Group 4: Pocket Amp

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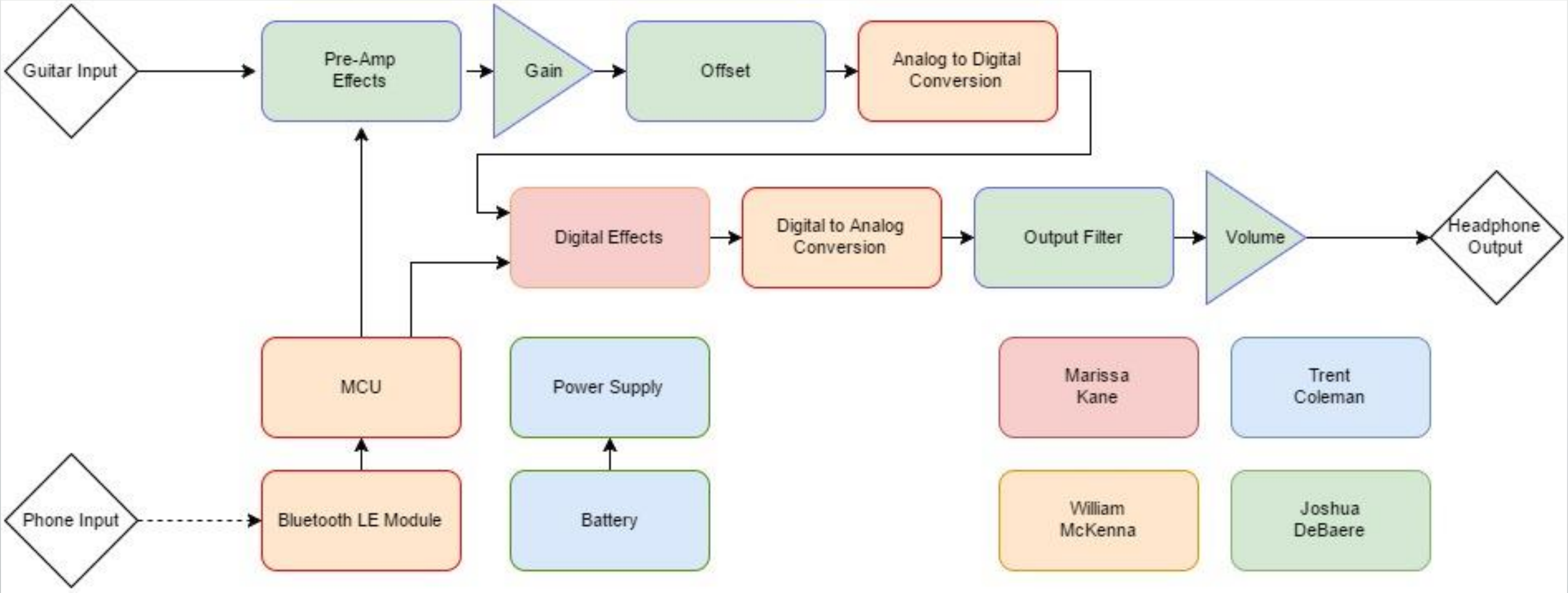
Motivation and Goals

- Portability – small and lightweight
- Extended battery life
- Affordability
- High quality of sound
- Ease of use

Requirements Overview

- External
  - 1-hour battery life
  - Weigh less than 5 lb
  - 6.35mm audio input jack
  - 3.5mm audio output jack
  - External charging port
- Internal
  - Powers headphones
  - MSP432 handles DSP
  - Samples 12 bits with 30 kHz frequency
  - Introduce less than 1% total harmonic distortion
- Effects
  - Delay
  - Reverb
  - Echo
  - Flanging
  - Chorus
  - Distortion
  - Overdrive
  - Tone Control

High Level Block Diagram



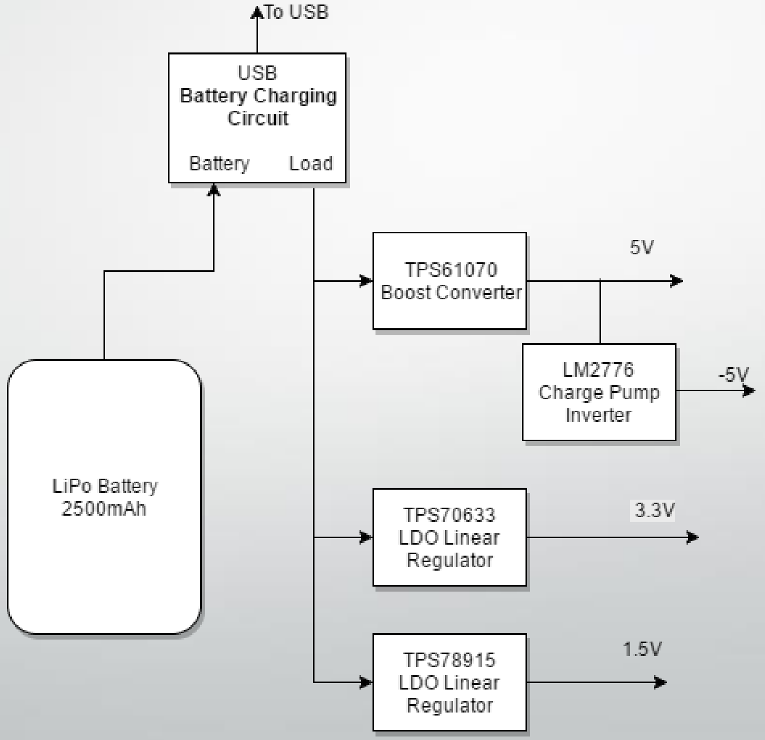
Subsystem	Primary	Secondary
Analog Signals	Joshua	Trent
Digital Signals	Marissa	William
Power Supply	Trent	Joshua
Software	William	Marissa

