Digital Guitar Effects Pedal

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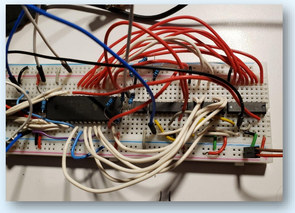
Introduction

Goal: Create a cost-effective guitar pedal capable of performing multiple digital effects.

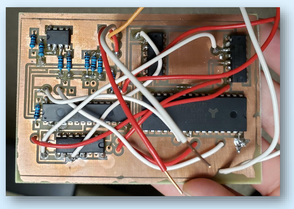
Motivation: Digital multi-effects pedals on the market can cost upwards of $500. Designated DSP and simple analog circuitry can achieve this at much lower cost.

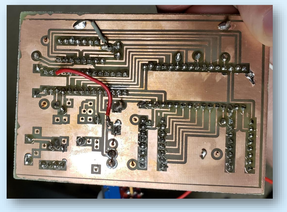
Requirements:
- Sampling rate of at least 44 kHz
- 12-bit depth sampling
- Multiple digitally processed effects
- Built in tuning capability

Preliminary Research



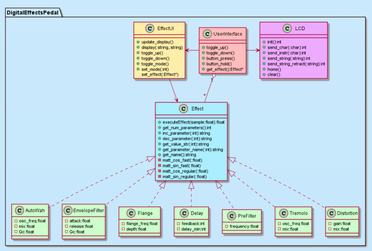
- Prototyped all effects in MATLAB
  - Optimized effects for C++ once the MATLAB was done
- Created Looper pedals in Fall 2020 & Spring 2021
  - First sampled at 10kHz and recorded for 5 seconds
  - Second sampled at 10kHz and recorded for 52 seconds

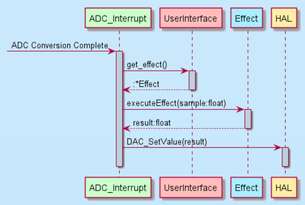




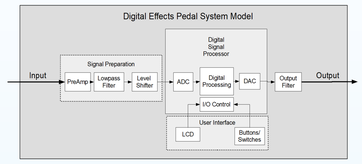
Software Design

- Written in C++ to leverage Object Oriented capabilities
- Created generic Effect class that all other effects are based off
  - Allows for easy addition of new effects
- Referenced ARM Cortex-M4 ISA to optimize effect execution
  - Utilized circular buffers, mass load/stores, and LUT sine/cosine functions to speed up execution

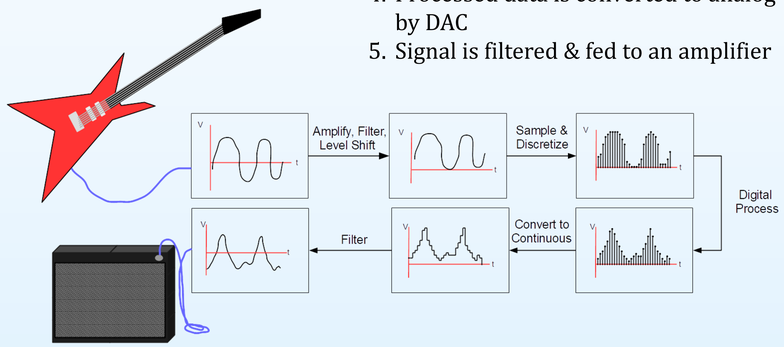




System Design

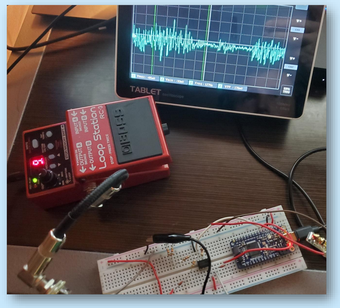


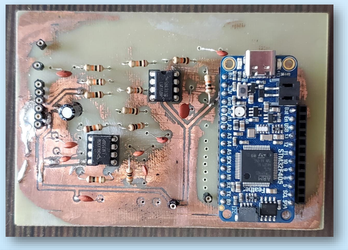
Five major steps in the system flow:
1. Guitar signal is amplified, filtered, and level shifted.
2. ADC samples the filtered data and converts to a digital value.
3. DSP Processor executes code to manipulate the data.
4. Processed data is converted to analog by DAC
5. Signal is filtered & fed to an amplifier

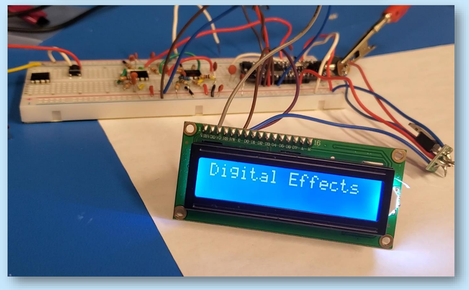


Circuit Design

- The goal was to keep the circuit design as simple as possible
- Four major parts of the circuit:
  - STM32F405 development board
  - Non-inverting Summing Amplifier/Preamp
  - 5th order Butterworth LPF
  - Button I/O and LCD screen
- Two-sided PCB was designed and build once the circuit was designed and verified







Outcomes

What I learned:
- How to combine digital and analog design into one circuit
- How to design and build PCBs
- Designing & optimizing multiple real-time digital guitar effects algorithms
- Designing & implementing binary search based DFT frequency detection algorithm

Final Product Details:
- 175kHz sampling rate
- 12-bit ADC and DAC resolution
- Six Effects + Tuner
- Cost less than $60

Future Improvements:
- Add more effects/improve effects
- Add capability to record loops
- Integrate full design onto one PCB

Component	Cost
LM358 Dual Op-Amp	$1
STM32F405 Development Board	$40
5V Linear Regulator	$1
LCD with i2c Backpack	$5
Switches, Connectors, Jacks	$10
Total	**$57**

Effects and Features

- More than 10 effects were prototyped in MATLAB and 6 made the final cut
  - Good quality reverb required too much processing time and memory
  - Ran out of time to implement Phaser & Vibrato
  - Did not find a good quality digital Octave algorithm

Effect	Quality (1-bad, 5-good)
Delay	3 (Only supports short delays)
Distortion	1 (Good tone but introduces unwanted noise)
Auto Wah	5
Envelope Filter	5
Tremolo	5
Flanger	5
Tuner	1 (Accurate but takes too long to process)

References

- Reiss, & McPherson, A. (2014). Audio Effects (1st edition). CRC Press.
- https://www.engr.scu.edu/~dlewis/book3/docs/Cortex-M4%20Proc%20Tech%20Ref%20Manual.pdf