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Guitar Pedal Project
Design Documentation

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Introduction:
This document aims to consolidate the information and documentation created during the design process of the guitar pedal project. The project consists of the design and creation of an electric guitar effects unit, also known as a guitar pedal. The unit is meant to be connected to an electric guitar, taking the guitar signal as an input, sending a processed and altered signal to the output which is connected to a guitar amplifier. The pedal in question aims to achieve an overdrive/distortion effect to the output signal. This document will provide insight into the design process for the project, as well as a detailed circuit analysis on the operation of the final circuit.

Background:
Distortion is a process where a signal changes from its original waveform. In audio, distortion is generally undesired, as changing the waveform of a signal will change the way it sounds. When trying to perfectly reproduce an audio signal, such as with audio speakers and headphones, this type of distortion can be particularly detrimental, and is avoided whenever possible [1] . However, one notable exception where audio distortion is very much desired is with electric guitar. The sound of the distorted electric guitar is greatly iconic, and has paved the way for many popular songs within the last few decades [2]. One main way to achieve this type of distortion is called clipping, where a signal is amplified beyond its hardware limitations, effectively cutting off, or clipping, an audio signal, and creating distortion [3]. Guitarists use a variety of ways to achieve this, one common way is through effects pedals, which are units that are connected between a guitar and amplifier, processing the signal in various ways [4].

Initial Considerations:
To approach the issue of what could be defined as a success from the design initially, a more qualitative approach was favored over a quantitative approach. This was because of the unique problem that the final product of this project was to be used to make music. Since the final product will affect the tone of the guitar signal, which is extremely subjective, the project was more centered around the desired features and functionality. Design choices that affected the subjective tone of the project were implemented using an iterative process once the main functionality of the design was ensured.

Functions:

The defining function for the entire project is to be able to create a distorted output signal from an inputted guitar signal. Following this main function, as well as the general topology of guitar effects design, a block diagram was conceived:

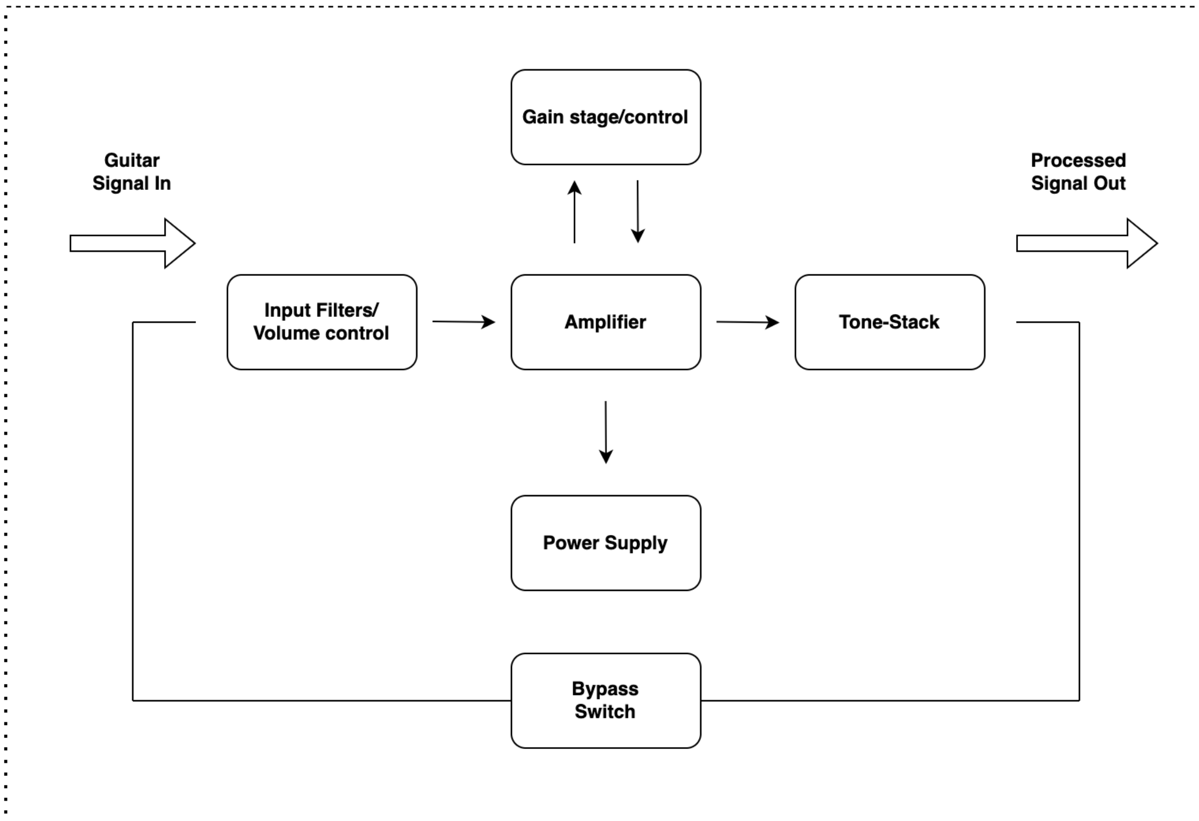

Figure 1. Block diagram for Final Design.

Objectives:

Initially, it was planned that two units would be made, one having less distortion, and one having more distortion. However, during the design stage, it was decided that the two functionalities of the two pedals would be merged into one pedal instead, adhering to the following objectives:

- Two toggle selections: one for less distortion, and one for more distortion
- Selection one sounds more similar to a warmer overdrive pedal.
- Selection two sounds more like a higher gain distortion pedal.
- A tone stack is present to shape the frequency response of the output signal.

Constraints:

Based on the functions and objectives for the design, the following constraints were generated:

- The design must only aim to distort the signal.
- The design must be purely analog based, without any digital circuitry.
- The design must fit on a PCB with dimensions of 900 x 500 mm.

- The design must be powered by a 9v battery or power supply.

Design Process:

Originally, the design was to consist of two pedals. Pedal A would serve to be a lower gain overdrive pedal, whereas pedal B would serve to be a higher gain distortion pedal. However, during the process of prototyping, the concepts for both designs were merged into one pedal that could achieve both functionalities.

