Analog and Digital Effects Processing Technology (ADEPT)

Group C

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Goals and Objectives

Motivation

- Open Source Musical Instrument Effects Processor
- Fusion of audio engineering, music technology, and sound design
- Close the gap between technology and music
- Provide new alternatives for musicians who want to stand out and shape their sound in a unique way
- Have a creative impact on musicians with an interest in electrical and computer engineering
- Realistic usable product for musicians and electronics hobbyists

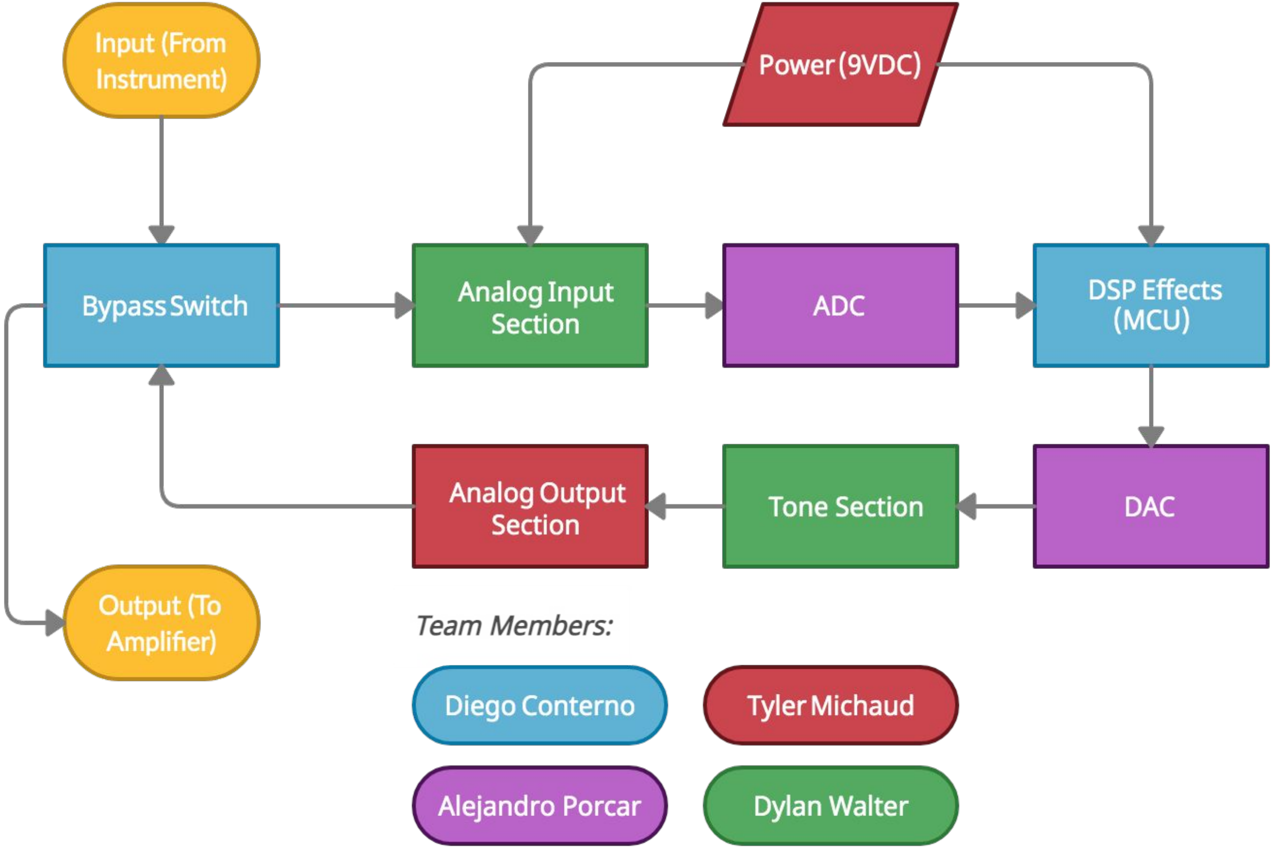
Goals & Objectives

- Portable
- Affordable
- Easy to Use
- Low Current Draw
- Low Noise Level
- Reliable

Requirements and Specifications

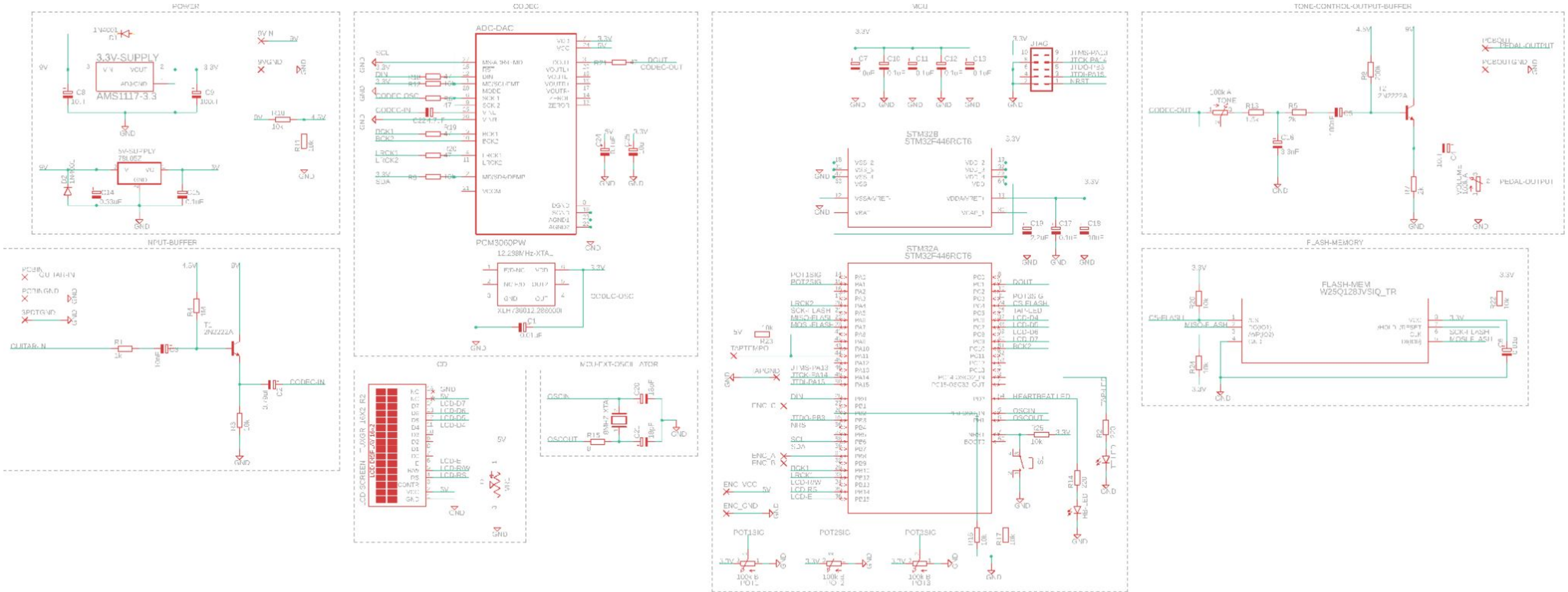
- Analog-to-Digital Conversion
- Minimal Added Noise (less than -14dB)
- High Input Impedance (~450kΩ)
- Low Output Impedance (~450Ω)
- Looper/Dual Footswitch Functionality
- Standard ¼” Instrument Cable Compatibility
- 9V Power
- JTAG/SWD Programmability
- LCD Menu and Selection Screen

