ANALOG RING MODULATOR GUITAR PEDAL

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PHYS 498 POM

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Introduction

The ring modulator is considered among the most interesting guitar pedals. It takes a guitar input, and multiplies the signal by an oscillator. This results in all frequencies present in the guitar signal to be summed and differenced with all frequencies in the oscillator signal. After the multiplication, the frequencies are not integer multiples of each other anymore, and the sound has very interesting timbral characteristics. Some love it for it's robot-like and bell-like tones, while others think it sounds downright nasty. Either way I wanted to design my own, so I did.

Design

The design of the ring modulator circuit can be broken down into six modules: multiplier, power supply, oscillator, nulling circuit, audio amplifier, and mixer.

Multiplier

The design of this pedal is based around an Analog Devices AD633 Four-Quadrant Analog Multiplier IC, shown in Figure 1 below.

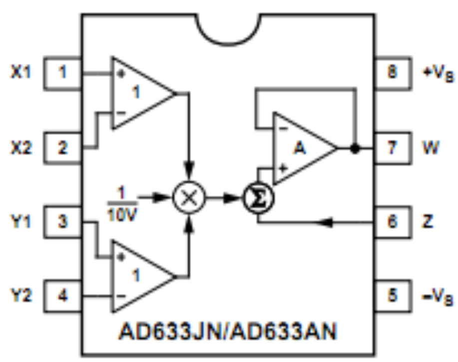

Figure 1: AD633 pin configuration

This chip takes in two fully differential inputs X and Y, performs an analog multiplication (also scaling the result by 1/10), and outputs the result W. In addition, the chip can take in an additional input Z to add in to the multiplied signal. This function is shown below in Equation 1.

$$W = \frac{(X1 - X2)(Y1 - Y2)}{10\ V} + Z$$

Equation 1

<u>*Power supply*</u>

While most guitar pedals operate on a single 9V battery or power supply, the AD633 requires a positive and negative supply voltage. I decided to experiment with the MAX1044 IC, a charge-pump voltage converter chip that outputs -9V when it is powered with +9V. Using this chip, I can obtain both +9V and -9V while powering the pedal with only one external +9V power source. The pinout is shown below in Figure 2.

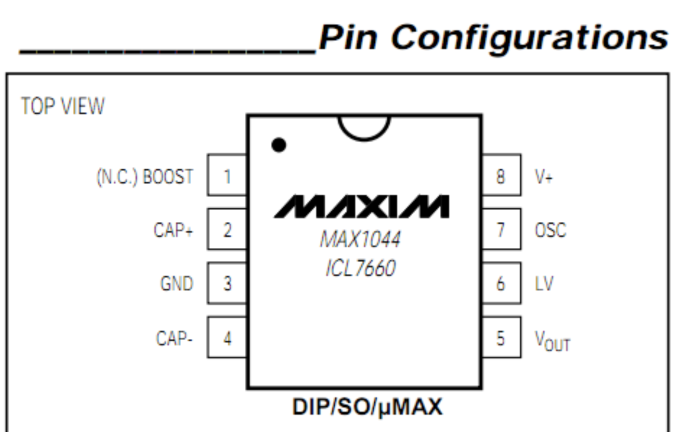

Figure 2: MAX1044 voltage converter

Since the chip is a charge pump circuit, it contains an onboard oscillator. The standard oscillator frequency is set at 5 kHz, but with the connection of pin 1 to Vcc, it can be increased by a factor of 6 to 30 kHz. This is important, because it moves the frequency outside the audio range, preventing the oscillator from being heard in the pedal's output.

Oscillator

The oscillator design consists of one TL072 dual opamp, surrounded by four resistors, two capacitors, and one potentiometer. One opamp functions as a Schmitt trigger, while the other is an inverting integrator. When they are wired together, shown in Figure 3, a square wave is generated at the output of IC3A, and a triangle wave is generated at the output of IC3B.