Once the target goals for the design were determined, the electrical prototyping process was begun. The original design of a known guitar effects unit called the mxr microamp, which is a lower gain boost pedal, was used as a base to create the new design. This was first done in NI multisim to ensure that the pedal would be functional as well as achieve the baseline requirements. When the simulations were to a satisfactory degree, the design was then migrated onto a breadboard. The pedal was connected to power, and the input of the pedal was an electric guitar signal, while the output of the guitar was connected to a guitar amp. This stage of the design was to test the practical functionality of the circuit, and to fine tune any values for a better tone. This step was necessary for the success of the project because while the design has proven to work in simulation, whether or not it meets its goals musically must be determined through practical testing.

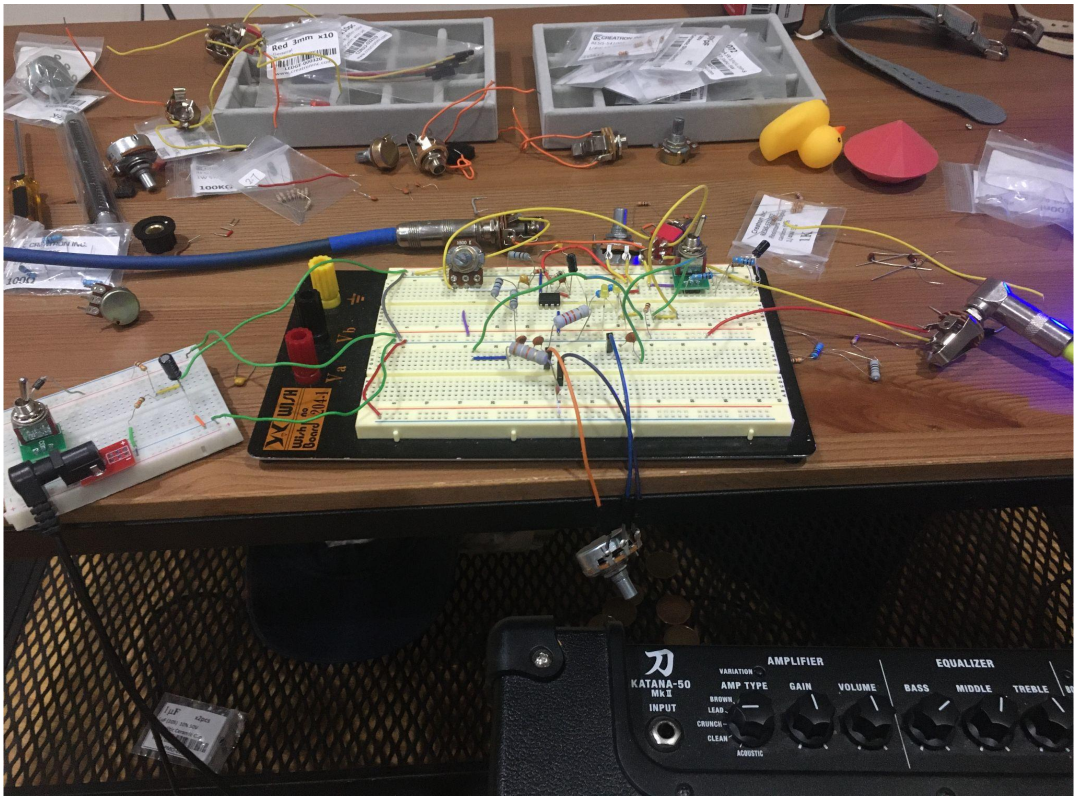

Figure 2. Breadboard setup for prototyping.

One major change that was added onto the breadboard that deviated from the simulation was at the power supply. For safety considerations as well as to prevent damage to equipment disconnected components, the power supply section was prototyped on a smaller, isolated breadboard. In addition, an extra SPDT switch was added in the power supply to act as a safe and reliable method to kill the power should it be required at any point.

Upon completion of the electrical prototyping stage, the design went to the PCB design stage, where the design was migrated a second time onto Altium Circuit Maker, which is a PCB design software. Once all the specific parts had been chosen, and the electrical rule check (ERC) on the software had been passed, the design was prepared to be created into a PCB.

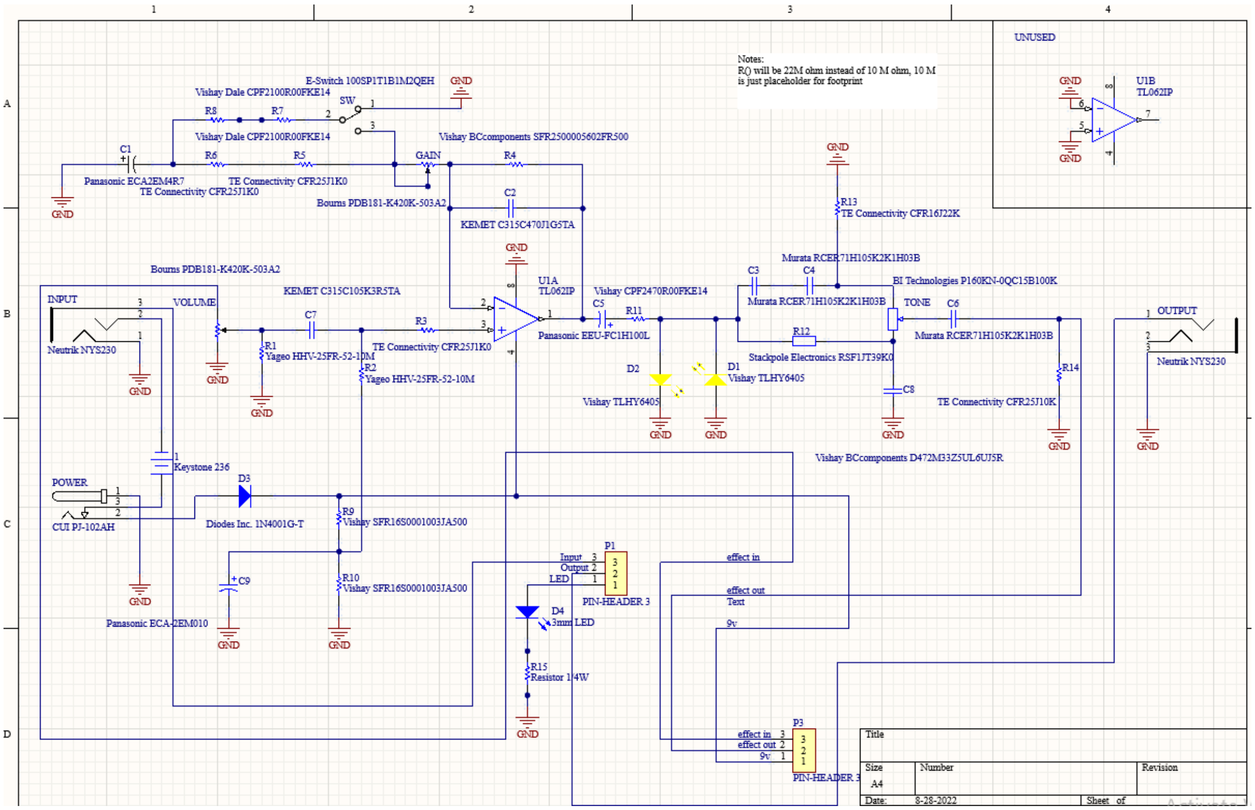

Figure 3. Altium schematic for final design.

