SDP23 Team 24: Good 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

FPR rubric

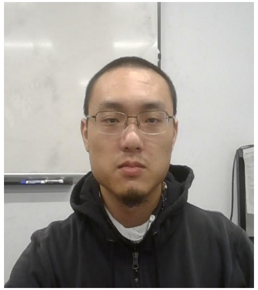
Presentation & Demo (10%)
The presentation:
- Includes the problem statement
- Demonstrates teamliness
- Was scheduled in a clear and professional manner
- Is well-rehearsed; the demonstration goes smoothly and communicates key points effectively

Documentation (Comprehensive) (30%)
- Include all forms of documentation necessary to describe the final system
- Include goals, specifications, and testing plans
- Include test results and analysis
- Include updated hardware block diagram(s)
- Include updated software block diagram(s)
- Provide justifications, explanations of all key hardware and software decisions
- Include final actual expenditures, Gantt chart

FPR System Performance (60%)
- System works, improves significantly on CDR version, and is robust
- FPR deliverables are achieved; any changes from the original plan are addressed satisfactorily
- System complies to specifications

Team Responsibilities

John Folliard
(CompE)
PCB Lead
Instrument Lead



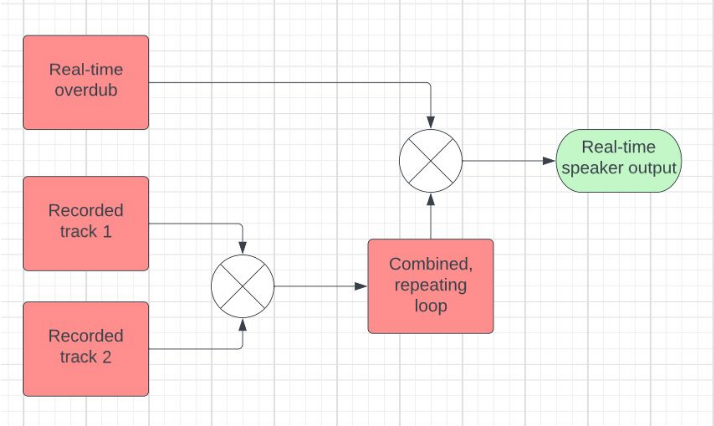
Buzhuo Chen
(CompE)
Software Lead

Yunrui Yu
(EE)
Hardware Lead

Ben Rotker
(CompE)
Logistics Lead
Enclosure Lead

Background

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



Guitar looping flowchart

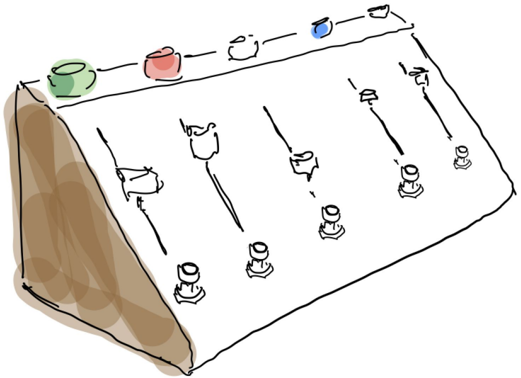
Problem Statement

- 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 and Test plans

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	Start and stop loop and measure latency using cursor function on Tektronics Digital Phosphor Oscilloscope
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

Specifications and Results

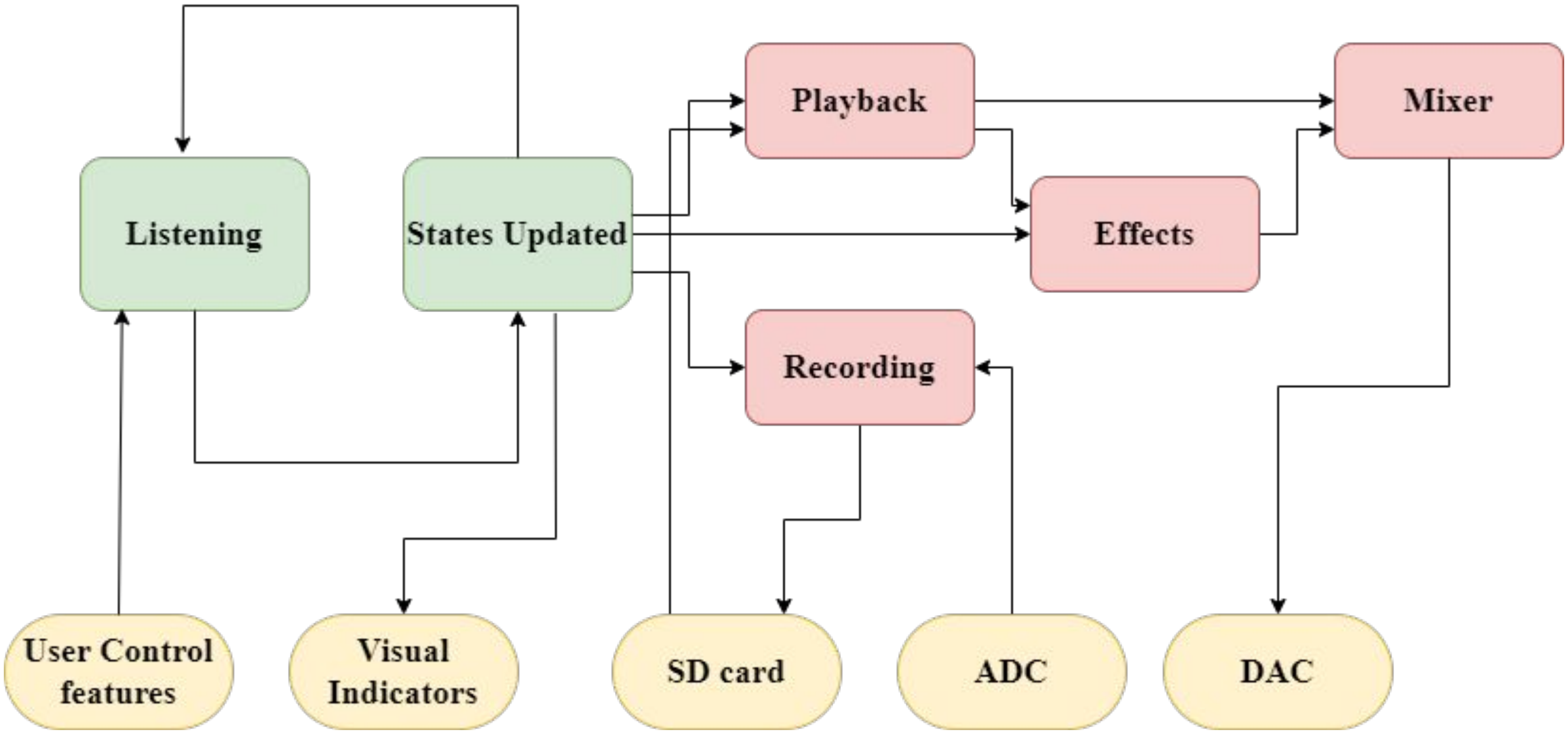
Specification	Result

2 tracks of Hi-Fi audio, i.e. f_s = 44.1 kHz, 16 bit	`(base) john@vl965-172-31-73-87 Untitled % ls -l TRACK_1.RAW`
	`-rwxrwxrwx  1 john  staff  5367552 Dec 31  2018 TRACK_1.RAW`
	$\frac{5367552}{60 \cdot 44100} \cdot 8 \approx 16.2284 \text{ bits/sample}$

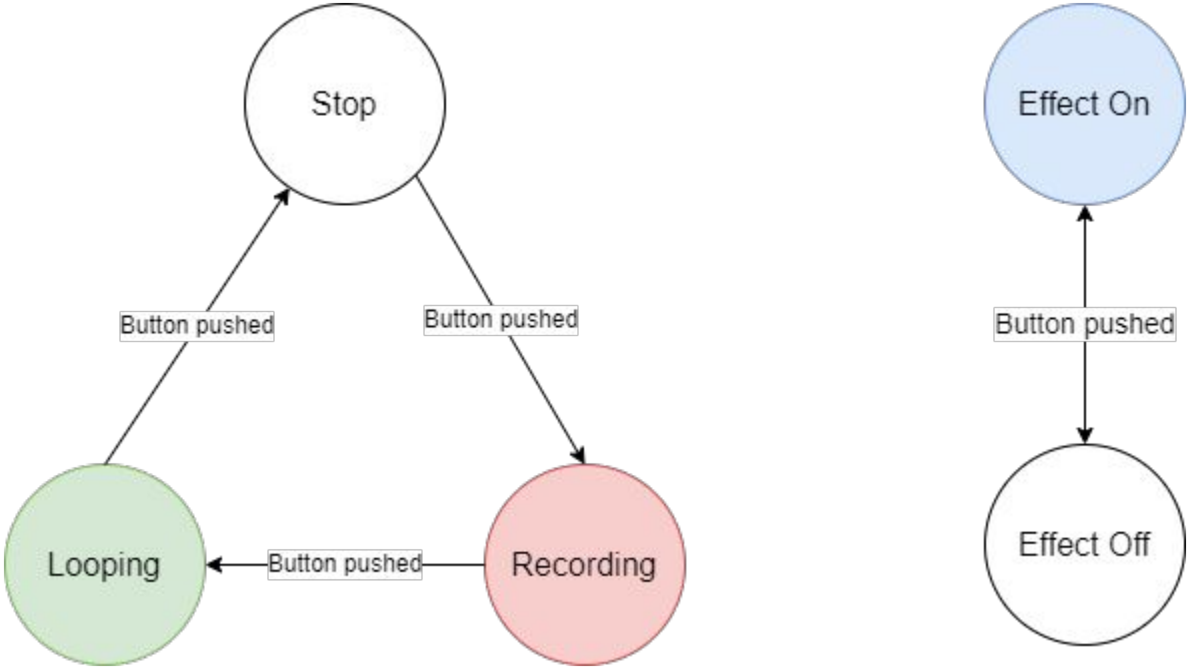
Imperceptible latency, i.e. less than 10 ms	
THD less than 1%	0.089% dry through, 0.5% looping
SNR greater than 70 dB	
UI visible from 6–8 feet	Viewer stands between 6-8 feet away, describes what they see on visual indicators, compare to known display

