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

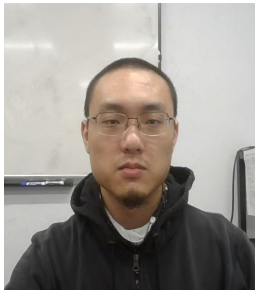
LOOPS Open Orchestrator Production System

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



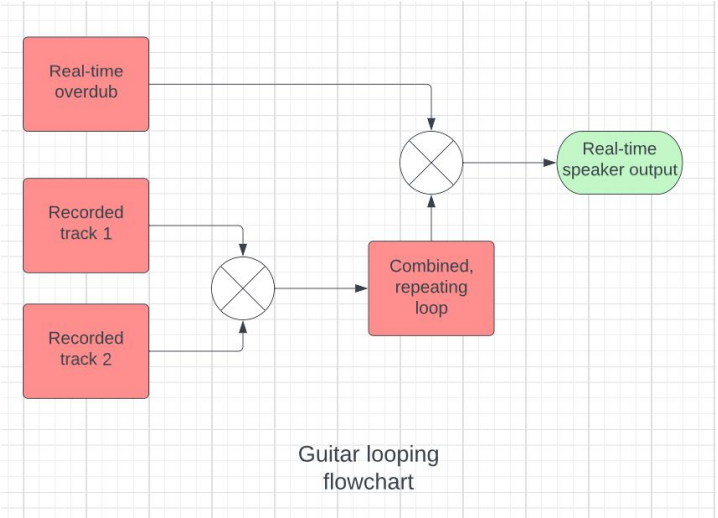
Buzhuo Chen
(CompE)
Software Lead

Yunrui Yu
(EE)
Hardware Lead

Ben Rotker
(CompE)
Logistics Lead
Form Factor Lead

Background

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



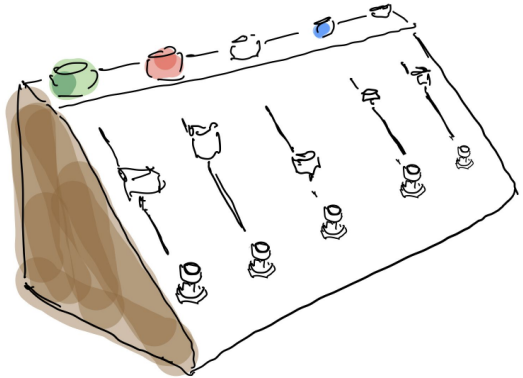
Problem Statement

- There is a lack of open source and extensible gear for performing musicians.
- Different effects typically need different pedals.
- Commercial products are almost exclusively closed source and not easy for an end user to make modifications.
- Some projects exist that combine the benefits of looper pedals and effects pedals into one singular user interface (also closed source).
- This makes it challenging to add effects without acquiring more gear, colloquially known as G.A.S. (Gear Acquisition Syndrome).

Goals, Specifications, and Testing Plan

Goals

- One product that records, loops, adds effects and overdubs audio
- Intuitive user interface that does not distract from performance
- High-fidelity audio
- Open source project so users can modify and collaborate as desired



Specifications

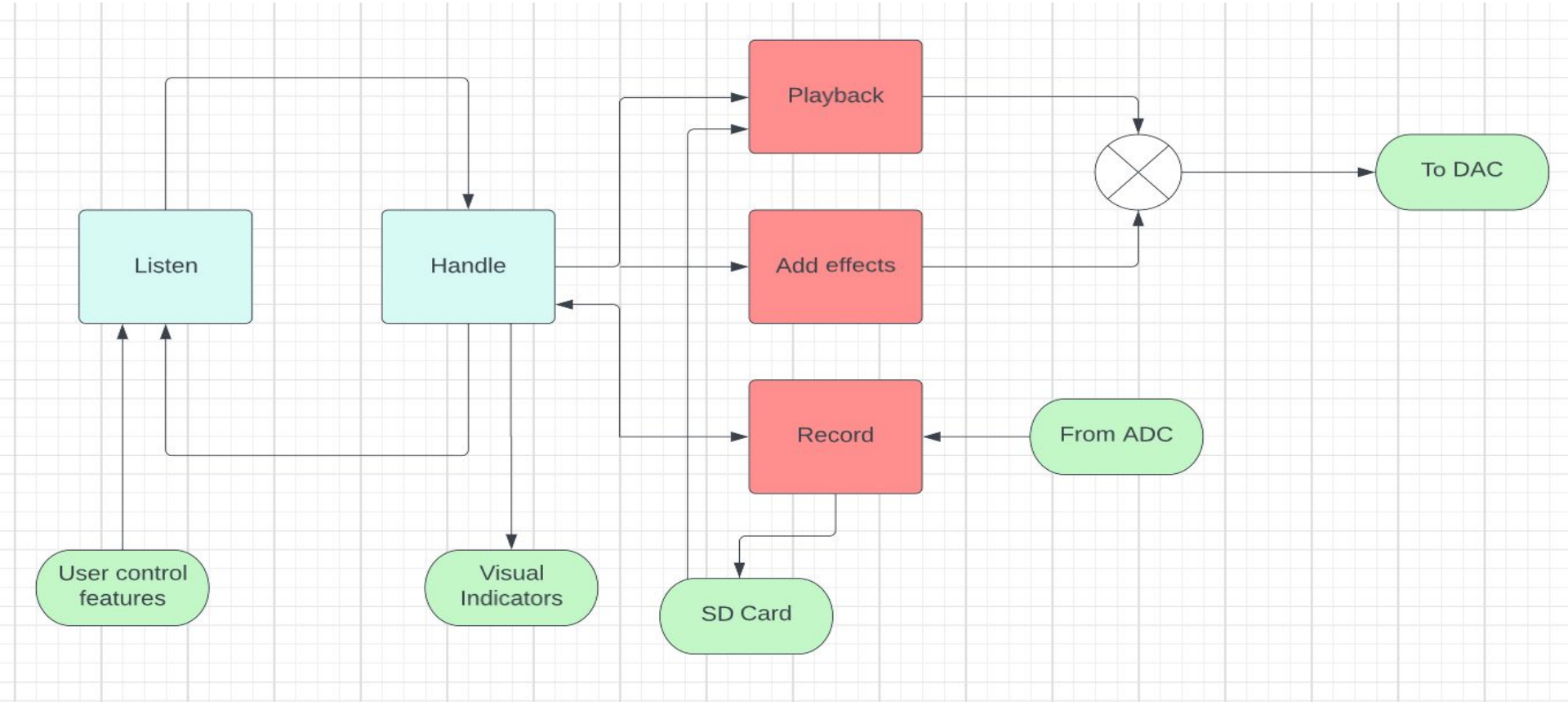
Specification	Test plan
2 tracks of Hi-Fi audio, i.e. f_s = 44.1 kHz, 16 bit	Play different frequencies on each track and playback simultaneously
Imperceptible latency, i.e. less than 10 ms	Measure the time between feedback pulses to get the sum of the output latency, input latency, and application overhead
THD less than 1%	Tektronics DPO4032 Digital Phospor Oscilloscope MATLAB
SNR greater than 70 dB	
UI visible from 6–8 feet	Viewer stands between 6-8 feet away, describes what they see on visual indicators, compare to known display