Block Diagram



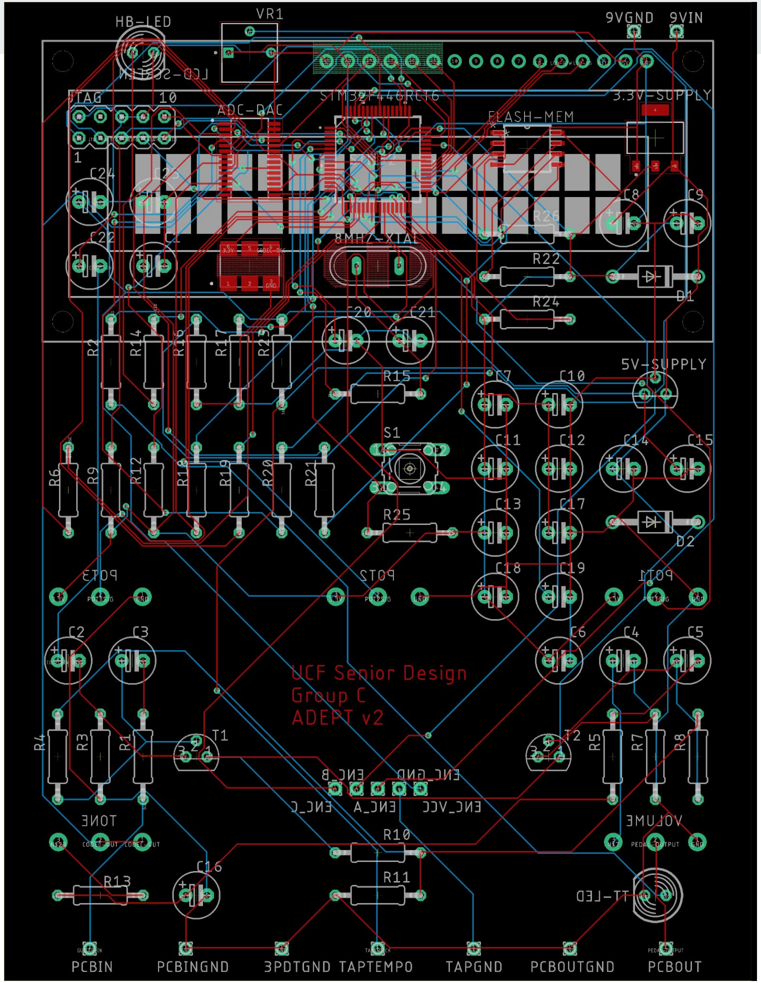
Hardware + PCB Design

Schematic


POWER
3.3V-SUPPLY
AMS1117-3.3
CODEC
ADC-DAC
PCM3060PW
MCU
STM32F446RCT6
TONE-CONTROL-OUTPUT-BUFFER
FLASH-MEM
W25Q128JVSIQ_TR

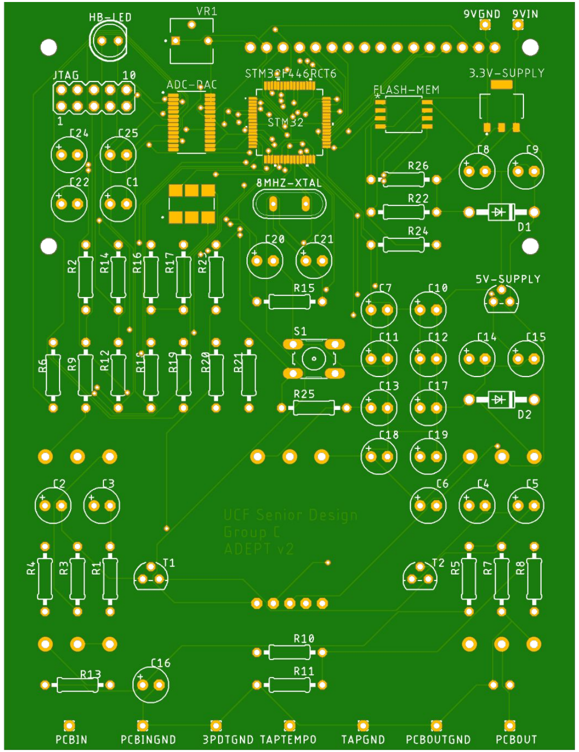
PCB Layout

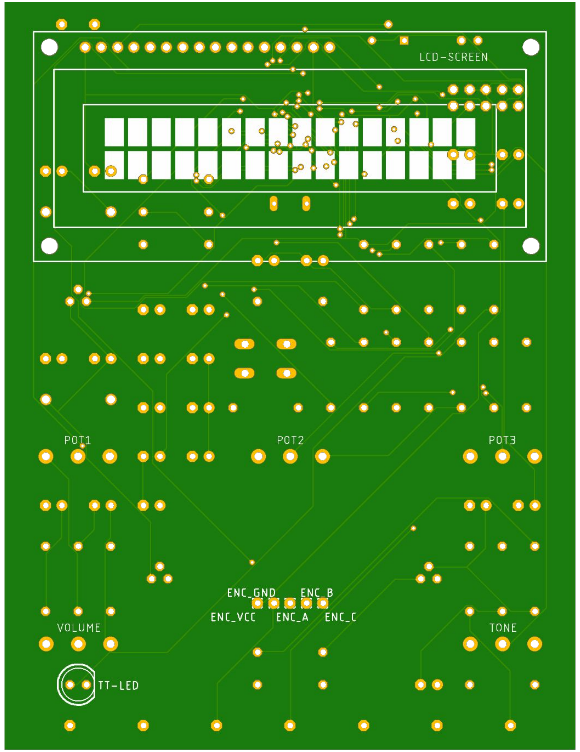
- Layout done using AutoCAD Eagle
- 2 board layers for simplicity
- Default trace widths and spacing used
- Utilized the tRestrict, bRestrict, and vRestrict layers to stop noisy traces from interfering with crystal oscillators.
- PCB Dimensions: 116.5mm x 88.90mm



PCB Layout

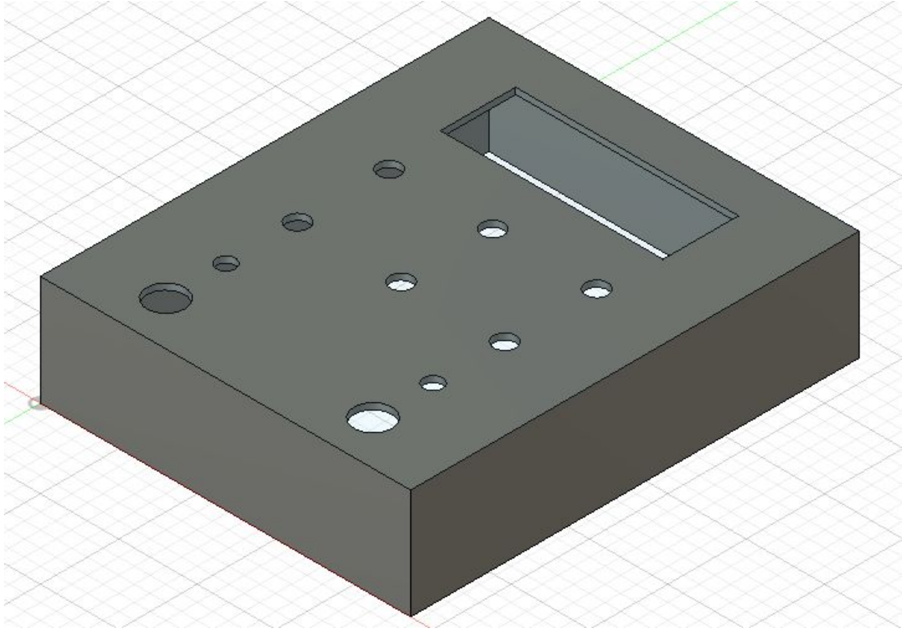
- PCB Fabrication done by OSH Park
- Both through-hole (THT) and surface mount (SMT) components integrated in our design





PCB Enclosure

- Hammond 1590XX enclosure
- Enclosure designed using AutoDesk Fusion 360
- Able to make precise measurements based on component and PCB dimensions

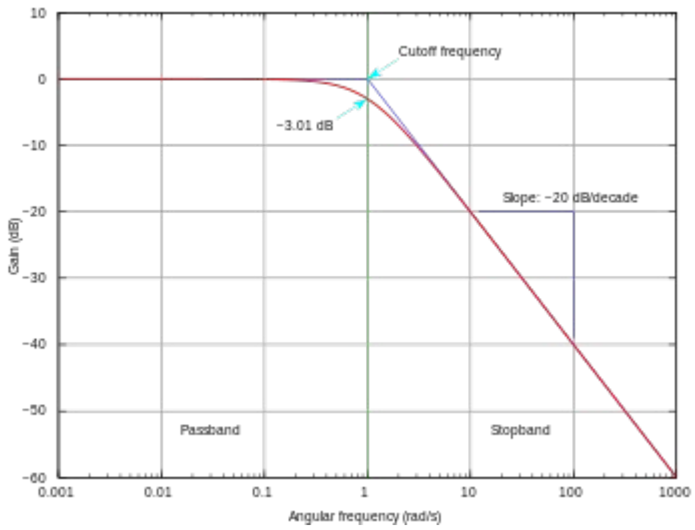


Footswitches

- 3PDT (3-Pole, Double Throw) mechanical true bypass latching footswitch
  - Used to turn the effect on and off
- SPST (Single Pole, Single Throw) momentary footswitch
  - Used for tap tempo and looper
- These plunge-type footswitches are the standard for guitar effects pedals due to their ability to be activated hands-free. Therefore, there was no need for a comparison with other types of switches.

