GUITAR PEDAL

EITF40 -Analogue and digital projects

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Purpose

The purpose of this project was to build an electric guitar pedal with multiple effects, namely distortion and deeper bass. Out of the many ways to create distortion, the method chosen in this project was to use diodes to clip the sinusoidal input signal from the guitar. Different clipping effects were created, using LED diodes and a zener diode, alternatively. In addition to adding distortion, a frequency divider was created to lower the output frequency in notes with input frequencies under approximately 400 Hz. This frequency divider would divide said frequencies in half, lowering the pitch by an octave.

Theory

<u>Distortion</u>

> *"Distortion (or warping) is the alteration of the original shape (or other characteristic) of something, such as an object, image, sound or waveform. Distortion is usually unwanted, and so engineers strive to eliminate distortion, or minimize it. In some situations, however, distortion may be desirable. The important signal processing operation of heterodyning is based on nonlinear mixing of signals to cause intermodulation. Distortion is also used as a musical effect, particularly with electric guitars."* [1]

There are many different types of distortion and many different ways to achieve distortion. Methods include the use of diodes, transistors, and operational amplifiers. In this paper, the method chosen was the use of various diodes to create distortion. The following provides a brief overview of the different types of diode clipping and their effects.

Hard diode clipping: Two diodes shunt to ground together in different directions will clip the peaks of the signal. Silicon diodes are usually used for this.

Soft diode clipping: Two diodes connected on the feedback loop of an opamp or transistor. This rounds "softer" the peaks of the signal.

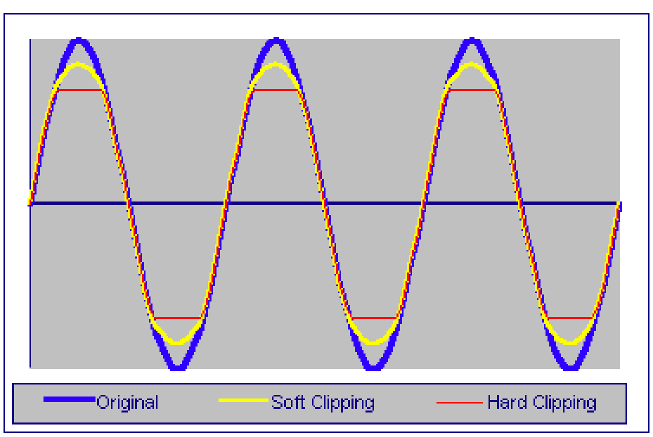
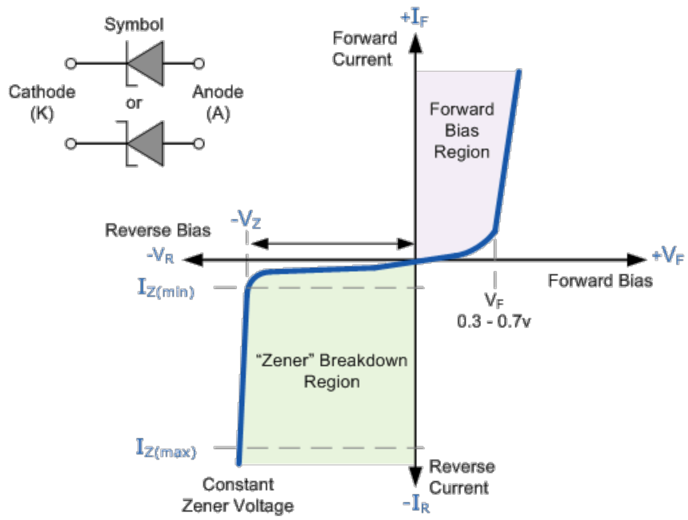


Figure 1: Hard vs. Soft clipping of a sinusoidal signal [7].



Zener diode clipping: Using a zener diode instead of two LED diodes will give us a different effect. Since the zener diode works in both direction but with different voltages, as shown by the I-V curve, the clipping will be asymmetric.

Figure 2: I-V Characteristics of a zener diode [8]

Filters

Both high- and low-pass filters were needed in the guitar pedal. A high pass filter blocks all signal except higher frequencies, and a low pass filter blocks all signal except lower frequencies. The cutoff frequency is calculated by $f = \frac{1}{2\pi \cdot C \cdot R}$ (1), where C is the capacitance and R is the resistance of the resistor used in the filter. The frequency is measured in hertz (Hz), the resistor in ohms (Ω), and the capacitor in farads (F).

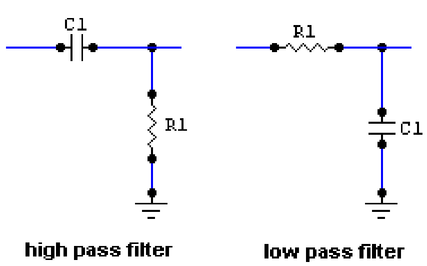


Fig. 2: Structure of high and low pass filters.[2]

Operational Amplifiers

In an ideal OpAmp, $V_+ - V_- = 0$.

This means that the voltage difference between the positive and negative voltage input is zero. Additionally, the inputs should ideally draw zero current.

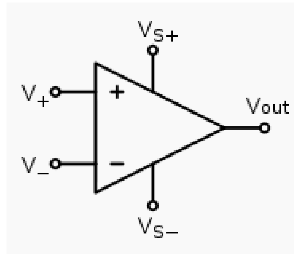


Figure 3: Symbol of an OpAmp.[3]

<u>Sinusoidal frequency and pitch</u>

A standard pitch of A4 has a frequency of 440 Hz. A pitch of half of that, or 220 Hz, would yield a pitch one octave lower, or A3.