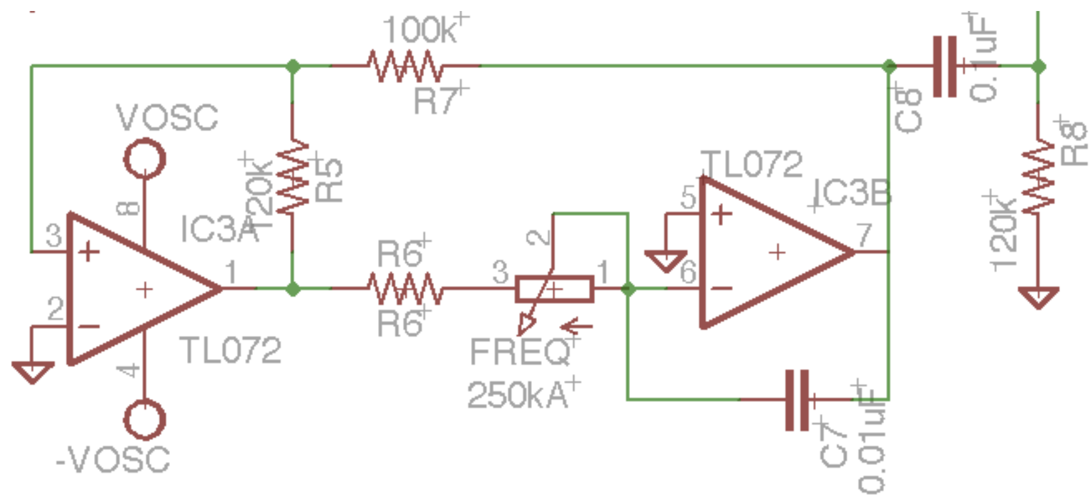

Figure 3: Triangle wave oscillator circuit

The frequency of the triangle output is set according to the expression in Equation 2:

$$f = \frac{R5}{R7}\frac{1}{4(R6 + R_{freq})C7}$$

Equation 2: Frequency of oscillator in Hz

The amplitude of the triangle output is set according to the expression in Equation 3:

$$V_{osc\ p-p} = 18 * \frac{R7}{R5}$$

Equation 3: Magnitude of triangle wave in V peak-peak

Audio Amplifier

Since the AD633 scales the output down by 10, the input signal from the guitar passes through an amplifier with a gain of 11. Even though the non-inverting amplifier has a high enough input impedance to accept a guitar signal (1MΩ), a buffer was added before the amplifier since there was an extra opamp available near the input of the pedal. Though it probably wasn't necessary, it ensures the amplifier sees a constant low impedance source. The buffer and amplifier stage are shown in Figure 4.