System Documentation

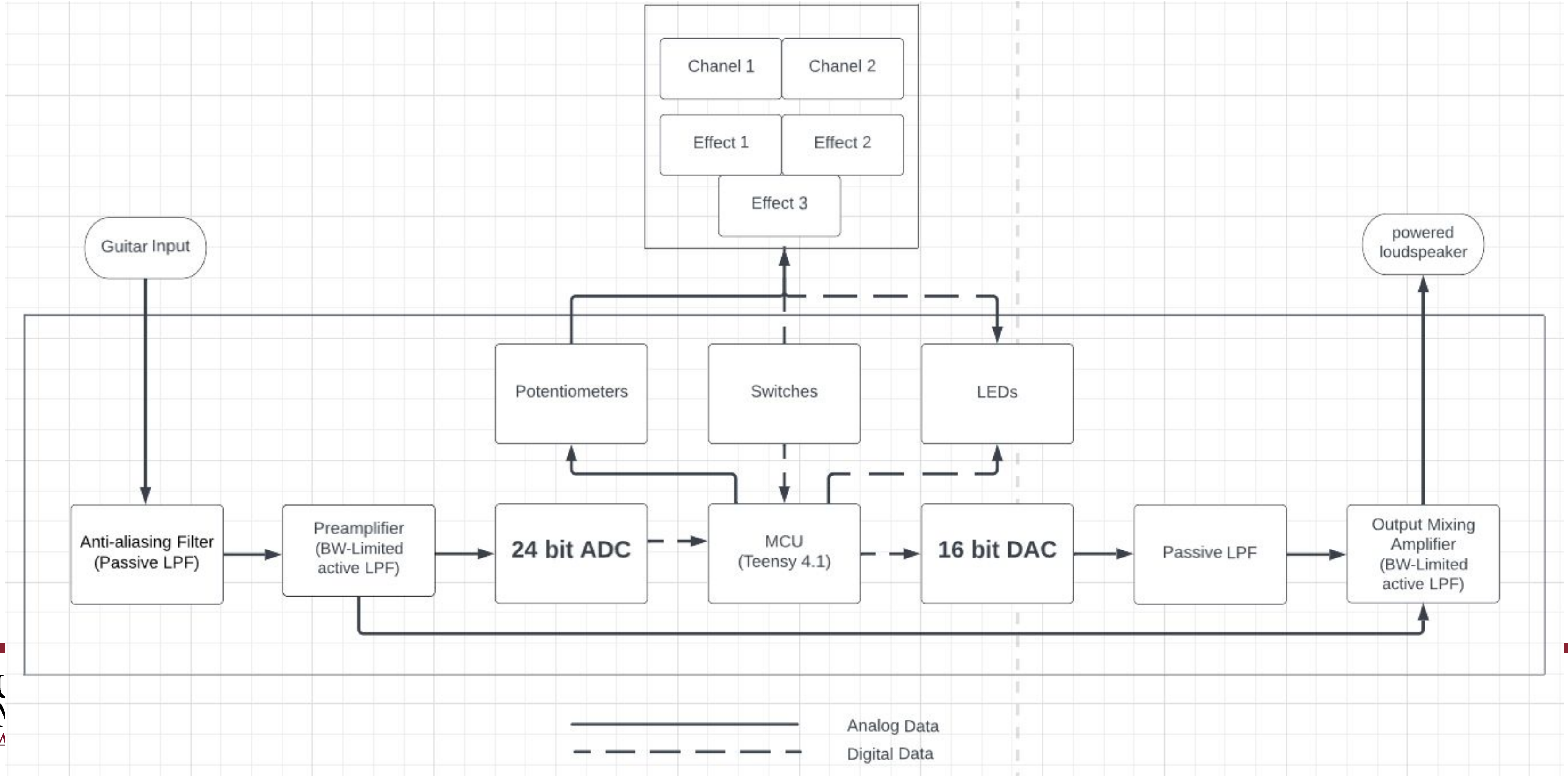
Software Block Diagram



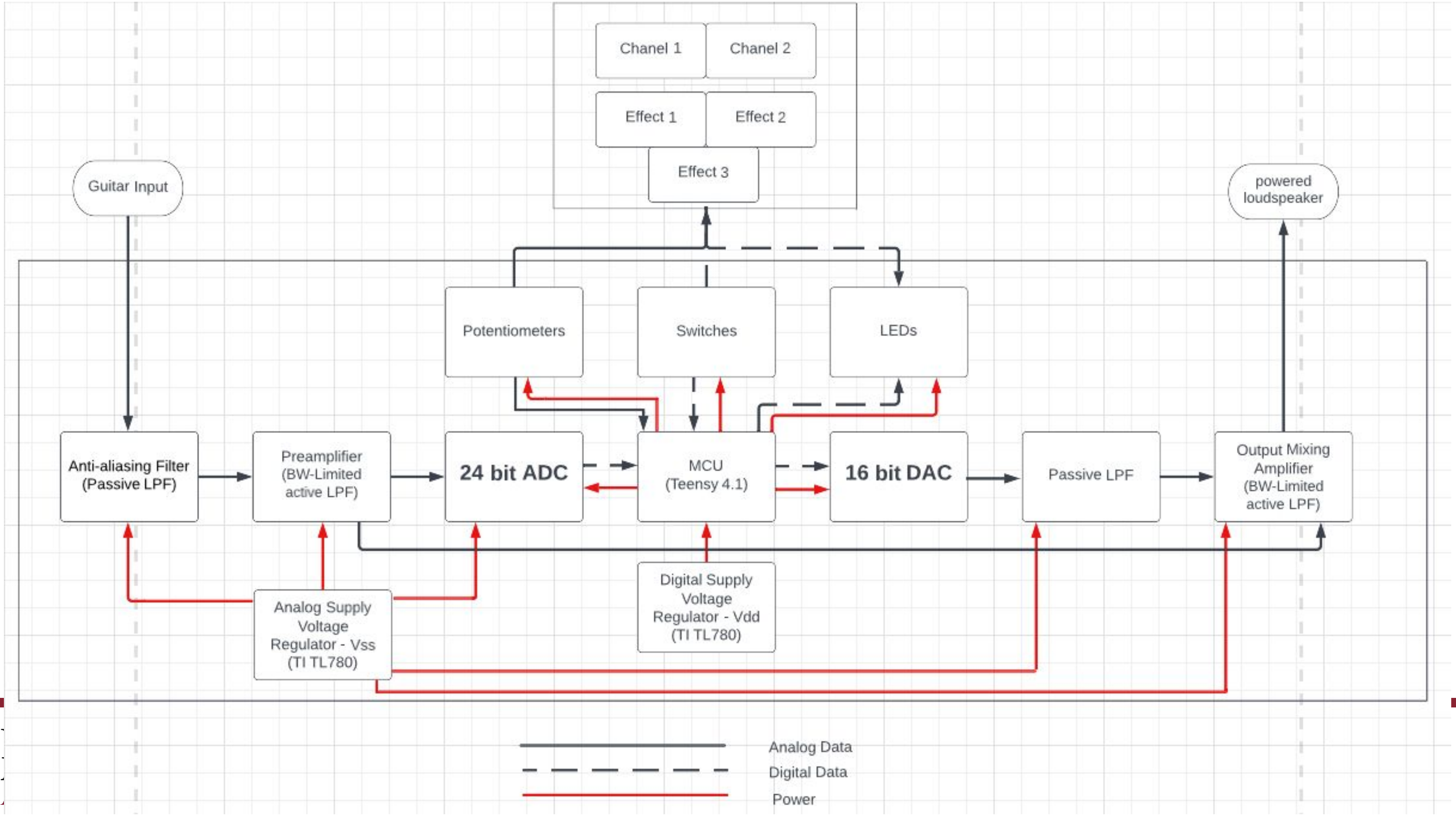
Pushbutton Control Flow



Hardware Block Diagram

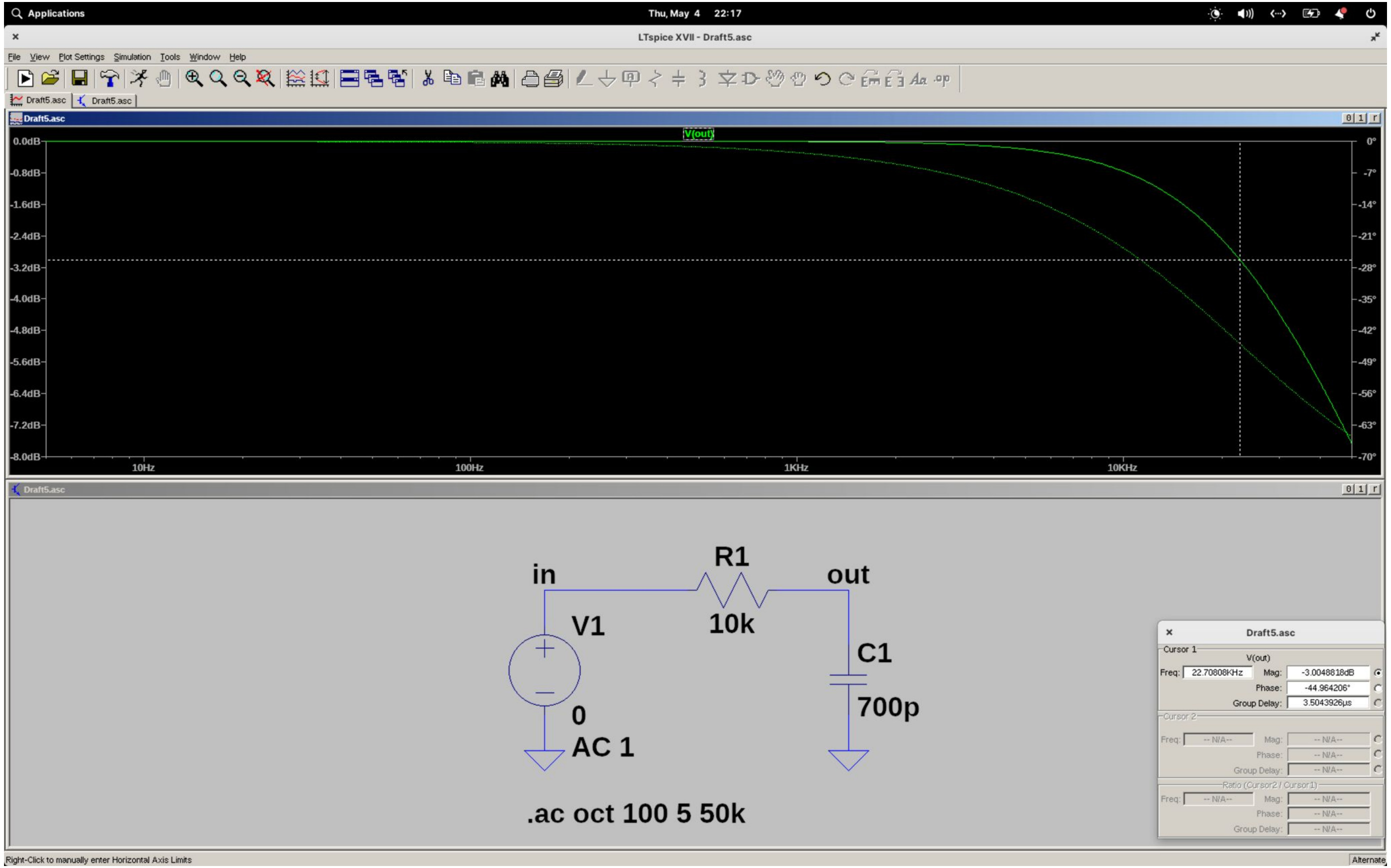


Hardware Block Diagram



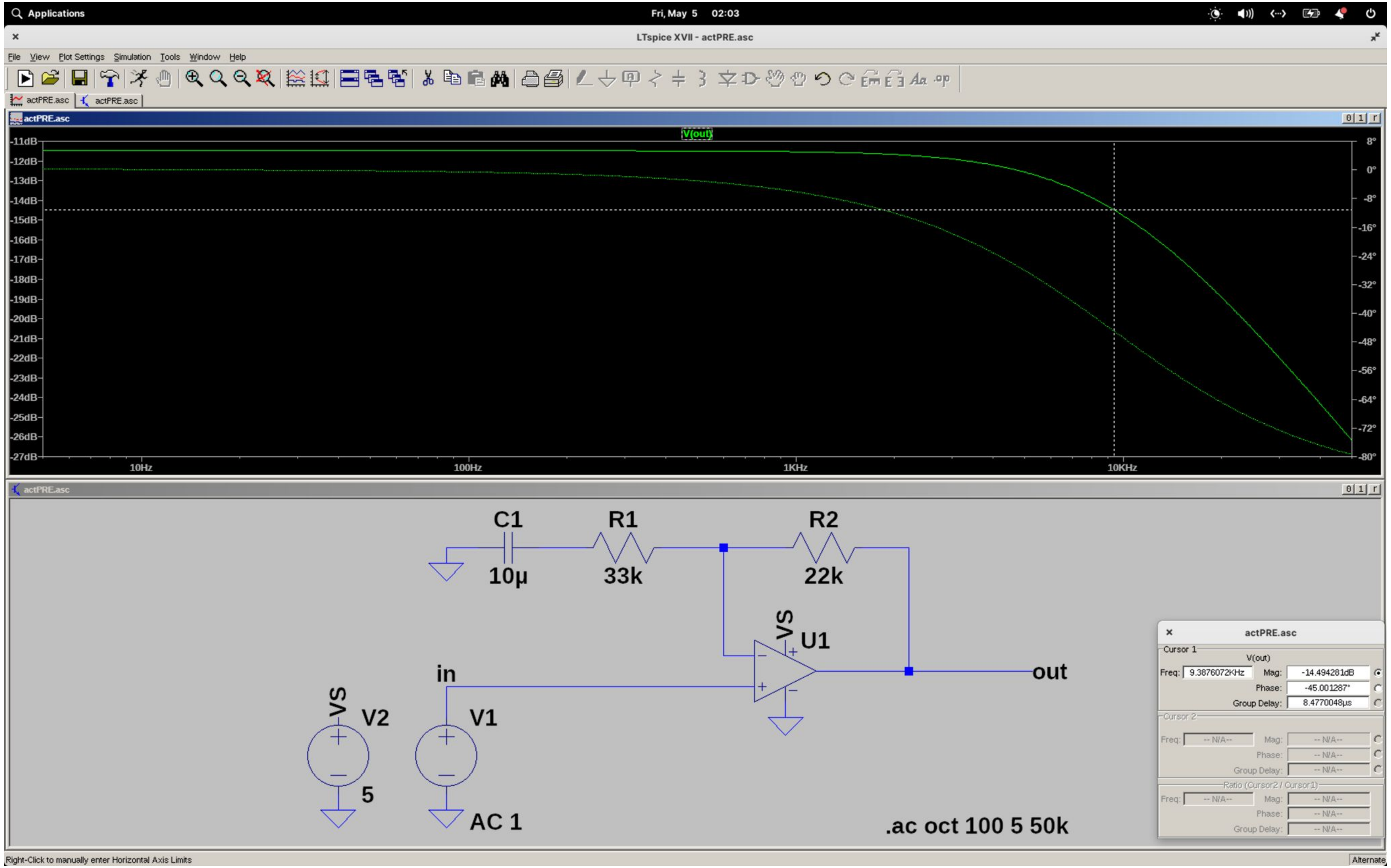
Filters and amplifiers

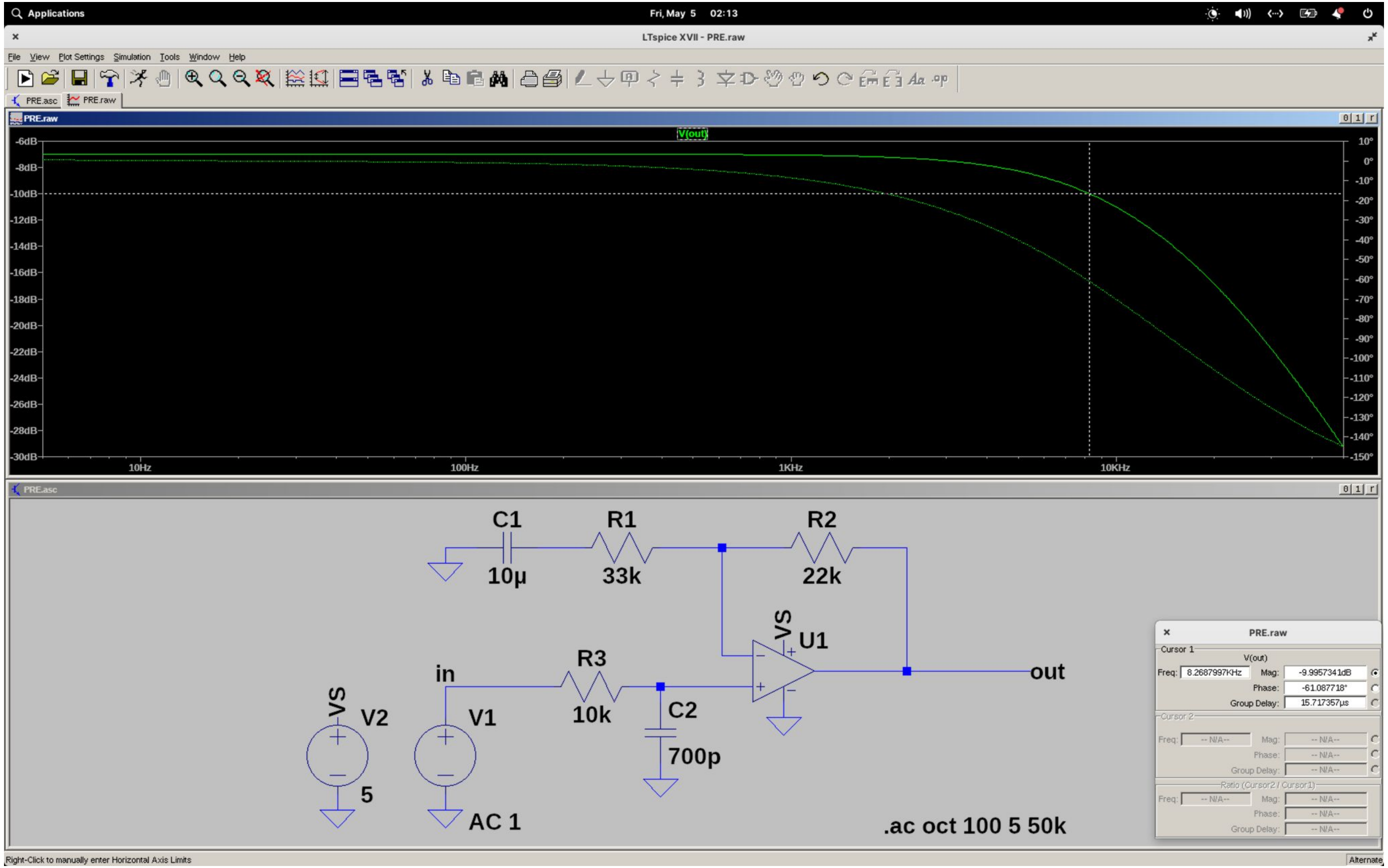
- **No more separate input buffer!**
  - We found unlimited bandwidth amplifier was putting a lot of inaudible hf noise after troubleshooting, testing, probing
  - The input buffer was not bandwidth-limited
  - Noise could have been aliased and causing noise or distortion