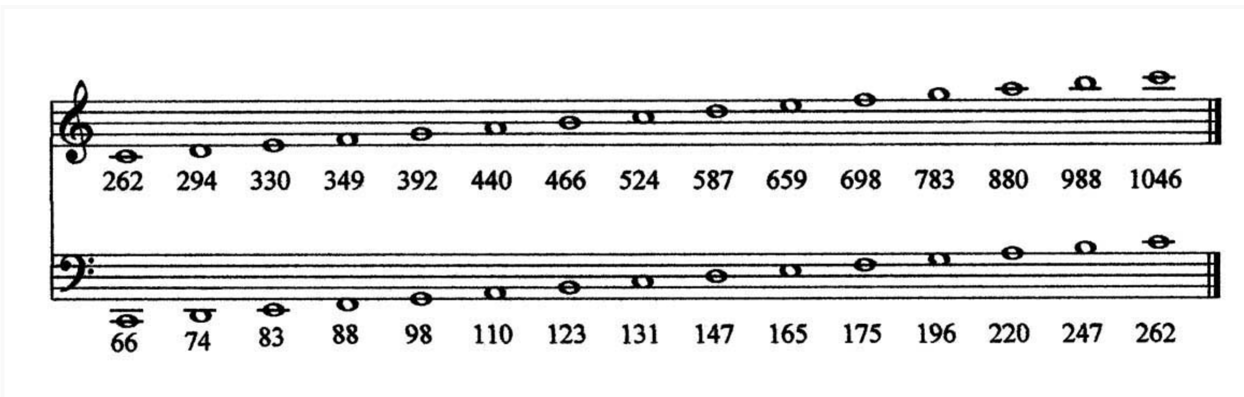


Figure 4: Pitches on a musical staff as correlated to frequency.

Because the sound of some types of music, such as heavy metal and rock, can benefit from a lowered bass, a frequency divider was created as part of the guitar pedal project. In this project, a frequency divider was created through a symmetrical system of transistors, resistors, and capacitors that divided the frequency equally between them. The output of the frequency divider was one leg of the frequency divider.

<u>Transistors</u>

Transistors were used to create a frequency divider that would halve the input frequency of a sinusoidal signal. The transistors used in the project are NPN-type Bipolar Junction Transistors (BJTs).

A BJT can be used to create an amplifier, switch, or oscillator. The operation of a BJT involves both semiconductors doped with electrons (N-type) and electron ‘holes’ (P-type).

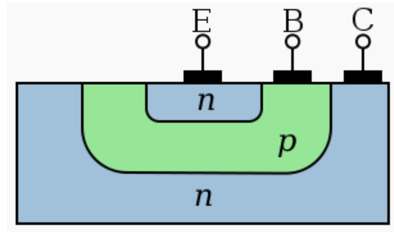


Figure 5: Simplified cross section of a NPN BJT.[4]

A BJT consists of three doped semiconductor regions: the emitter, the base and the collector. For an NPN-type BJT, the emitter and the collector are N-type, while the base is P-type.

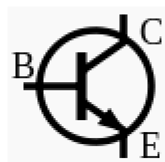


Figure 6: BJT type NPN symbol.[4]

BJTs have different regions of operation, which can be described in terms of applied voltage. The BJTs used are of NPN polarity. The properties of NPN BJTs are as follows.

The greek symbols alpha and beta show current relationships, given by:

$$\alpha_F = \frac{I_C}{I_E} \quad (2.)$$

$$\beta_F = \frac{I_C}{I_B} \quad (3.)$$

1. Forward active: The applied voltage in the base is higher than the one in the emitter, and the voltage in the collector is higher than in the base. In this case, the current in the collector is proportional to β_F. $V_{BC} < 0$, $V_{BE} > 0$

2. Saturation: $V_{BC} > 0$, $V_{BE} > 0$

3. Cut-off: $V_{BC} < 0$, $V_{BE} < 0$

4. Reverse-active: $V_{BC} > 0$, $V_{BE} < 0$

Methods

<u>Signal Clipping</u>

Both soft and hard clipping effects were created. LED diodes were used to create a hard clipping effect, while a zener diode was used to create a soft clipping effect. Both have jumpers which act as switches. The two methods are not intended to be used together.

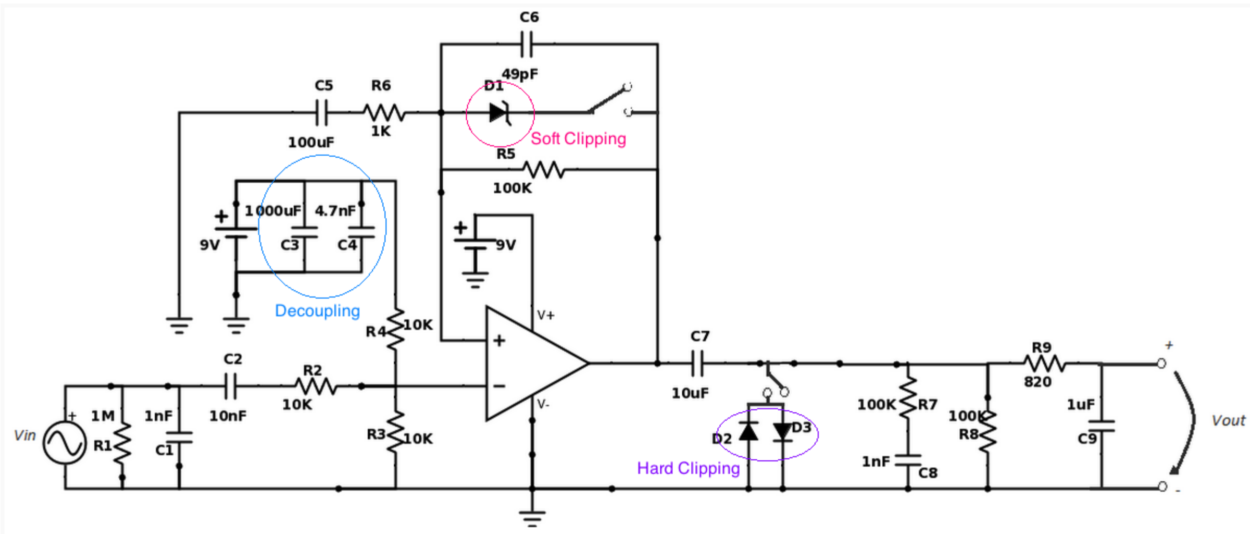


Figure 7: Schematic from the first stage in the circuit. Hard and soft diode clipping.