Tone and Volume Controls

- Tone Control
  - Adjusts the cutoff frequency of the instrument signal in order to make the effect sound brighter or darker
  - Linear Potentiometer in series with First Order RC Low Pass Filter
- Volume Control
  - Logarithmic Potentiometer placed at the end of pedal circuit to control overall volume

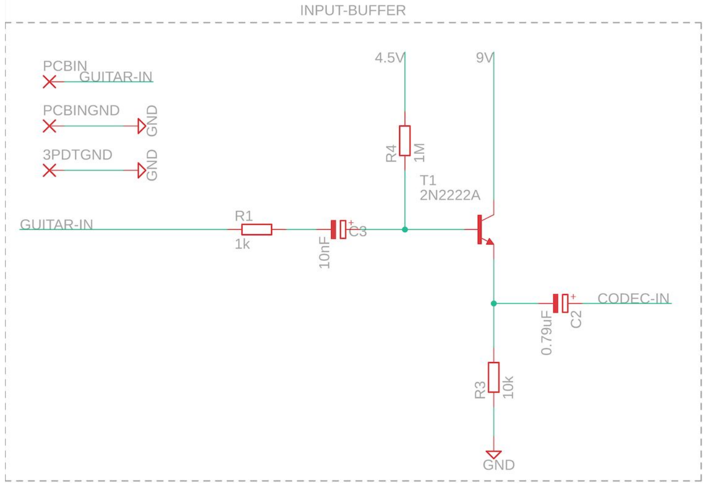


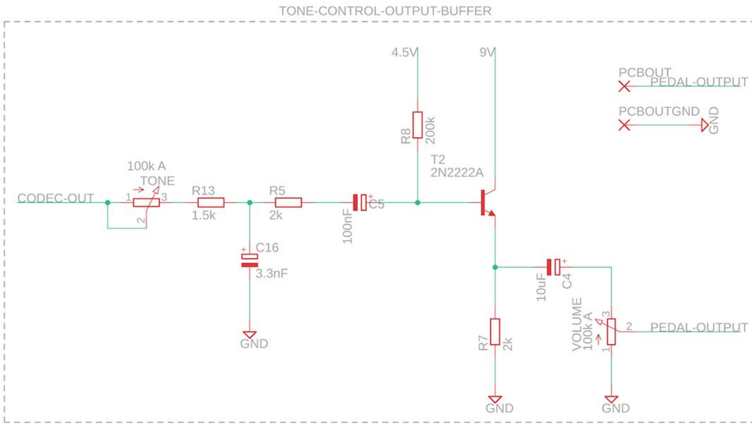
Tone Control Comparison

Tone Control Configuration	Number of Parts	Frequency Response	Simplicity	Cost
Bluesbreaker	3	First Order LP	Very simple	$2.00
Big Muff	5	First Order HP/LP	Simple	$3.50
Tube Screamer	11	Second Order LP	Complex	$6.00

Analog Input and Output Buffers

- Active electronic circuit that can provide a change in electrical impedance.
- Maintains signal integrity going in and out of the system.
- Low energy, voltage driven signal.
- High input impedance to low output impedance.
- Emitter follower configuration (standard practice).
- 2N2222A BJT





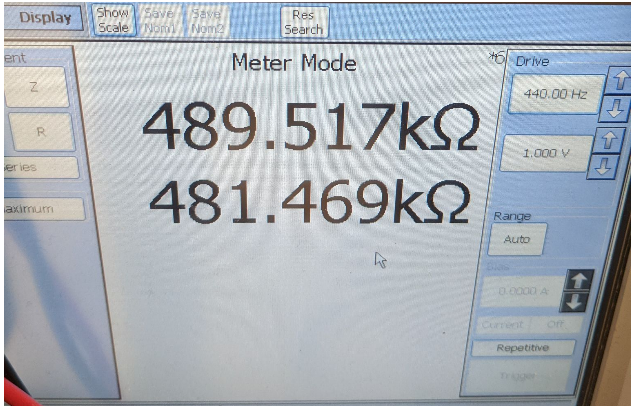
Analog Input and Output Buffer Comparison

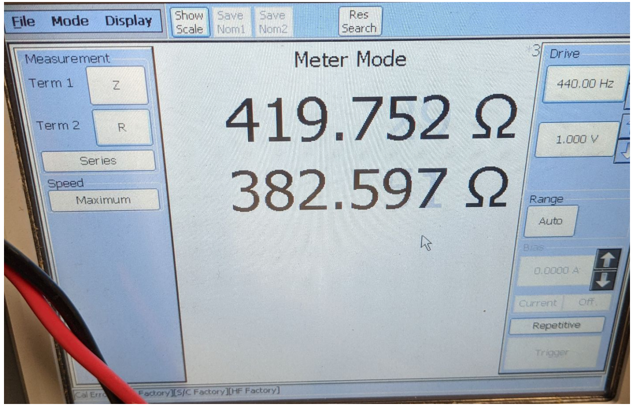
- -0.13 dB loss is negligible. Price outweighs performance in this case.

Buffer Type	**Cost**	**Complexity**	**Performance**
JFET	~$4.24	Simple	0 dB Loss
Emitter Follower	~$0.43	Simple	-0.13 dB Loss
Op Amp	~$2.75	Simple	0 dB Loss

Input and Output Impedance

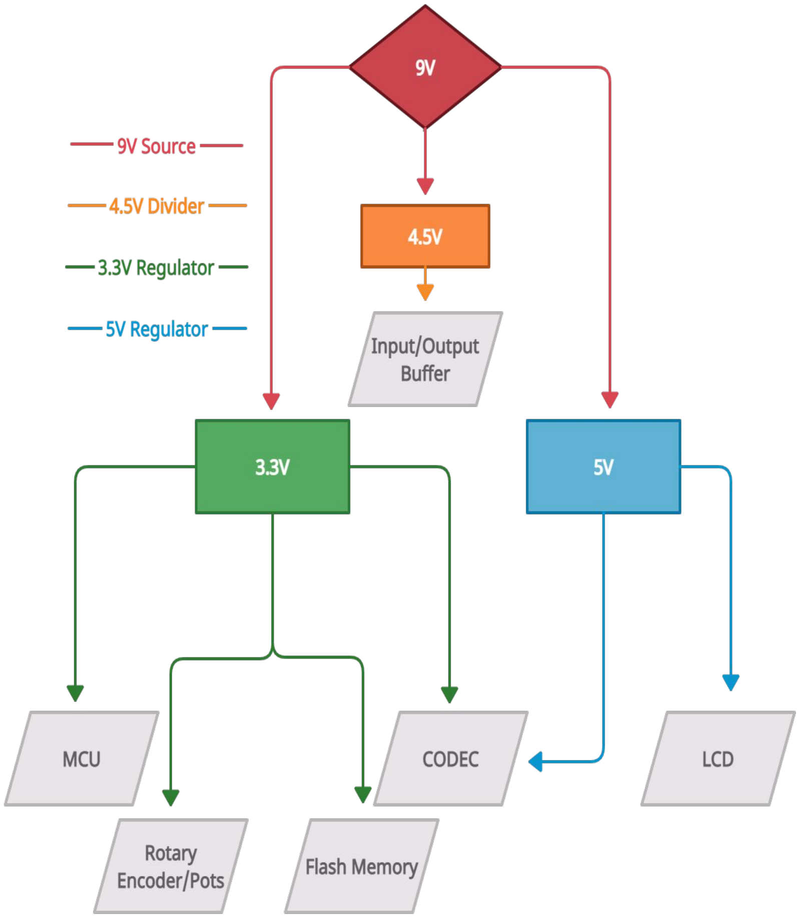
- High Input Impedance
- Low Output Impedance
- This was an important test to perform, since it is an important factor in the overall sound quality of our design.
- We later confirmed that these buffers greatly improved the tone and clarity of our circuit compared to connecting directly to our CODEC without the buffers.





Power (9VDC)

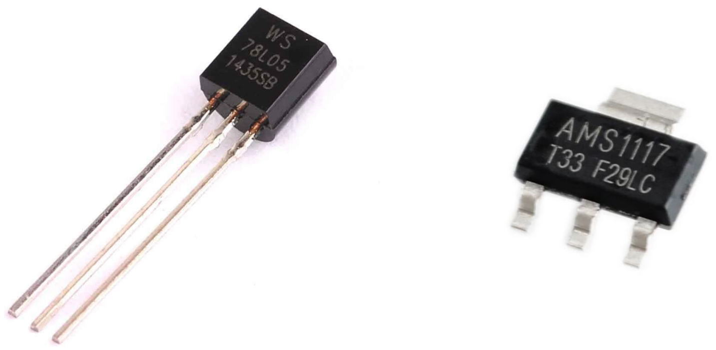
- 9V to 5V and 9V to 3.3V voltage regulation.
- Linear voltage regulators for microcontroller, CODEC,and flash memory.
- 78L05 for 5V and AMS1117 for 3.3V.
- Not power efficient but less noisy.
- 9V and 4.5V(using voltage divider) used to bias input and output buffers.
- Coaxial power jack(2.1mm inside diameter and 5.5mm outside diameter).
- 500mA rating.
- Proper Transient suppression and configuration



Voltage Regulator Comparison

- Switching (*MC34063ACN*) vs linear regulators (*LM1117-3.3* & *LM7805*) Comparison. Linear regulators trump switching regulators for noise level and cost. No batteries needed. Therefore, power efficiency is not important.