Power System

Power System Goals

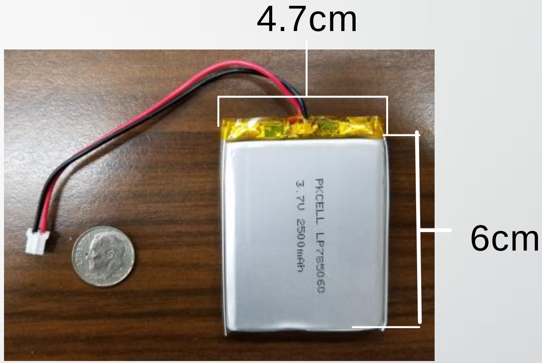
- Provide a compact, safe and sufficient power source for the Pocket-Amp
- Provide ±5V for powering the Op-Amp Rails
- Provide 3.3V for Potentiometers, Microcontroller and I2C communication
- Provide 1.5V for a voltage shift for the ADC
- Provide voltages while minimizing noise
- Perform charge management of the energy storage system

Power System Block Diagram



Power System Components: Lithium-Ion Polymer Battery

- High nominal voltage of 3.7V
- High energy density 2500 mAh package
- Flat case easier to place within package
- Protection circuits in place against short circuits
- The LiPo is able to be packaged in a rectangular case and thus able to fit better with the rest of the components



Power System Components

±5V **Voltage Supply**

- Initial Choice TPS65132 ($2.38)
  - Split-Rail Converter producing a programmable ±5V at maximum current of 80mA
  - Numerous Design issues, ultimately faced severed voltage drop on the negative rail
- Ultimate Design TPS61070 ($1.33) and LM2776 ($1.06)
  - TPS61070 provides a set boosted 5V output at maximum current of 350mA
  - SOT-23 package is much simpler to implement and the fixed resistor output is easier to determine
  - LM2776 provides an inverted voltage of the input at maximum current of 200mA
  - Higher current output able to handle the five Op-amps

Power System Components

3.3V Voltage Supply

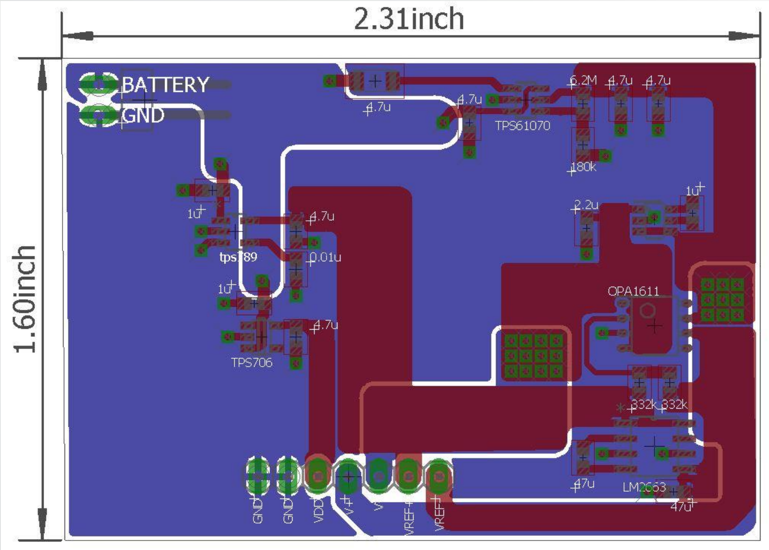
- Initial Choice – LP2989 ($2.84)
  - Ultralow Dropout, Low Noise, With Error Flag Faced numerous design difficulties, ultimately could not get to function on either the breadboard or on the PCB.
- Ultimate Design – TPS70633 ($0.77)
  - Low Dropout, Low Noise
  - Much easier design, operated correctly on the first implementation, Simpler SOT-23 package, much cheaper design.