Preliminary results and justifications

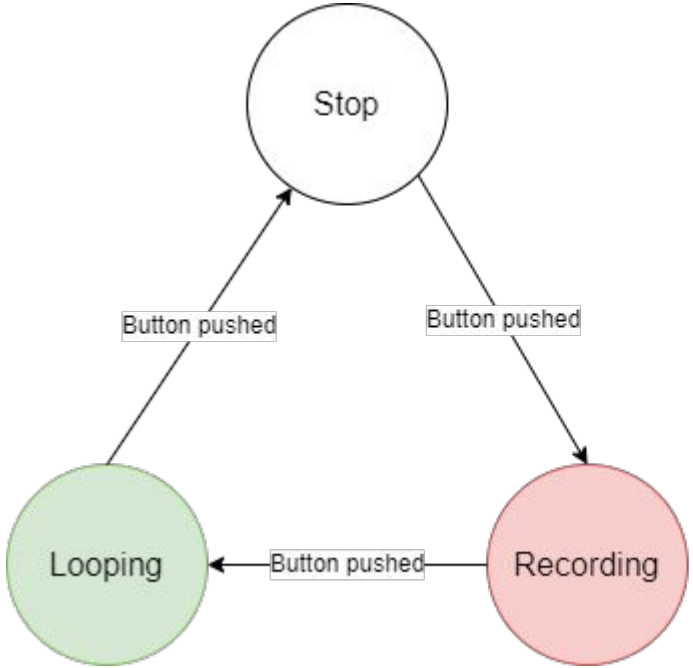
- We have decided to use an isolated DC power supply
  - Battery life unacceptable due to digital components' current draw
  - Many digital effect pedals encourage the use of an isolated power supply and many do not have option to power by battery
  - The supply we have chosen is commonly used and available at music shops
- We have demonstrated throughout that our UI elements are visible from 6–8 ft away
- SNR 14.76 dB
- THD -6.84 dB
- Latency in mid-teens to low-20's ms, max 22.4 ms