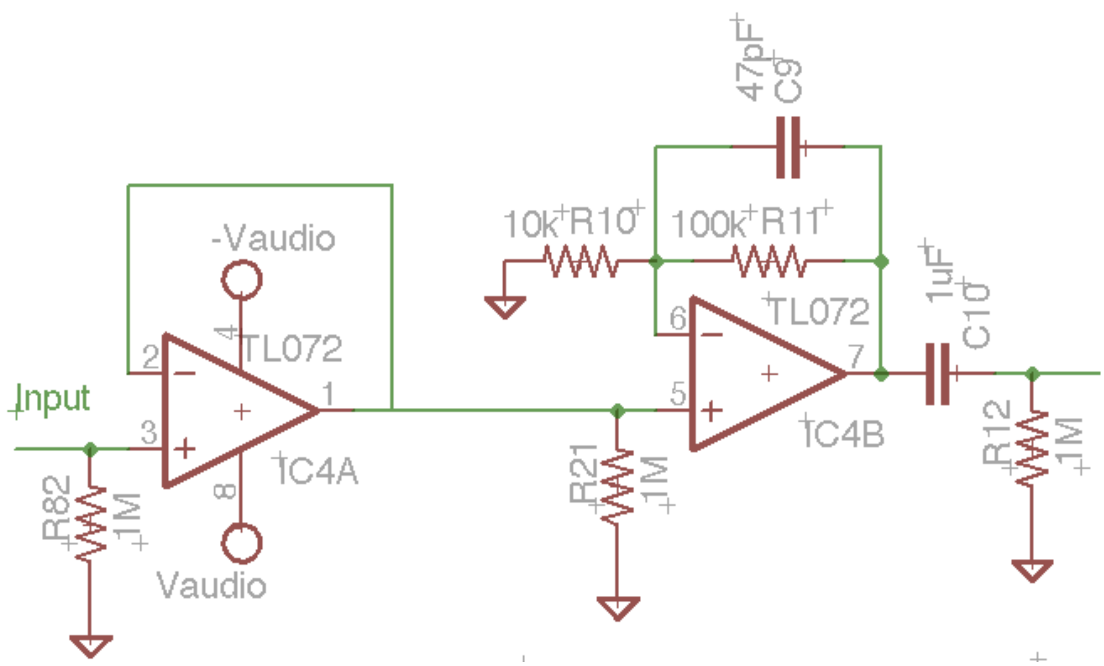

Figure 4: Input buffer and non-inverting amplifier

Mixer

The last sub-circuit in the signal chain is a mixing circuit. It takes the clean signal from the non-inverting amplifier and mixes it in to the wet ring-mod signal. There are two separate volume potentiometers, allowing the user to separately set the levels of ring modulated signal and clean signal. The circuit is shown in Figure 5.

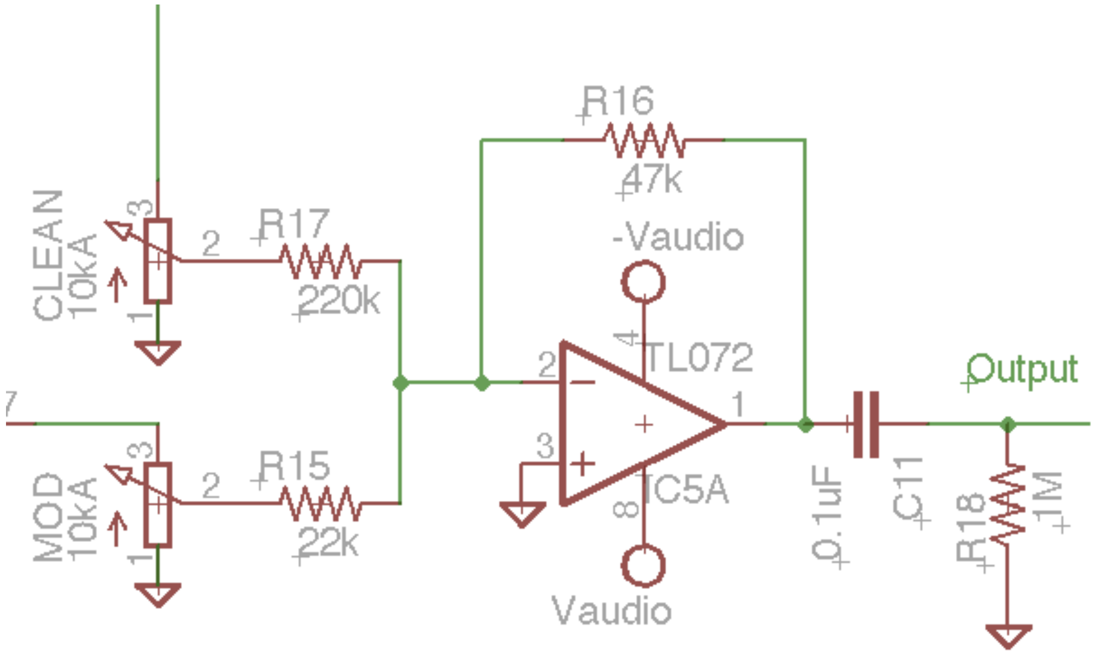

Figure 5: Mixing sub-circuit

<u>*Nulling circuit*</u>

One of the most important considerations in this design was the DC level of the signals fed to the AD633. If there is a slight DC difference between the X and Y signals, the oscillator will be heard in the output W. Even with DC blocking capacitors and pull-down resistors, the oscillator is still present in the output. To correct this, instead of grounding the Y2 signal, a nulling circuit was used in its place, to null the presence of the oscillator in the output. The circuit allows the user to select a small DC voltage between -0.1V and +0.1V to use as the Y2 signal. The trimpot inside the pedal is adjusted so the volume of the oscillator heard in the output is at a minimum. This circuit is shown in Figure 6.

