Guitar Boost Blues Pedal

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Introduction

This project started because I wanted a new guitar pedal, and I figured I might as well use the knowledge that I've gained throughout my schooling and experience to do it myself. I've always had a passion for playing guitar and I took this as an opportunity to explore my curiosity and apply analog design skills revolving around how guitar pedals work and the stages that make them possible. I also had the urge to build something meaningful all by myself and looked at it as an engineering challenge. This write-up will go through my design process throughout each stage and my reasoning behind what I chose to incorporate in my guitar pedal. I also attached my individual simulations for each stage in my Git repo, as well as notes that I took regarding the concept of each stage and what I was aiming to create. I wanted a sharper “bluesy” tone which inspired some of my design decisions. Below in Figure 1 you can see the overall schematic of my blues pedal before I explain the purpose and design of each individual stage. I also link all of my schematic simulations for a better look.

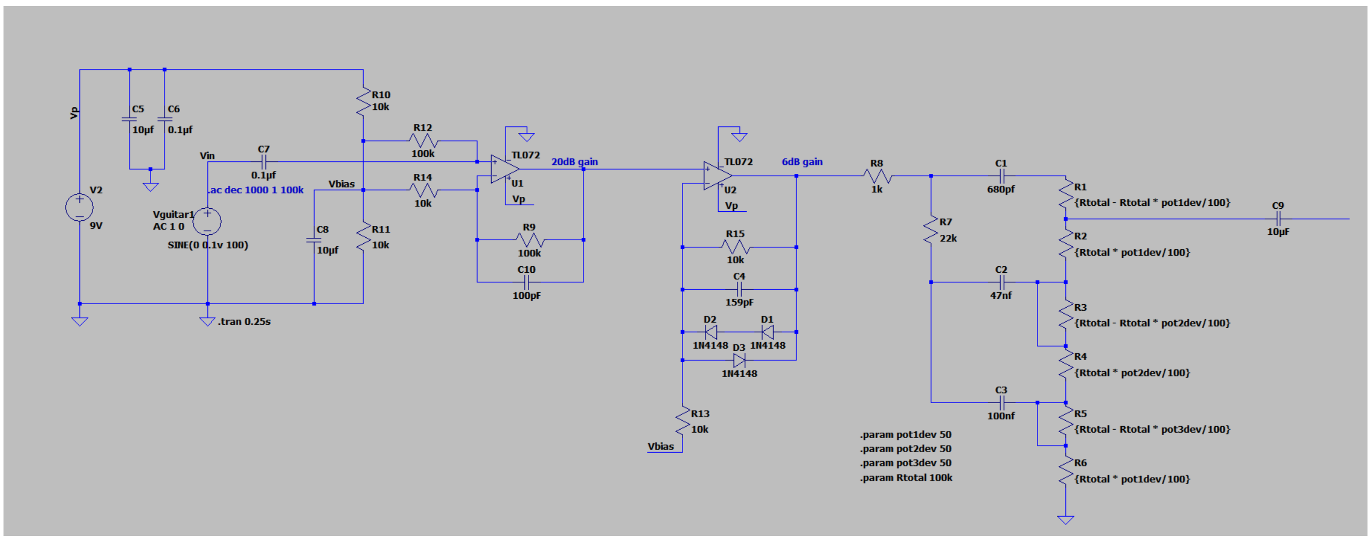

Figure 1, Overall Schematic of Guitar Pedal (Gain - Clipping - Tone Stack)

Gain Stage

My first step was to create a gain stage that could boost the raw signal from the guitar. The typical output from a guitar pickup is 100-300 mV. I learned that this wouldn't be enough to drive later tone stages or clipping, so a hefty gain stage is necessary before any tone shaping is done. To solve this problem I designed a non-inverting op amp amplifier stage to boost the signal. I used a TL072 because it is commonly used in audio applications because of its limited noise.

I only wanted to use one 9V battery so I biased the op amp’s input to half of the 9V supply. This allowed for the center of the sine wave signal to be at 4.5V staying within the op amp's rails as seen in Figure 2. The green signal being the biased output signal and the blue being the input signal from the guitar pickups.