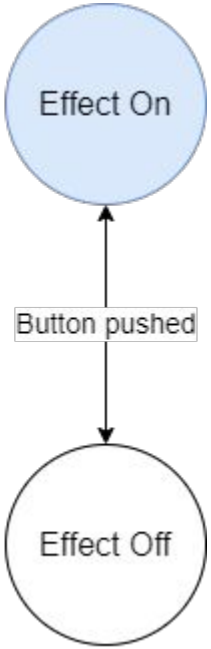
System Design Documentation

Software Block Diagram

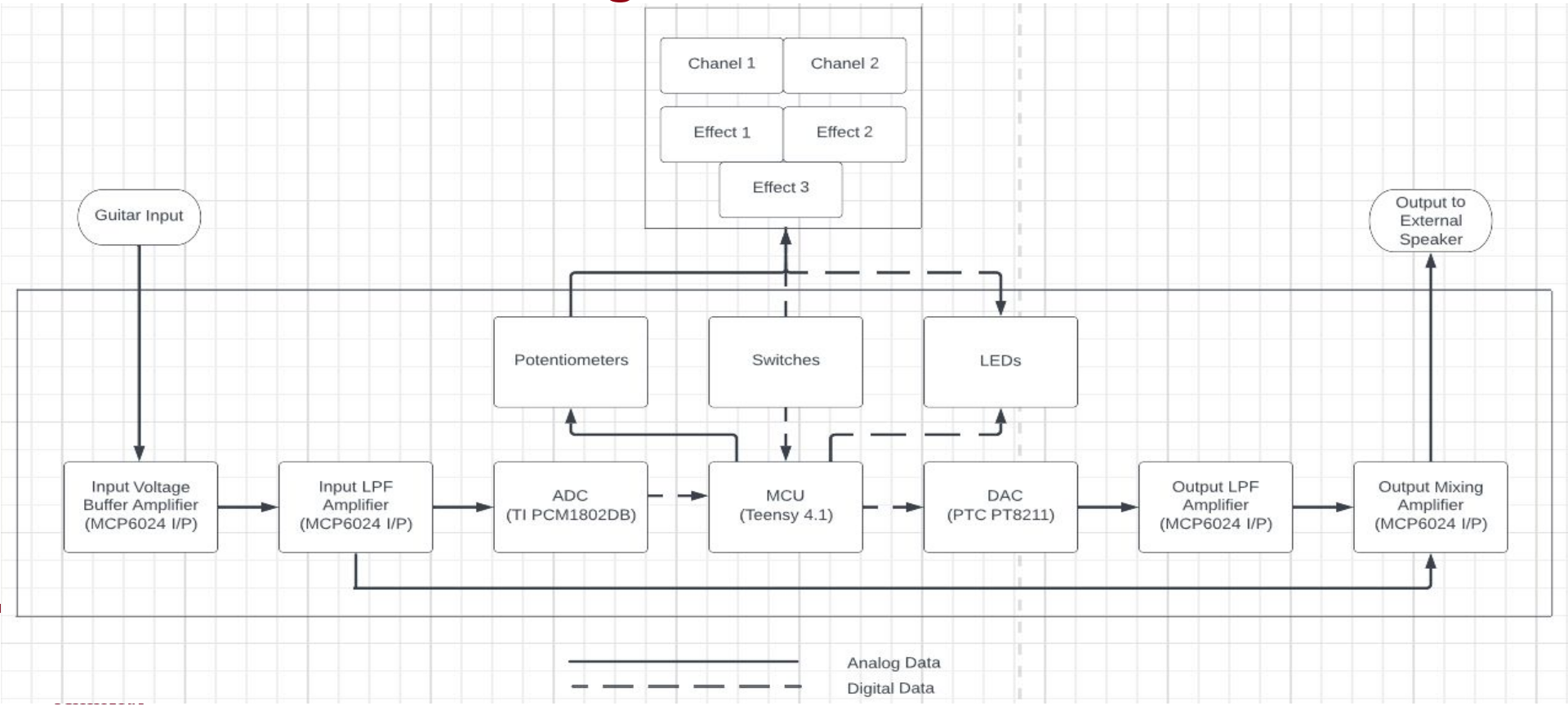


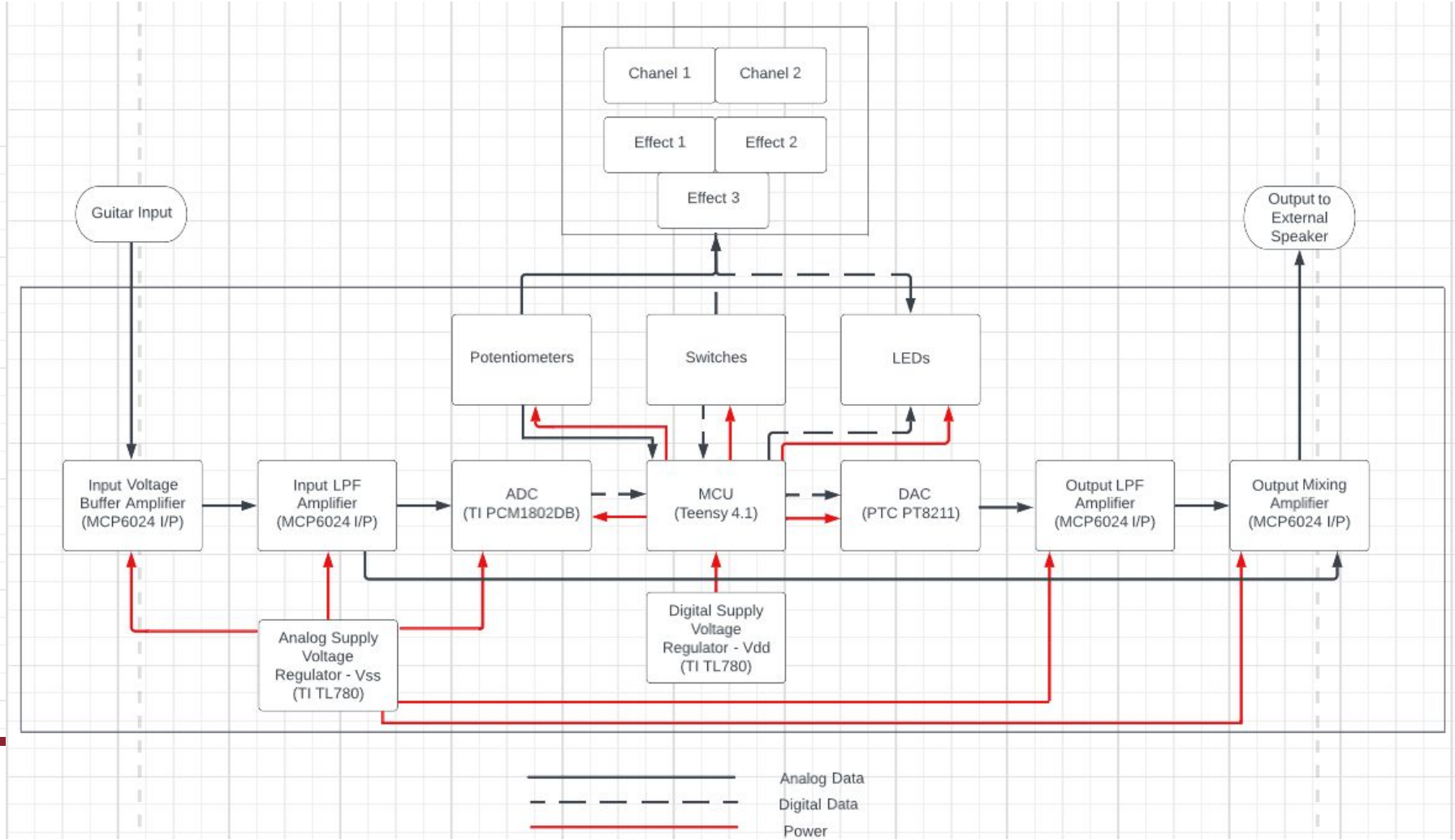
Pushbutton Control Flow





Hardware Block Diagram




Chanel 1
Chanel 2
Effect 1
Effect 2
Effect 3
Guitar Input
Output to External Speaker
Potentiometers
Switches
LEDs
Input Voltage Buffer Amplifier (MCP6024 I/P)
Input LPF Amplifier (MCP6024 I/P)
ADC (TI PCM1802DB)
MCU (Teensy 4.1)
DAC (PTC PT8211)
Output LPF Amplifier (MCP6024 I/P)
Output Mixing Amplifier (MCP6024 I/P)
Analog Supply Voltage Regulator - Vss (TI TL780)
Digital Supply Voltage Regulator - Vdd (TI TL780)
Analog Data
Digital Data
Power

