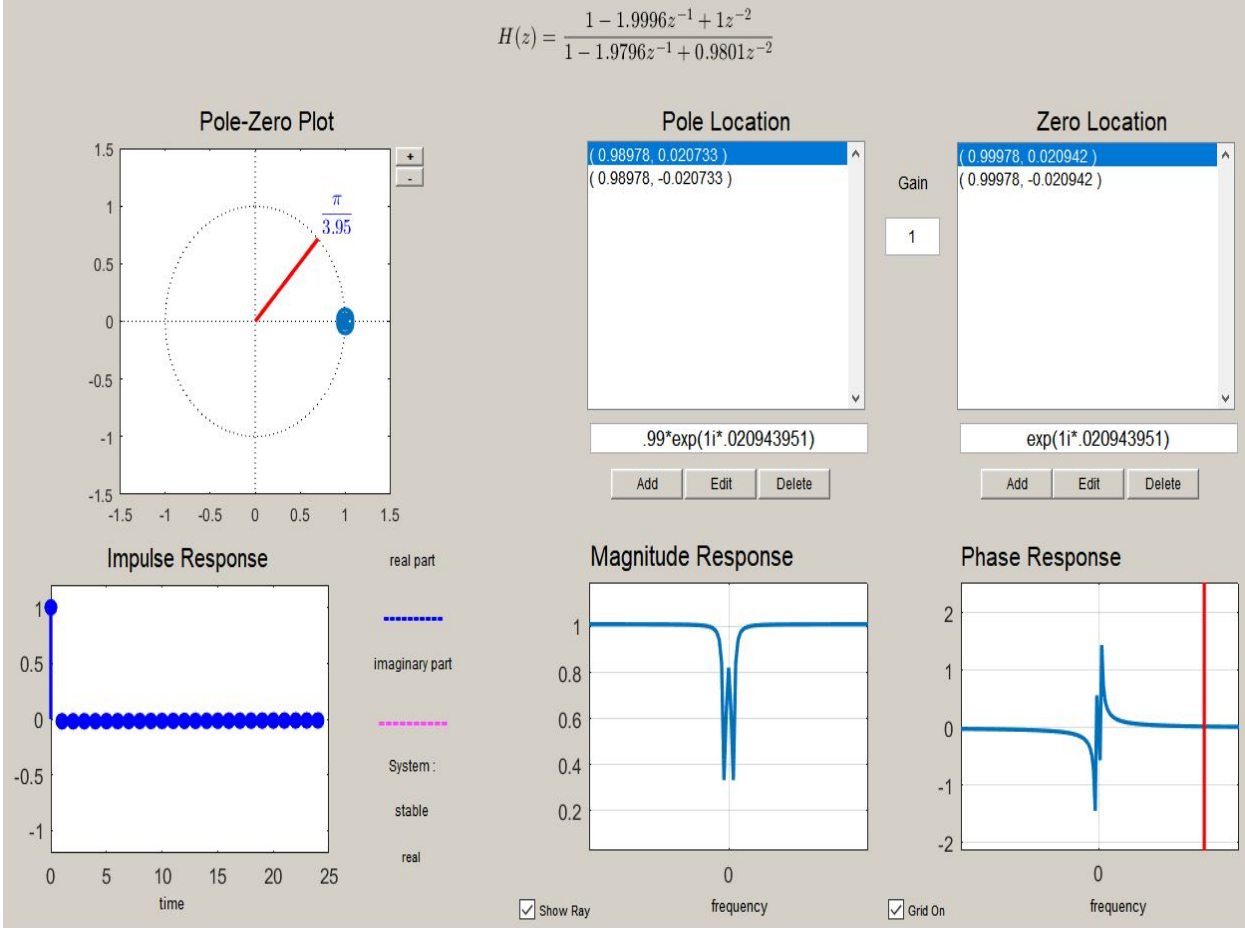
Distortion factor *THD* (*k*) 36.9402644 %

THD		
k	k (%)	a_k (dB)
factor	percent	decibel
1	100	0
0.5	50	−6
0.2	20	−14
0.1	10	−20
0.05	5	−26
0.02	2	−34
0.01	1	−40
0.005	0.5	−46

Source:
http://www.sengpielaudio.com/calculator-thd.htm

SNR - Alt. test

- Digital notch filter
- 3rd string on an electric guitar is D3 (Fi = 147 Hz)*
- Fs = 44,100 samples/sec
- DT angular frequency Ω = 2π(Fi/Fs)
- Check SNR after A->D conversion



*Source: http://www.swarthmore.edu/NatSci/ceverba1/Class/e5_2006/MusicalScales.html

Expenditure List Until MDR

Item	Amount	Cost
Teensy 4.1 without Ethernet (Header pins)	2	$81.50
Voltage Regulator 9V to 5V	6	$5.34
CS4272 codec	2	$24.22
SD card 8GB	1	$6.99
Op Amps	8	$17.43
Misc Electronics		$114.69
PCB	5	$25.81
Total		$250.17

CDR Expenditure List

Item	Amount	Cost
PCB	5	$30.00
Audio Codecs for testing	6 (2 of each)	$30.00
Misc Electronics		$50.00
Subtotal		$110.00
Total		$360.17

MDR Deliverables (From our PDR Presentation)

A benchtop, breadboarded proof of concept that can record one track of audio and playback along with the direct analog-dry-through signal.