- **Passive low passing**
  - Used LTspice to find a suitable low pass filter to use both before ADC for anti-aliasing as well as after the DAC for smoothing
  - 3 dB cutoff frequency approx. 22.7 kHz

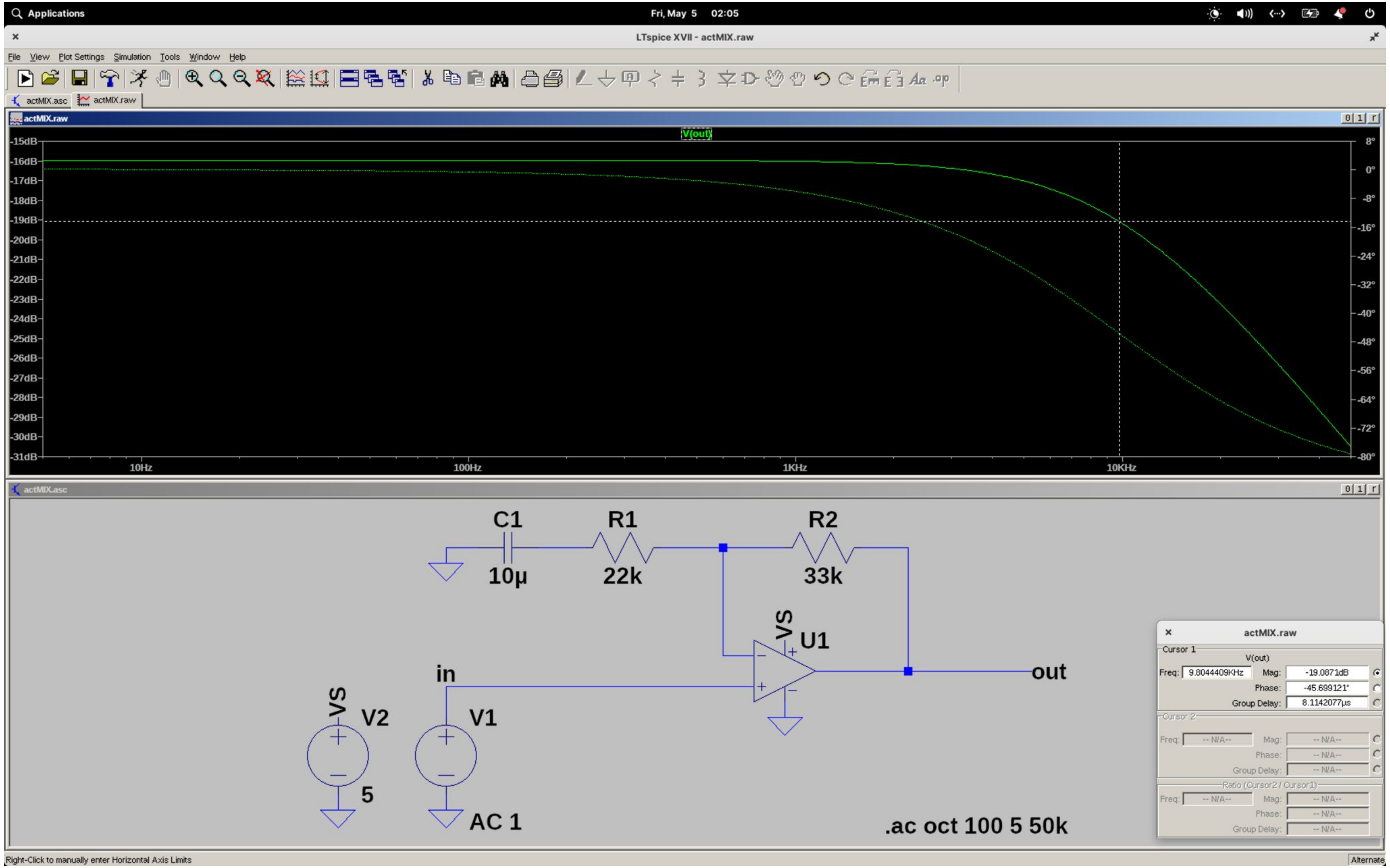

LTspice XVII - Draft5.asc
V(out)
0.0dB
-0.8dB
-1.6dB
-2.4dB
-3.2dB
-4.0dB
-4.8dB
-5.6dB
-6.4dB
-7.2dB
-8.0dB
0°
-7°
-14°
-21°
-28°
-35°
-42°
-49°
-56°
-63°
-70°
10Hz
100Hz
1KHz
10KHz
in
R1
out
V1
10k
C1
0
AC 1
700p
.ac oct 100 5 50k
Cursor 1
V(out)
Freq: 22.70808KHz
Mag: -3.0048818dB
Phase: -44.964206°
Group Delay: 3.5043926µs