R_1 cuts out the clicks and other unpleasant sounds from the signal. C_2 filters the DC voltage. R_1 and C_2 form a high pass filter. R_2 and C_1 form a low pass filter which rolls off radio frequencies. R_3 and R_4 are a voltage divider, for biasing the opamp. R_5 and C_5 are a LPF, and R_5 and C_6 a HPF.

C_7 prevents the DC voltage to get in the OpAmp. C_7 and R_8 form a HPF. C_9 's value should be high enough to prevent the roll off frequencies from interfering. R_7 and C_8 form a LPF. We connect another LPF (C_9, R_9) before the connection with the next stage.

At the beginning, C3 and C4 were not in the circuit, however it was decided later the importance to have them as they form a decoupling circuit which prevents any unwanted signal get into the rest of the circuit.

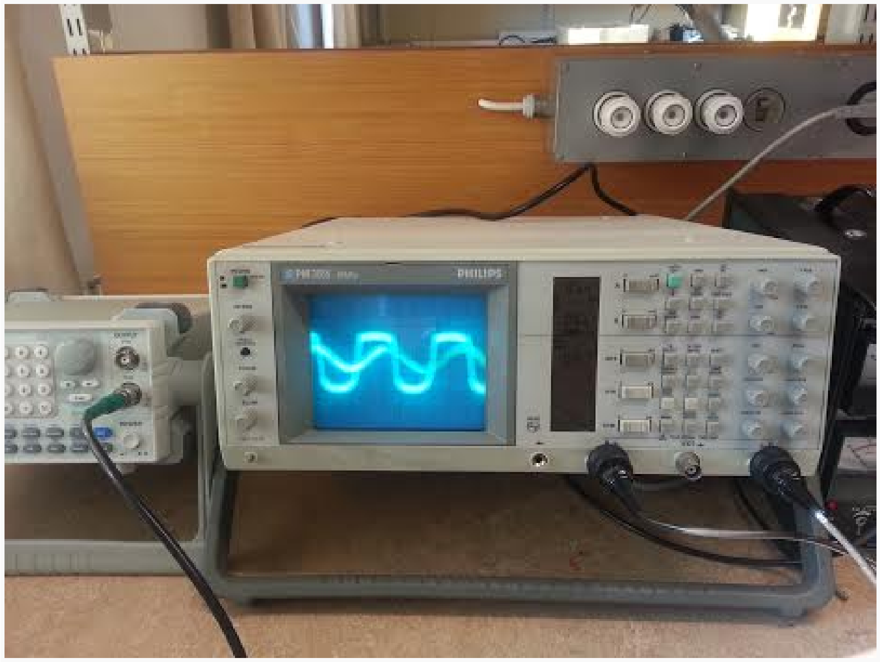
First, a simulation of the circuit was done through a schematic created using a software. The simulation predicted how the signal clipped should look like.

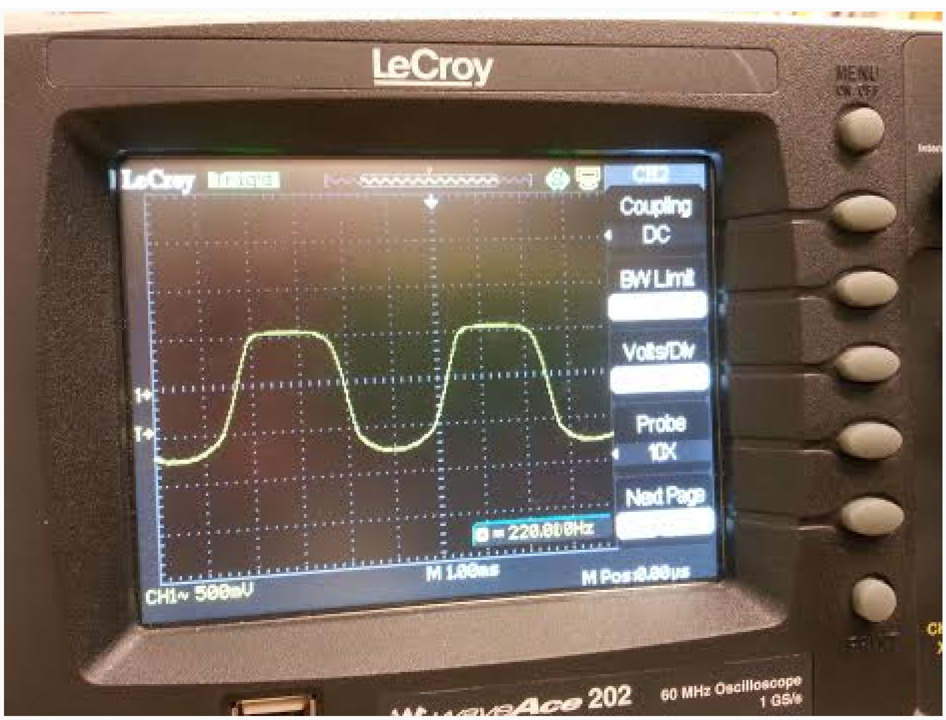
After successfully simulating the circuit and figuring out the values of all components, the parts for the actual circuit were ordered as follows.

OpAmp used: TL071 [5]

In the actual circuit, instead of using a 10 nF capacitor, two 22 nF in series were used, which is equivalent to a 11 nF capacitor.

V_{cc} was set to 9 v.





Figures 8 and 9: Oscilloscope showing soft clipping effects using one zener diode.