After the design was prepared to be routed onto a PCB, the board size was determined, and each component was routed on. Beneath are pictures of the PCB file, as well as the 3D view of what the physical design would look like.

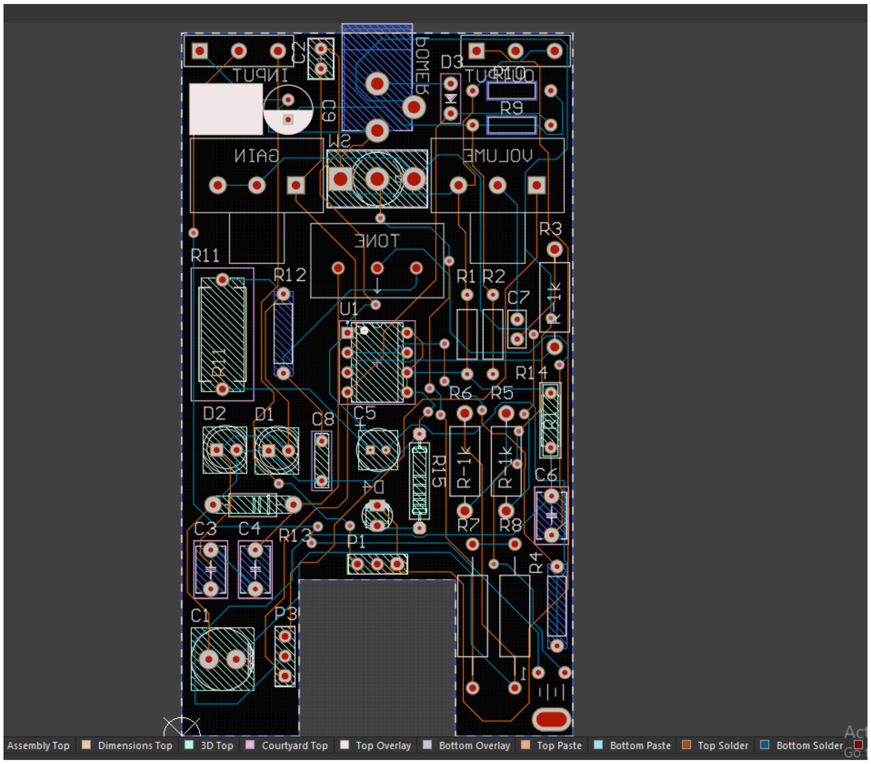

Figure 4. PCB layout for the final design.

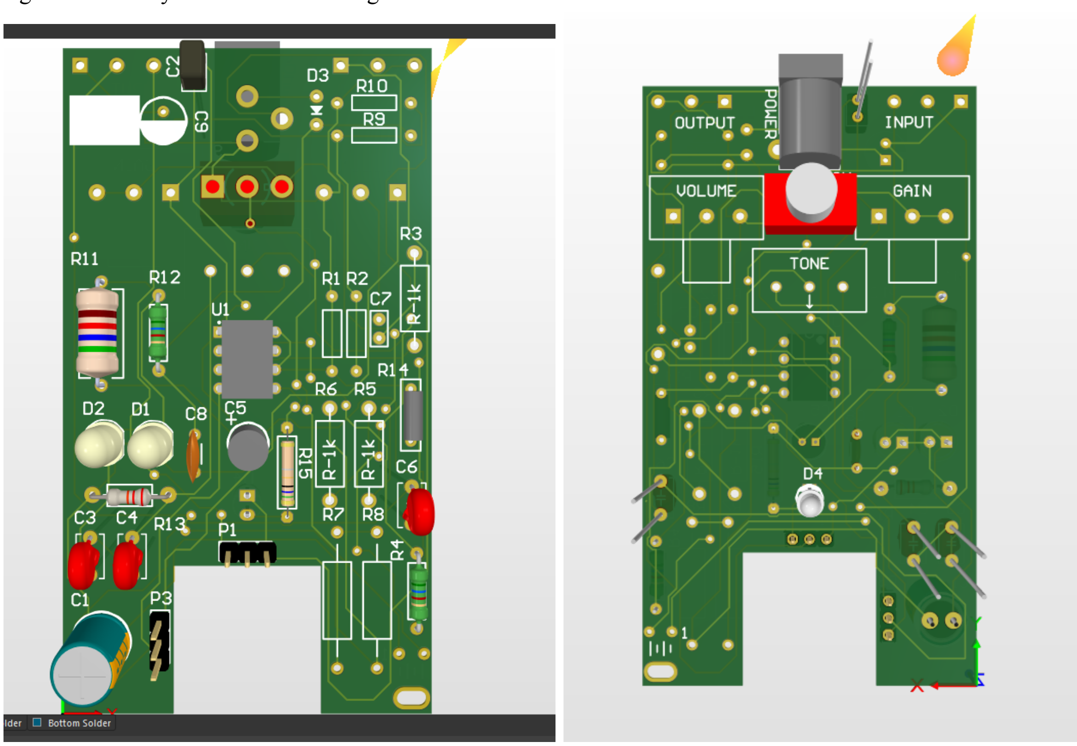

Figure 5. 3D view of completed PCB schematics

Circuit Analysis:

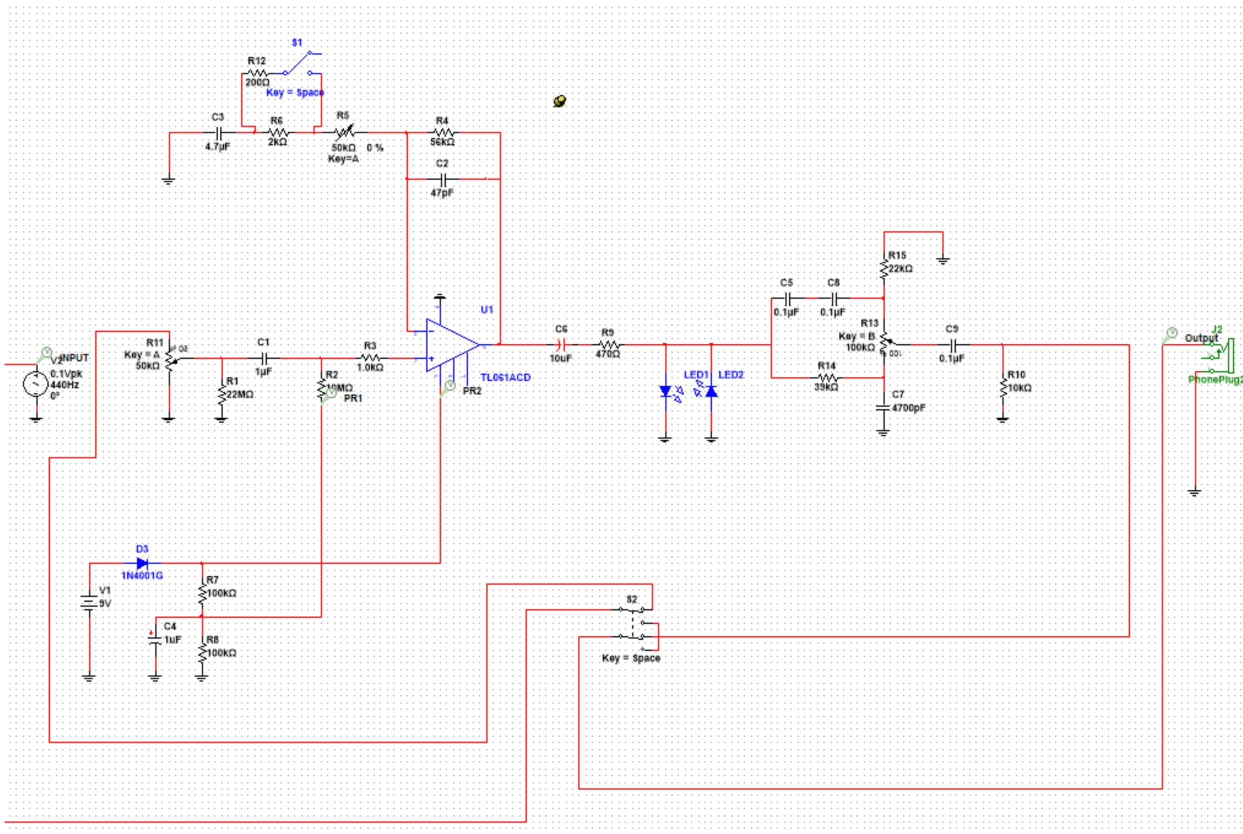

Figure 6. NI Multisim simulation for the design.

The electrical design of the proto-drive was based on a guitar pedal by MXR called the microamp, albeit with a large number of modifications. The original circuit was designed as a booster pedal, which increased the level of the input signal coming from the guitar. A detailed analysis of the original guitar pedal can be found here [5]. Much of the modifications and design considerations were based on the original circuit analysis. The electrical analysis for the proto-drive will be divided into different sections based on what each section contributes to the overall sound of the pedal. Each section will consist of a theoretical explanation of the functionality, as well as a brief discussion on the design choices that were implemented.

I. Power Supply

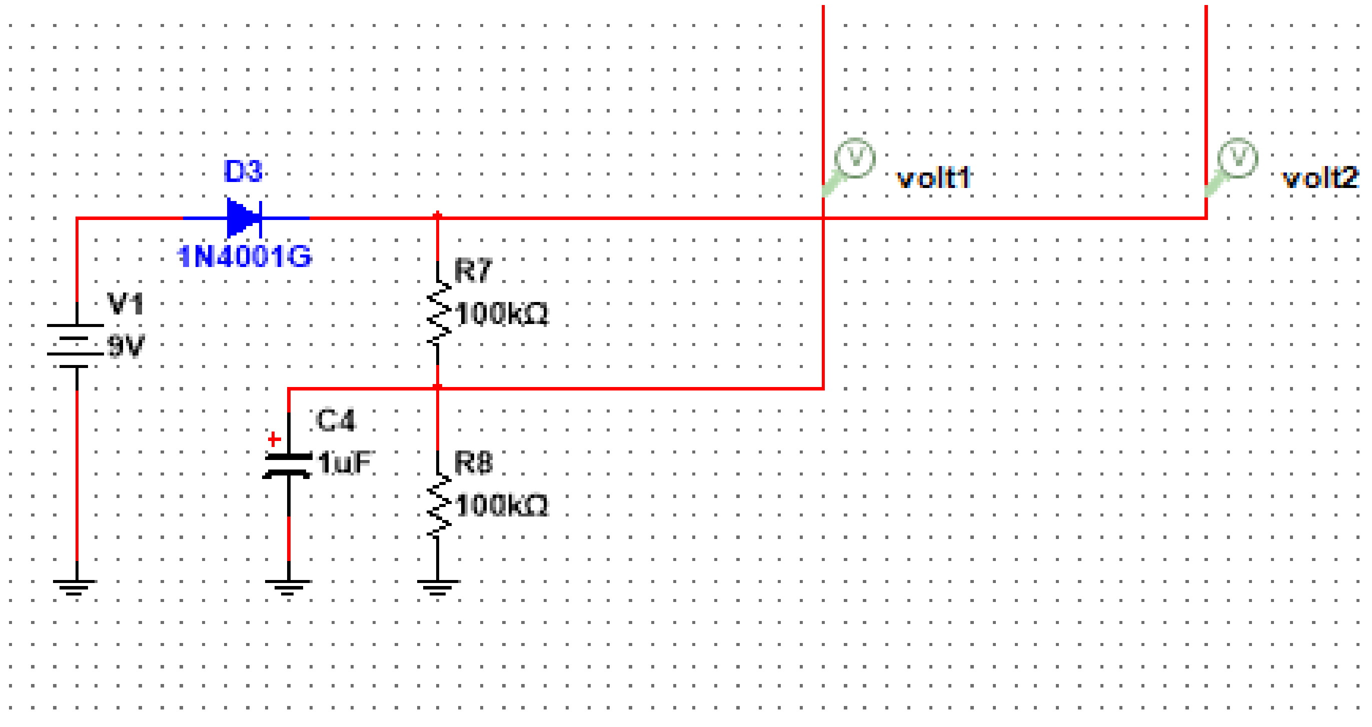

Figure 7. Power supply circuit design.