Regulator	Noise	Avg Cost	Power efficiency
MC34063ACN	300 mVp	~$1.00	80%-89%
LM1117-3.3	53 uVp	~$0.50	~ 50%
LM7805	40 uVp	~0.50	~ 50%

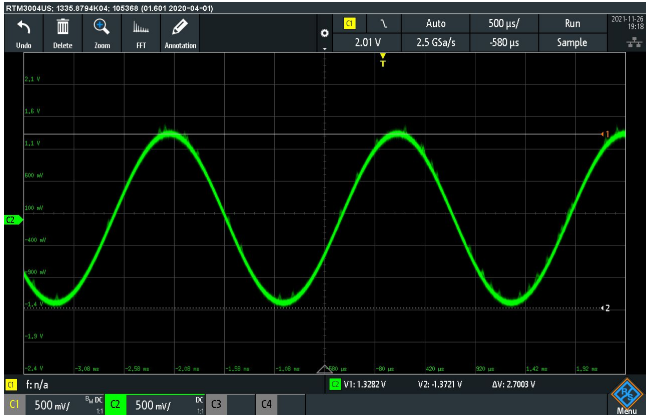


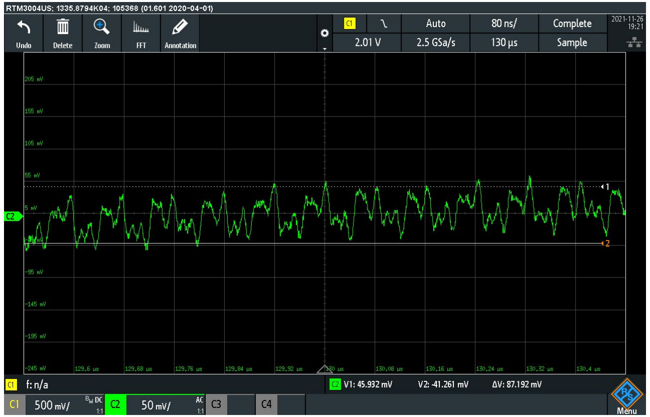
Power Transient Response

- Rise times of our linear voltage regulators upon plugging in our 9VDC wall plug:
  - 3.3V - 25ms
  - 5V - 50ms
  - 9V - 80ms
- We wanted to observe the stability of transient response during power on and power off.
- Looking for overshoot or damping

Signal to Noise Ratio

- SNRdB = 10log10 (Vsignal / Vnoise)
- Vsignal = 2.7V
- Vnoise = 0.087V
- SNRdB = 14.92dB
- Original goal of 14dB reached
- SNRdB can be improved slightly via the use of the onboard tone control to remove high frequency noise.



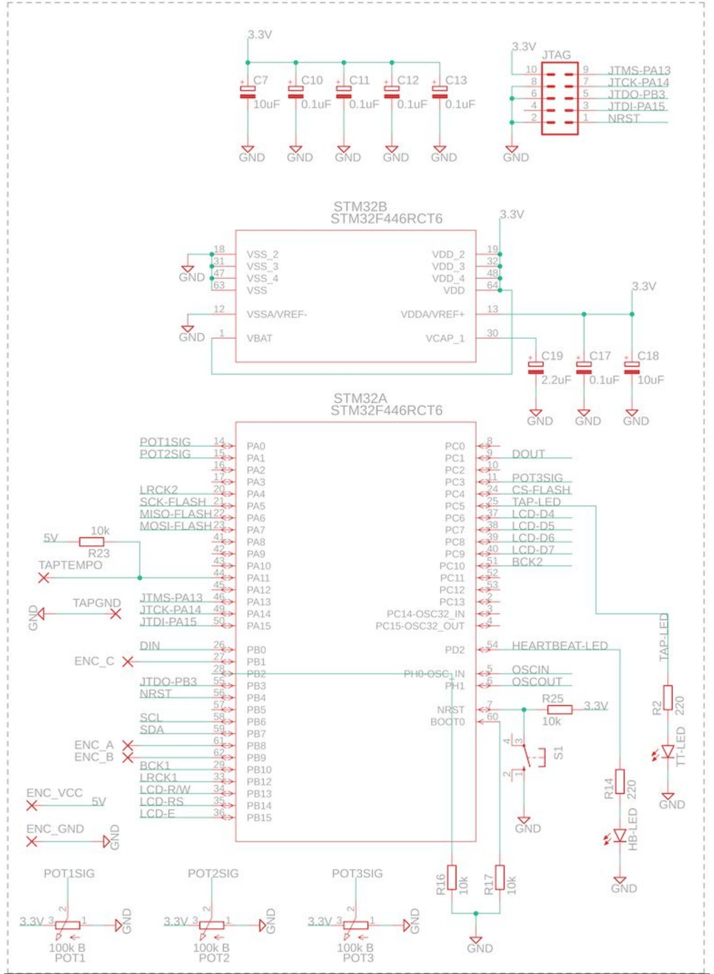


MCU Comparison

MCU	Clock Speed	Memory	RAM	GPIO Count	Cost
FV-1	48kHz	768 B	4096 B	3	$17.75
MSP430G2	25MHz	256 KB	512 B	16	$2.38
Teensy 3.2	72MHz	256 KB	64 KB	40	$11.46
STM32F446	180 MHz	256 KB	128 + 4 KB	50	$7.45

MCU (STM32F446RE)

- Processing performance
- FPU
- Integrated configurable debug
- Cost
- DMA 1 & 2

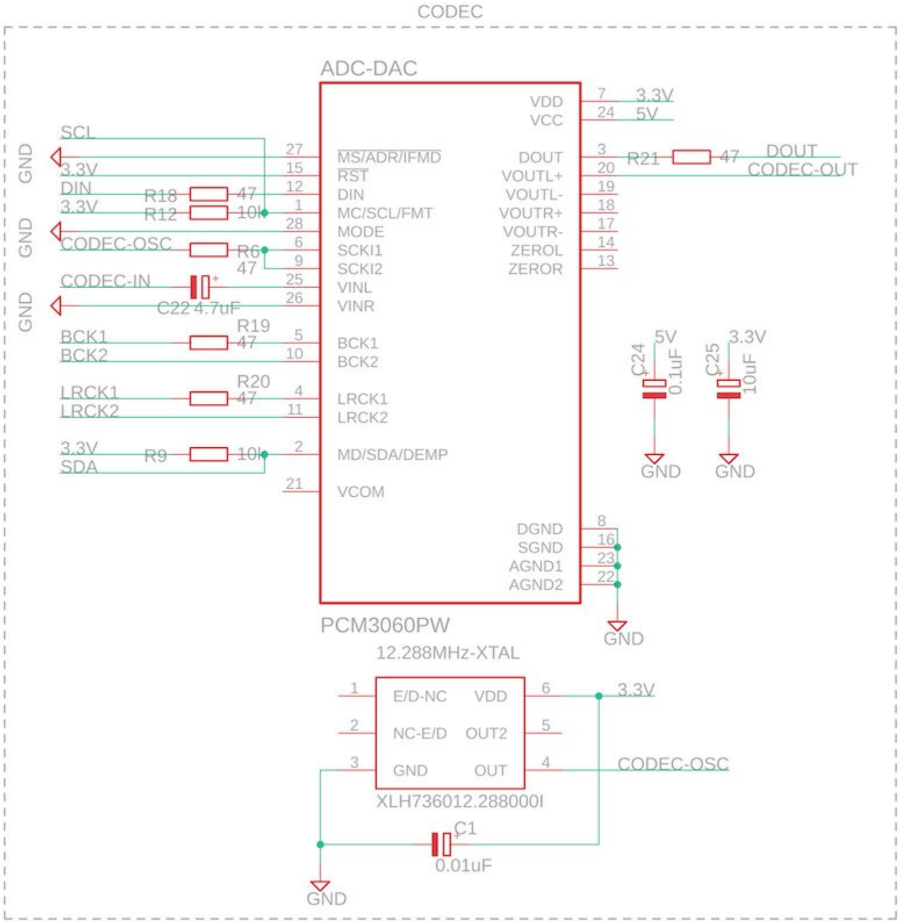


CODEC Comparison

Name	Resolution	Max Sample Frequency	Cost
MAX98050	16, 24, 32 Bits	192 kHz	$5.06
PCM3060	16, 24 Bits	96 kHz	$5.69
TLV320AIC23	16, 20, 24, 32 Bits	96kHz	$10.15