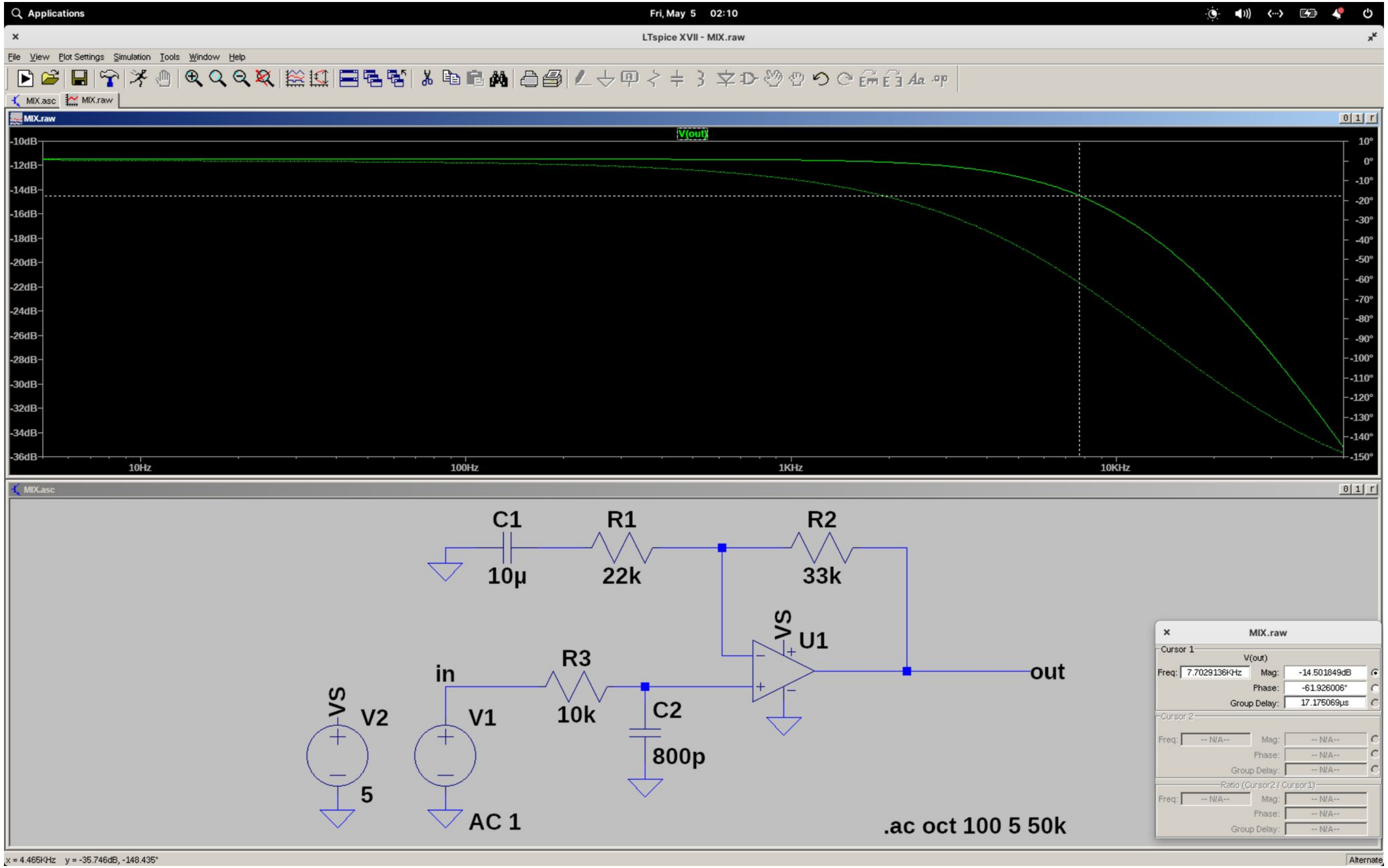
Filters and amplifiers cont'd

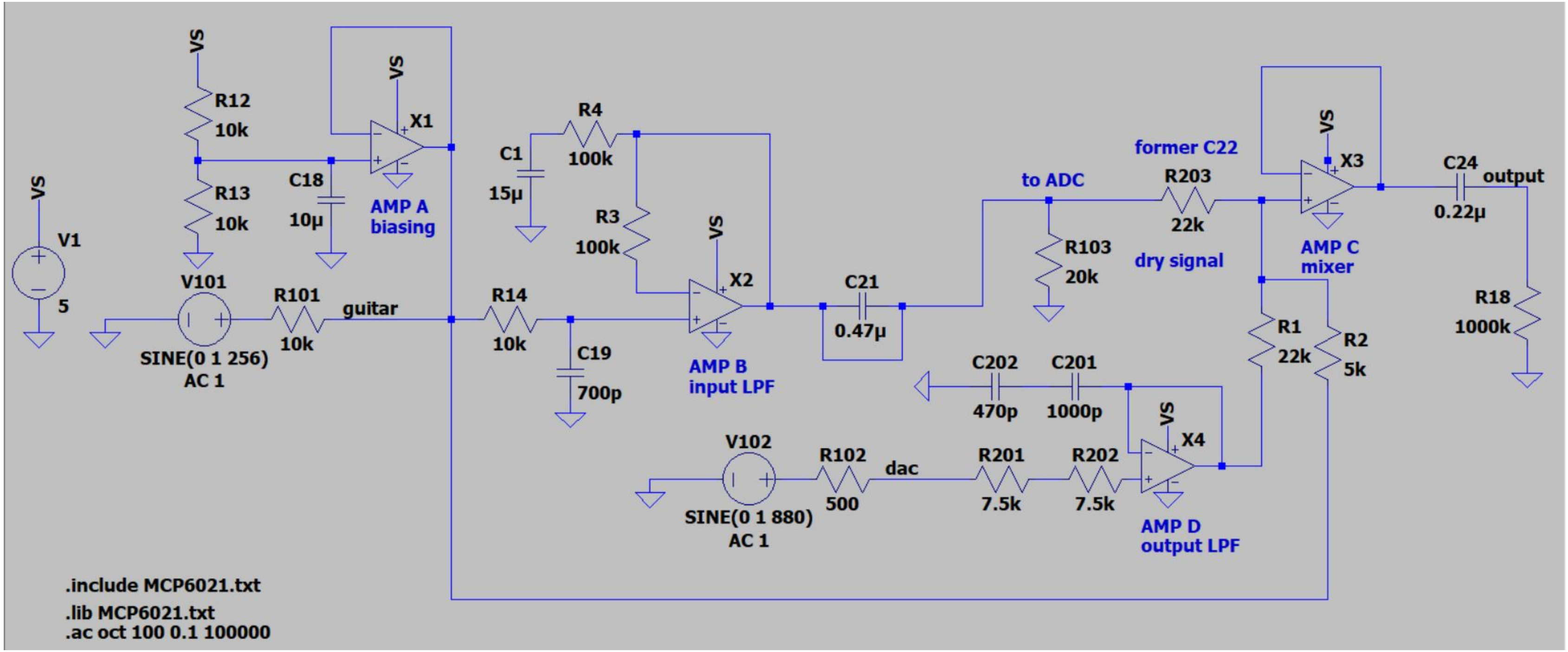
- **No more unity gain!**
  - Used LTspice and opamp equations to make up gain lost to filtering
  - This gave a huge improvement in SNR!
  - Preamp: $G_V = 1 + \frac{22\ \text{k}\Omega}{33\ \text{k}\Omega} \approx \frac{5}{3}$
  - Mixer: $G_V = 1 + \frac{33\ \text{k}\Omega}{22\ \text{k}\Omega} \approx 2.5$
- **Bandwidth limited!**
  - Limited bandwidth of each amplifier with an additional low pass filter
  - Cutoff frequency just under 10 kHz

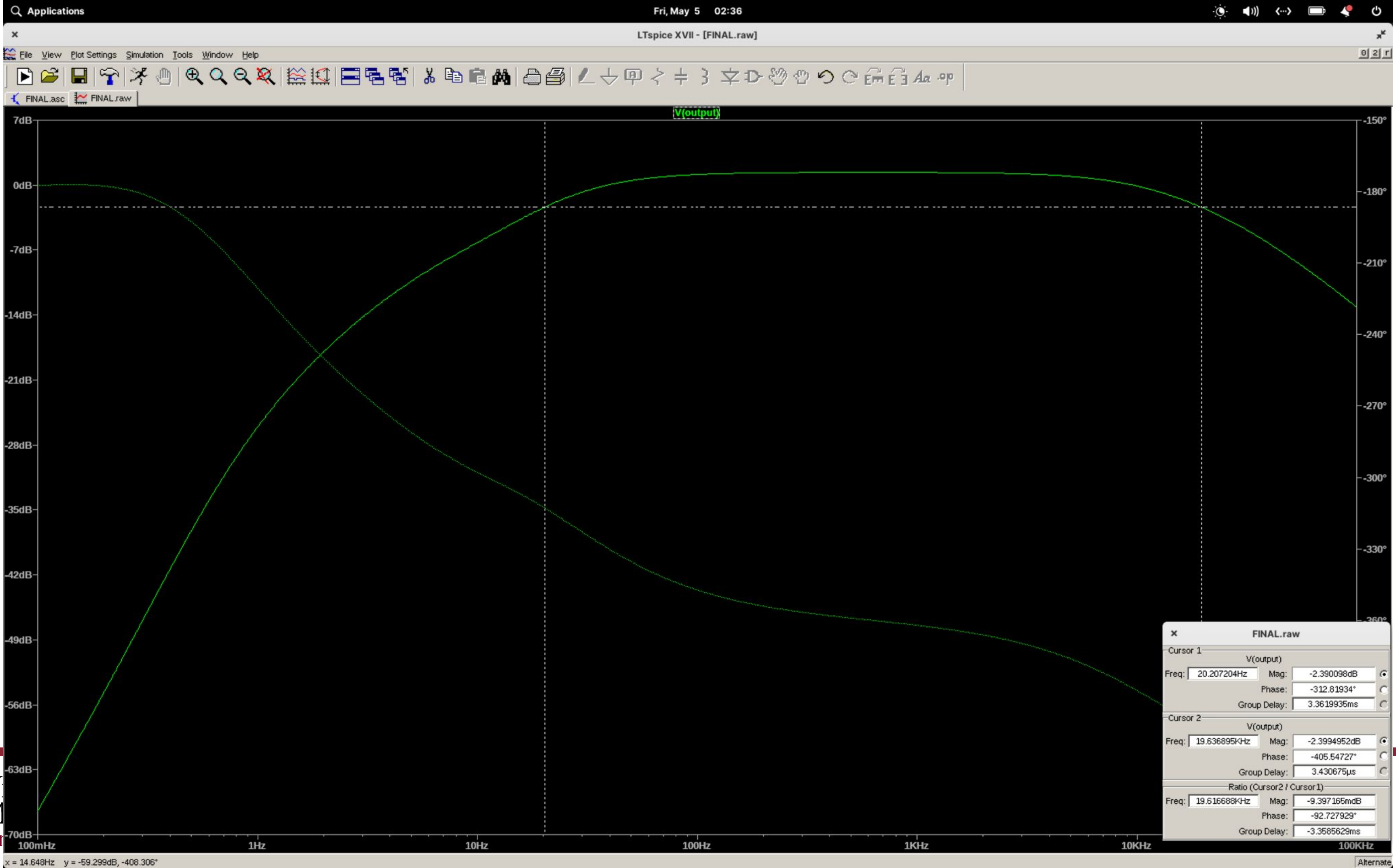

LTspice XVII - actPRE.asc
V(out)
10Hz
100Hz
1KHz
10KHz
C1
10µ
R1
33k
R2
22k
U1
in
out
V2
5
V1
AC 1
.ac oct 100 5 50k
Cursor 1
Freq: 9.3876072KHz
Mag: -14.494281dB
Phase: -45.001287°
Group Delay: 8.4770048µs
Right-Click to manually enter Horizontal Axis Limits