The main purpose of this section is to supply the amplification stage of the pedal with the necessary 9V and 4.5V power and bias voltages. An input of 9v from either a dc power source or a 9v battery is fed through to a simple voltage divider circuit consisting of resistors R7 and R8, which then create a 4.5V source, as well as the original 9V source. The diode D3 and the capacitor C4 act as failsafes to prevent any power-related issues from damaging the rest of the circuit. The purpose of the diode D3 is to prevent issues stemming from reverse polarity, while C4 acts as a decoupling capacitor, making sure the rest of the circuit does not become affected by any ripples in the power source. The design of this stage is the same as that of the original design of the MXR microamp booster pedal, as it was able to reliably supply power to the circuit.

II. Amplification Stage

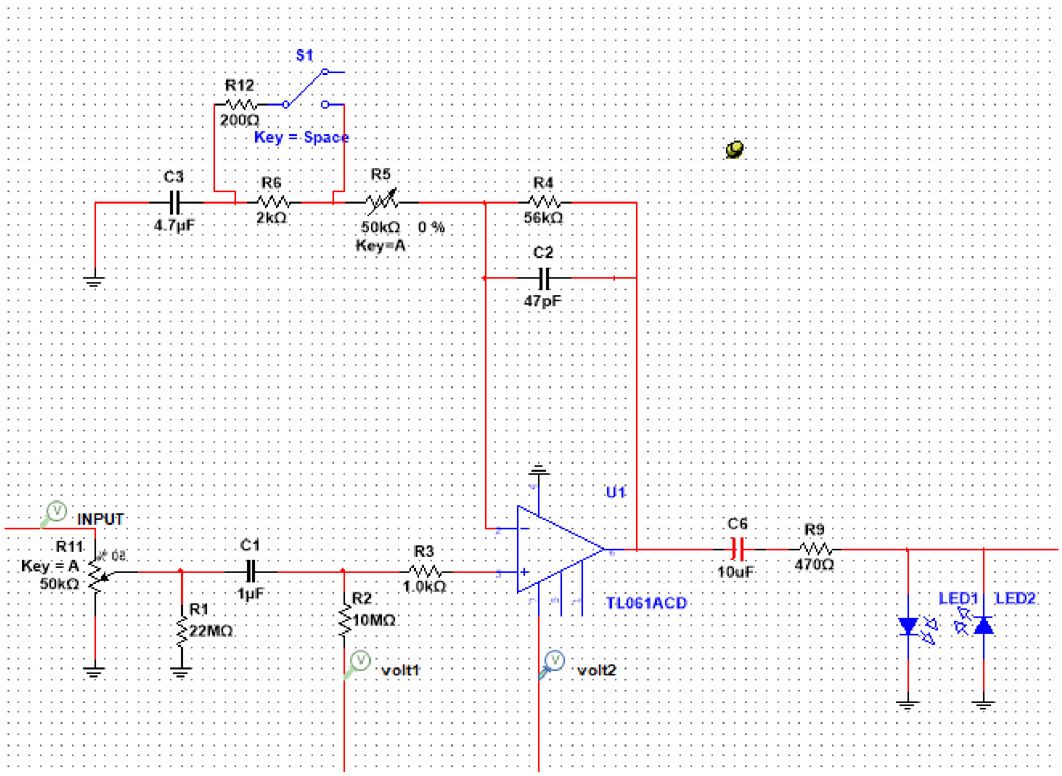

Figure 8. Amplifier circuit design

This is arguably the most important subsection of the entire circuit, as this section amplifies and distorts the input signal. The theory behind the operation of the amplification stage works on the same principle as the MXR Microamp's amplification stage. However, a number of extra features and changes were implemented in order to achieve the desired objectives.

The base circuit's amplification stage functioned through a non-inverting Op-amp configuration, with a potentiometer to control the level of gain that was being generated. In order to achieve the goal of changing the design from a booster circuit to an overdrive circuit with more clipping and gain, two changes were made. In order to achieve distortion through higher gain, the resistor value to the left of the gain potentiometer was changed. There was an inversely proportional relationship for that resistor with respect to the overall gain, so the value was decreased from the original.

To create a little more clipping for the output signal, the second change that was made was to add two yellow LEDs, LED1 and LED2 after the Op-amp stage to clip the signal. While this addition only clips the signal minimally compared to the other modification, it creates a unique effect in which the LEDs will light up more based on the level of the guitar input, which could create some unique possibilities for the design of the artwork of the pedal if desired.

The other main objective of this design was to be able to toggle from lower gain overdrive to a higher gain distortion circuit. This is achieved through the switch S1. When S1 is in the off position, the resistance of R6 is just 2k Ohms. However, when the switch is engaged, the resistor R12 is brought in parallel with R6, greatly decreasing the equivalent resistance. As shown previously, R6 is inversely proportional to the gain of the circuit, so greatly bringing down the resistance will greatly bring up the gain. This is up to a point which exceeds the physical limitations of the Op-amp itself, clipping the signal, and hence producing distortion.

$$G_V = \left(\frac{R_{10}}{R_9 + R_{10}}\right) \cdot \left(1 + \left(\frac{R_4}{R_5 + R_{eq}}\right)\right)$$

$$= \left(\frac{10{,}000}{10{,}470}\right) \cdot \left(1 + \frac{56}{0 + (2k // 200)}\right) \quad \left(\begin{matrix}\text{Sw on,} \\ R_5 = 0\,\Omega\end{matrix}\right)$$

$$= 0.95\left(1 + \frac{56}{0.181}\right)$$

$$= 0.95(310)$$

$$= 294.5 \text{ V/V}$$

$$= 20\log(294.5)$$

$$= 49.38 \text{ dB}$$

$$\approx 50 \text{ dB}$$

Figure 9. Amplifier gain calculation.

The mxr microamp, or the original pedal this design is based off of, had around 20 V/V of gain at its highest setting, being a boost pedal with minimal distortion. After calculations, it was determined that the new design has around 295 V/V of gain, which is around 14 times as much as the original. This pushes the Op amp well beyond its clean limit, creating saturation and clipping, distorting the signal by a significant amount. This achieves the goal of having a distortion setting with relatively high gain.