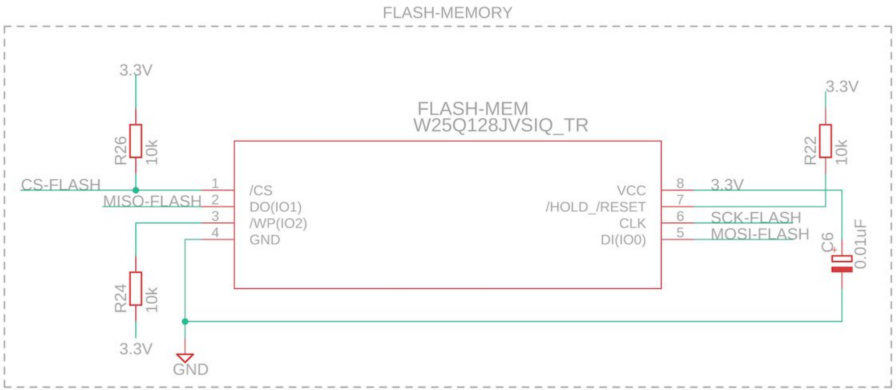
CODEC (PCM 3060)

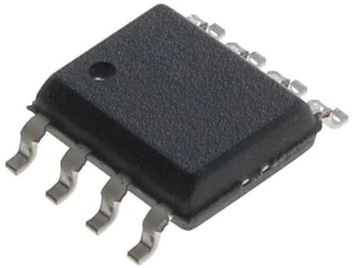
- A CODEC contains both an ADC and DAC
- We chose the PCM 3060 because:
  - 24 bit Stereo Resolution
  - Up to 96kHz Sampling rate (we are using 48kHz)
- We will be using I2S Interface to communicate with this chip



External Flash Memory

- Purpose:
  - Extra storage for audio
- Record audio at 48 kHz
  - 24-bit sample resolution
- Example: 1 second track recording
  - 1 sec * 48k samples/sec * 24 bit/sample = 1152,000 bits (144 kB of memory required)
- Common recording length
  - 10 s - 1 min
- 16 MB of memory available





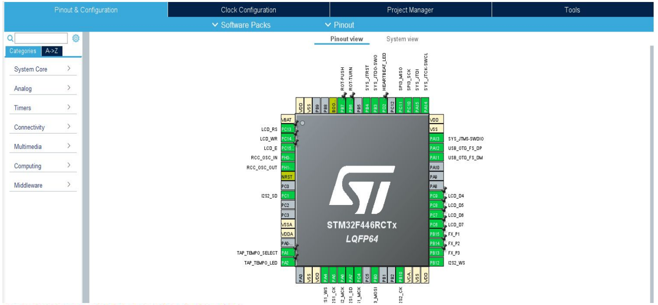
Software + Digital Design

Software Overview

- STM32, IDE, and Drivers
- Testing & Debugging Tools
- System Concept
- UML & Firmware Architecture
- Peripherals
- Clock Configuration
- Memory Management
- Relevant Algorithms
- Effects

STM32CubeIDE & HAL

- The IDE provides a graphical software configuration tool for GPIO and clock configuration. Handles and configures the user set up.
- The IDE provides auto generated function prototypes with the configurations selected
- The HAL drivers include a complete set of ready-to-use APIs that simplify the user application implementation.

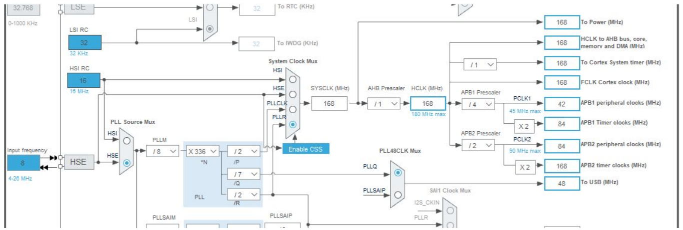



```
static void MX_GPIO_Init(void)
{
  GPIO_InitTypeDef GPIO_InitStruct = {0};

  /* GPIO Ports Clock Enable */
  __HAL_RCC_GPIOC_CLK_ENABLE();
  __HAL_RCC_GPIOH_CLK_ENABLE();
  __HAL_RCC_GPIOA_CLK_ENABLE();
  __HAL_RCC_GPIOB_CLK_ENABLE();
  __HAL_RCC_GPIOD_CLK_ENABLE();

  /*Configure GPIO pin Output Level */
  HAL_GPIO_WritePin(GPIOC, LCD_RS_Pin|LCD_WR_Pin|LCD_E_Pin|LCD_D7_Pin
                          |LCD_D6_Pin|LCD_D5_Pin|LCD_D4_Pin, GPIO_PIN_RESET);

  /*Configure GPIO pin Output Level */
  HAL_GPIO_WritePin(TAP_TEMPO_LED_GPIO_Port, TAP_TEMPO_LED_Pin, GPIO_PIN_RESET);
```

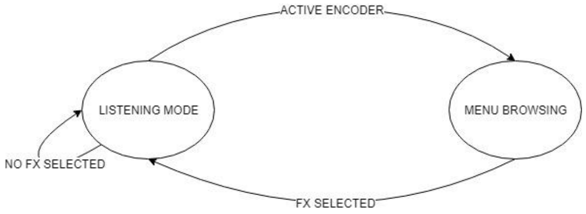


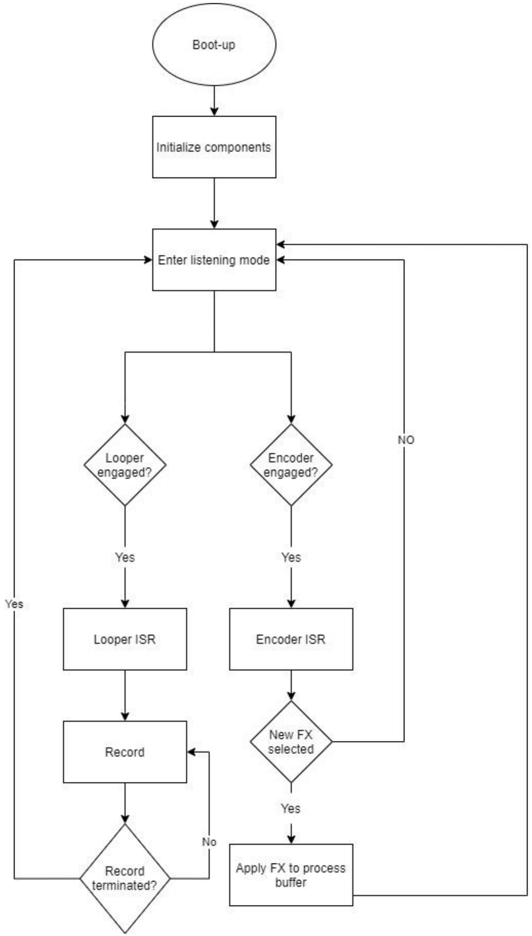
Testing and Debugging Tools

- Development board/breadboarding/prototyping
- STM32CubeIDE provides register watch as well as live expression watch of current variable values while on debugger mode
- Lab tools utilized for analyzing clock frequencies, analog input/output signals, etc.
- Development board has the same MCU (STM32F446RE)

Firmware System Concept

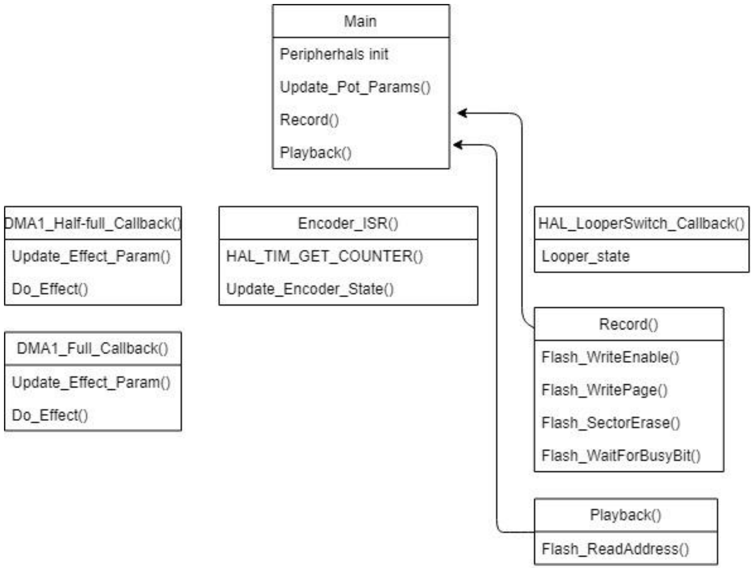
- The system is non-conclusive in nature, meaning that from the moment it is initiated, it won't stop until it is shut down.
- The system is centered around the "listening mode" state. (i.e. constant flow from input to output with no interruptions).
- "Encoder engaged" process in which we select an effect or the looper mode.