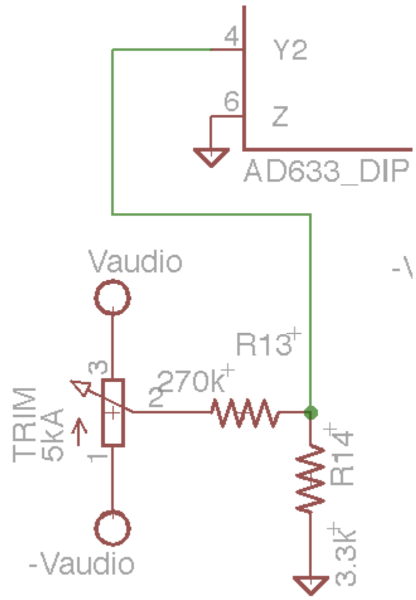

Figure 6: Nulling circuit

Layout and Construction

Ring modulators are unique in that they are one of only a few types of pedals that require an onboard oscillator that is in the audio range. This can (and did) cause problems in the design and layout of the pedal. The oscillator can leak into the DC power supply, couple through the air, or cause ground to hop up and down, all of which cause the oscillator tone to be audible in the output of the pedal. This is obviously an undesired effect, and was taken into consideration during design and layout. For this reason, a PCB was designed to more easily control currents and minimize other coupling effects. The PCB layout is shown in Figure 7.

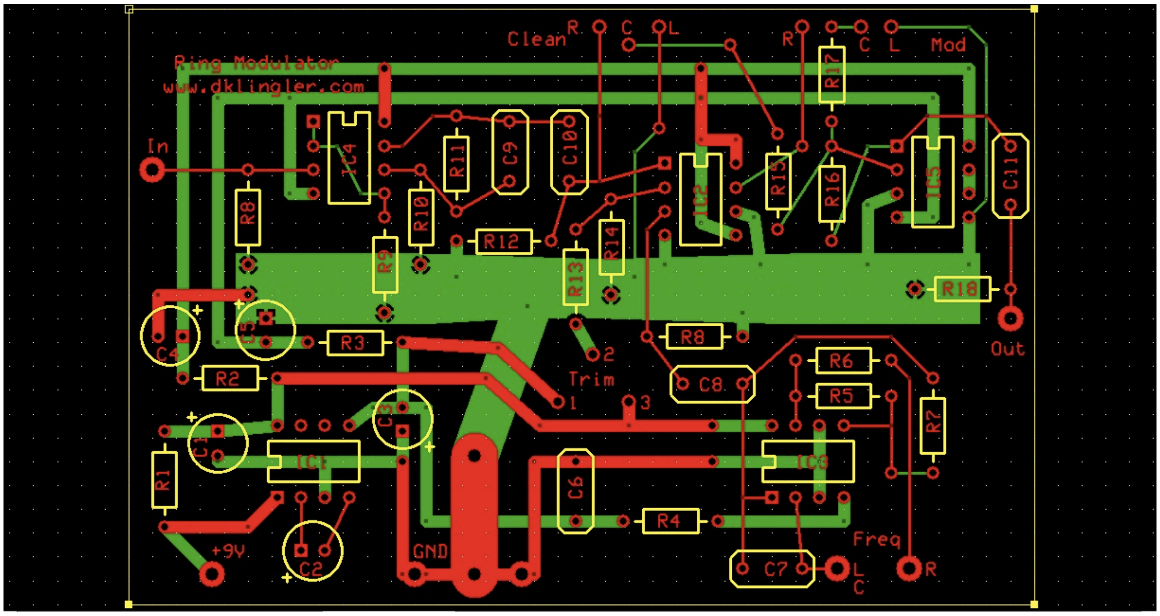

Figure 7: PCB layout

In the layout, it can be seen that the grounds for the oscillator, power converter, and audio circuitry are separated, only touching at the GND point on the PCB. This was done to reduce current pulses from passing by sensitive audio circuitry. In addition, there are decoupling capacitors nearby to provide an impedance minimum and a local charge reservoir for the oscillator and power converter. Another design consideration was to place the in and out connections very close to where the input and output jacks would be mounted to the enclosure, to keep runs of wire as short as possible.

To construct the pedal, all I needed to do was place the components on the PCB, and wire in the switches, jacks, pots, and LED. The finished pedal is shown in Figures 8 and 9.