Hardware Components Justified

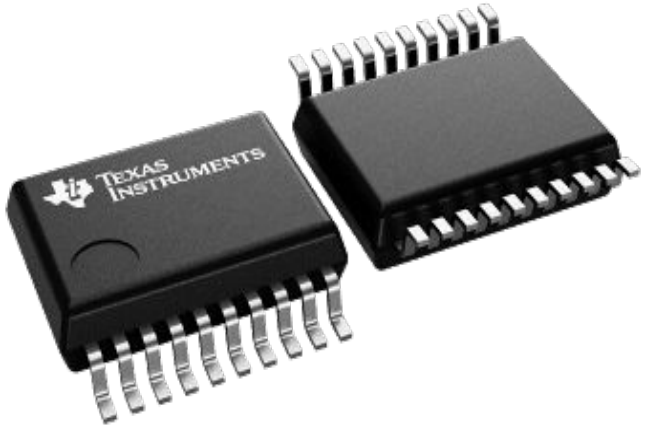
Microchip MCP6024 Operational Amplifier

- 4 op amps in a single 14-dual inline package
- Input noise current density: **3 fA/√Hz** at f = 1kHz
  - Typ. 0.1 fA/√Hz to 10 pA/√Hz
- Input noise voltage density: **8.7 nV/√Hz** at f = 10kHz
  - Typ. 1 nV/√Hz to 20 nV/√Hz [2]
- Typ. 10 MHz Bandwidth
- Accepts 2.5 V to 5.5 V power supply [2]

[2] : MCP6024 Datasheet
[3] : Input noise current/voltage density

Hardware Components Justified

Texas Instruments PCM1802DB

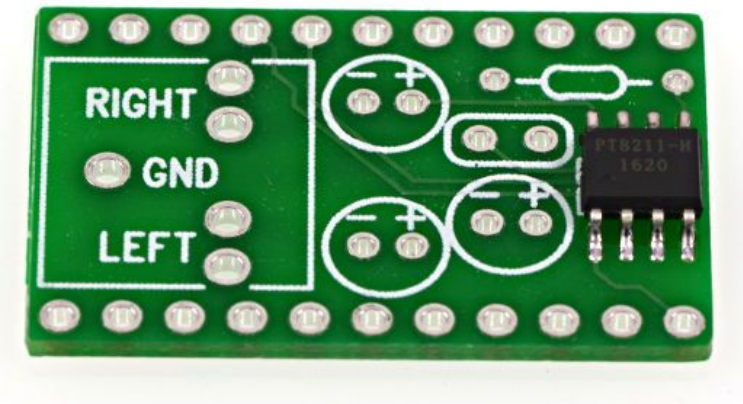


- Stereo 24 bit ADC
- Sampling Rate: 16 kHz to 96 kHz
- THD+N: 96 dB
- SNR: 105 dB
- Single-Ended Voltage Input