Applications
Fri, May 5 02:13
LTspice XVII - PRE.raw
File View Plot Settings Simulation Tools Window Help
PRE.asc
PRE.raw
V(out)
-6dB
-8dB
-10dB
-12dB
-14dB
-16dB
-18dB
-20dB
-22dB
-24dB
-26dB
-28dB
-30dB
10Hz
100Hz
1KHz
10KHz
10°
0°
-10°
-20°
-30°
-40°
-50°
-60°
-70°
-80°
-90°
-100°
-110°
-120°
-130°
-140°
-150°
C1
10µ
R1
33k
R2
22k
VS
U1
in
R3
10k
C2
700p
out
VS
V2
5
V1
AC 1
.ac oct 100 5 50k
PRE.raw
Cursor 1
V(out)
Freq: 8.2687997KHz
Mag: -9.9957341dB
Phase: -61.087718°
Group Delay: 15.717357µs
Cursor 2
Ratio (Cursor2 / Cursor1)
Right-Click to manually enter Horizontal Axis Limits
Alternate

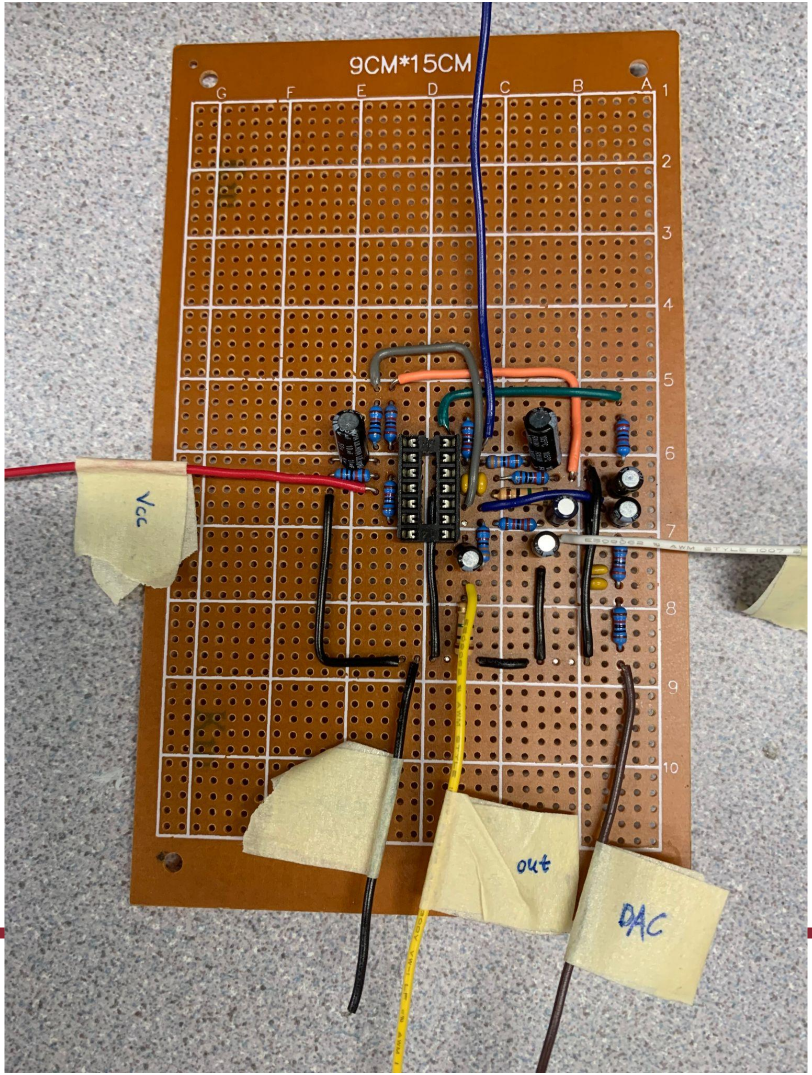

LTspice XVII - actMIX.raw
V(out)
10Hz
100Hz
1KHz
10KHz
C1
10µ
R1
22k
R2
33k
U1
in
out
V1
AC 1
V2
5
.ac oct 100 5 50k
Cursor 1
Freq: 9.8044409KHz
Mag: -19.0871dB
Phase: -45.699121°
Group Delay: 8.1142077µs


LTspice XVII - MIX.raw
V(out)
10Hz
100Hz
1KHz
10KHz
C1
10µ
R1
22k
R2
33k
U1
in
R3
10k
C2
800p
V2
5
V1
AC 1
out
.ac oct 100 5 50k
MIX.raw
Cursor 1
V(out)
Freq: 7.7029136KHz
Mag: -14.501849dB
Phase: -61.926006°
Group Delay: 17.175069µs
x = 4.465KHz y = -35.746dB, -148.435°

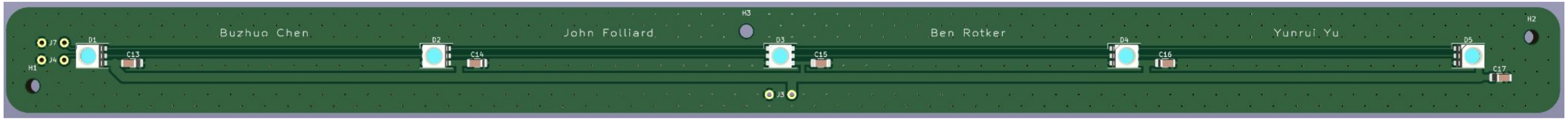

VS
R12
10k
R13
10k
C18
10μ
X1
AMP A
biasing
V1
5
V101
SINE(0 1 256)
AC 1
R101
10k
guitar
R14
10k
C19
700p
C1
15μ
R4
100k
R3
100k
X2
AMP B
input LPF
C21
0.47μ
to ADC
R103
20k
former C22
R203
22k
dry signal
X3
AMP C
mixer
C24
0.22μ
output
R18
1000k
R1
22k
R2
5k
C202
470p
C201
1000p
X4
AMP D
output LPF
V102
SINE(0 1 880)
AC 1
R102
500
dac
R201
7.5k
R202
7.5k
.include MCP6021.txt
.lib MCP6021.txt
.ac oct 100 0.1 100000

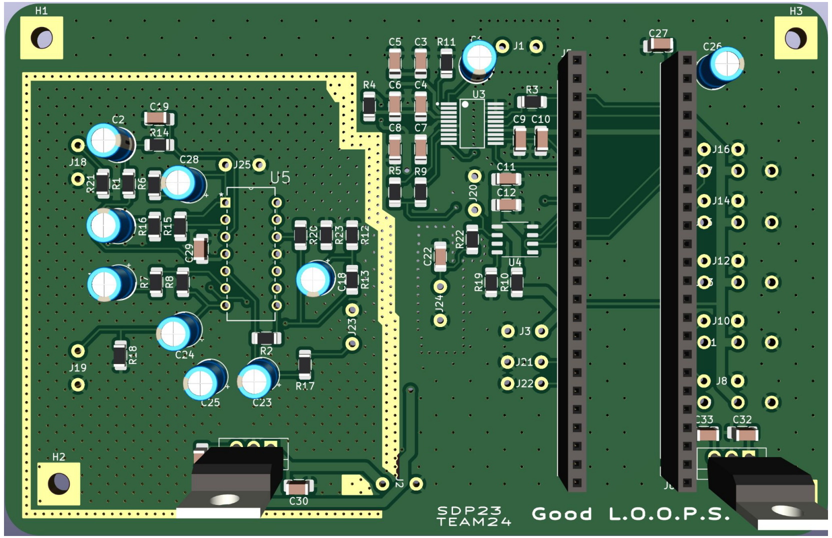


LTspice XVII - [FINAL.raw]
File View Plot Settings Simulation Tools Window Help
FINAL.asc
FINAL.raw
V(output)
7dB
0dB
-7dB
-14dB
-21dB
-28dB
-35dB
-42dB
-49dB
-56dB
-63dB
-70dB
-150°
-180°
-210°
-240°
-270°
-300°
-330°
100mHz
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
FINAL.raw
Cursor 1
V(output)
Freq: 20.207204Hz Mag: -2.390098dB
Phase: -312.81934°
Group Delay: 3.3619935ms
Cursor 2
V(output)
Freq: 19.636895KHz Mag: -2.3994952dB
Phase: -405.54727°
Group Delay: 3.430675µs
Ratio (Cursor2 / Cursor1)
Freq: 19.616688KHz Mag: -9.397165mdB
Phase: -92.727929°
Group Delay: -3.3585629ms
x = 14.648Hz y = -59.299dB, -408.306°
Alternate