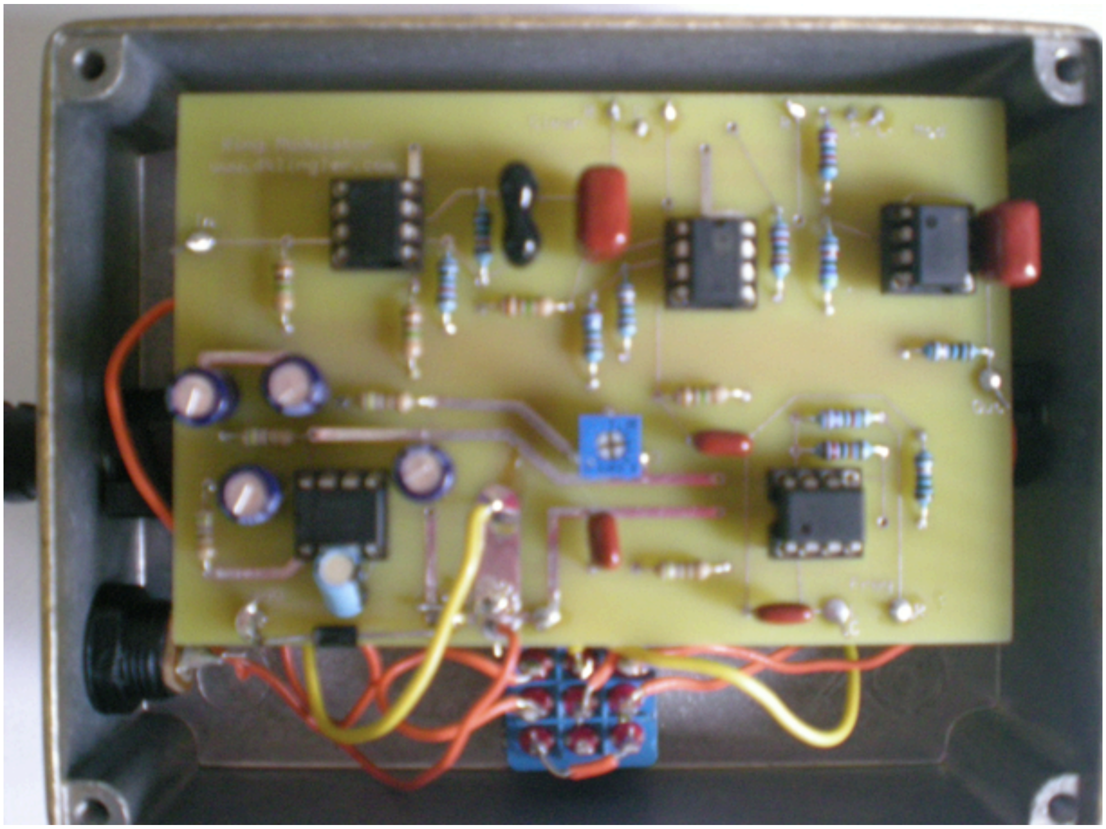

Figure 8: PCB with installed components

Figure 9: Completed pedal in enclosure

Measurements and Results

The first measurement I took was the idle current draw of the pedal. It measured 28.4 mA, which falls in the normal range for guitar pedals. Next, I performed some subjective listening tests, paying close attention to the presence of the oscillator in the output. Although the sound of the triangle wave was completely nulled out, the upper harmonics of a square wave could still be heard mixed in the output. The volume of the oscillator was quiet compared to the volume of the guitar signal, but it is probably noticeable enough to annoy the average user. The oscillator signal is shown together with the noise floor in Figure 10. The oscillator can barely be seen at 200 Hz, aligned with the first vertical division.