[4] : PCM1802 Datasheet

Hardware Components Justified

Princeton Tech. Corp. PT8211

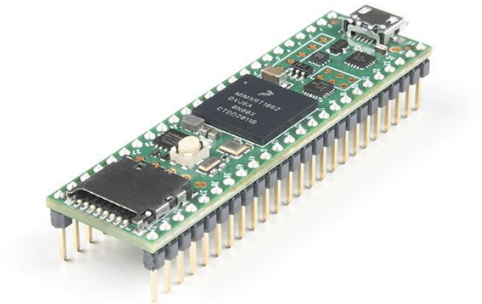


- Dual channel, 16 bit DAC
- Up to 384 kHz sampling rate
- THD: 0.1% with 1KHz
- SNR: 93 dB
- Single-Ended Voltage Input
- Recommended by Teensy website

[5] : PT8211 Datasheet

Hardware Components Justified

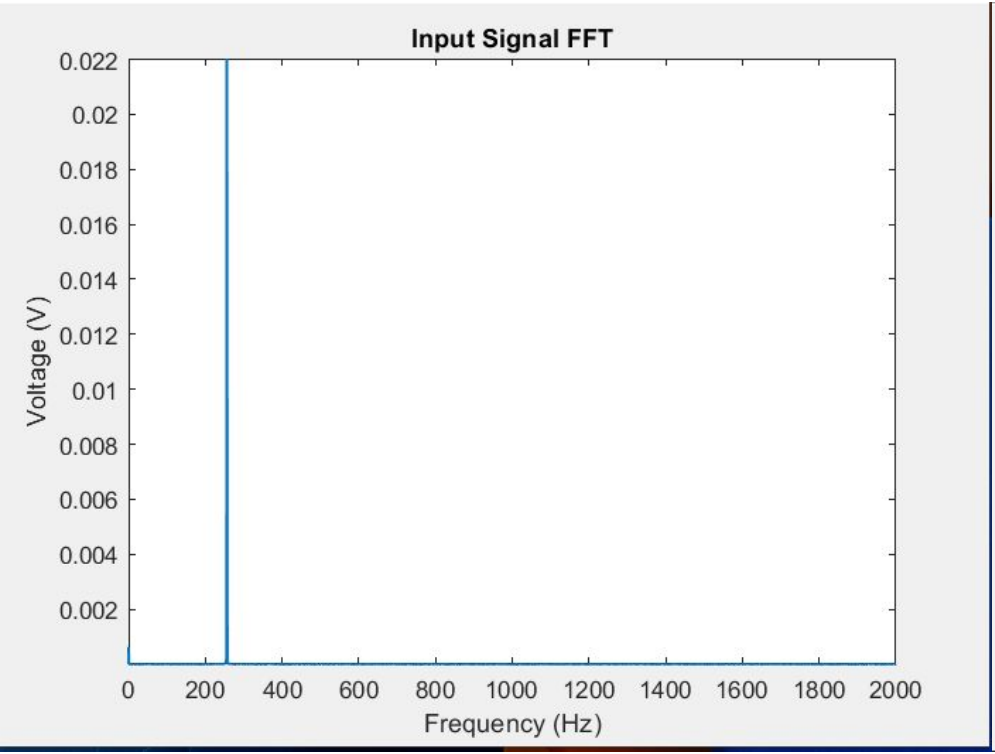
Teensy 4.1 Development Board

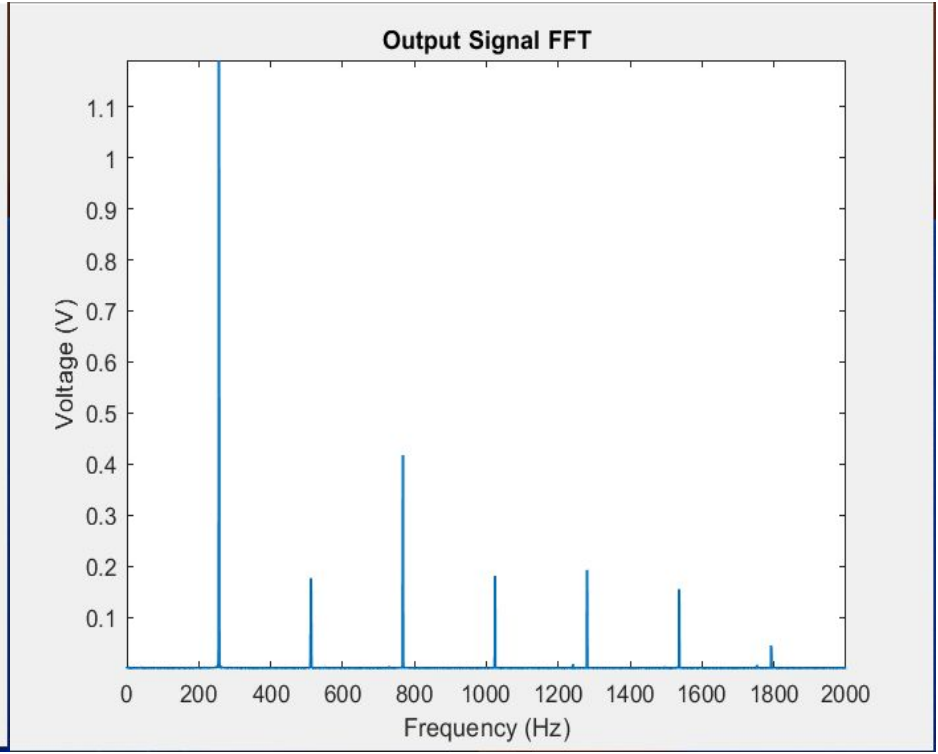


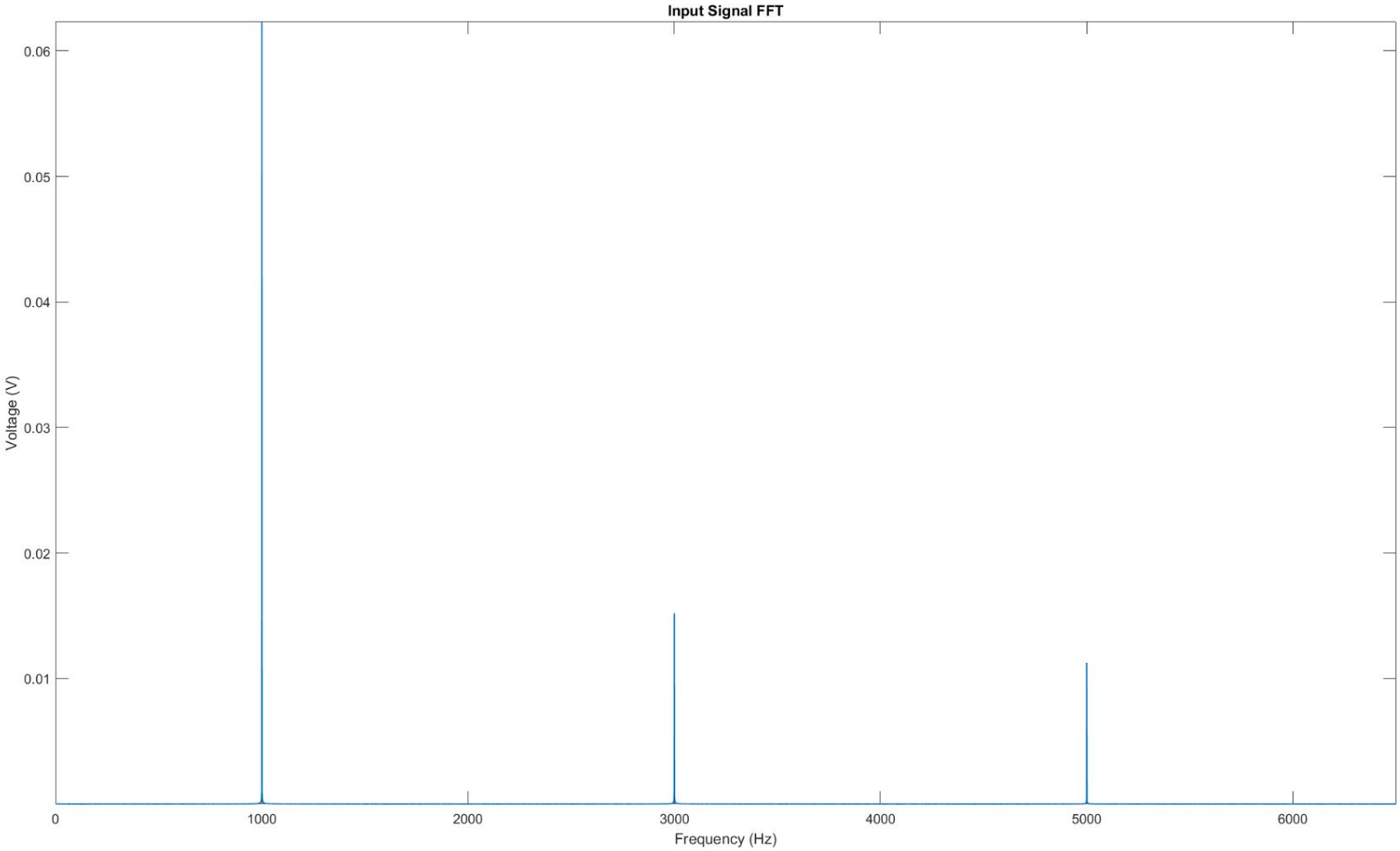
- ARM Cortex M7 at 600 MHz
- 55 digital I/O pins
- 18 analog input pins
- SD card slot
- 3 SPI ports
- 2 I2S ports