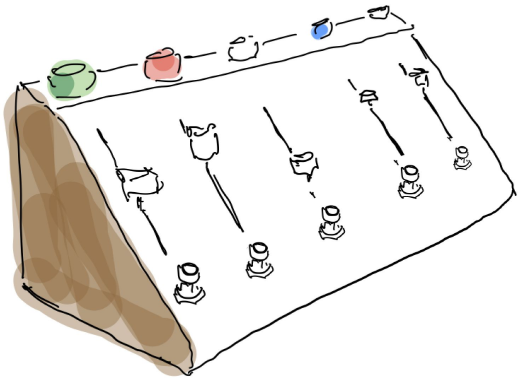

9CM*15CM
G
F
E
D
C
B
A
1
2
3
4
5
6
7
8
9
10
Vcc
out
DAC

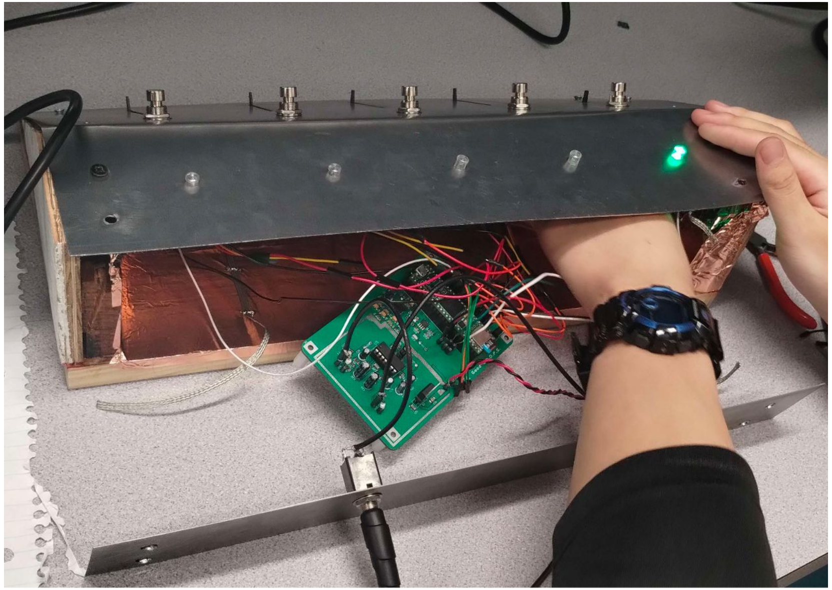
Final PCBs


Buzhuo Chen
John Folliard
Ben Rotker
Yunrui Yu

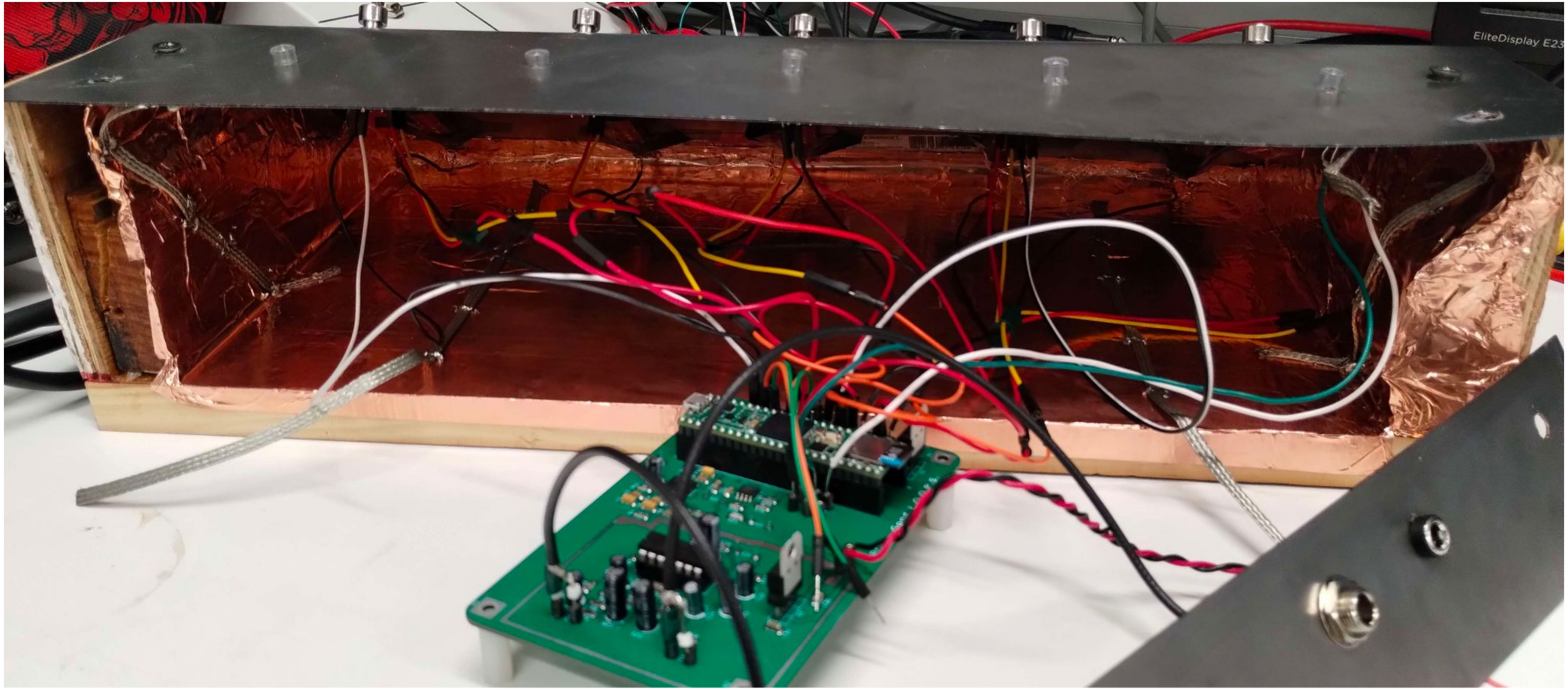

SDP23
TEAM24
Good L.O.O.P.S.

Enclosure

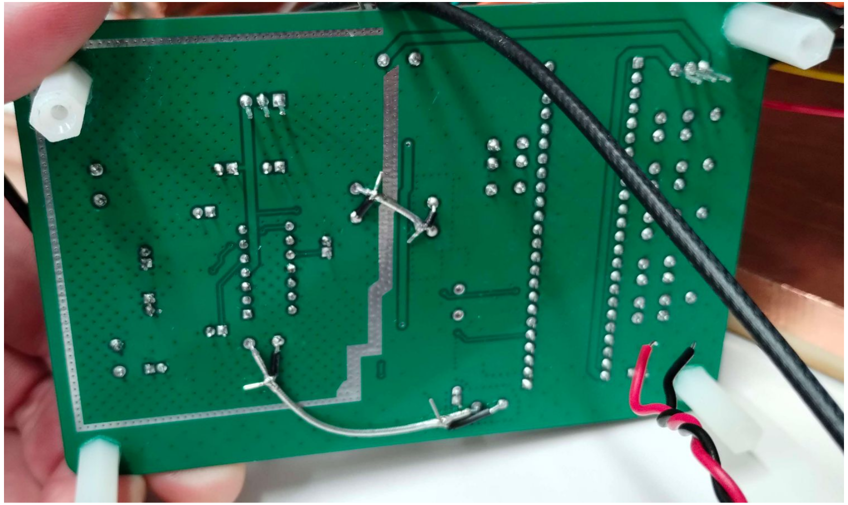


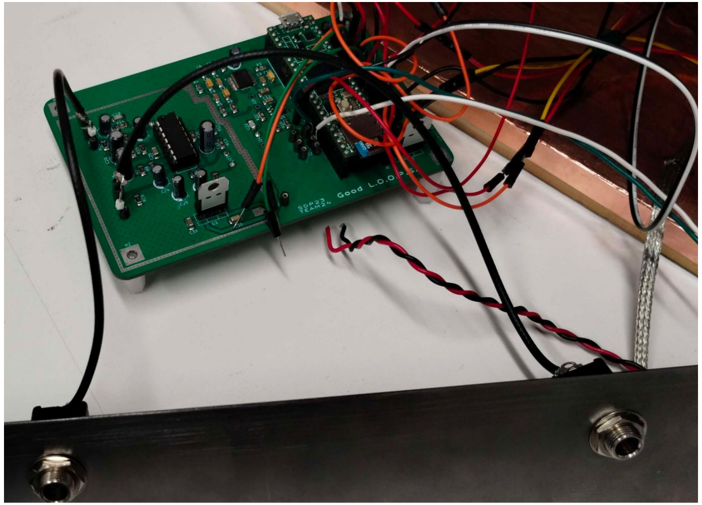


Shielding and bonding



Coaxial cables





Hardware Components Justified

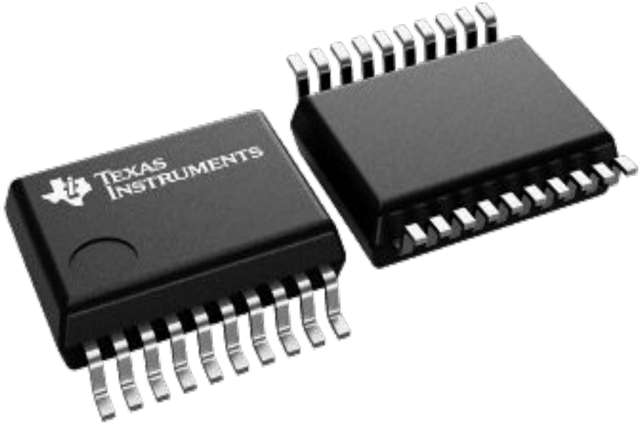
Microchip MCP6024 Operational Amplifier

- 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

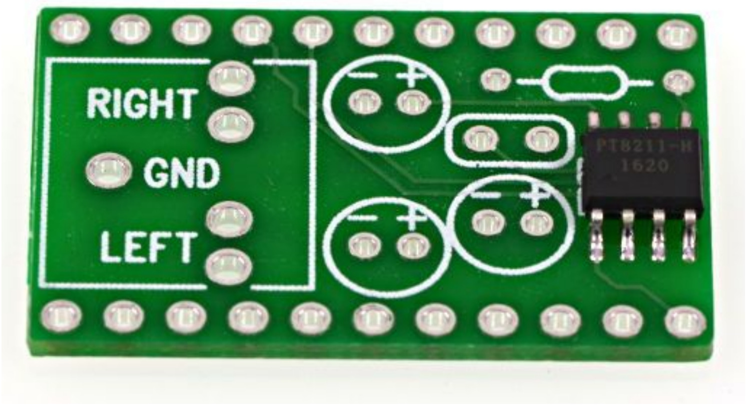


- Stereo 24 bit ADC
- Sampling Rate: 16 kHz to 96 kHz
- THD+N: 96 dB
- SNR: 105 dB
- Single-Ended Voltage Input

[4] : PCM1802 Datasheet

Hardware Components Justified

Princeton Tech. Corp. PT8211

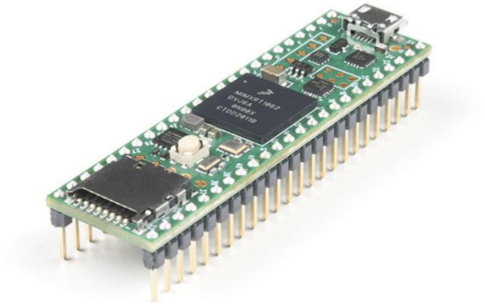


- Dual channel, 16 bit DAC
- Up to 384 kHz sampling rate
- THD: 0.1% with 1KHz
- SNR: 93 dB
- Single-Ended Voltage Input
- Recommended by Teensy website