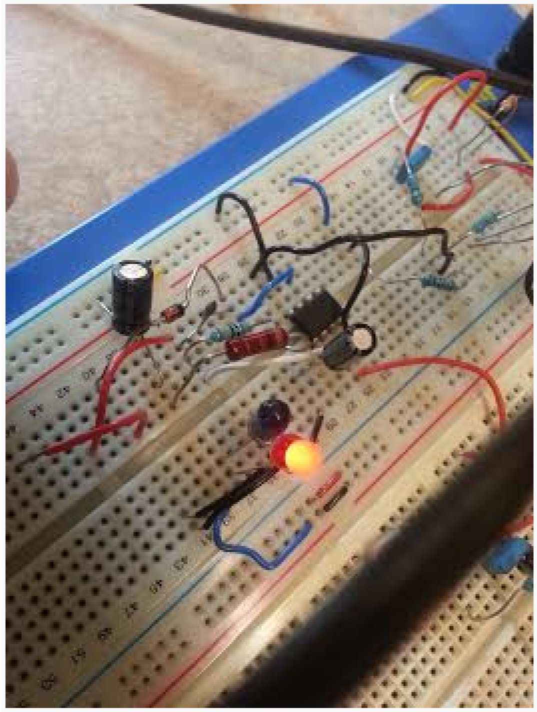


Figure 10: Circuit showing the first stage with hard clipping using two LED diodes.

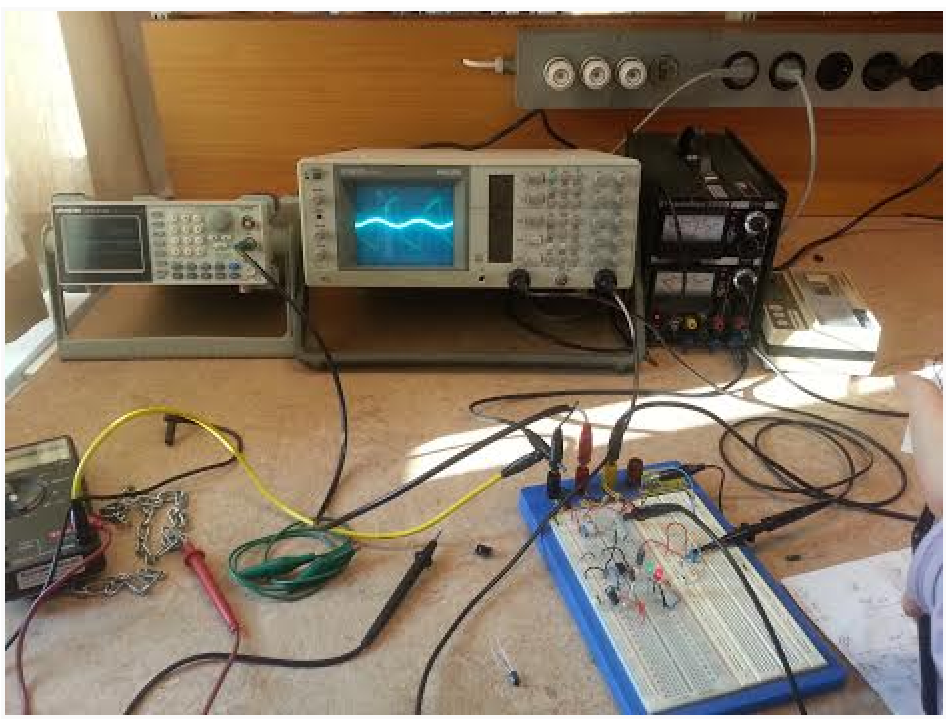


Figure 11: The whole set up. The oscilloscope shows a hard clipping using two LED diodes.

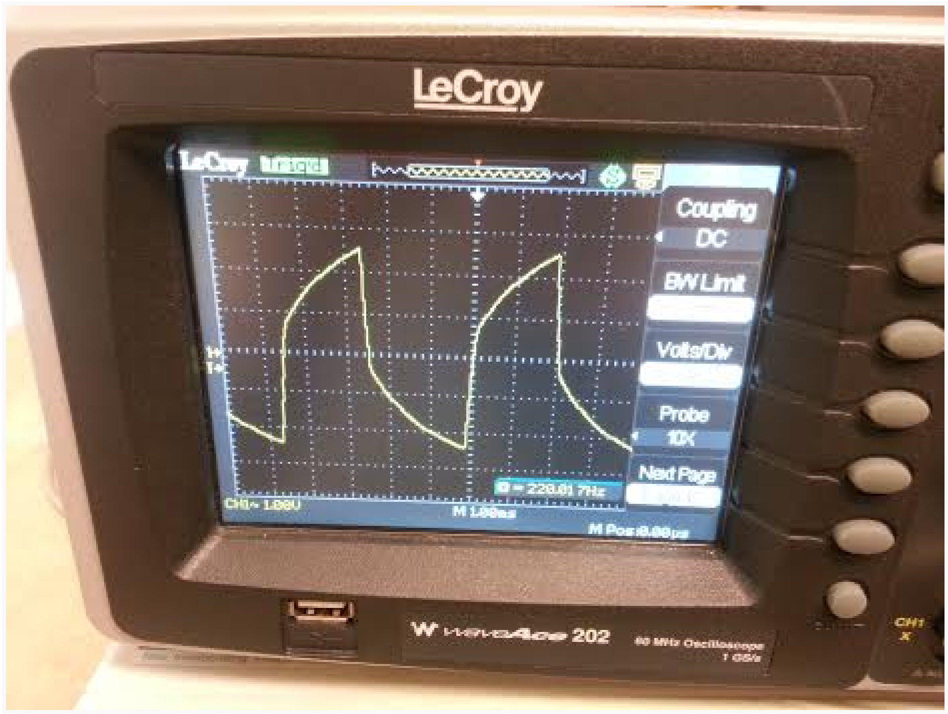


Figure 12: Hard clipping using two LED diodes.