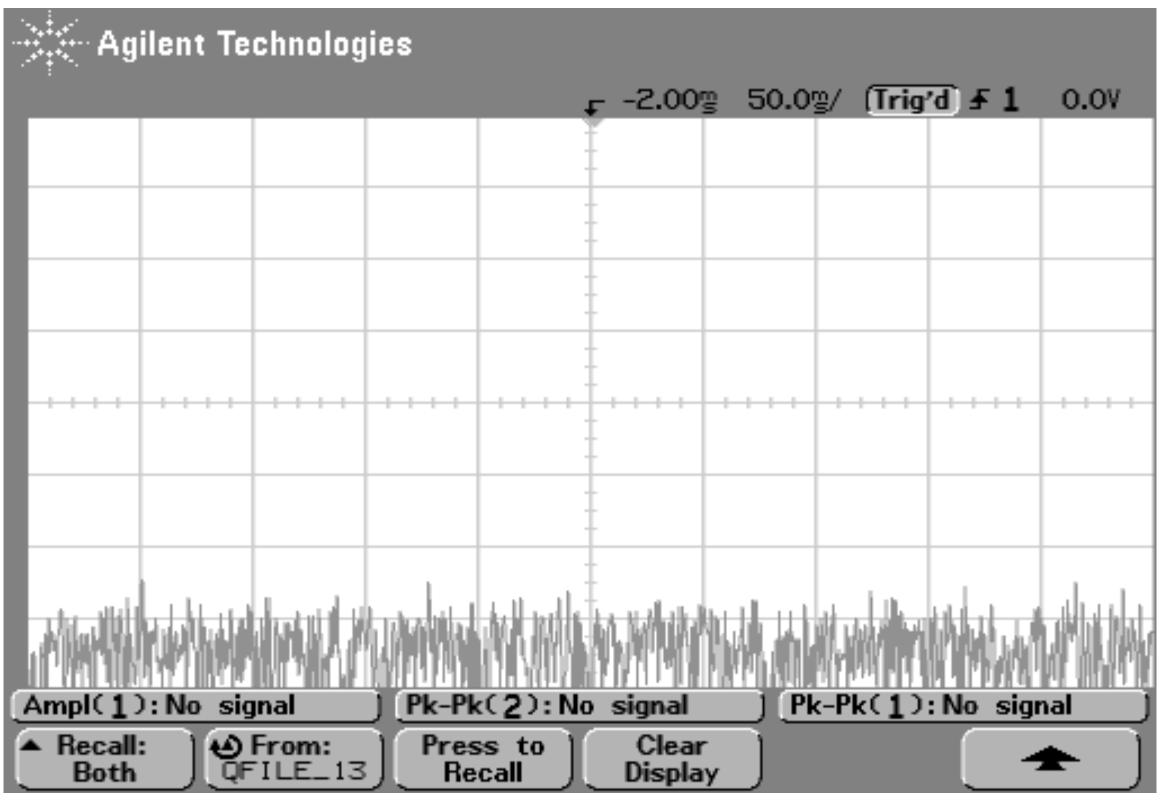

Figure 10: Spectrum of the oscillator + noise floor with 10 dB/div and 200 Hz/div

Oddly, the oscillator could be faintly heard even when the pedal was true bypassed. This indicates to me that the signal ground is still hopping up and down with the oscillator. However, when the pedal was inserted in series with all my other pedals, the oscillator was so faint that it was well below the noise floor of the amplifier. This is probably because the additional ground points at the other pedals are helping to anchor ground to a true 0V.

Some screenshots were taken with a 200 Hz sine wave input, to view the effect the ring modulator has in the time domain.