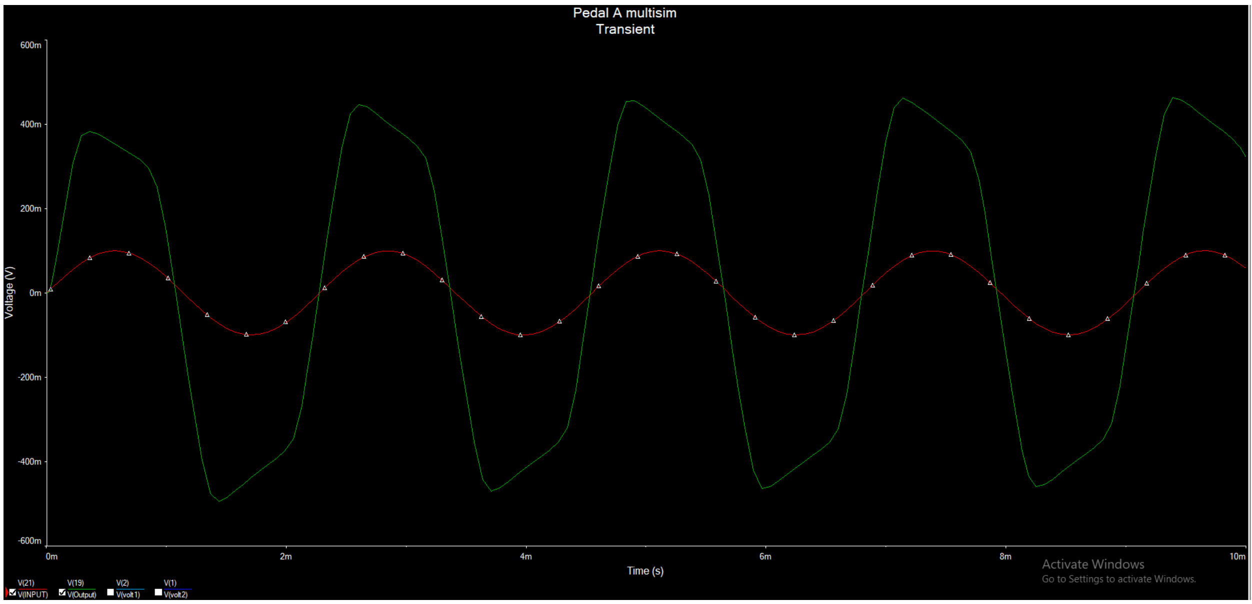

Figure 10. Output vs input signal at low gain toggle setting.

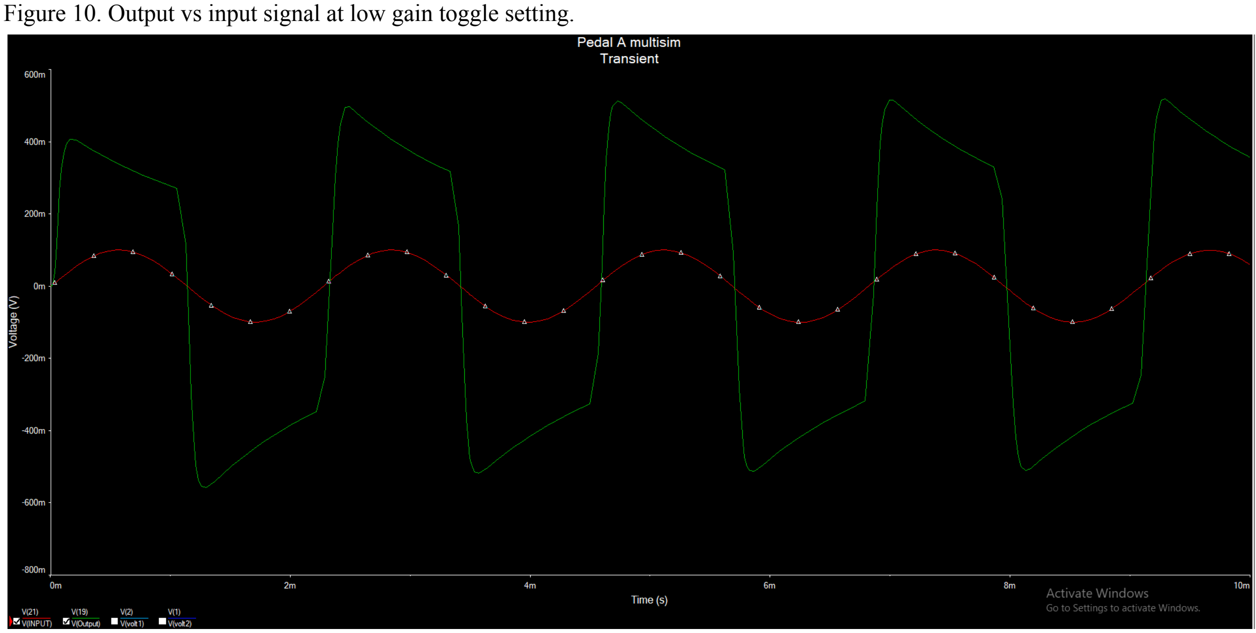

Figure 11. Output vs input signal at high gain toggle setting.

Displayed above is a side by side comparison of the output of the design when the gain potentiometer is set on the highest setting. The red signal represents an idealized version of a sinusoidal input signal, and the output represents the distorted output signal. The top graph shows the output without the switch engaged, and the bottom shows output when the switch is engaged. In both cases, the output can be seen to be much higher than the input. It can also be seen that with the high gain toggle switch engaged, the output waveform is a lot less rounded at its peaks than when the toggle is disengaged. This indicates that the signal is more clipped, since as the signal reaches the hardware limit, it will start to get flattened more. This will also result in an increase to the distortion of the signal.