<u>Delay</u>

Next, an attempt was made to make a delay circuit that would create a sustain effect. For this part, an all pass filter was used.

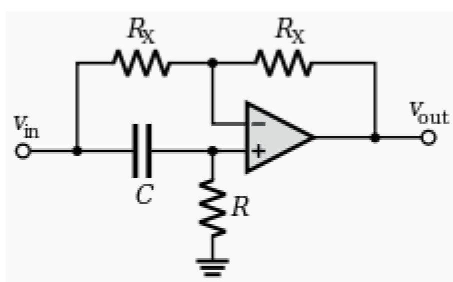


Figure 13: Schematic of an all pass filter.[9]

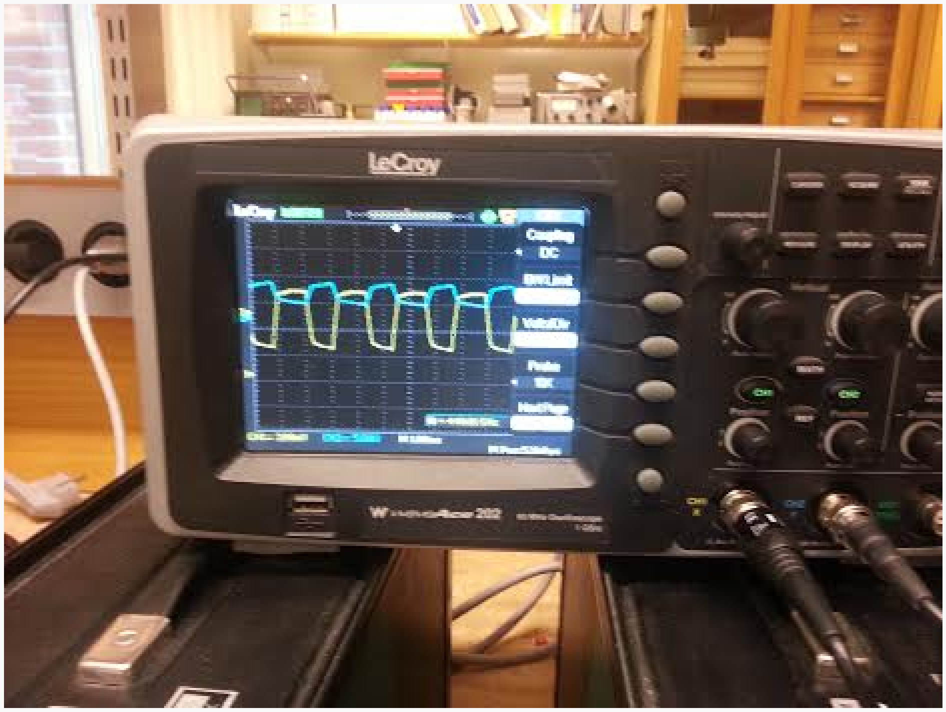


Figure 14: Oscilloscope showing the 180º shift of phase.

It was quickly discovered that using only one filter of this kind would give us some milliseconds of delay, which would be indiscernible to the human ear. In order to get an effect that would be possible to discern, a much more complicated circuit using several all pass filters and a clock would be necessary. It was then decided not to build a delay stage since it would make our circuit much complicated. The all pass filter was taken out of the breadboard.

<u>Frequency divider</u>

Next, a circuit was built to device the input frequency in half. To achieve this, BJTs were used.

The first element needed was a LPF, because the goal was to affect the lower pitches of the input. The LPF was connected to the output of the previous stage.

During this process, the importance of measuring the values of the R's before connecting them into the circuit became clear. Some resistances in the drawers were not in the right case and led to many problems with the circuit and a strange behaviour. This was one important problem encountered during the building of the frequency divider.

After testing the circuit, some changes were made. First of all, decoupling capacitors were added to eliminate any self-oscillation of the circuit. The decoupling capacitors consist of a large capacitance and a lower capacitance connected in parallel to the voltage source, and prevent any unwanted DC current from entering the circuit. Specifically, two capacitors (1000 µF and 47 nF) were connected in parallel to V_{cc}. The schematic of the circuit is shown in figure 15.

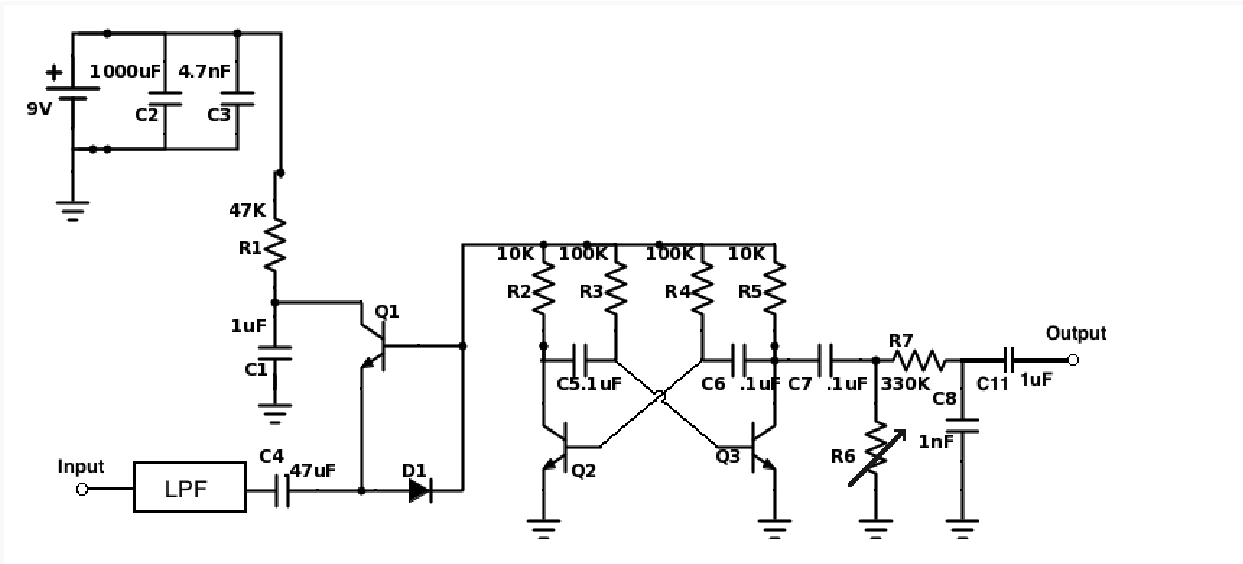


Figure 15: Schematic of frequency divider, Trial 1 (unbalanced pedals)