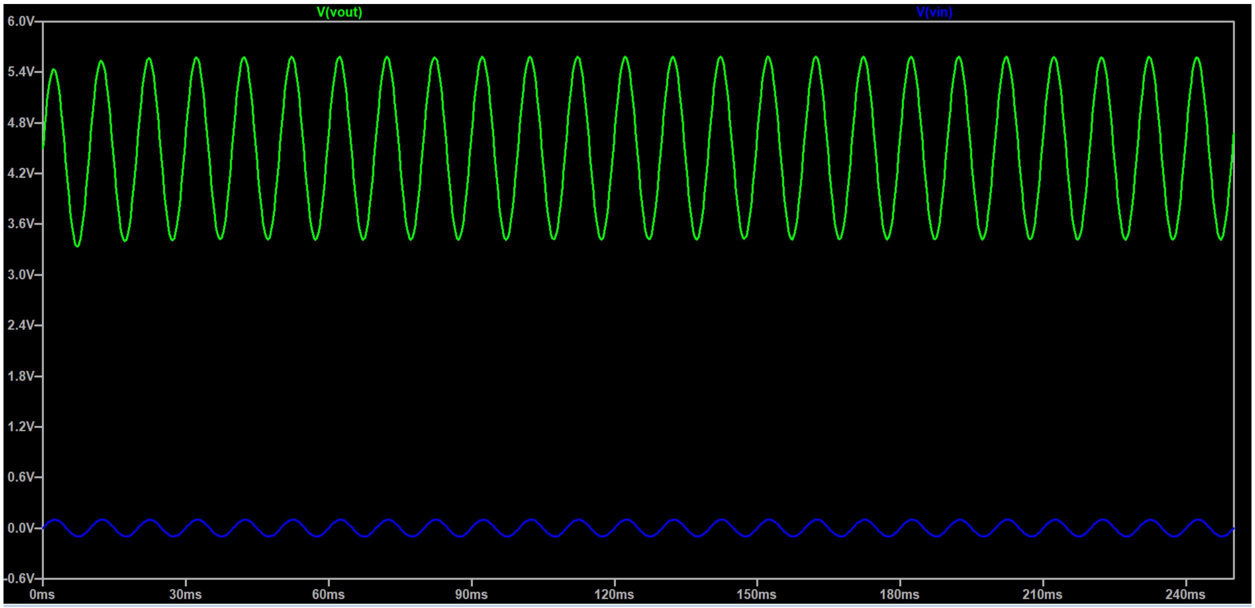

Figure 2, Biased Output of Gain Stage

Using the gain equation for a non inverting amplifier configuration (A = 1 + Rf/Rin) I set the max gain with a 100k potentiometer to be 11x or slightly over 20dB gain. This gain being completely user adjustable due to the potentiometer (R2).

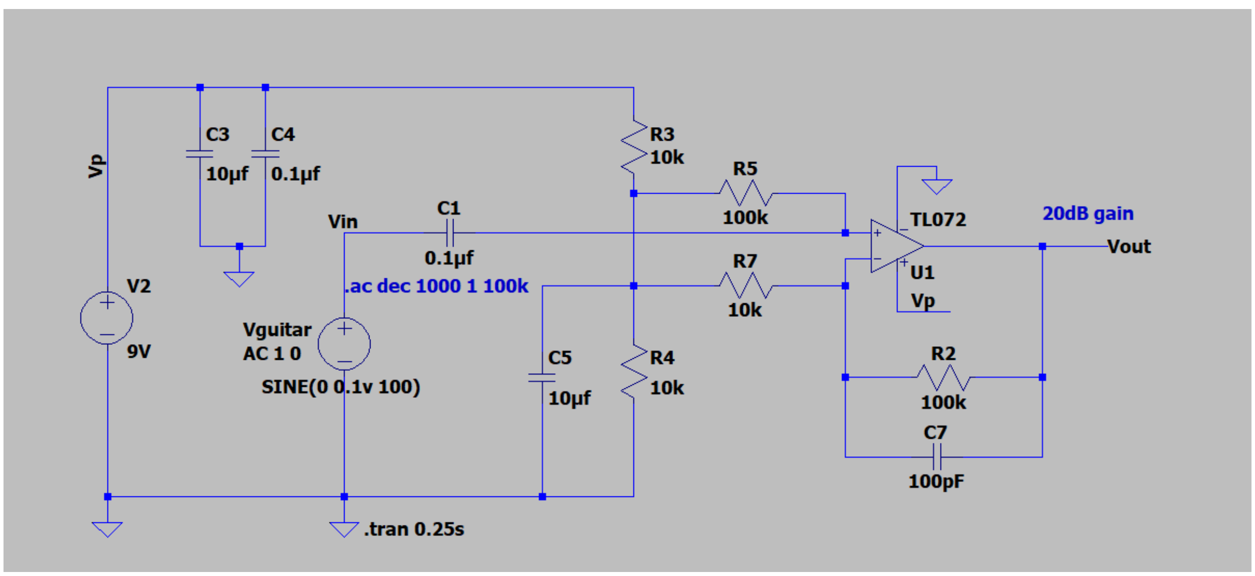

Figure 3, Gain Stage Schematic

There are decoupling caps for both my input voltage and bias voltage to increase power stability and a coupling cap at the input of my gain stage to protect my guitar pickups from DC voltage as well. The low pass filter over the feedback pot (R2) sets a cutoff frequency for 15.91KHz (Marker 2) when R2 is 100k, that is to help stay clear of radio signals but more precise filters are created in the tone stack stage. Input coupling cap is setting the high pass filter for this gain stage at 15.91Hz (Marker 1), no DC is being amplified while the op amp is stable. Both first order filter cutoffs were calculated using Fc = 1/2piRC. Ultimately the gain stage provided a biased output signal amplified and ready for the clipping then the tone stack stage.