[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

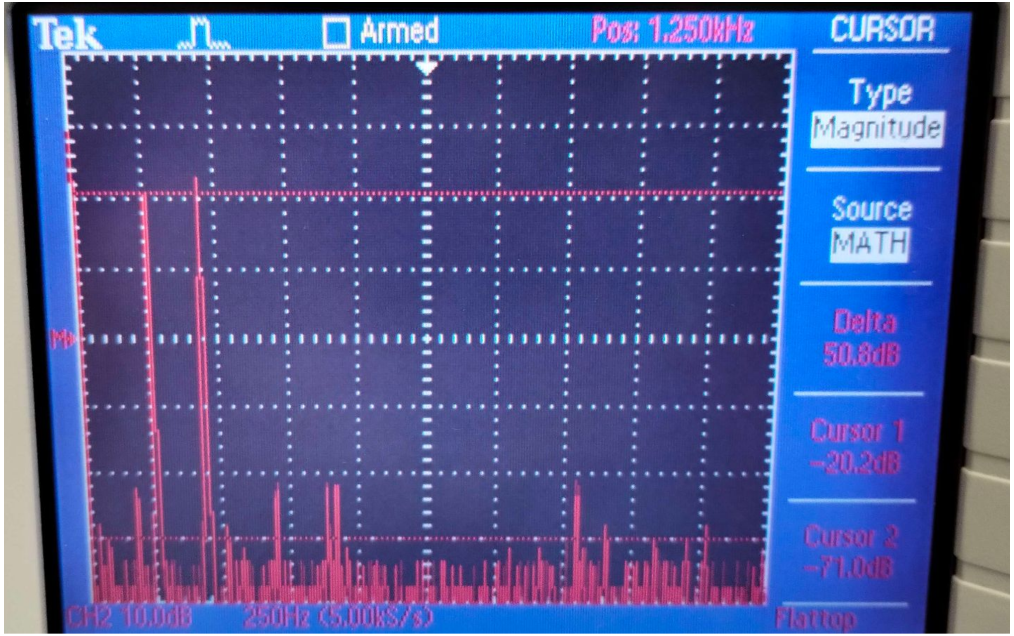
Performance

Measurement Equipments

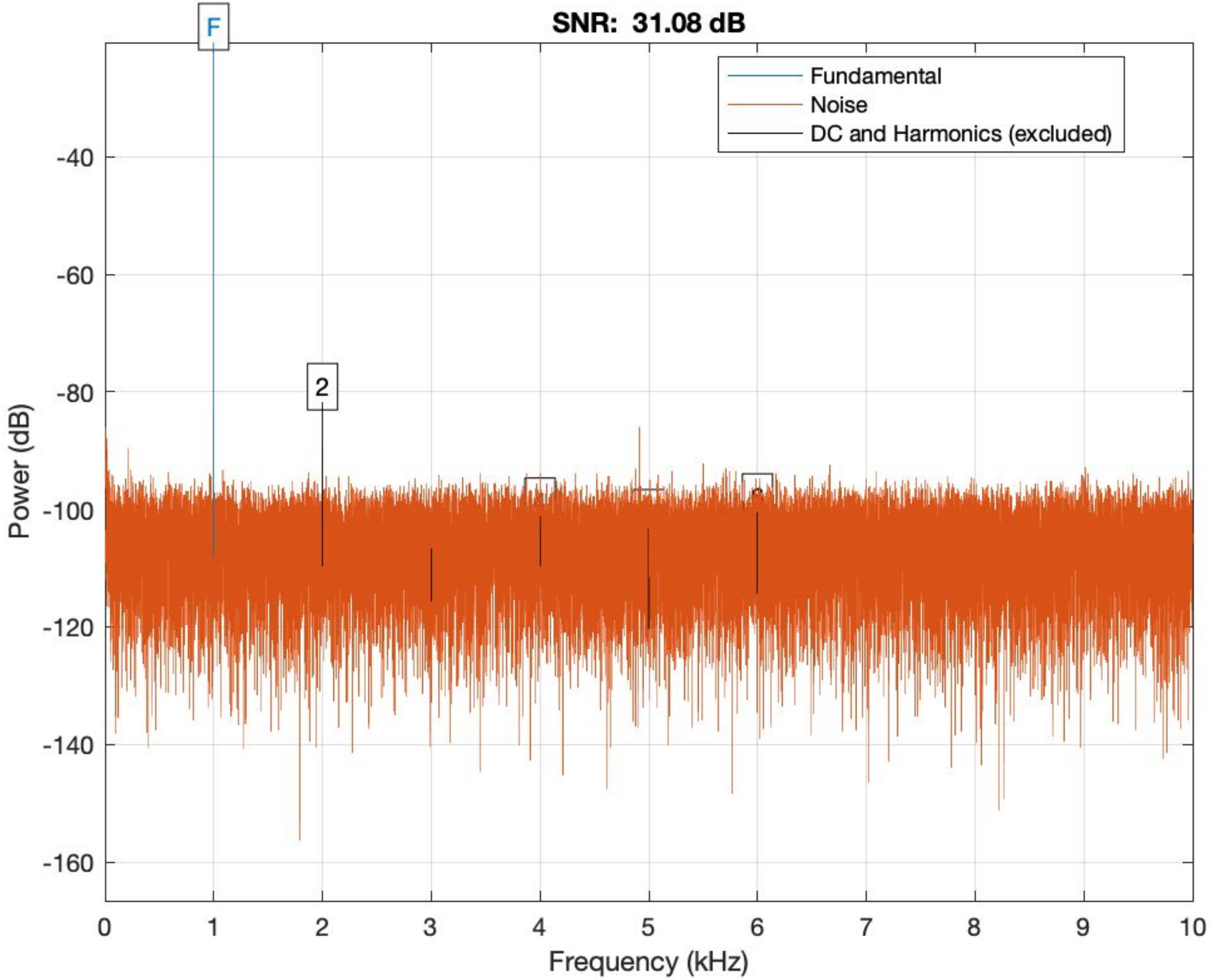
- **KEYSIGHT 33220A Waveform Generator**
  - Non-harmonic spurious = 70 dBc at 0 ~ 1 MHz
  - THD ~= 0.04% at 0 ~ 20 kHz
  - Vertical resolution: 4 digits (< 14 bits)

- **Tektronix DPO 4032 Oscilloscope**
  - Maximum sampling rate: 2.5 GHz
  - Vertical resolution: 8 bits (Hi Res: 11 bits)

First [admittedly-crude] SNR > 40 dB (?)

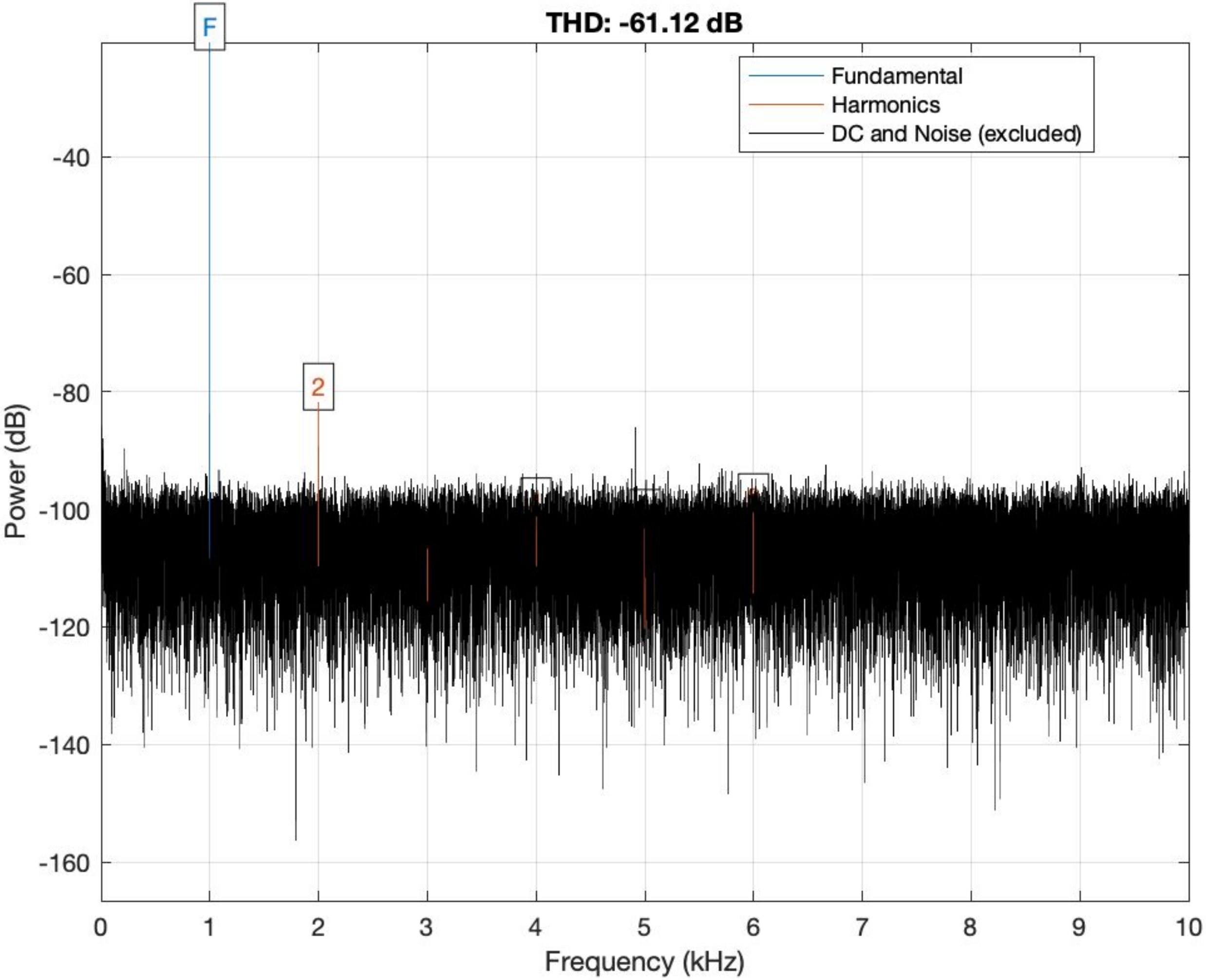


Dry



SNR: 31.08 dB
F
2
Fundamental
Noise
DC and Harmonics (excluded)
Power (dB)
-40
-60
-80
-100
-120
-140
-160
Frequency (kHz)
0
1
2
3
4
5
6
7
8
9
10