- No enclosure at this point
- Volume of looping track can be controlled on the fly
- Start testing additional effects
- Include functional footswitches and led indicators
- System can playback recorded track with no audible distortion (measured between instrument in and line out)
- Draft kicad PCB layout and 3d model of user interface including control features and visual indicators
- Will demonstrate model by looping a guitar riff and adding effects

MDR Deliverables (Refactored)

MDR Specification	Complete?
Record 1 track and loop	
Mix loop track and analog dry through	
Switches control recording, playing back, and adding an effect	
Switches control indicators for each of the above functions	
Play recorded loop with no audible distortion	
Functional UI PCB*	
Control looping track volume	

*Original PDR spec had to be modified

CDR Deliverables

- Accomplishes all MDR deliverables (except no audible distortion)
- SNR >35 dB (FPR Specification: >70 dB)
- THD <10% (FPR Specification: <1%)
- Attempt using a better codec (such as SGTL5000) or separated AD/DAC
- Revised PCB design
  - New voltage regulator, onboard microcontroller, onboard amplifiers
- Demonstrate in same way as MDR demo
  - Loop a guitar solo and add effects

Gantt Chart

L.O.O.P.S

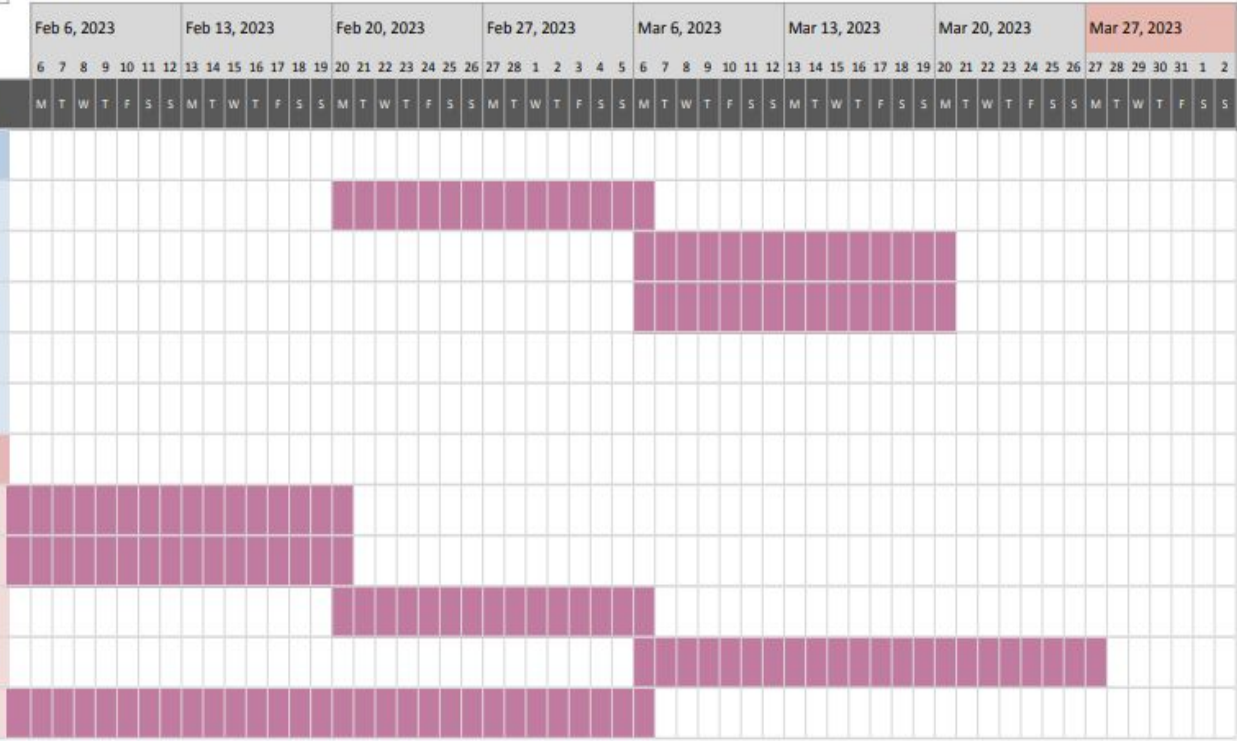
SDP 23

Buzhuo Chen, John Folliard, Ben Rotker, Yunrui Yu

Project Start: Mon, 2/6/2023

Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Software				
Coding for new codec	Buzhuo		2/20/22	3/6/22
Add new effect	Ben		3/6/22	3/20/22
Add new track	Buzhuo		3/6/22	3/20/22
Hardware				
Set up new codec	Buzhuo, Yunrui		2/6/23	2/20/23
Set up new ADC	Buzhuo, Yunrui		2/6/23	2/20/23
Solve SD card	Buzhuo, Yunrui		2/20/23	3/6/23
Improve SNR and THD	John, Ben		3/6/23	3/27/23
PCB design	John, Ben		2/6/23	3/6/23



QUESTIONS & ANSWERS

University of Massachusetts Amherst