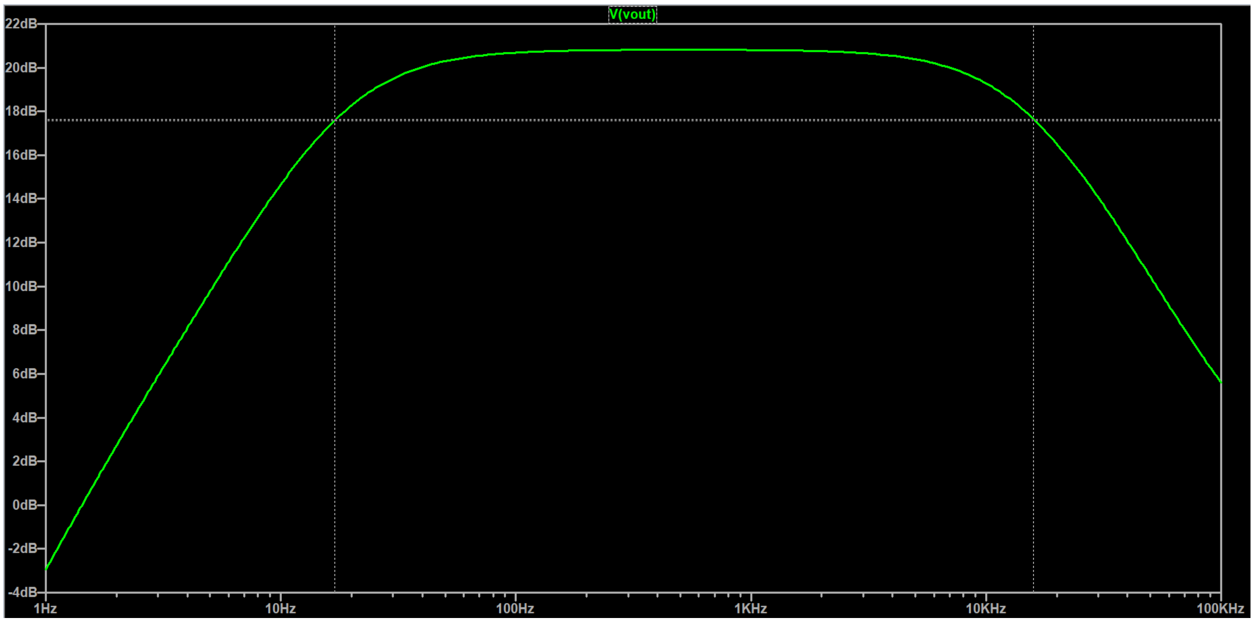

Figure 4, Gain Stage Frequency Response

Shown below in Figure 5 is my first constructed gain stage, soldered on the perfboard. My main struggle was getting the bias to be stable. There was some inconsistency with the op amp railing when on a breadboard so I transitioned to soldering very quickly.

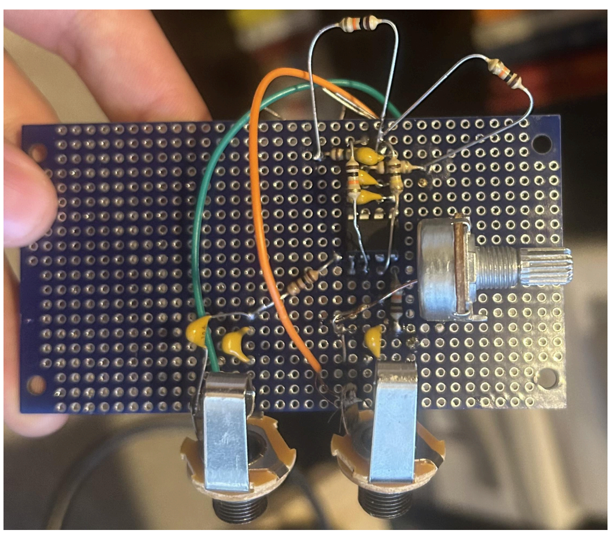

Figure 5, Gain Stage Completion Picture

Buffer Clipping Stage

After boosting the guitar signal, the next stage I added was to shape the signal with controlled clipping. As the name implies you can imagine clipping as snipping off the top of the sine wave, rounding off the tops of the wave more aggressively and quickly. This introduces harmonic distortion and was necessary to achieve a sharper “bluesy” overdrive for my purpose. I wanted to use diodes because it allows for clipping to take place in smoother fashion and becomes more customizable rather than slamming a signal's edges into an op amp's rails (another way to clip).

In order to achieve this clipping stage I configured another TL072 op amp as a unity gain buffer and placed a pair of diodes across the feedback resistors in opposite directions as seen in Figure 6. In this configuration with my biased signal, when the sine wave exceeds the diode's forward voltage threshold plus the 4.5 bias, the diode will activate causing the wave to be “clipped”. The diode in the opposite direction allows for the same behavior when the lower part of the sine wave is lower than 4.5 minus the threshold of the diode. This is specifically called “soft clipping”. Hard clipping takes place when diodes are configured straight to ground from the output signal causing the sine wave to get chopped off aggressively instead of rounded earlier. Below in Figure 6 you can see the setup for hard clipping, soft clipping, and no clipping and the affected output waves accordingly in Figure 7. I used simulation to decide for myself what I wanted to use as well as testing on my own pedal. Voltage threshold for all diodes was 0.7V.