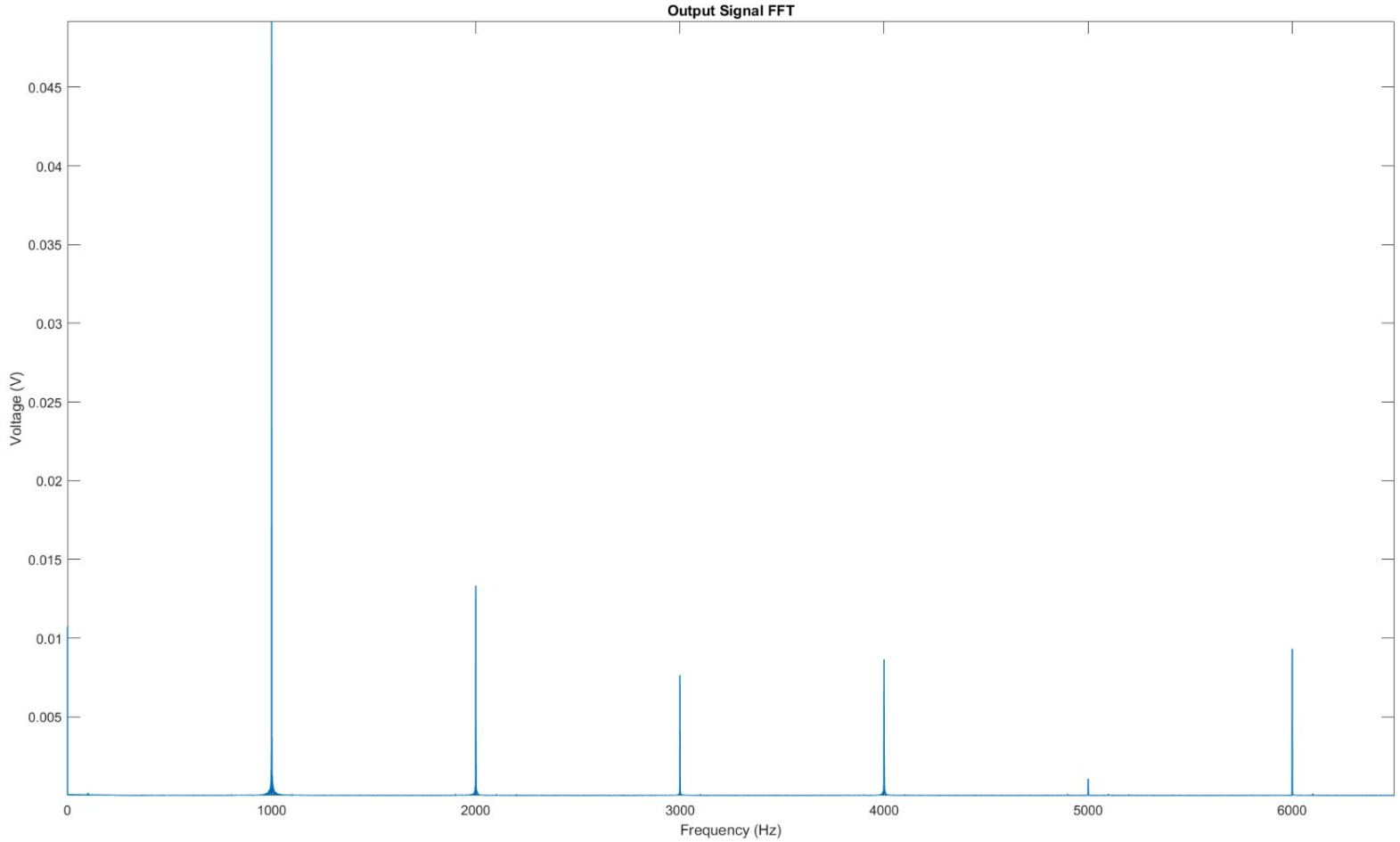
[6] : Teensy 4.1 Datasheet

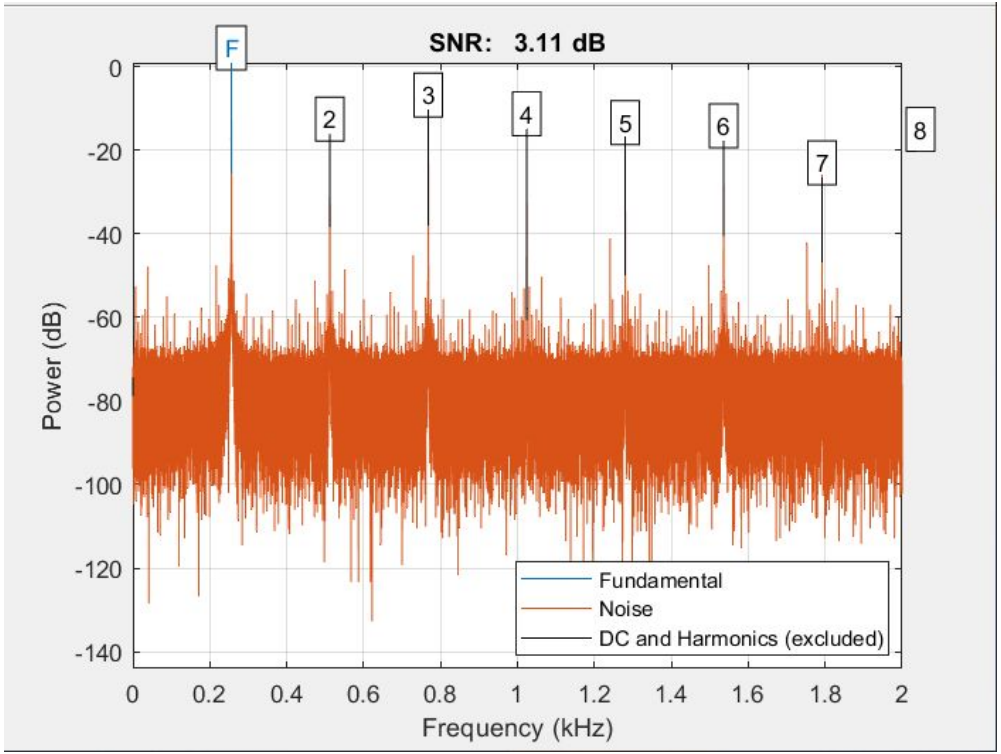
Performance

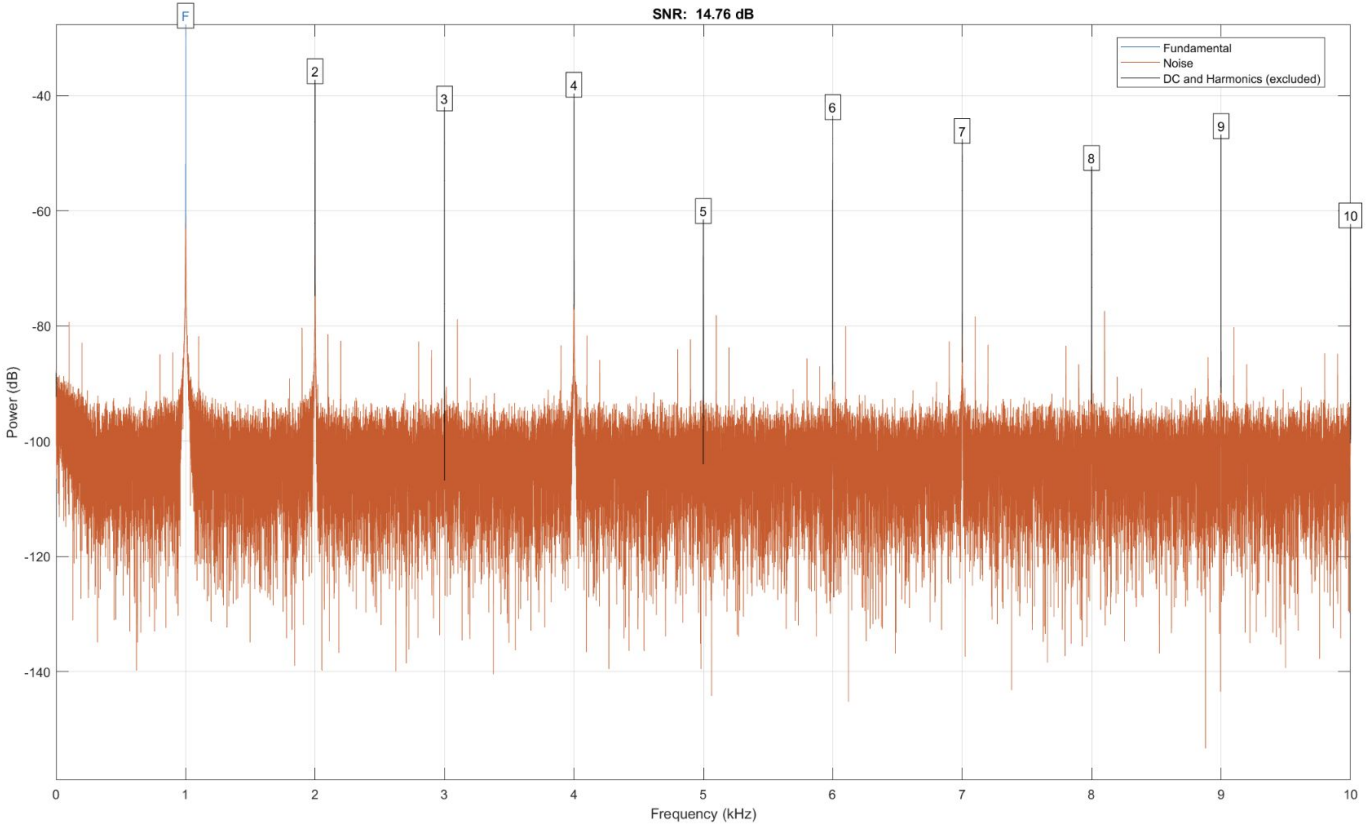

Input Signal FFT
Voltage (V)
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Frequency (Hz)