Power System Components

±1.5V Voltage Shift

- Ultimate Design - TPS78915 ($0.88)
  - Provides a fixed output of 1.5V
  - Ultralow power and low noise LDO
  - Easy SOT-23 package

Power System PCB Layout

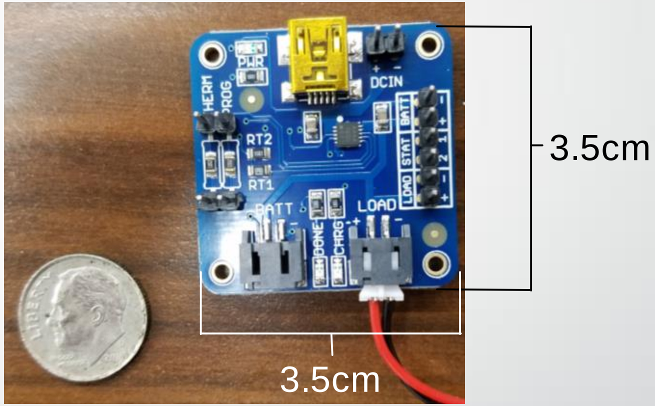


- Increased trace width to minimize current limitation from the PCB
- Redundant 1.5V Inverters
  - Only one installed at a time
  - Ultimately not necessary

Power System Components

Battery Charging Schemes

- Battery charging is an essential par of the Pocket Amp's portability
- Charging can be the most expensive and risky part of the power system



- Failure with a battery charging scheme can be an expensive and dangerous
- A prebuilt charging scheme based on the MCP73833 was purchased to help guarantee safe charging

Power System Challenges

±5V **Voltage Supply Challenges**

- TPS65132
  - Massive voltage drop on the negative rail
  - Poor efficiency often out of specification
  - Drew large currents even when under minor loading
- TPS61070 and LM2776
  - TPS61070 output signal had a severely low frequency.
  - Output frequency should be roughly 1.2MHz
  - Actual output frequency was 100Hz causing the LM2776 to operate incorrectly and causing large amounts of noise within the system.

Power System Challenges

Lessons Learned

- Moving to Backup Designs
  - Once troubleshooting reveals an issue that is unsolvable or too costly move to the next design
  - Held on to the TPS65132 design for too long despite its shortcomings
- Comprehensive Testing
  - Utilize every reasonable piece of equipment to properly study the output
  - If each output of the TPS61070 and LM2776 had been tested with an oscilloscope from the beginning its noisy output would have been spotted much sooner.
- Locating Errors
  - Errors which are easily fixable can still point to large errors in the system as a whole

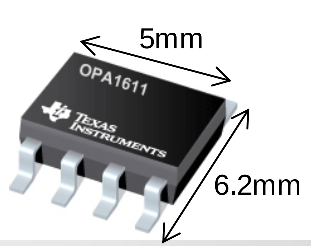
Analog System

Analog System Overview

- Amplification
  - Linearly amplify guitar input of approximately 10mV - 1V to ADC input of 0V – 3.3V
- Filtering
  - Ensuring only frequencies in the range of the electric guitar will be amplified to improve efficiency and sound quality
- Effects
  - Equalization
  - Overdrive

Op-Amp Selection

Amplifier	Pros	Cons
LME49723	Inexpensive	Noisy, Low slew Rate
OPA1611	Good all around performance	Not exceptional at anything
OPA1632	High GBWP, very low noise	Expensive, High offset voltage



Filter Types

- Combat the 60Hz Hum if needed
- Pass 80Hz with minimal attenuation
- Attenuate frequencies less than or equal to 60Hz by at least 3 dB

Passive Filters

- 3 dB drop at 60 Hz
- Doesn’t return close to 0 dB until near 500 Hz

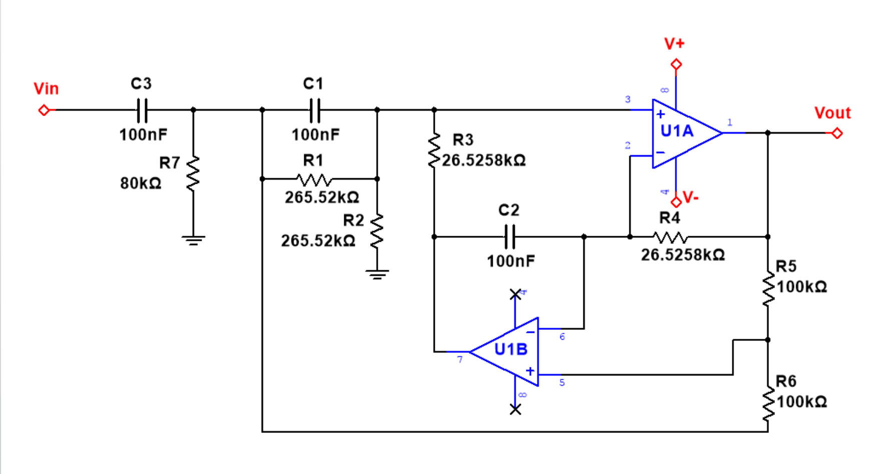
Fleige

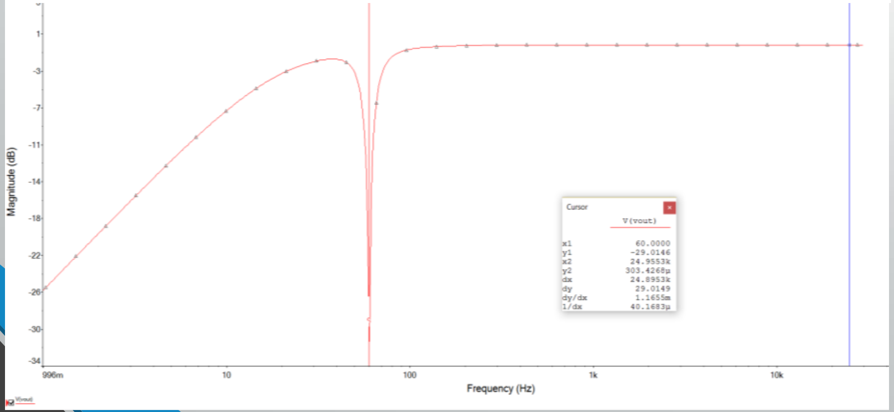
- Active notch filter
- Requires two op-amps in addition to a low-pass filter
- Dramatic reduction in 60 Hz with little attenuation above 80 Hz