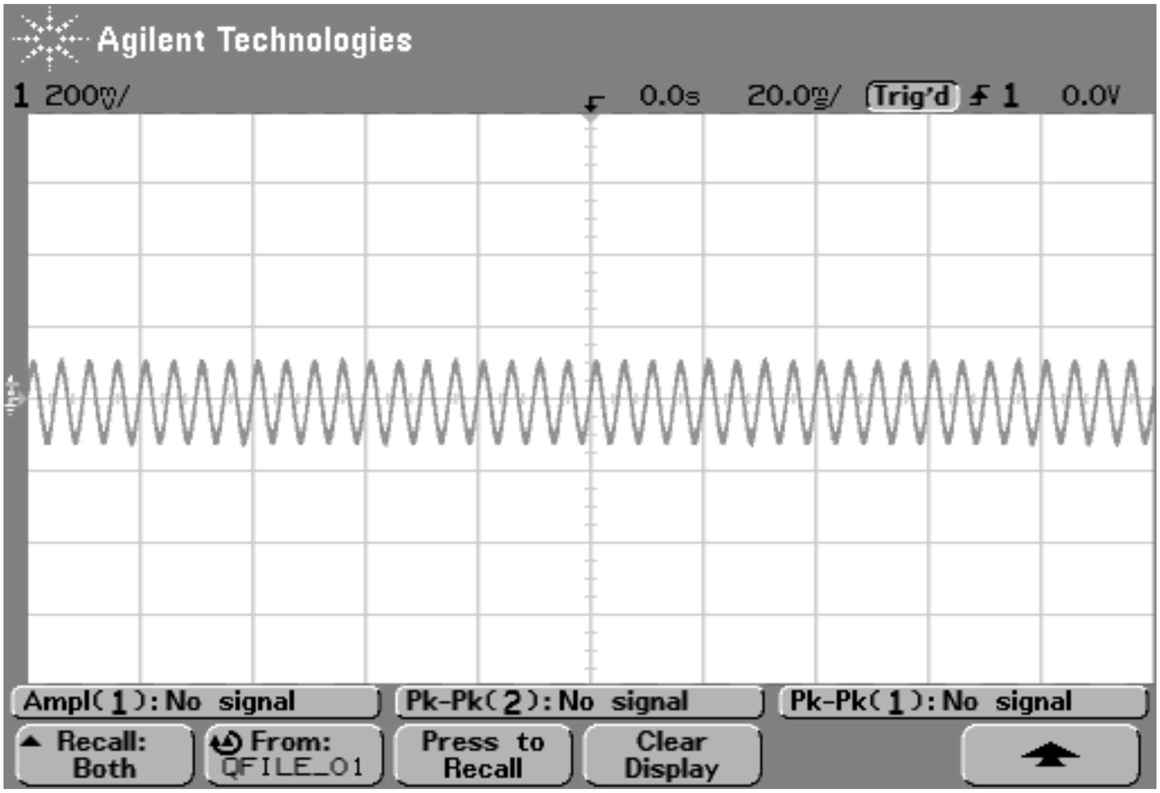

Figure 11: Dry input sine wave

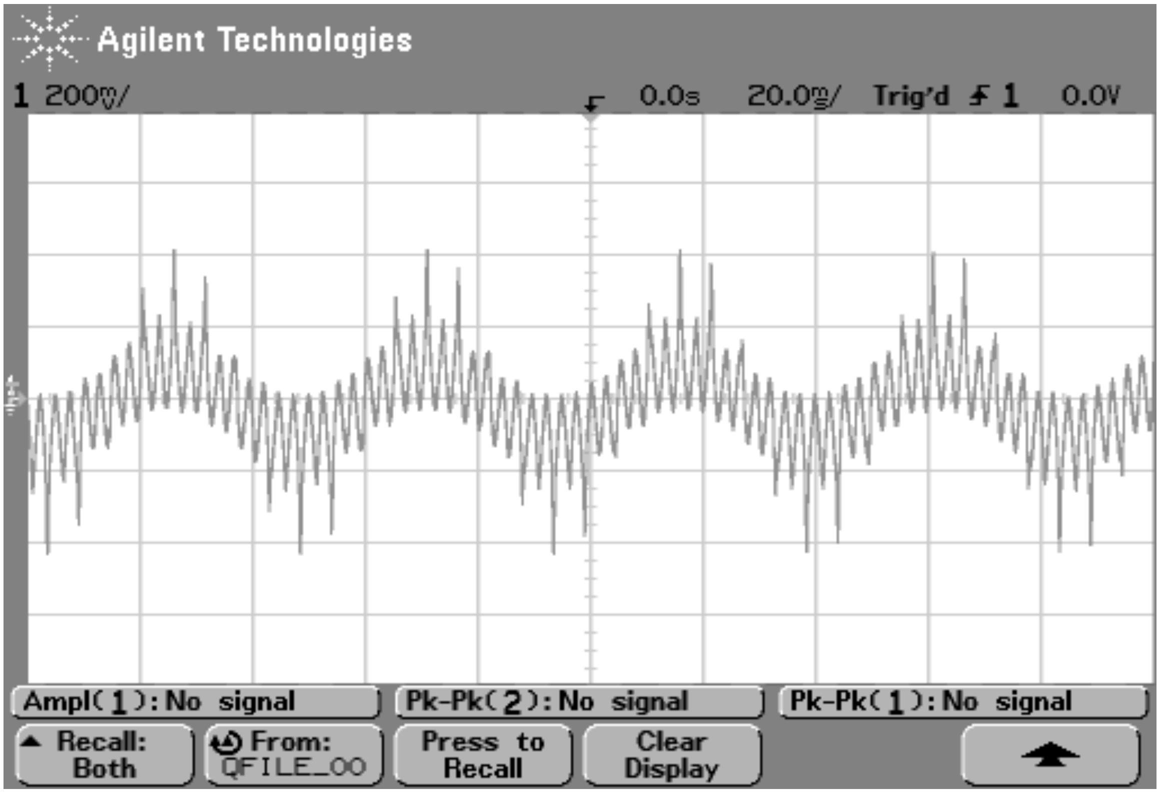