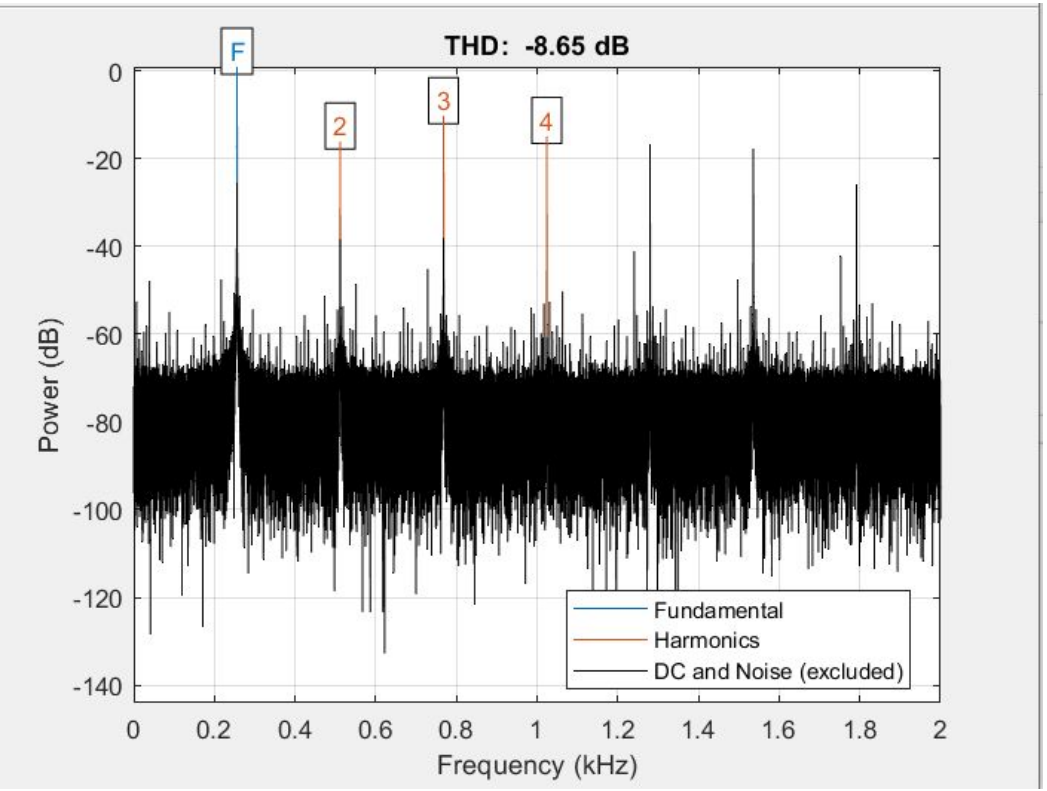

Output Signal FFT
Voltage (V)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Frequency (Hz)


Input Signal FFT
0.06
0.05
0.04
0.03
0.02
0.01
Voltage (V)
0
1000
2000
3000
4000
5000
6000
Frequency (Hz)


Output Signal FFT
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
Voltage (V)
0
1000
2000
3000
4000
5000
6000
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)


SNR: 14.76 dB
Fundamental
Noise
DC and Harmonics (excluded)
F
2
3
4
5
6
7
8
9
10
Power (dB)
-40
-60
-80
-100
-120
-140
0
1
2
3
4
5
6
7
8
9
10
Frequency (kHz)



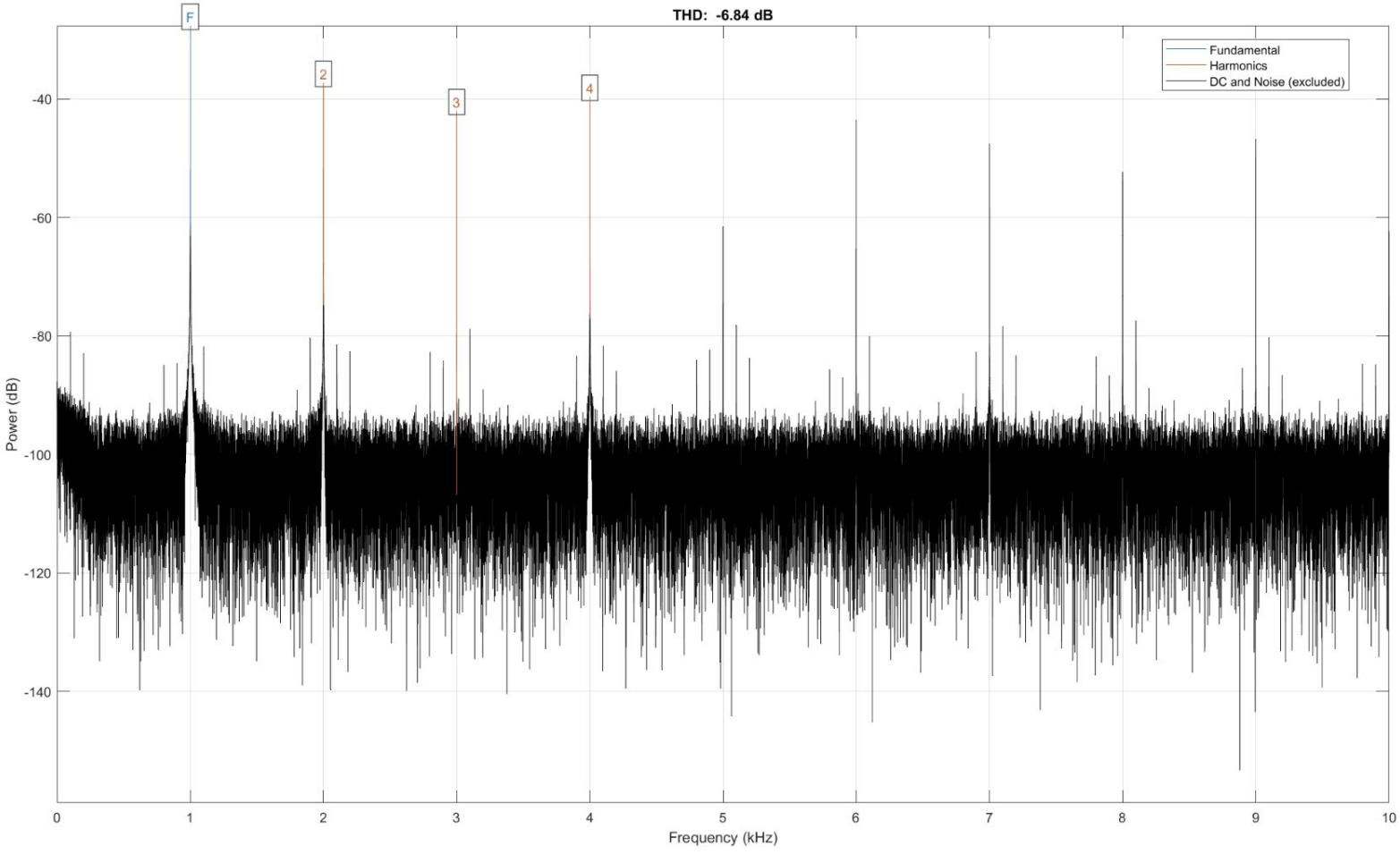
Distortion attenuation *a* -8.65 dB

↓ calculate

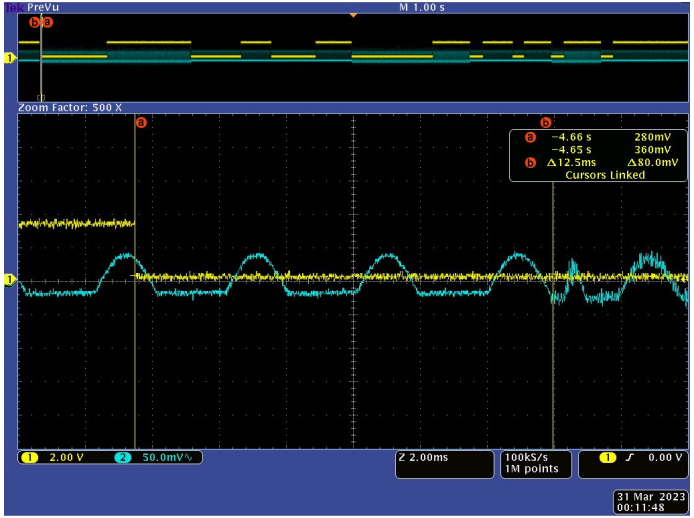
Distortion factor *THD* (*k*) 36.9402644 %