Sallen-Key

- Active notch filter
- Extremely high sensitivity at required Q factor
- Would require variable resistance to tune

Fliege Filter Topology



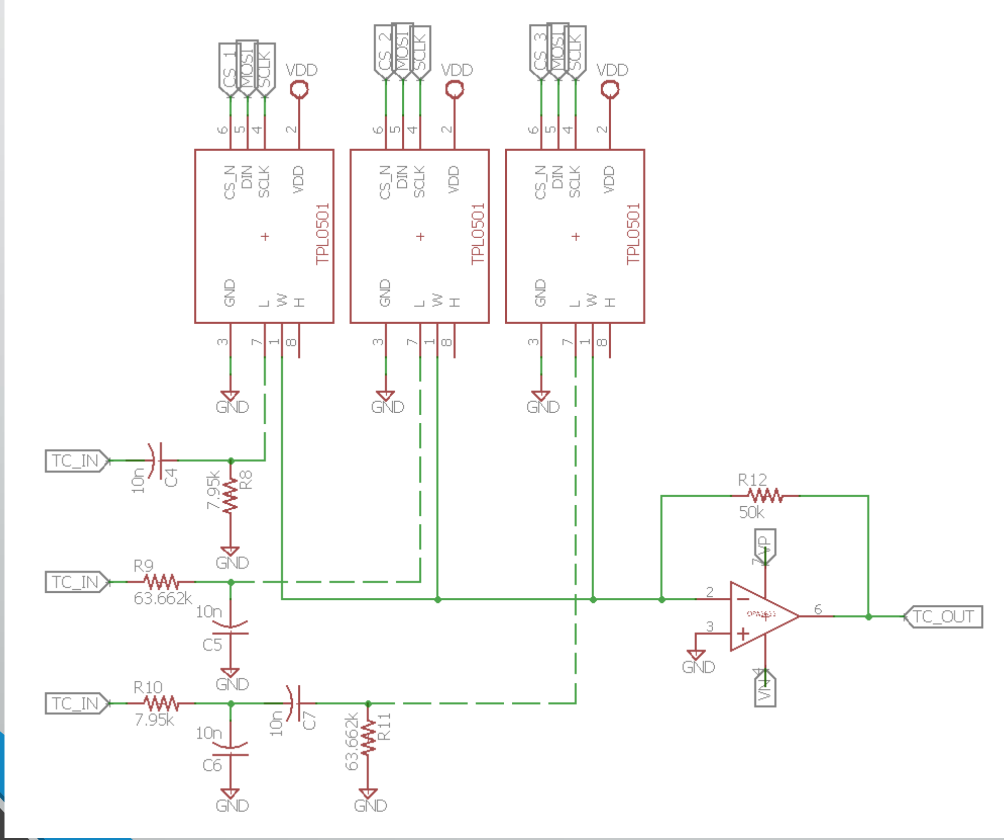


- Voltage Controlled Notch Filter
- Unity Gain pass band
- 20 Hz notch at Q=5
- Attenuates by ~ 1dB at 80 Hz
- $R = R_3 = R_4$, $R_Q = R_1 = R_2$
- $C = C_1 = C_2$
- $F_{notch} = \frac{1}{2\pi RC}$
- $Q = \frac{2R}{R_Q}$ 12

Courtesy Texas Instruments

http://www.ti.com/lit/an/sloa096/sloa096.pdf

Tone Control



- Equalization over multiple channels
  - $f_{High} \geq 12.5\ kHz$
  - $1.5\ kHz \leq f_{Mid} \leq 12.5\ kHz$
  - $f_{Low} \leq 1.5\ kHz$
- Some overlap in channels due to low order filters used
  - Lower complexity, space and cost
- Gain of each stage controlled by potentiometer

Overdrive

- Tube Amplifier
  - Expensive
  - Large Footprint
  - "Warm" Sound
    - Soft Clipping
  - Preferred by audio enthusiasts