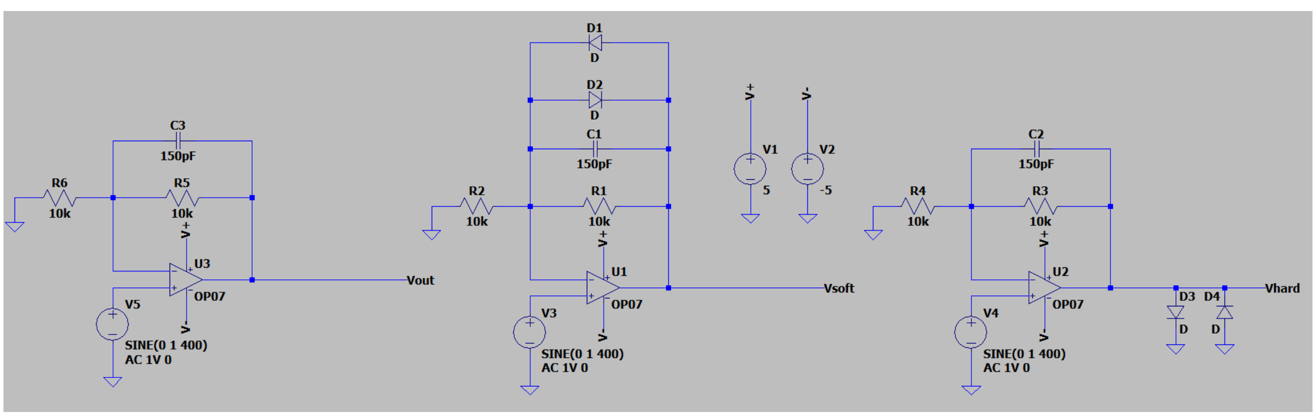

Figure 6, Clipping Simulation Schematic (None - Soft - Hard)

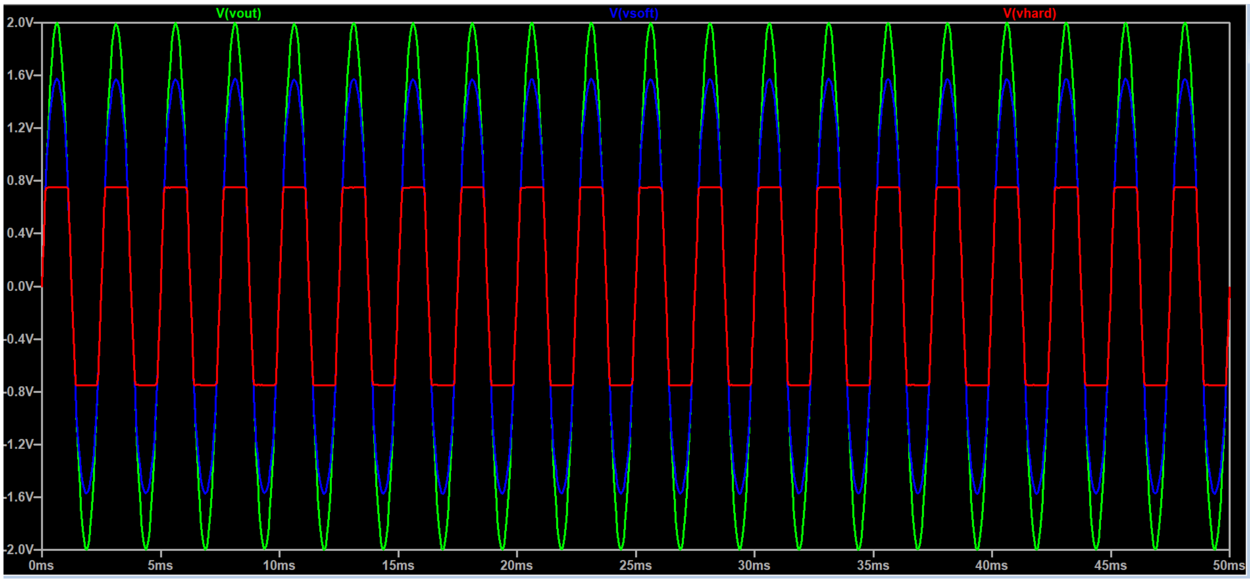

Figure 7, Output Signals of Clipping Examples (Blue -Soft) (Red - Hard) (Green - None)

As seen above I chose soft clipping because it provides a good middle ground of distortion and also maintains a crisp and full tone. I tested both on my circuit and definitely preferred the soft clipping. I left the plug in socket for hard clipping as well so I can still play around with it!

The customizable portion of this stage comes not only from the type of diode you use but also the amount. This introduced the idea of asymmetrical clipping to me throughout this design process. I experimented with two different types of diodes, a standard red led and germanium diodes. Germanium diodes are known for giving a warmer tone with a lower forward voltage threshold while red leds can have a more extreme cutoff. I decided on asymmetrical clipping because it changes the harmonics of the signal due to the uneven waveform that it creates. This tone is described to be more "rich" and seemed to be the standard with the circuits and designs that I researched. I added plug in sockets across my feedback network so I was able to plug and play a bunch of different combinations which was fun and I can still do to this day! I landed on asymmetrical clipping with germanium diodes. It gave a clearer distortion with a rich tone that you can hear in my demo video.

Tone Stack Stage

After shaping the waveform with the gain and clipping stages, the last step for my guitar pedal was to sculpt the frequency response of the signal using a tone stack. A tone stack is essentially a "stack" of three paths that together create a highpass, lowpass, and a midrange scoop filter. Each incorporates a potentiometer resistor allowing the player to adjust and emphasize bass, middle, or treble frequencies. For my design I used a three band passive tone stack which splits control into those same three categories, bass, mid and treble. You can see the tone stack circuit below in Figure 8, paths from top to bottom represent treble, bass, mid.