However and even after adding the decoupling capacitors, the circuit did not work as we wanted. In order to further remedy the situation, another filter was added to the left part of the circuit so the system would be symmetric. This gave the desired effect, since it allowed the resistivities of the two pedals to be equal. The schematic of the corrected circuit is shown in figure 16.

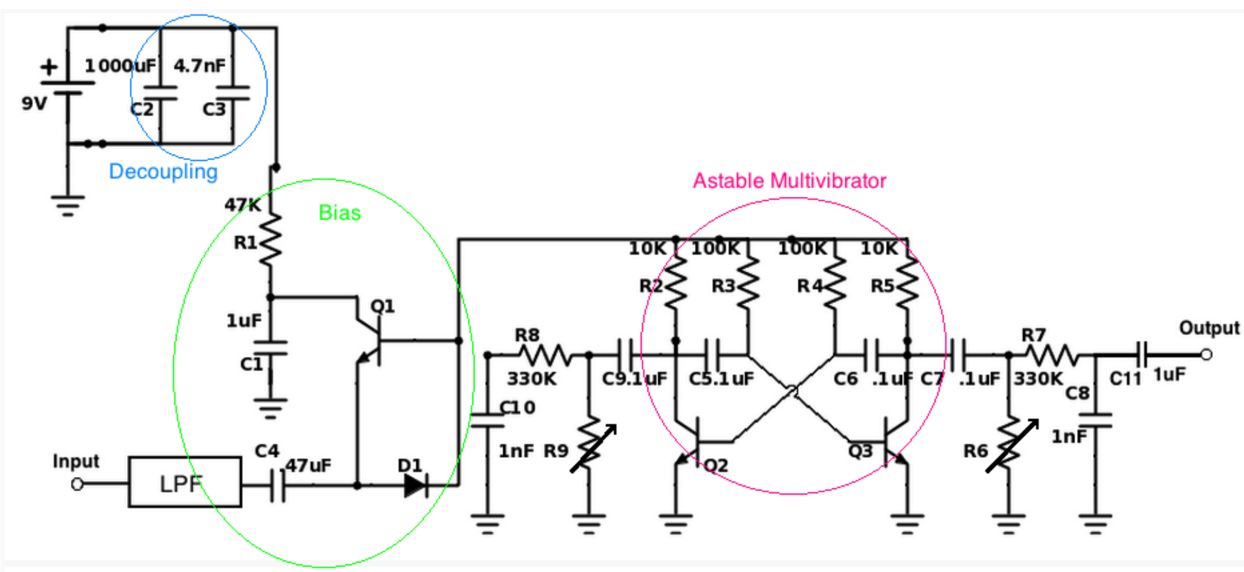


Figure 16: Schematic of frequency divider, Trial 2 (balanced pedals)

To explain the operation of this stage, the astable multivibrator should be introduced. The part marked with red in figure 16 consist of an astable multivibrator. This type of circuit is used to implement oscillators. The astable multivibrator has two different states, neither of which is stable, causing it to continually switch from one state to other.

The collector leg from both of the BJTs have complementary states. When one has a high voltage, the other will have a low voltage. The decoupling capacitors ensure the voltage will not change instantly. One fully charged capacitor discharges slowly thus converting the time into and exponentially changing voltage. At the same time, the other capacitor, which is empty, quickly charges thus restoring its charge. In each state, one BJT is switched ON and the other one is OFF. The forward-biased base-emitter junction of the switched ON bipolar will provide a path for capacitor restoration.[10]

If this astable multivibrator is synchronized to an external chain of pulses, which is the case, the circuit will act as a frequency divider. However, since the stability of this technique is quite poor, any little alteration can make the circuit not to work properly. This problem was found during the construction of the final stage and will be explained later.

The following pictures show the signal after getting through this second stage.

Figure 17: Trial 2: output (yellow) vs. signal after the limiters (blue) f. Frequencies under 300 Hz.