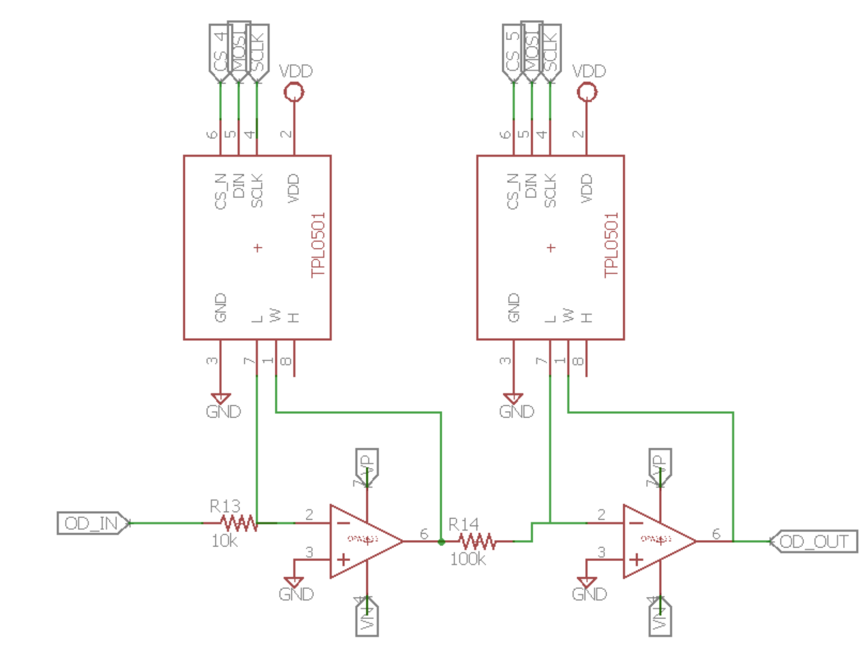
Solid State Amplifier

- Inexpensive
- Small Footprint
- Electronic Sound
  - Introduction of Odd Order Harmonics due to Hard Clipping
- Criticized for not sounding natural

Clipping Network

- Least Expensive
- Small Footprint
- Would require variable voltage sources to change level of effect