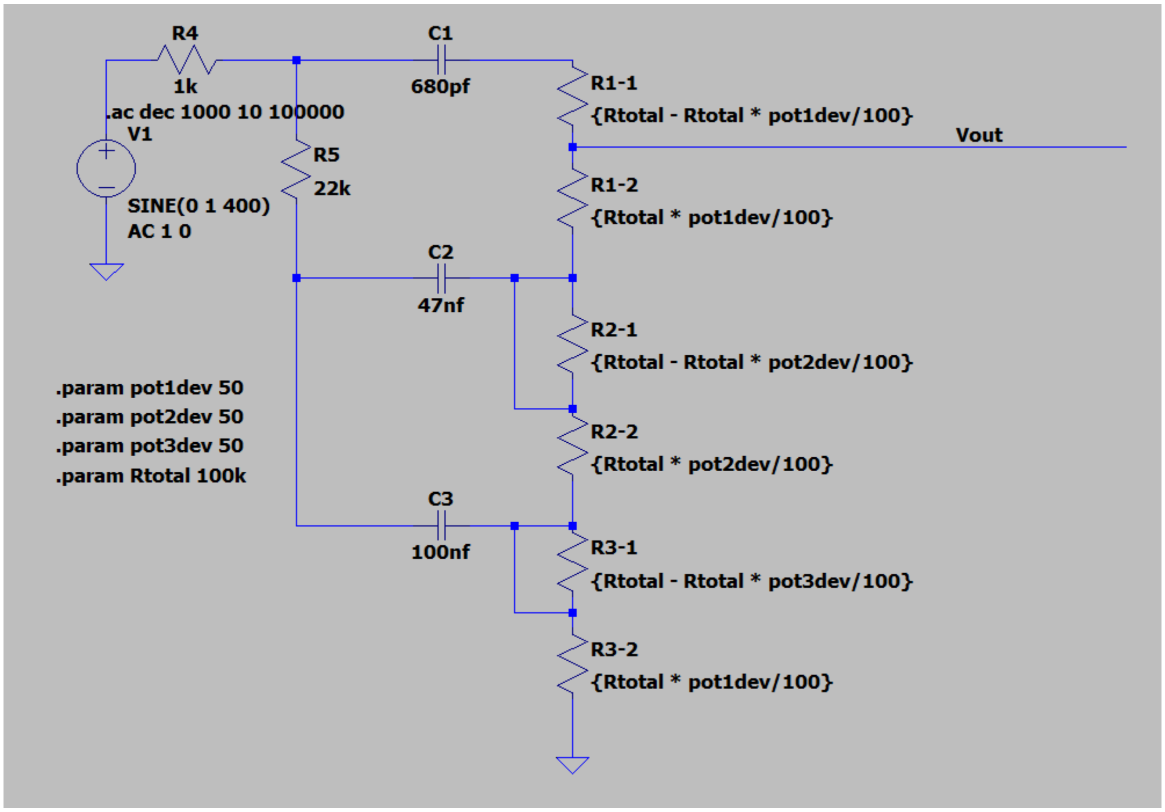

Figure 8, Tone Stack Final Schematic (Treble - Bass - Mid)

At first sight you might recognize that all paths look like high pass RC filters but stacked together it forms three filters that all have interactive effects on each other. The resistors in line can affect the loads that all the signals see on output, especially since bass and mid frequencies travel up resistors to output. The key to this tone stack is recognizing the high pass of the treble top path but then recognizing that R5 creates a low pass filter with C2 and C3 for the lower two paths. This only allows the bass and mid frequencies to reach the band stop (notch) filter and the low pass bass filter (Two bottom paths).

With all attenuations set to 50k the frequency response attenuation is as shown below in Figure 9.