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


THD: -6.84 dB
Fundamental
Harmonics
DC and Noise (excluded)
F
2
3
4
Power (dB)
-40
-60
-80
-100
-120
-140
0
1
2
3
4
5
6
7
8
9
10
Frequency (kHz)

Min and Max Latency



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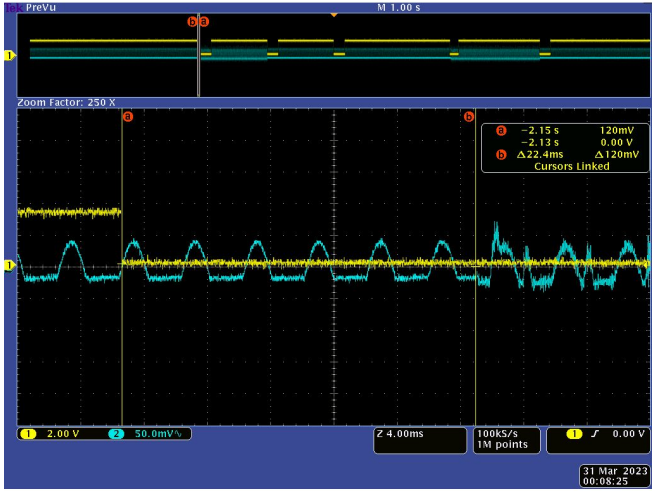

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Deliverables

CDR Deliverables - Page 1/2

CDR 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	
Functional UI PCB	
Control looping track volume	

CDR Deliverables - Page 2/2

CDR Specification	Complete?
SNR > 35 dB	
THD < 10%	
Better codec or separate ADC / DAC	
Revised PCB Design (New voltage regulator, onboard MCU, onboard amplifiers)	
Demonstrate by looping a guitar solo and adding effects	

SD Cards

- **Slow random access speed of SD card would cause clips and dropouts**
- **Goal: reading: 44.1*2*2 = 176.4 KB/s; writing: 44.1*2*1 = 88.2KB/s; as low latency as possible**
- **Test with 512 bytes per r/w, 2 16-MB files simultaneously, access SD card via SDio**
- **Card 1: Gigastone 8GB micro SCHC class 10**
- **Card 2: SAMSUNG EVO Select SDXC U3 128GB**

	Max Latency (us)	Total speed (KB/s)	Speed/File (KB/s)
Card 1 reading	23716	421.07	210.53
Card 2 reading	3119	1100.47	550.24
Card 1 writing	111007	154.27	77.13
Card 2 writing	30523	266.44	133.22

Project Expenditures and Management

Expenditure List - Integrated Circuits

Item	Quantity	Cost
Codecs	3	$28.60
ADCs	7	$28.38
Amplifiers	10	$16.47
Voltage Regulators	9	$10.62
DACs	4	$10.60
ADC Breakout Board	1	$7.99
Amplifier Breakout Board	1	$5.95
Shift Registers	3	$3.78

Expenditure List - PCBs + Components

Item	Quantity	Cost
PCBs	5	$30.80
MCUs	2	$83.76
Adaptor Boards	4	$27.82
Capacitors	34	$21.52
SD Card	1	$16.95
Resistors	28	$7.48
PCB Standoffs	8	$1.55

Expenditure list - User Interface Components

Item	Quantity	Cost
Footswitches	4	$26.40
Slide Potentiometers	6	$12.48
Audio Jacks	2	$6.72
Teensy Headers for PCB	2	$2.10
Component Total	-	**$351.95**
Shipping	-	**$143.05**
Grand Total	-	**$495.00**

Gantt Chart

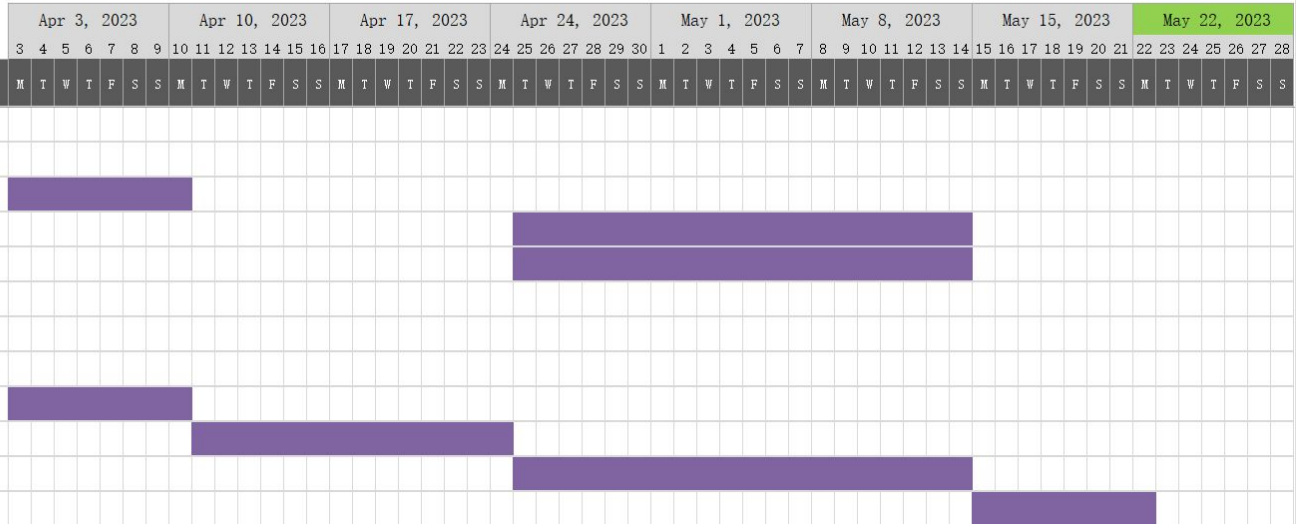
L. 0. 0. P. S.

SDP 23

Project Start: Mon, 4/3/2023

Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Software				
"Adjust LED brightness" function			4/3/23	4/10/23
Reduce noise from software side			4/25/23	5/14/23
Measure THD and SNR			4/25/23	5/14/23
Hardware				
Redesign PCB			4/3/23	4/10/23
Assemble and solder PCB			4/11/23	4/24/23
Improve SNR and THD			4/25/23	5/14/23
Assemble the finished looper			5/15/23	5/22/23



QUESTIONS & ANSWERS

University of Massachusetts Amherst