III. Tone Stack

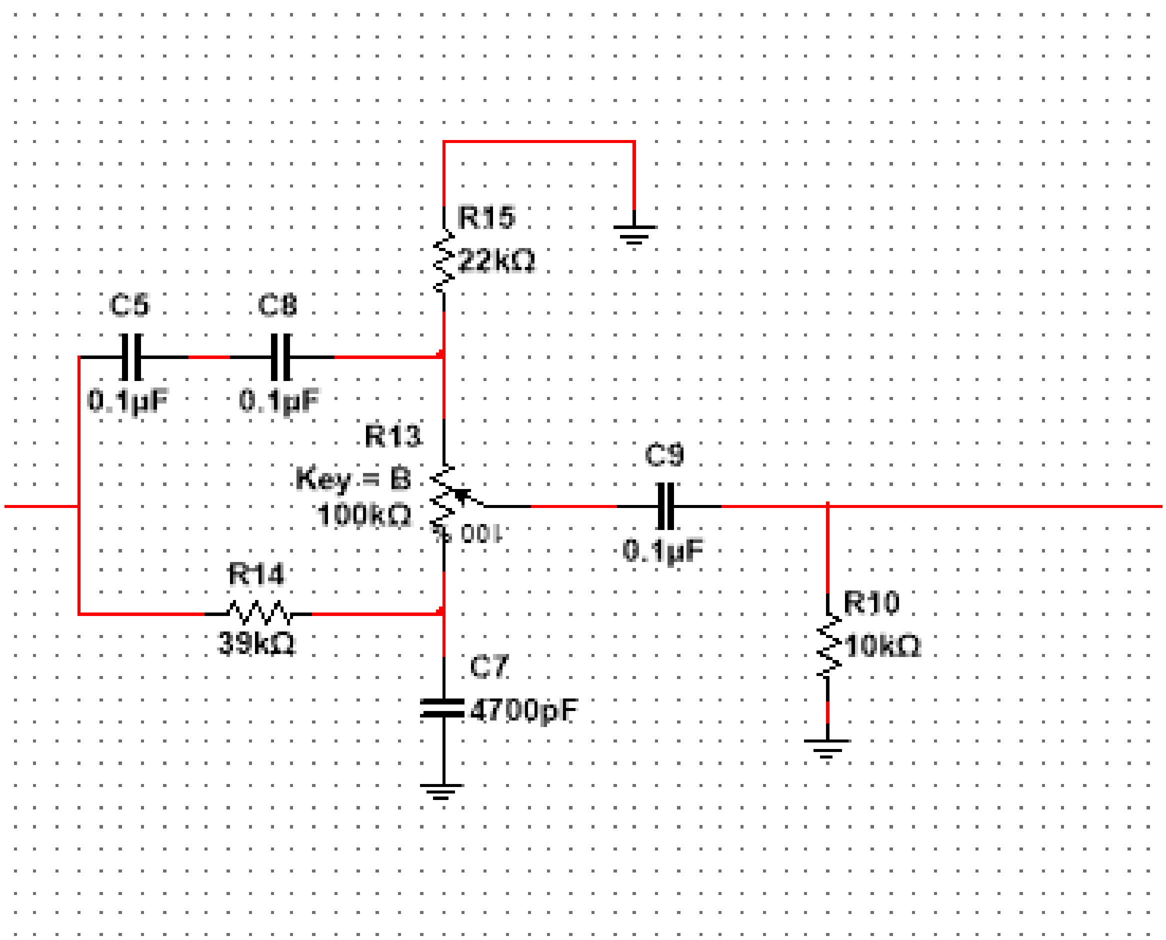

Figure 12. Tone-stack circuit design.

Another major feature of the proto-drive is the presence of a tone stack circuit. The main purpose of this circuit is to shape the frequency response, or the tone of the guitar pedal. For the Proto

Drive, the tone stack circuit was designed based on a modified version of the iconic big muff fuzz pedal's tone stage [6]. This circuit is a very simple yet robust design consisting of three passive RC filters. Two filters, one low pass filter consisting of R14 and C7; as well as a high pass filter consisting of the equivalent of C5 and C8 with R15 are separated by the potentiometer R13. By twisting the potentiometer knob, the presence of each filter can be adjusted, changing the range of the filter frequencies, altering the tone of the circuit. Finally, C9 and R10 create a fixed high pass filter that is meant to cut off a bit of extra low frequencies on the circuit. The specific equations that were used to determine the frequencies can be found here:

Here is what the tone stack circuit looks like in simulation. The first picture is when the potentiometer is turned all the way down, only allowing for the presence of the low pass filter.

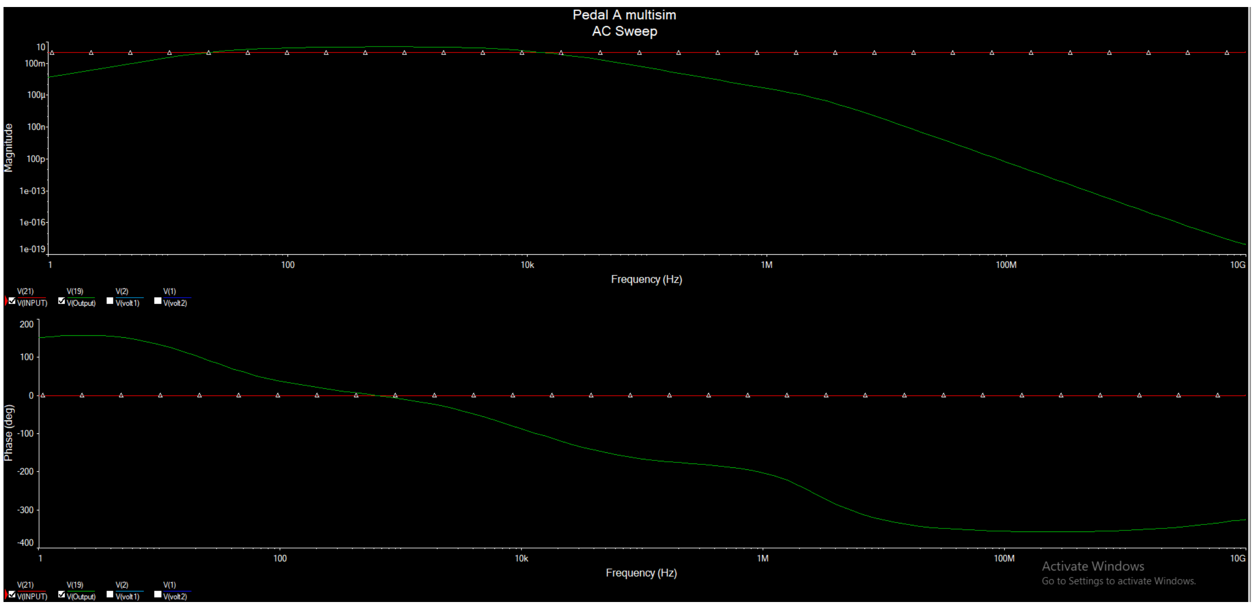

Figure 11. Tone stack potentiometer at 0%.