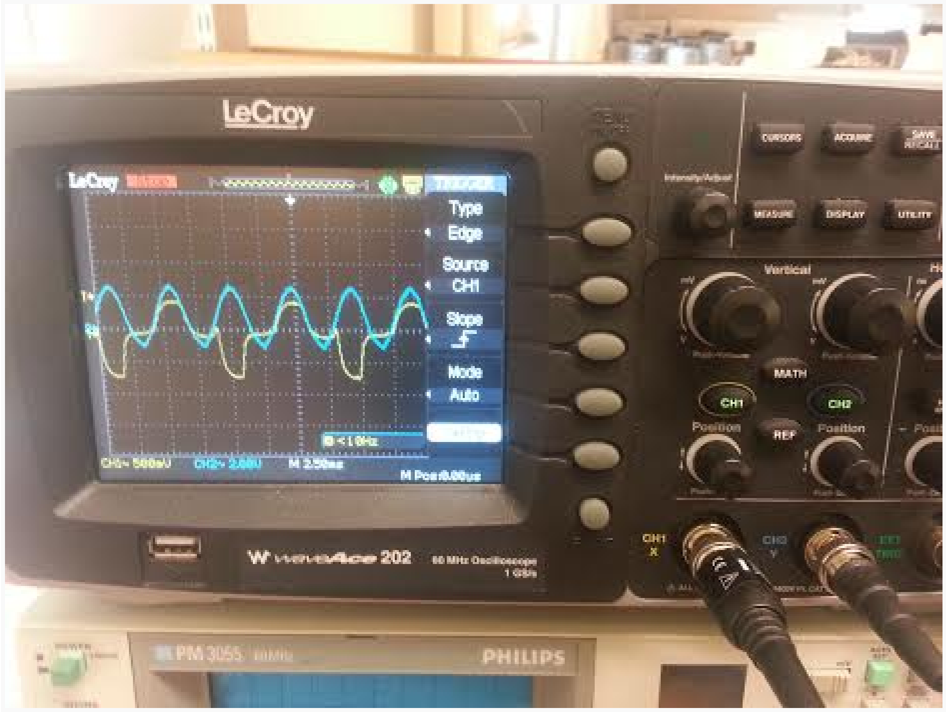


Figure 18: Trial 2: output (yellow) vs. input (blue). Frequencies under 300 Hz,.

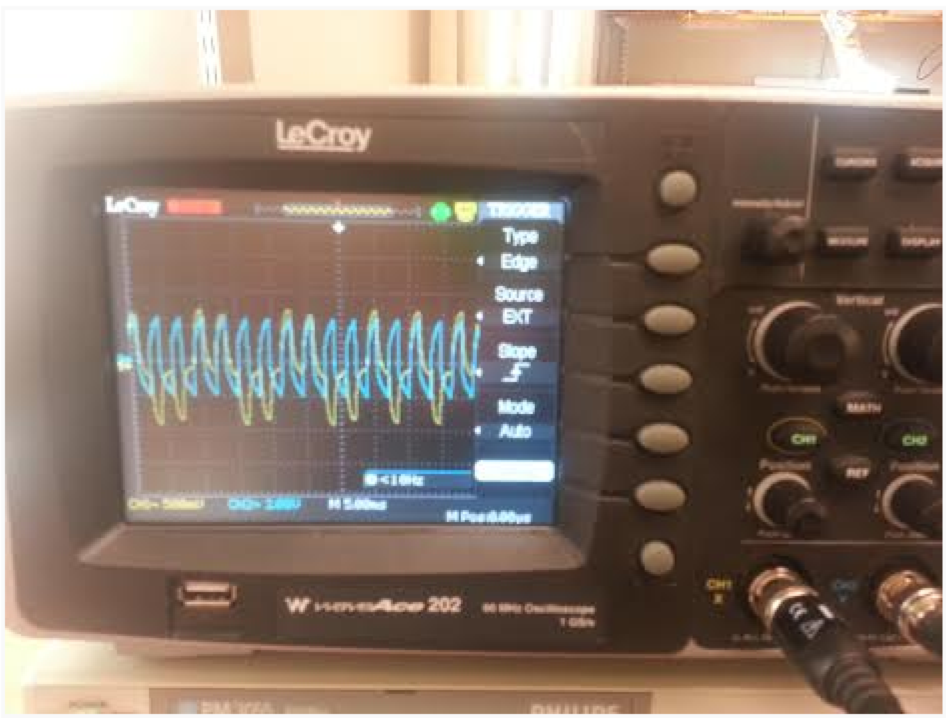


Figure 19: Trial 2: output (yellow) vs. signal after the limiters (blue). Frequencies above 400 Hz.

Summation Circuit

After completion of the distortion circuits, it was time to put them together into one final output. The summation circuit is as follows.

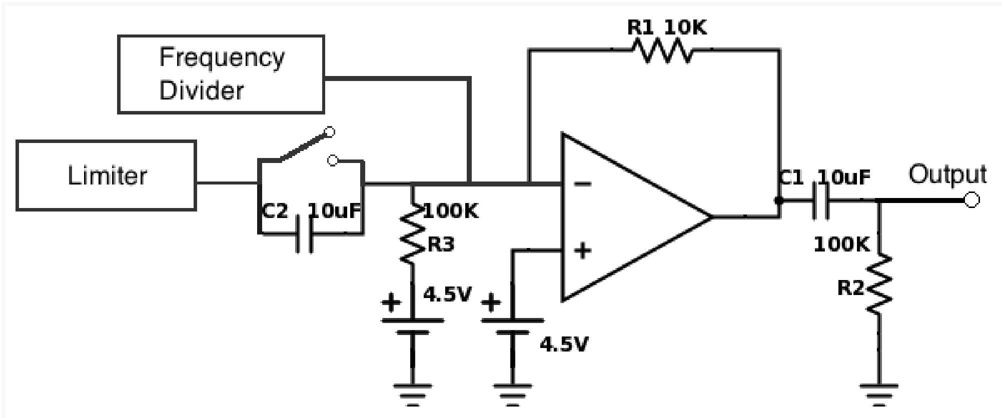


Figure 20: Summation circuit.

As it was said before, there were some problems found during the construction of this last part. Due to the poor stability of the previous stage, when connecting the summation circuit, the outgoing signal from the frequency divider lost amplitude and stopped working as it should. This issue is caused because of the low impedance after the frequency divider. Whenever working with oscillators, it is important to keep in mind that the impedance in the next stage should be very high. To fix this, a buffer was connected after the frequency divider and before the summation circuit as shown in figure 21.

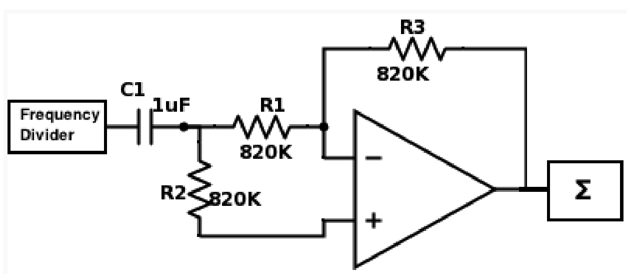


Figure 21: Buffer for frequency divider.

The final results are shown in the pictures below.