Overdrive



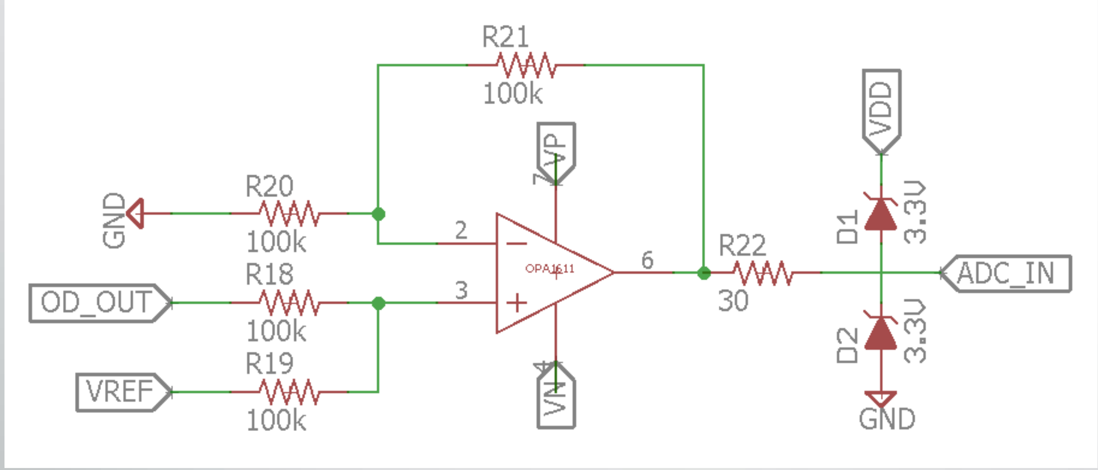
K_1

- Driven Rail to Rail when Overdrive is wanted

K_2

- Attenuates clipped signal to no more than 3.3V

ADC Offset



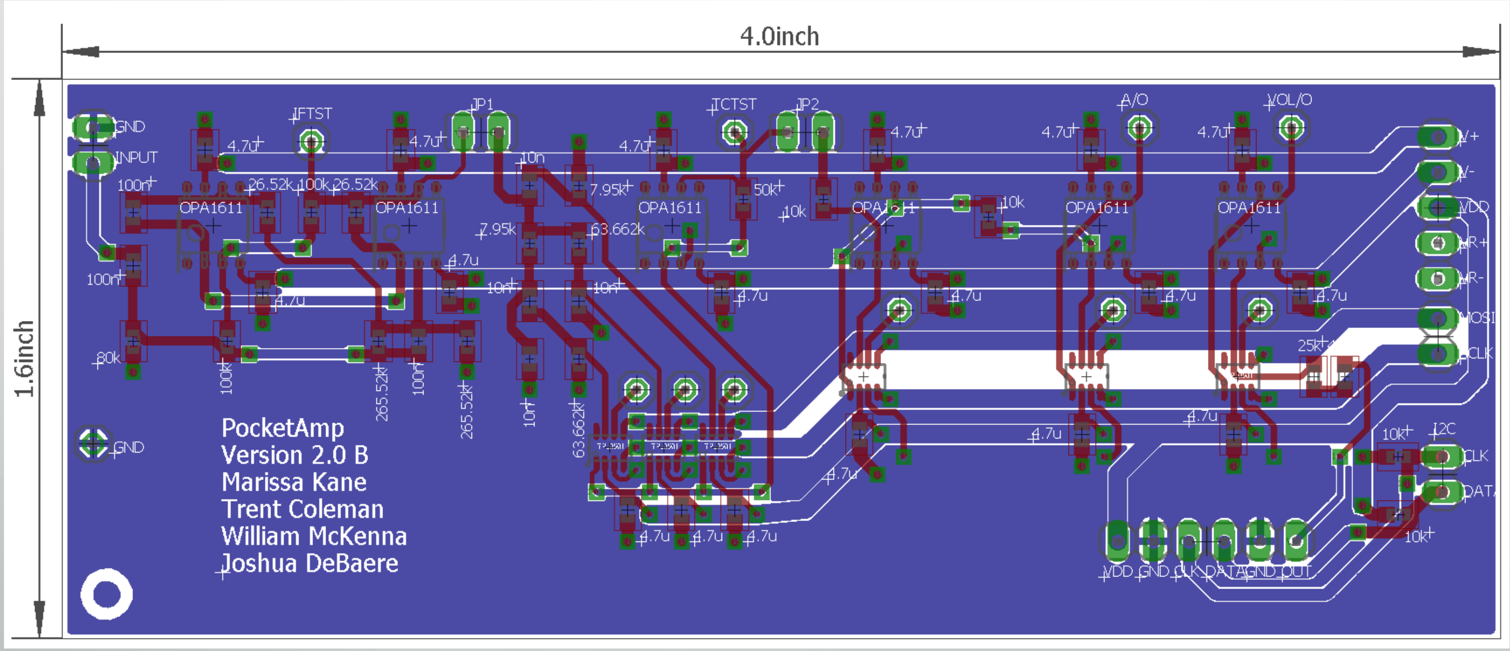
- MSP432 ADC input voltage rated for

  $0V < V_{ADC} < VDD+0.3V$
- Diode Network protects MSP432 input with resistance chosen by maximum Diode Current.

Volume

- Variable gain inverting Amplifier
  - Allows for changes in play style
  - Allows for changes in headphone impedance
- Acts as output buffer for DAC
  - Ideally greater than 5 kOhm

Audio PCB


4.0inch
1.6inch
PocketAmp
Version 2.0 B
Marissa Kane
Trent Coleman
William McKenna
Joshua DeBaere
GND
INPUT
OPA1611
OPA1611
OPA1611
OPA1611
OPA1611
OPA1611
JP1
JP2
IFTST
TCTST
A/O
VOL/O
V+
V-
VDD
I2C
CLK
VDD GND CLK DATA GND OUT

Digital System

Digital Effects

- Delay base effects in time domain
- Delay, Flanger, Reverb, Chorus, Echo
- Samples are stored in array
- Previous samples are mixed with current sample

Delay, Echo, and Chorus Effects

- Delay
  - Signal is saved and held back for a specified amount of time before the sound is produced
- Echo
  - Signal is delayed then added back into current signal
- Chorus
  - Effect where it sounds like multiple instruments are playing the same signal

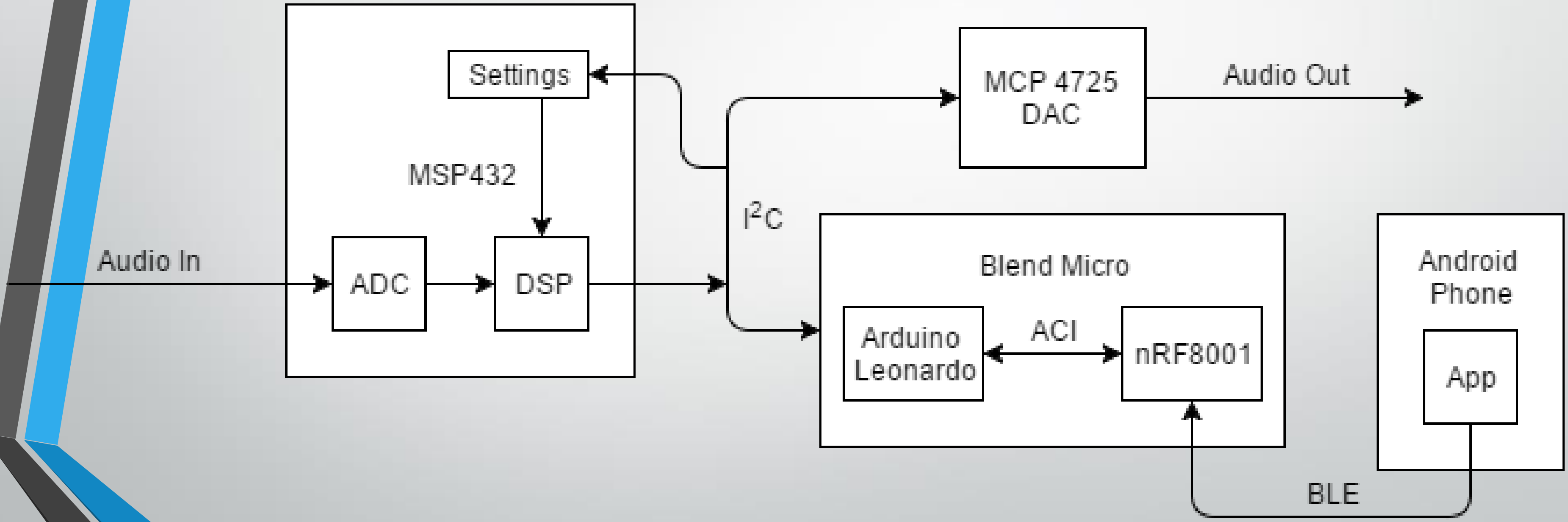
Reverb Effect

- Reverb is when a signal is echoed repeatedly after an original impulse
- A recursive feedback loop is used to add reflections
- The signal is delayed then the new signal is added back to the original. This process is repeated to implement multiple echoes.