Dry



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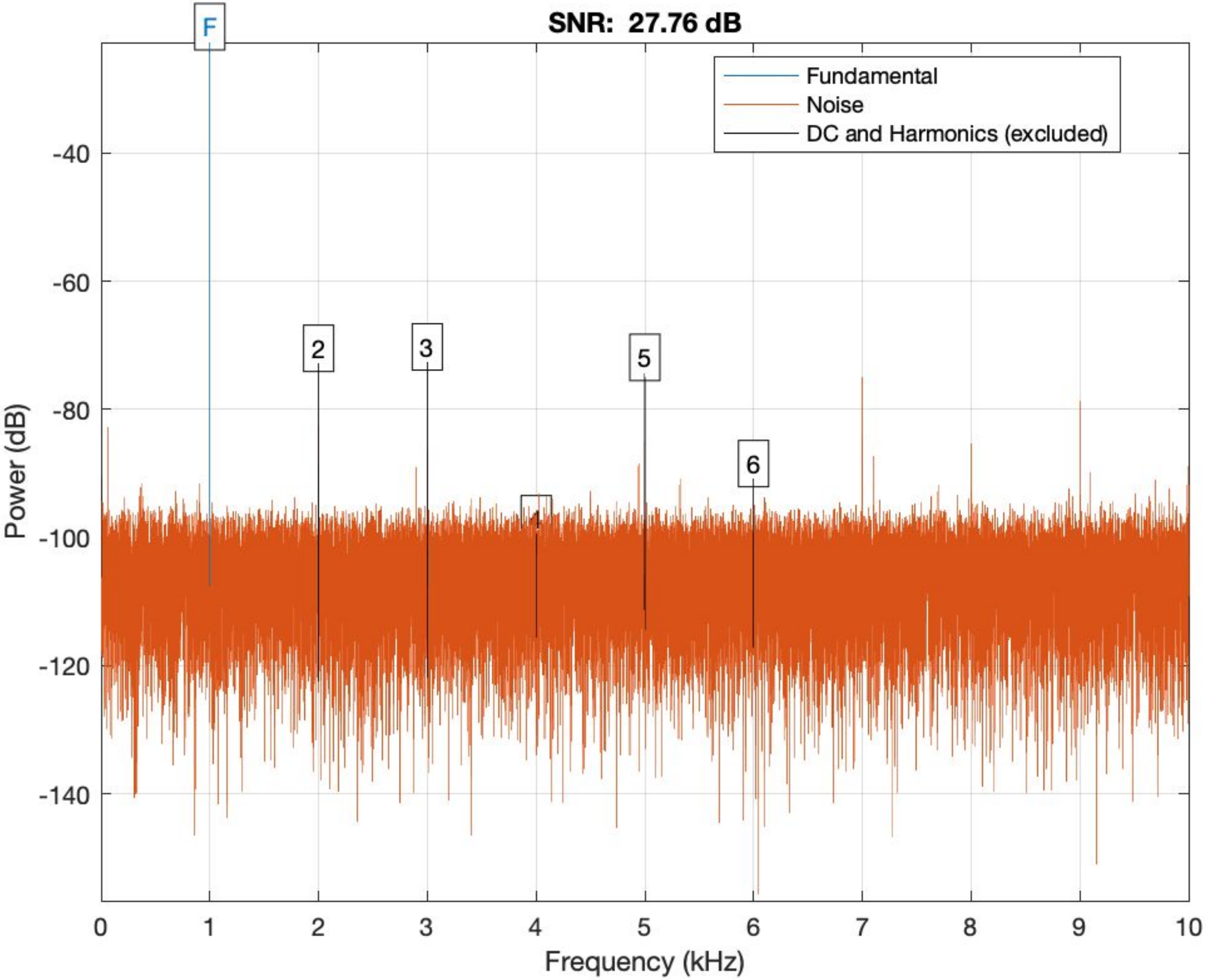
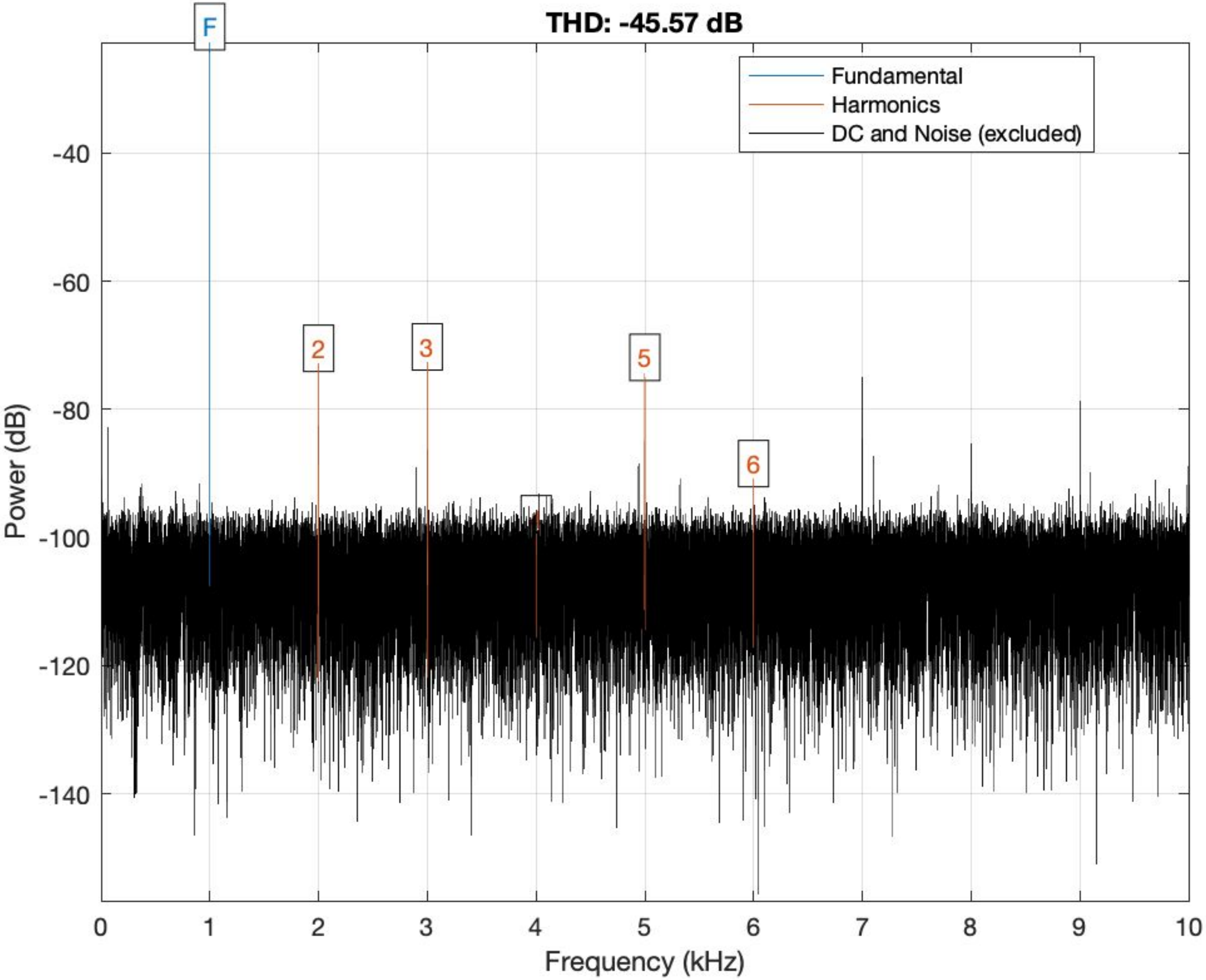
Loop


SNR: 27.76 dB
Fundamental
Noise
DC and Harmonics (excluded)
F
2
3
5
6
Power (dB)
-40
-60
-80
-100
-120
-140
0
1
2
3
4
5
6
7
8
9
10
Frequency (kHz)

Loop



THD: -45.57 dB
F
2
3
5
6
Fundamental
Harmonics
DC and Noise (excluded)
-40
-60
-80
-100
-120
-140
Power (dB)
0
1
2
3
4
5
6
7
8
9
10
Frequency (kHz)

Calculated SNR

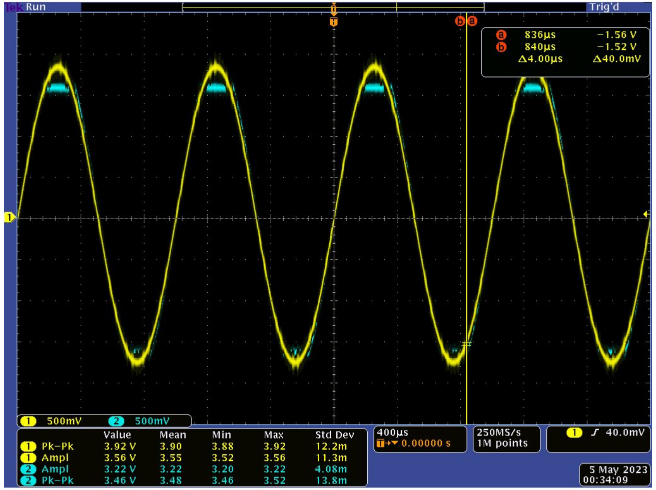
- Dry Through

Output (0.125V)	0.259842 V
Output (0.250V)	0.129987 V
Y-intercept	1.37*10^-4 V
Max Output	3.22 V
SNR	87.4223 dB

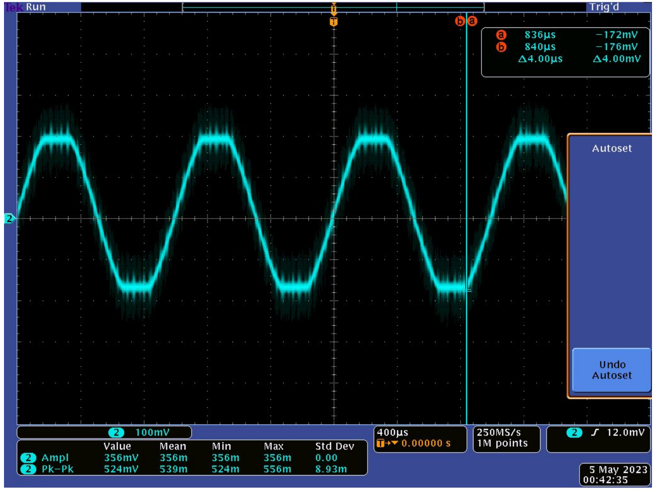
- Looping

Output (0.125V)	0.128655 V
Output (0.250V)	0.20606 V
Y-intercept	0.0513 V
Max Output	0.356 V
SNR	15.4751 dB

Distortion with high input amplitude

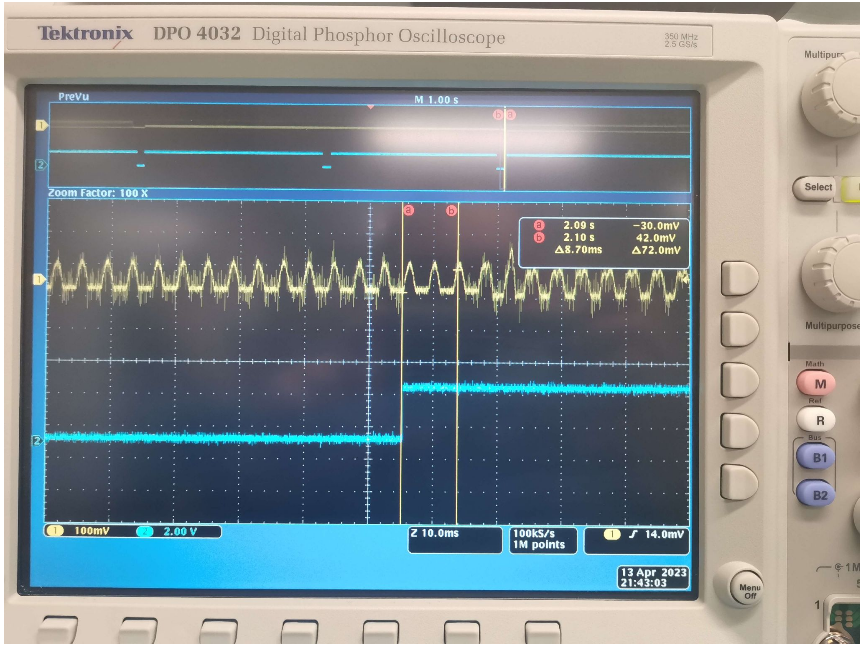


DPO4032 - 7:05:52 PM 5/4/2023



DPO4032 - 7:14:19 PM 5/4/2023

Min and Max Latency (Min: 8.7 ms; Max: 12.2 ms)



Project Expenditures and Management

Expenditure List - Integrated Circuits

Item	Quantity	Cost
ADCs	8	$33.89
Codecs	3	$28.60
Amplifiers	11	$19.19
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	10 (2 orders)	$81.60
MCUs	2	$83.76
Adaptor Boards	4	$27.82
Capacitors	51	$27.36
SD Card	1	$16.95
Resistors	54	$8.85
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	4	$4.20
Component Total	-	**$418.31**
Shipping	-	**$176.69**
Grand Total	-	**$595.00**

Gantt Chart

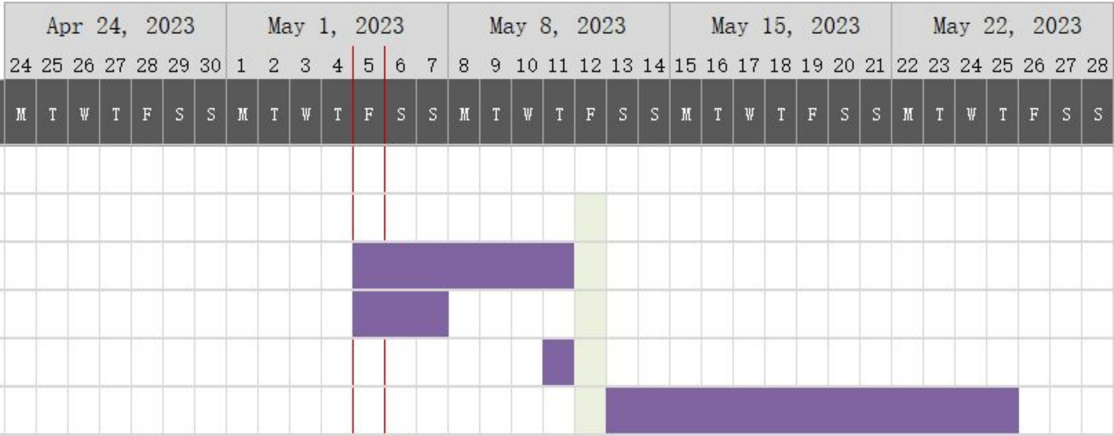
L. O. O. P. S.

SDP 23 Team 24

Phase Start: Fri, 5/5/2023

Today: Fri, 5/5/2023

TASK	ASSIGNED TO	PROGRESS	START	END
Paperwork				
Website			5/5/23	5/11/23
Project Poster			5/5/23	5/7/23
Demo video			5/11/23	5/11/23
Preject Report			5/13/23	5/25/23



QUESTIONS & ANSWERS

University *of* Massachusetts Amherst