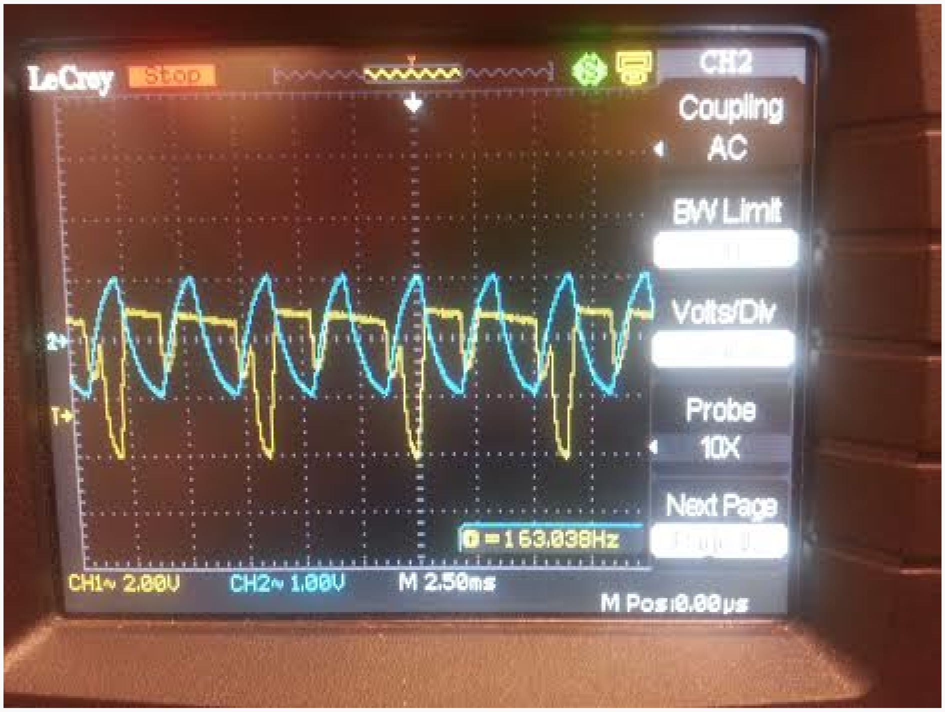


Figure 22: Input signal coming out of the clipping (blue) vs. output signal coming from the summation circuit (yellow).

Figure 23: Output signal from the summation circuit.

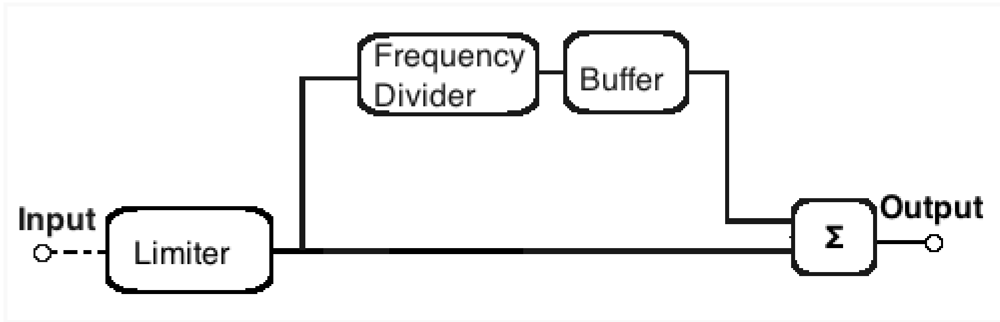


Figure 24: Complete block diagram of the final circuit.

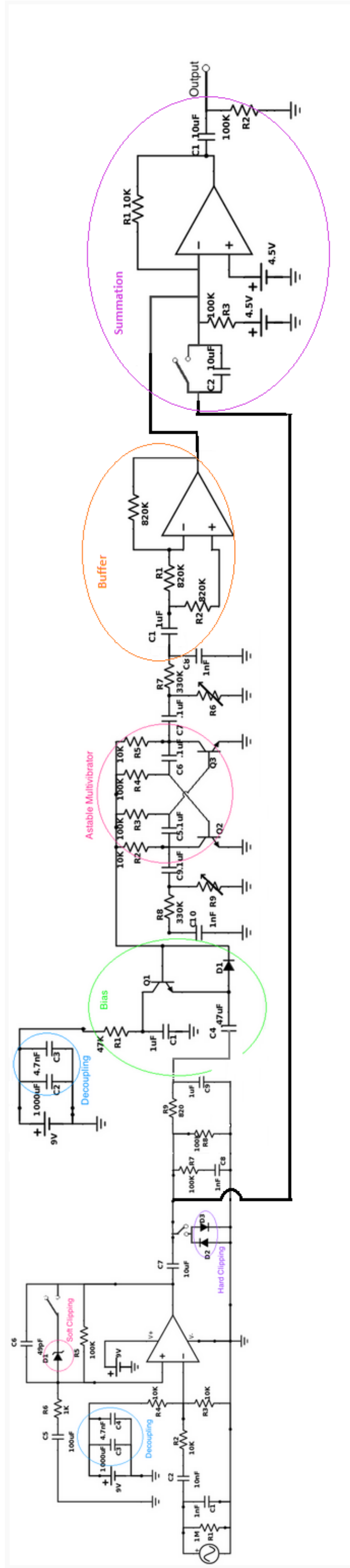


Figure 25: Complete schematic of the final circuit.

Conclusion

Through the manipulation of sinusoidal amplitude, distortion effects can be made from a clean electric guitar input signal. By dividing the input frequency of the electric guitar, the pitch of the notes can be brought down an octave. In this project, both effects were achieved through the use of analog circuit components. Amplitude clipping was made possible through the use of diodes, and an oscillator to divide frequency was created through the use of NPN BJTs. High- and low-pass filters provided control over the range of frequencies for which the pedal was effective. The effects created by the guitar pedal in this project allows for new, unique sounds to be achieved with an electric guitar.

References

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