Flanging Effect

- Effect that creates a whooshing noise
- A variable delay between 1 ms and 20 ms is added and then superimposed on the original signal
- Taylor series is used to approximate a sine wave
- Sine wave is run through linearly to determine size of the delay and to continuously vary it

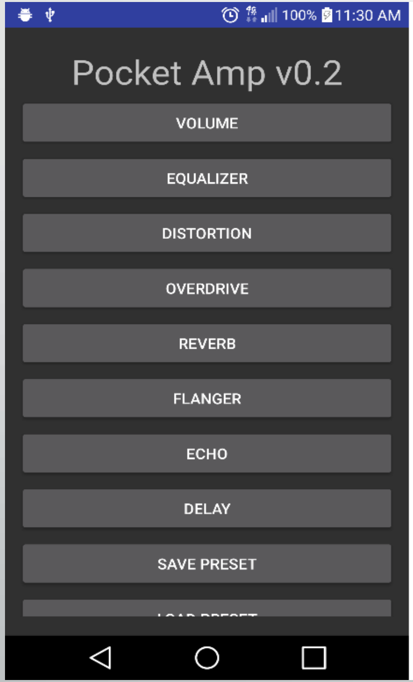
Digital Block Diagram

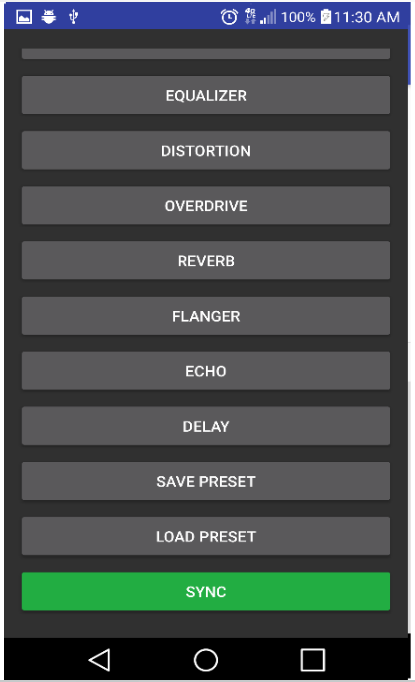


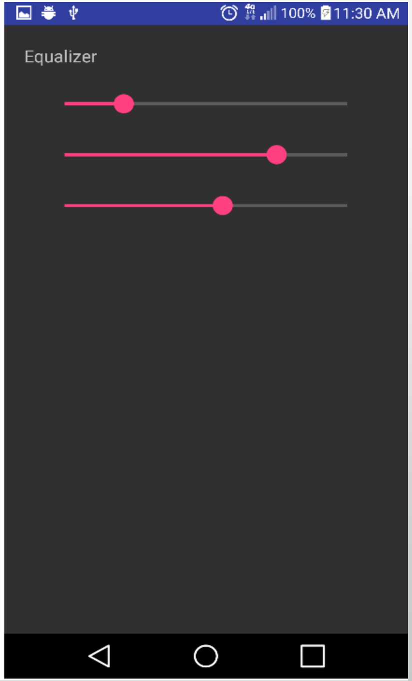
Digital Requirements

- Use an onboard MSP432 MCU to handle digital signal processing
- Use MSP432 built-in ADC
- Amplify the standard range of guitar and bass guitar sounds
- Sample at least 12-bits with a frequency of at least 30kHz
- Communicate through Bluetooth with smartphone application
- App will be developed for Android devices
- App will control effects
- App will control volume

Phone Application



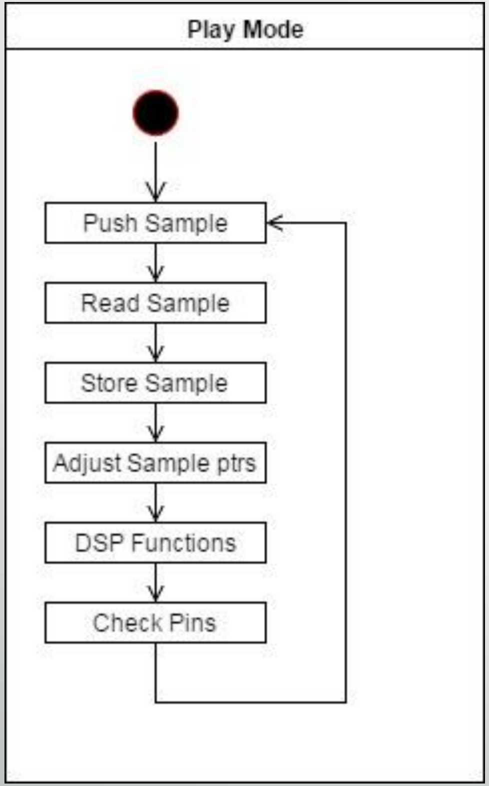




Microcontroller Overview

- **MSP432**
  - 48-MHz, 32-bit MCU
  - Onboard 14-bit 1MSPS ADC
  - ARM Cortex-M4F
  - DSP instructions, including Fast Fourier Transform
  - Launchpad debugging, programming, and power regulation
  - Jumpers to detach dev features