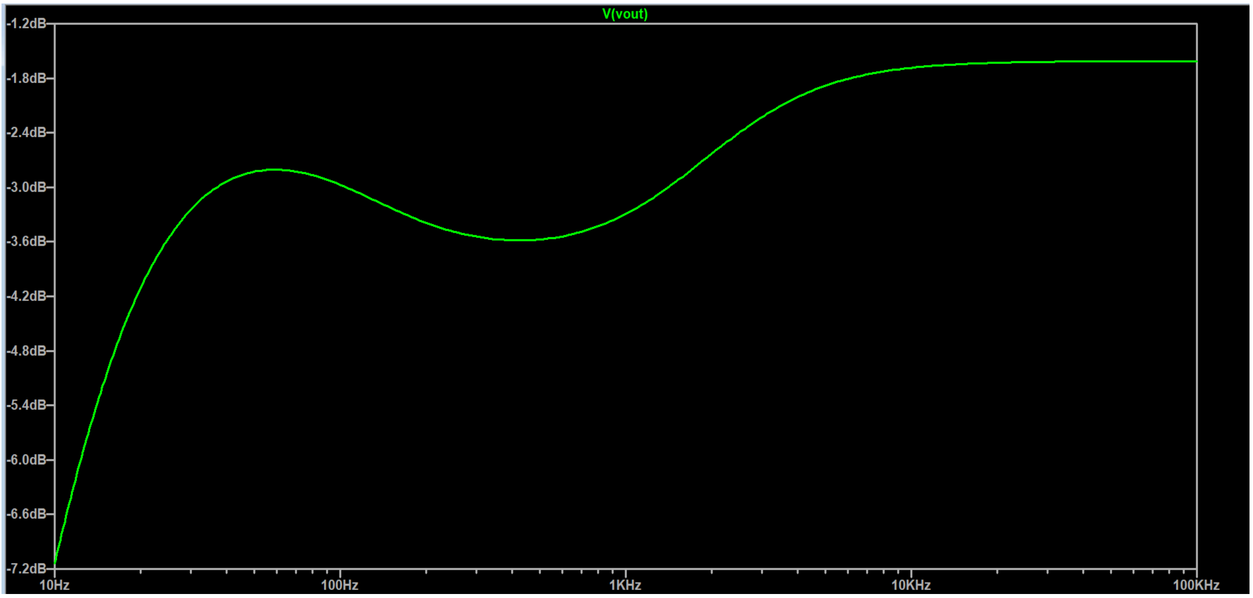

Figure 9, Frequency Response at 50k attenuation (All Potentiometers)

This frequency response serves as a middle ground setting that can then be adjusted to a player's liking. At the bottom of the stack you can see a 100nF capacitor with a 100k potentiometer shunted to ground. If you could imagine this being a high pass filter at the RC node, it is actually high passing the bass and mid frequencies to ground. Leading to this part of the stack provides low pass functionality for the bass and mid frequencies for the Vout node. The higher the R resistance, the less of the bass and mid gets erased at ground therefore the more signal gets to the output. This creates a low-pass functionality. I wanted to choose a frequency cutoff when my pot is at 100k that sits at the lowest edge of the bass bandwidth (high passing to ground). Therefore I chose 100nF and 47 nF, having a cutoff of 15.91Hz and 33.86Hz when attenuation is maxed at 100k (not letting signal through). Below in Figure 10 you can see a sweep of the Bass potentiometer and the effect that it has on lower bass frequencies. The green line being the most attenuated setting (100k potentiometer max). Also in Figure 11 you can see the sweep of the Middle potentiometer and the “scoop” effect it has on the center frequencies. The green line also representing the max attenuation and potentiometer setting (100k)

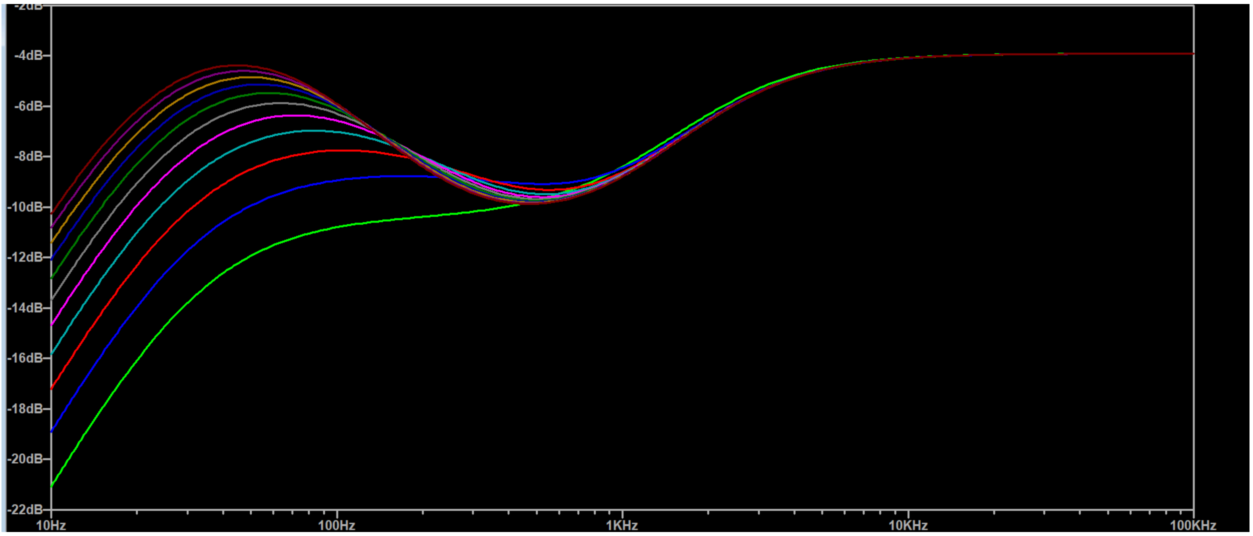

Figure 10, Frequency Response of Bass Pot Sweep (10k - 100k)