As can be seen in the second picture, when the potentiometer is turned all the way up, the tone stack circuit only allows for the high pass filter to pass through.

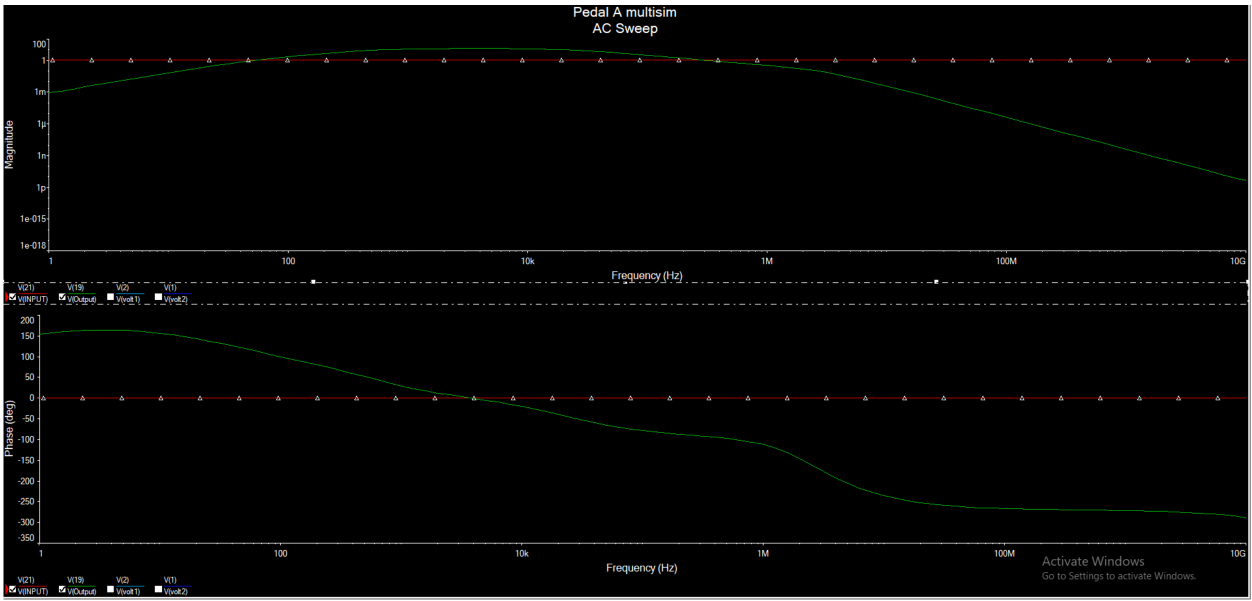

Figure 12. Tone Stack potentiometer at 100%

$$C_{eq} = \frac{C_5 \cdot C_6}{C_5 + C_6} = 0.05\,uF$$

$$f_{cutoff\,LPF} = \frac{1}{2\pi R_{14} C_7} = \frac{1}{2\pi \cdot 33k \cdot 0.047u} = \underline{1026.14\,Hz}$$

$$= \frac{1}{2\pi \cdot 33 \cdot 0.0047 \times 10^{-3}}$$

$$f_{cutoff\,HPF} = \frac{1}{2\pi R_{15} C_{eq}} = \frac{1}{2\pi \cdot 22k \cdot 0.05u}$$

$$= \frac{1}{2\pi \cdot 22 \cdot 0.05 \times 10^{-3}} = \underline{144.68\,Hz}$$

Figure 13. Tone stack filter calculations

Through the calculations, it can be seen that the high cutoff is approximately 1.026 kHz, while the low cutoff is around 144 Hz. The level of cutoff for these two frequencies will be determined by the position of the potentiometer.

This stage was not present in the circuit of the base design. Because the base was being modified into an overdrive pedal, a tone-stack was desired in order to be able to shape certain frequencies of the distorted signal to the user's liking.

Testing Procedure:

The testing procedure was carried out once the PCB was successfully assembled. The process was similar to how the design was tested in the prototype stage.

1. Make sure all the settings on the design are set to the lowest, and the gain switch is turned off.
2. Connect an electric guitar to the input jack of the design using a ¼ inch cable.
3. Connect the output jack of the design to the input of a guitar amplifier using another ¼ inch cable.
4. Connect a 9v power source to a power outlet. Connect that to the power jack of the design.
5. Turn on the guitar amplifier, adjust the settings while playing the guitar until a satisfactory, non-distorted tone is achieved.
6. Engage the bypass switch of the design
7. Turn all three of the potentiometers: volume, tone and gain at the 12 o'clock position, make sure that each knob works.
8. Vary each knob to make sure that the range of settings for the design is functional.
9. Engage the gain switch, and keep varying the settings.
10. When all the features have been confirmed, and a satisfactory tone is achieved, disengage the bypass switch of the design, turn off the guitar amplifier, and unplug everything.

Next Steps:

Looking forward, after everything about the design has been confirmed, the PCB will be mounted on an aluminum casing to make the completed design into a proper guitar effects unit. To enhance the final product, a stylized design will be inserted on the top face of the pedal through a thin, laser etched piece of wood.

Conclusion:

To conclude, this document summed up the design process as well as an electrical analysis of the Guitar Pedal Project, which successfully yielded the circuitry for a guitar effects unit that produces a range of lower gain overdrive and higher gain distortion tones. Familiarity with such a design process should pave the way for future projects related to audio processing circuits.

Citations:

[1]: “What is sound distortion? dr sound explains distortion,” Konftel. [Online]. Available: https://www.konftel.com/en/academy/dr-sound-explains-distorsion#:~:text=Distortion%20is%20a%20deviation%20from,is%20significantly%20degraded%20by%20distortion. [Accessed: 13-Oct-2022].

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[3]: M. Mcallister. "What Is Audio Clipping and Why Is It Important?" Produce Like A Pro. [Online]. Available: https://producelikeapro.com/blog/audio-clipping/. [Accessed: 13-Oct-2022].

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[5] "mxr-microamp". Electrosmash [Online]. Available https://www.electrosmash.com/mxr-microamp. [Accessed Oct-13-2022].

[6] "BIG MUFF TONESTACK : DEALING WITH MIDS FREQUENCIES." Coda Effects [Online]. Available: https://www.coda-effects.com/p/big-muff-tonestack-dealing-with-mids.html. [Accessed Oct-13-2022].