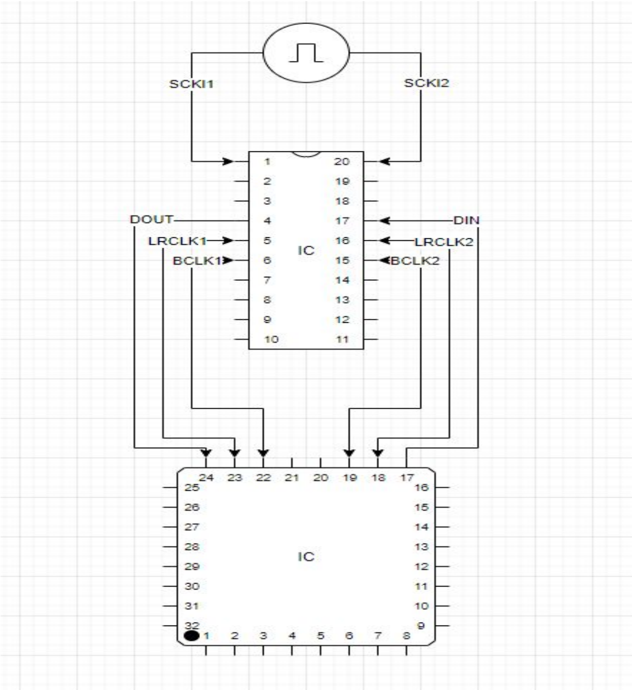
UML & Firmware Architecture

- Main()
  - SysClk, Peripherals, HAL, and variables are initialized
  - In while(1) update LCD and Pot parameters.
    - If in looper mode, determine record or playback based on looper_state
- DMA1 Callbacks
  - Updates effects parameters
  - Input/output audio buffer disassembly and reassemble
  - Apply effects processing
- Encoder Interrupt
  - Update menu cursor “position” to indicate LCD update display
- LooperSwitch Interrupt
  - Update looper_state if looper mode engage



Clock Configuration

- Purpose:
  - Prevent phase shift between CODEC and MCU
- Compatibility
  - 4 - 26 MHz - MCU
  - 12.288 MHz - CODEC
- A high speed external clock is provided to the CODEC and a separate one for the MCU.
- MCU will act as slave when communicating with CODEC through I2S.

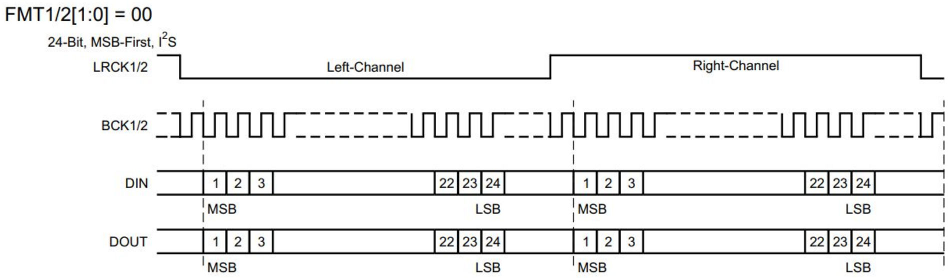


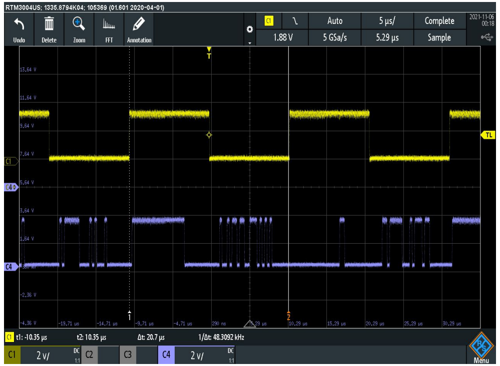
Peripherals

- 16x2 LCD
  - Provide user with visual feedback
- Potentiometers
  - Used as dials to adjust parameters available for each effect.
  - Implemented by giving the potentiometers 3.3 volts to the input and reading the outpu
- Encoder
  - Gives the user the ability of scrolling through the effects menu in both directions
  - Implemented using two channels of the same timer
- Looper Switch
  - SPST switch for looper feature commands (record, playback)
  - To implement we used external system interrupts and a timer for debouncing

Data transmission CODEC - MCU

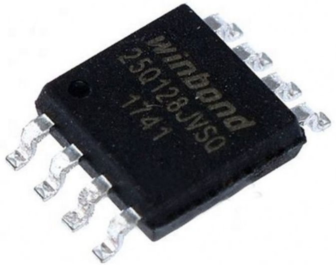
- I2C CODEC Configuration
  - ADC Master mode
  - 256 * Fs
  - DAC Master mode
  - ADC & DAC normal operation
  - DAC output single ended
- I2S MCU Configuration
  - Enable DMA with Circular mode
  - Data Width set to half-word
  - Half-duplex slave mode
- 24-bit sample in a 32-bit frame
- 48kHz sample frequency





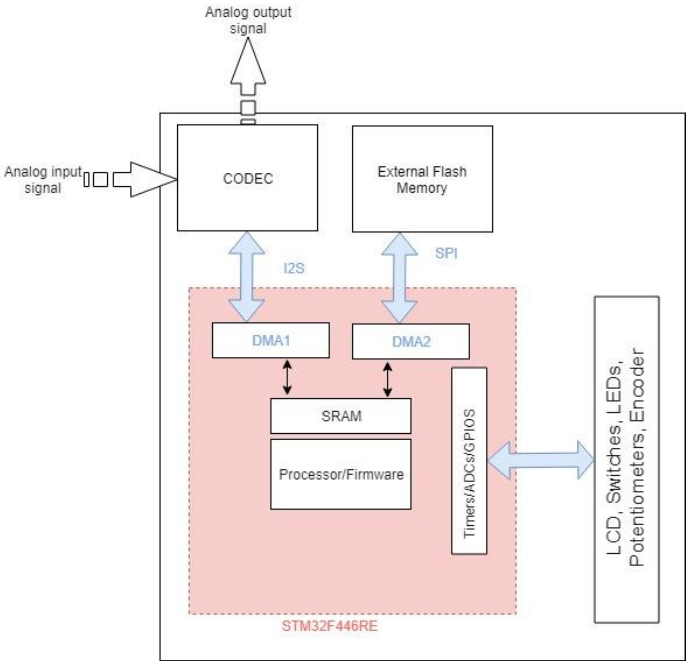
Data transmission: Flash Memory - MCU

- Standard SPI communication
  - 1 Byte transfer size with MSB Alignment
- Flash Memory is byte addressable
- Data to write to flash is grabbed from audio buffers one byte at a tir
- Data is retrieved from flash memory and fills up the audio buffer
- Implemented functions to handle transmission
  - WriteEnable()
  - SectorErase()
  - WritePage()
  - FlashRead()
  - CheckBusyBit()



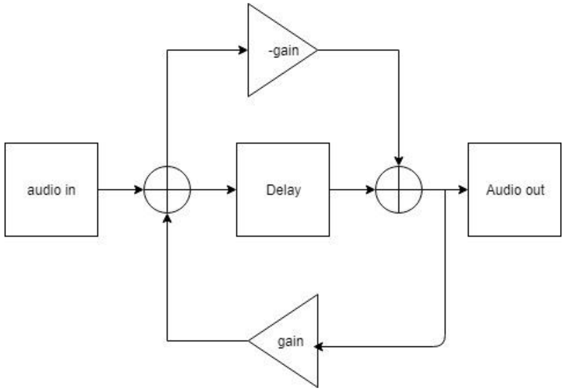
Memory Management

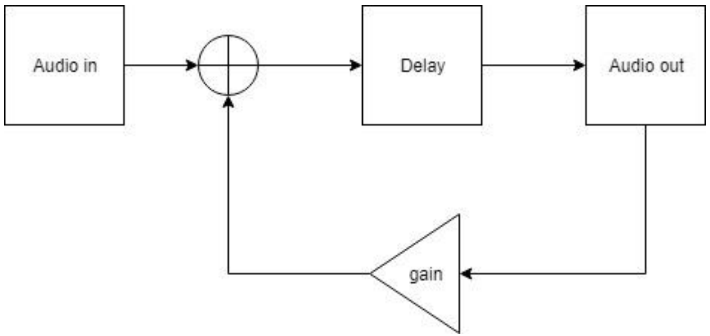
- Our main priority is to provide a stable and reliable audio experience. Code complexity can produce a lot of slow downs that can result in a delayed output signal.
- DMA provide high-speed data transfers between peripherals-to-memory and memory-to-memory.
- Effects such as delay and reverb can be memory demanding.