- **RedBearLab Blend Micro**
  - Arduino Leonardo, 8-16MHz 8-bit MCU
  - nRF8001 Bluetooth Low Energy chip
  - Onboard power regulation
  - Onboard USB programming and debugging
  - I2C and SPI built in



MSP432 Code Overview

- Infinite loop, only interrupt is to handle I2C byte sending
- Predictable length, limiting factor is generally I2C bus or digital effect calculations
- Removing an effect reduces computation time
- Stores sine lookup table for flange on startup, reduces computation cost

Programming Issues

- **Clocks**
  - I2C clocks very different on DAC vs Leonardo
    - DAC requires high enough clock rate to send samples (1.2MHz – 1.4MHz)
    - Leonardo has low clock rate (100kHz – 400kHz)
    - MSP432 has one clock tied to I2C
    - Re-init is messy
  - MSP432 clock issues

- **Bluetooth Low Energy**
  - New standard
    - Software and hardware stacks are of varying levels of maturity
    - Android programming support is limited
  - Many generic attribute profiles
    - Essentially non-standardized presets
    - Much trial and error required to get working with app

Programming Issues

- **Noise**
  - High speed I2C is built for communication on PCB
  - Our communication wires creates noise in 3.3v reference for DAC
  - Sampling rate can amplify noise from analog components
  - Digital noise reduction caused overdriven harmonics

- **Sample Arithmetic**
  - Any samples being added together or amplified must be shifted back down
  - DC offset varies based on unknown factors
    - Moving and weighted averages tried
    - Startup sampling tried
  - Integer overflow causes extreme distortion and volume

Administration

Budget

Purpose	Type	Component	Quantity	Cost @ 1000	Total Cost
	Resistor	R100 kOhm	2	$ 0.006	**$ 0.012**
	Capacitor	C100 nF	3	$ 0.090	**$ 0.270**
	Resistor	R10 kOhm	4	$ 0.015	**$ 0.060**
	Capacitor	C10 nF	4	$ 0.286	**$ 1.144**
	Resistor	R25 kOhm	1	$ 1.120	**$ 1.120**
	Resistor	R26.25 kOhm	2	$ 0.002	**$ 0.003**
	Resistor	R265.25 kOhm	2	$ 0.077	**$ 0.154**
	Capacitor	C4.7 uF	19	$ 0.070	**$ 1.330**
	Resistor	R50 kOhm	1	$ 1.120	**$ 1.120**
Audio	Resistor	R63.662 kOhm	2	$ 0.020	**$ 0.040**
	Resistor	R7.95 kOhm	2	$ 0.009	**$ 0.018**
	Resistor	30 Ohm	1	$ 0.040	**$ 0.040**
	Diode	3.3V Zener Diode	2	$ 0.210	**$ 0.420**
	Resistor	R80 kOhm	1	$ 0.015	**$ 0.015**
	Op-Amp	OPA1611AIDR	6	$ 2.360	**$ 14.160**
	Connector	1/8" Female	2	$ 0.363	**$ 0.726**
	Connector	1/4" Female	1	$ 0.653	**$ 0.653**
	Potentiometer	TPL0501-100DCNR	6	$ 0.709	**$ 4.254**
	PCB	Audio PCB	1	$ 4.990	**$ 4.990**
MCU	MCU	msp432p401r	1	$ 12.990	**$ 12.990**
	Bluetooth	Blend Micro	1	$ 19.900	**$ 19.900**

Purpose	Type	Component	Quantity	Cost @ 1000	Total Cost
	Boost Converter	TPS61070	1	$ 0.506	**$ 0.506**
	Inverting Charge Pump	LM2776	1	$ 0.405	**$ 0.405**
	LDO	TPS70633	1	$ 0.259	**$ 0.259**
	LDO	TPS78915	1	$ 0.338	**$ 0.338**
	Inductor	4.7 uH	1	$ 0.090	**$ 0.090**
	Capacitor	4.7 uF	4	$ 0.059	**$ 0.236**
Power	Capacitor	2.2 uF	1	$ 0.037	**$ 0.037**
	Capacitor	1 uF	3	$ 0.017	**$ 0.051**
	Capacitor	0.01 uF	1	$ 0.035	**$ 0.035**
	Resistor	1.62 Mohm	1	$ 0.018	**$ 0.018**
	Resistor	180 kOhm	1	$ 0.107	**$ 0.107**
	PCB	Power PCB	1	$ 2.640	**$ 2.640**
	Battery	1200 mAh	1	$ 7.960	**$ 7.960**
	Charger	LiPoly Charger	1	$ 10.000	**$ 10.000**
	Total:				**$ 86.10**