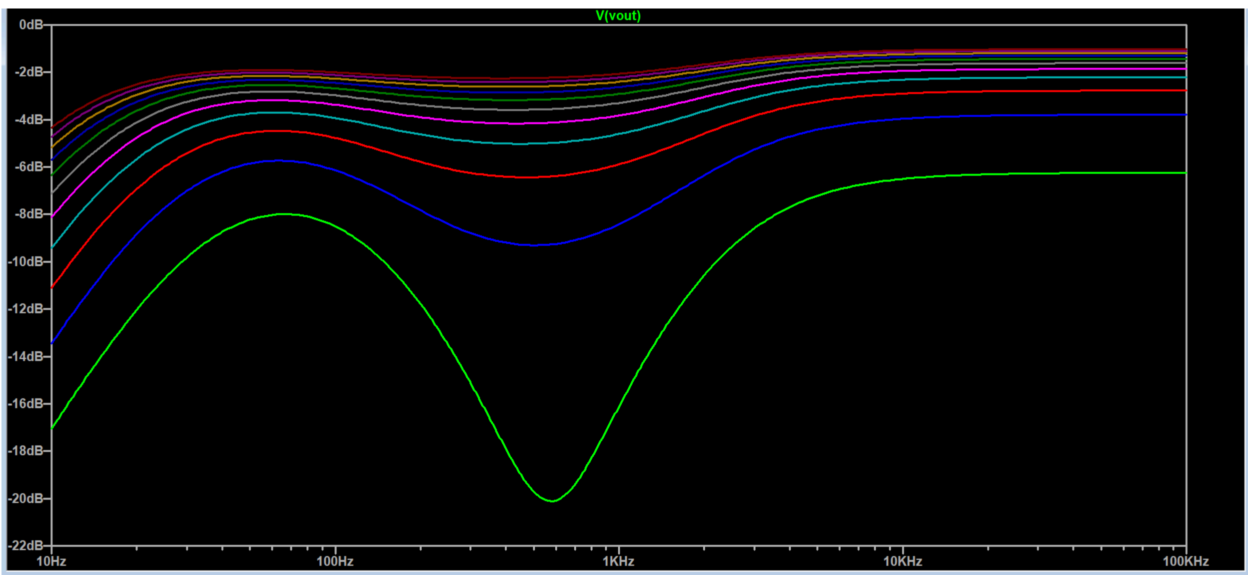

Figure 11, Frequency Response of Middle Pot Sweep (10k - 100k)

The last path of the stack is the only one that performs how it looks! This high pass filter for treble is the easiest to understand because as the R is increased, the cutoff frequency gets lower therefore letting more treble in. It does have an overall inverse relationship from the other knob direction for bass and treble. Seen below in Figure 12 is the sweep of the potentiometer for the treble high pass filter.

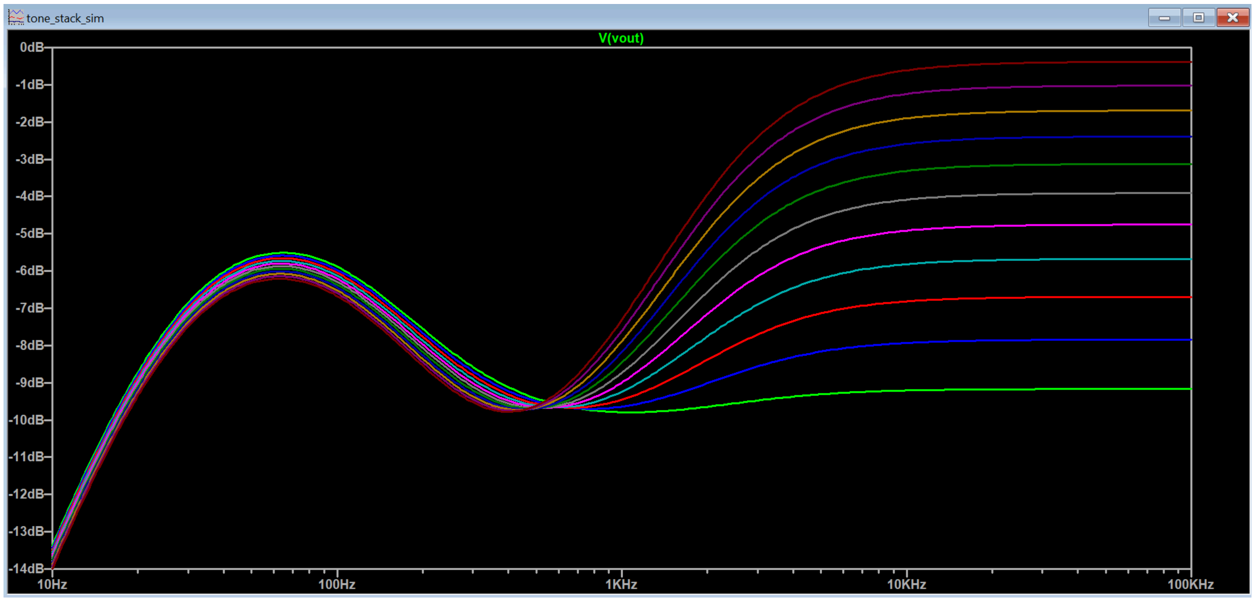

Figure 12, Frequency Response of Treble. Pot Sweep (10k - 100k)

Conclusion

This project started out as a personal challenge to build and design something meaningful from scratch, and it ended with a fully functioning guitar pedal that combined one of my favorite hobbies with my engineering work. Starting by amplifying my guitar signal, experimenting with diode clipping combinations, and designing a three band tone stack, I was able to create a pedal that works electrically and delivers the sharp bluesy tone I set out to achieve.

Throughout the engineering process I learned a lot about biasing and designing stable amplifier configurations, the different types and effects of clipping, as well as the frequency response behavior of interactive tone stacks. This project pushed me to do circuit analysis, with simulation and hands-on testing until I had a sound that I was completely satisfied with.

The final result is something I created that feels personal, I now understand the three stages that make a guitar pedal what it is. I know how to deliver the exact tone that I was chasing. One thing I've loved about having this circuit now is that I can tinker and change things to achieve new tones due to my understanding of what takes place where. Below in Figure 13 you can see my fully soldered perfboard circuit along with the complete transient signal simulation in Figure 14.