Effects

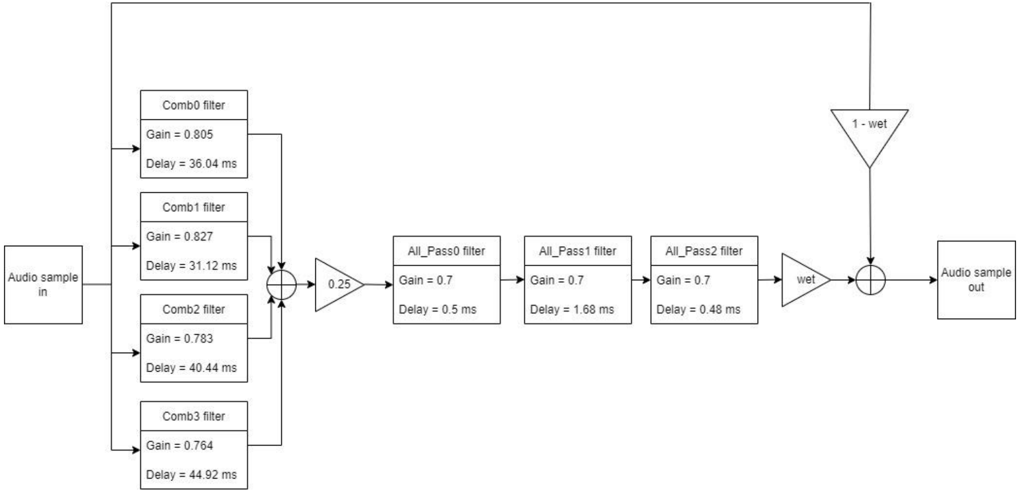
- “Pipe” Effect (Allpass Filter)
  - Gain adjusted to 0.7
  - Basic building
- Delay (Comb Filter)
  - Stability of the system
  - Usage of memory

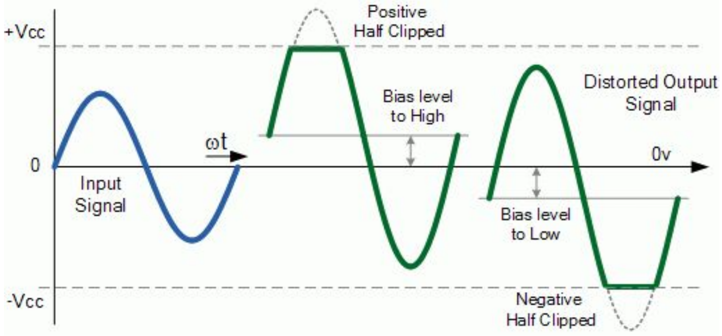




Effects (cont.)

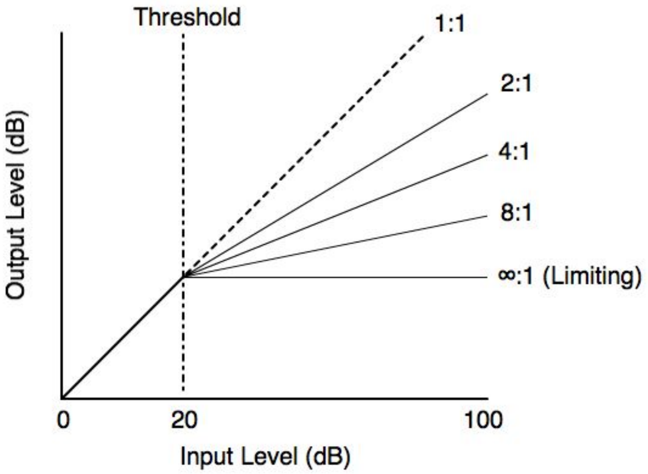
- Reverb
  - Feedforward Dry/Wet Mixer
- Distortion
  - Lower & upper Thresholds
  - Overall gain

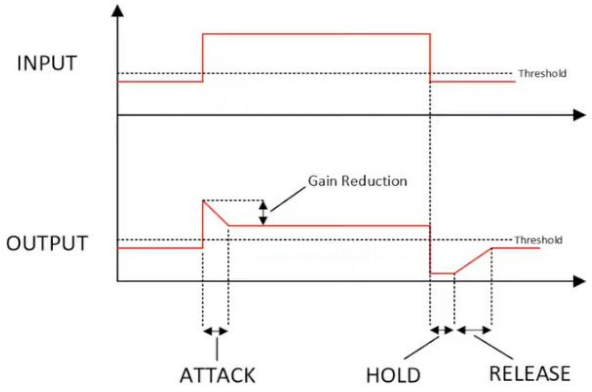




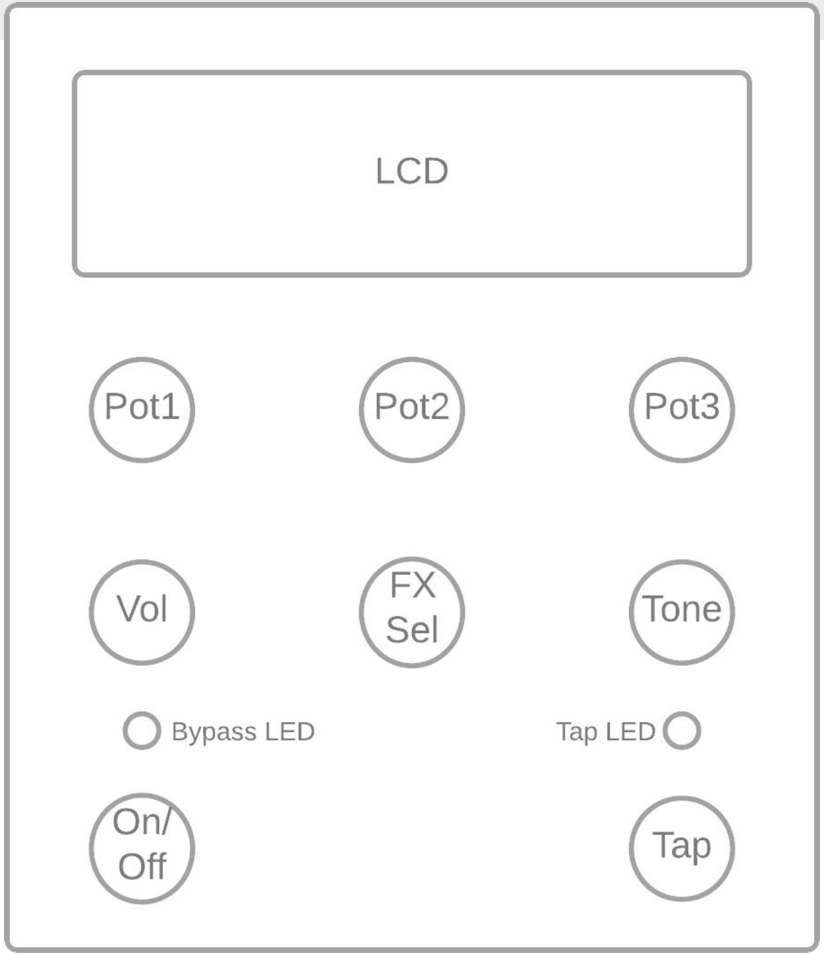
Effects (cont.)

- Pitch-Shift
  - Shift
  - Dry/Wet Mixer
- Compressor
  - Attack
  - Hold
  - Release

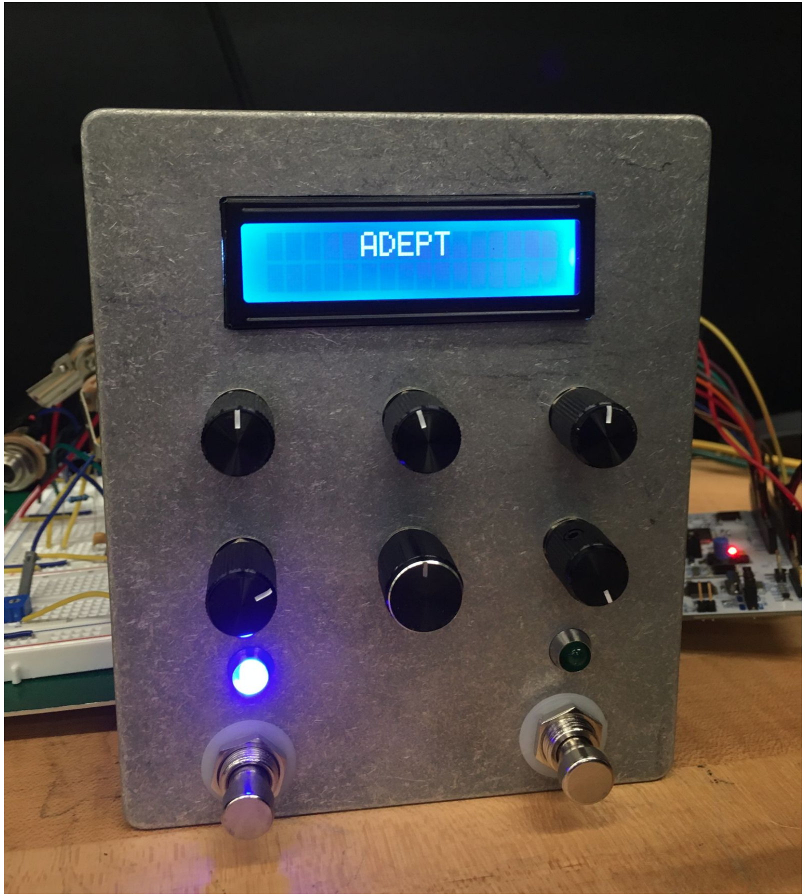




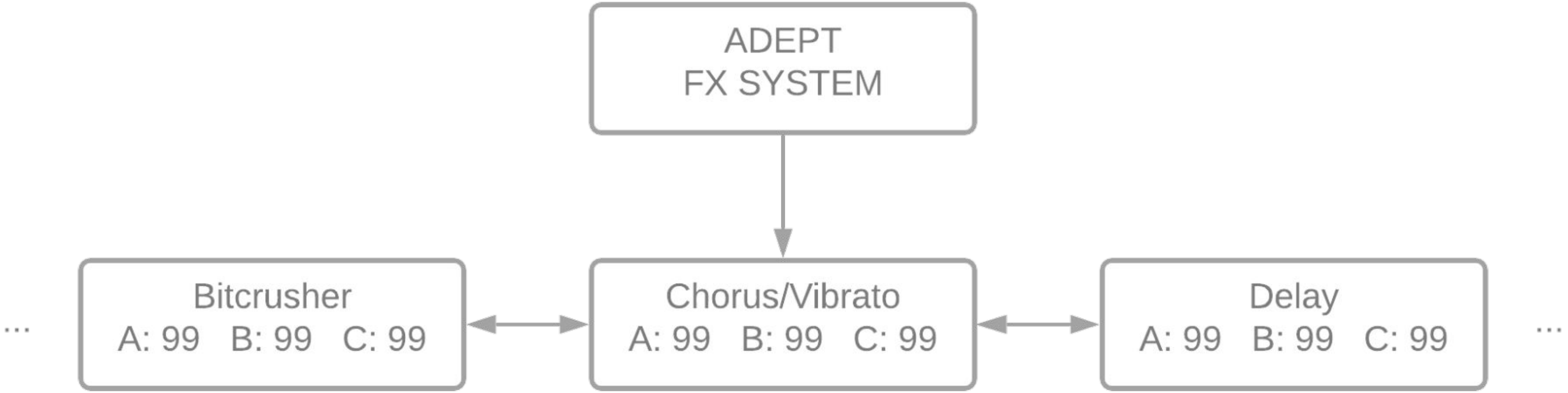
Pedal Layout Diagram



Physical Prototype



User Interface

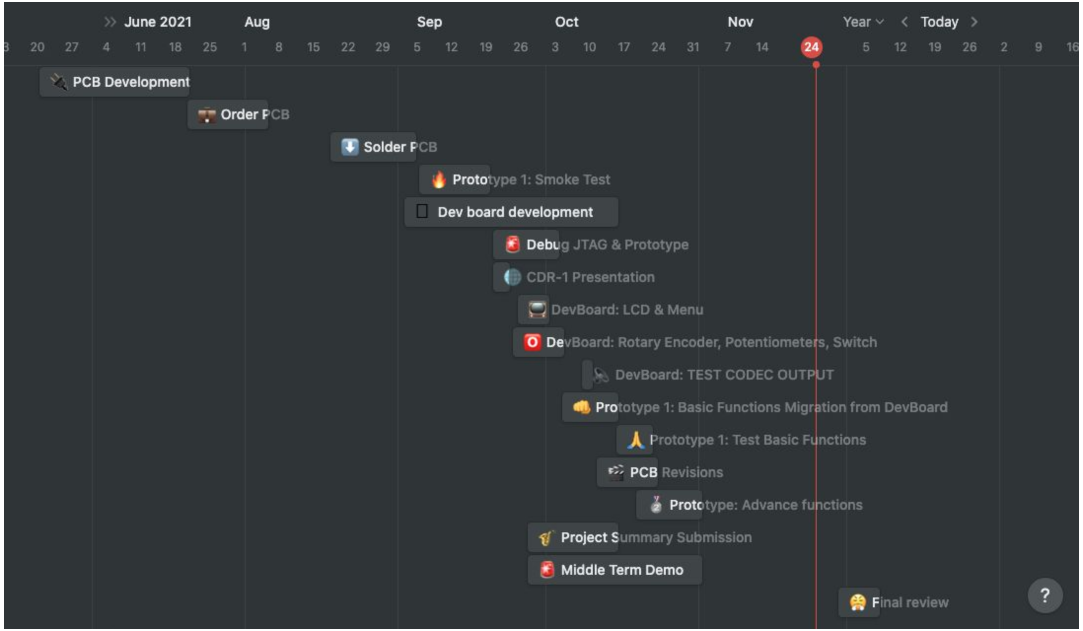


Administrative Content

Project Planning Tools

- Notion
  - Project Management
- Github
  - Code Backups and Version Control
- Google Drive
  - Store/Share Documents
- Discord
  - Team Communication

Progress Chart



Cost of Materials

Part	Cost
PCB	*$60*
PCM3060 CODEC	*$5.69*
Resistors	*$2.50*
Capacitors	*$2.50*
Diodes	*$0.50*
Transistors	*$0.25*
Potentiometers	*$1.65*
STM32 MCU	*$7.45*
Flash Memory	*$1.69*
External Oscillator	*$19.97*
Switches	*$7.80*
LEDs	*$0.25*
Mono input/output jacks	*$4.00*
Metal Enclosure	*$18.00*
ST-LINK/V2 USB connector	*$5.93*
Regulators	*$4.50*
TOTAL	*$142.68*

Progress percentage

TASK	ASSIGNED TO	PROGRESS	START	END
Research, Documentation & Design				
Block Diagram	Dylan	100%	1/25/21	1/29/21
Components and parts list	Alejandro, Dylan, Tyler, Diego	100%	1/27/21	4/1/21
Microcontroller/Microprocessor	Diego & Alejandro	100%	1/27/21	4/1/21
ADC/DAC/CODEC	Alejandro & Diego	100%	1/27/21	4/1/21
Network & connections schema	Diego & Dylan	100%	1/27/21	8/1/21
Effects	Diego & Alejandro	100%	1/27/21	8/1/21
Power supply	Tyler & Dylan	100%	1/27/21	8/1/21
PCB layout	Tyler & Dylan	100%	1/27/21	8/1/21
Development				
Tone section breadboarding	Dylan	100%	3/1/21	8/1/21
MCU/CODEC External Clock	Diego & Alejandro	100%	5/1/21	8/1/21
MCU & CODEC Communication	Diego & Alejandro	100%	5/1/21	11/14/21
Power Supply	Tyler & Dylan	100%	5/1/21	8/1/21
Systems Check Routine	Diego & Alejandro	100%	5/1/21	10/1/21
Switches & User interface	Diego & Alejandro	100%	5/1/21	11/20/21
DSP Effects	Diego & Alejandro	80%	5/1/21	11/28/21
PCB layout	Tyler & Dylan	100%	5/1/21	8/1/21

Testing & Verification				
Tone section breadboarding	Dylan	100%	3/1/21	8/1/21
MCU/CODEC External Clock	Diego & Alejandro	100%	5/1/21	8/1/21
MCU & CODEC Communication	Diego & Alejandro	100%	5/1/21	11/15/21
Power Supply	Tyler & Dylan	100%	5/1/21	8/1/21
Systems Check Routine	Diego & Alejandro	100%	5/1/21	8/1/21
Switches & User interface	Diego & Alejandro	100%	5/1/21	11/20/21
DSP Effects	Diego & Alejandro	80%	5/1/21	8/1/21
PCB layout	Tyler & Dylan	100%	5/1/21	8/1/21

Challenges

- Improper voltage level sent to the MCU
- ADC pot parameters have a small level of jitter due to 12.288MHz external clock
- CODEC-MCU communication/setup
- CODEC & Encoder interrupt in conflict
- Loss of codebase
- Flash Memory-MCU communication/setup
- Intrapersonal relations

Team Responsibilities

Diego Conterno	DSP Effects, GPIO Configurations, Project Management
Tyler Michaud	Output Buffer, Power Supply, Prototype Testing
Alejandro Porcar	ADC/DAC, LCD Menu, Looper/Tap Function
Dylan Walter	Input Buffer, Tone/Volume Control, Team Lead

Thank you!

Questions?