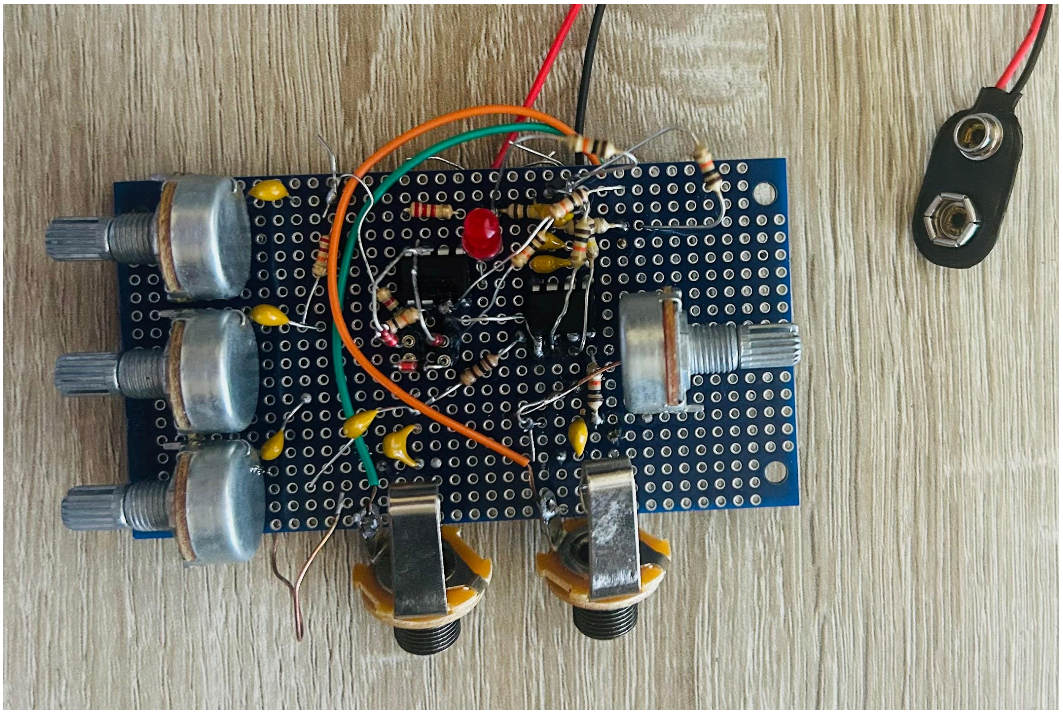

Figure 13, Fully Soldered Guitar Pedal Circuit

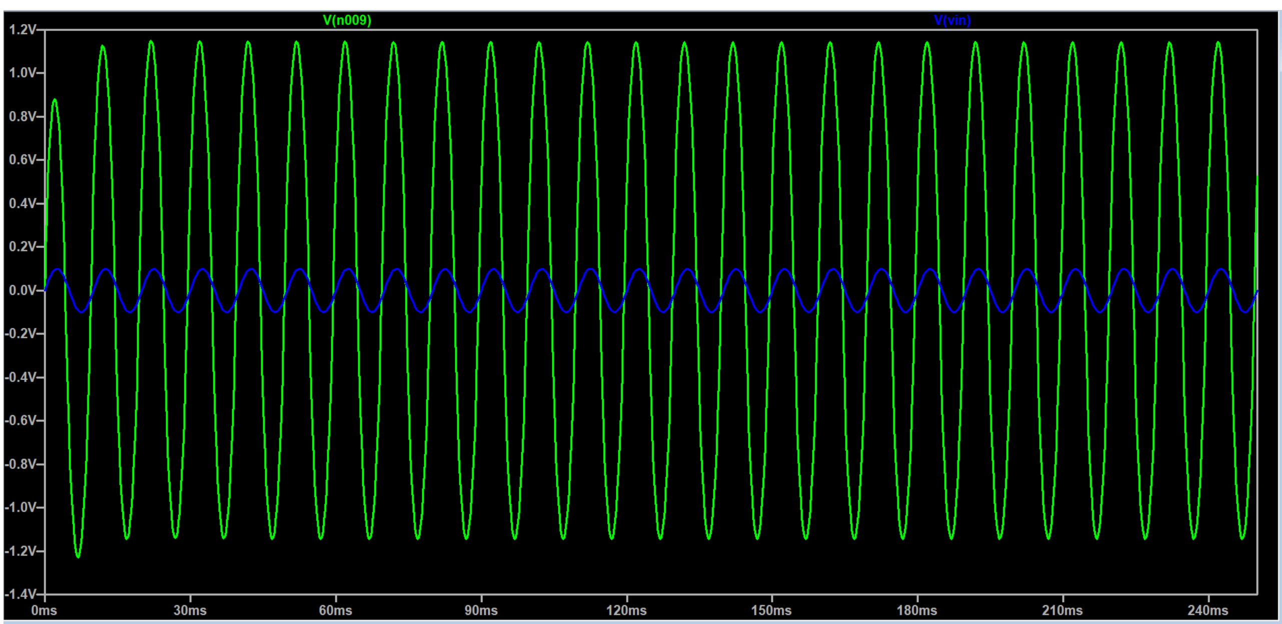

Figure 14, Transient Analysis of Complete Pedal (Green - Output) (Blue - Input)