Figure 12: Ouput with freq. pot at 12:00

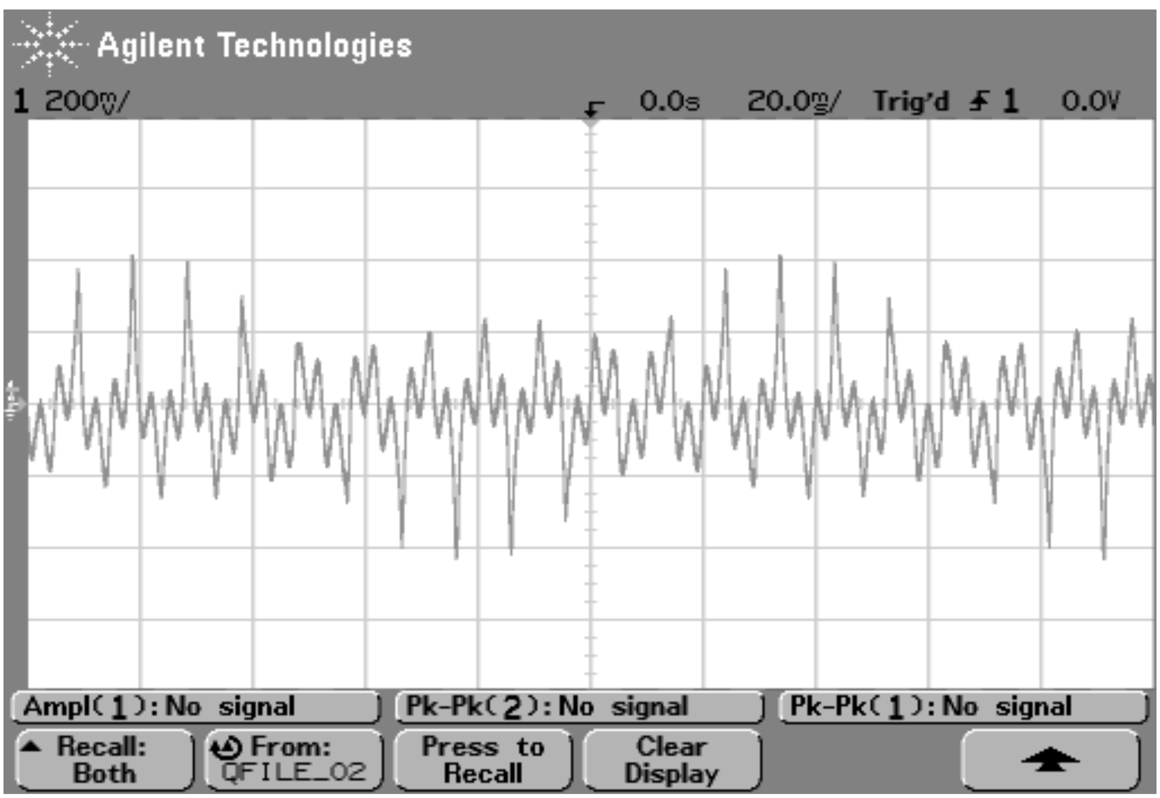

Figure 13: Output with freq. pot at 7:00

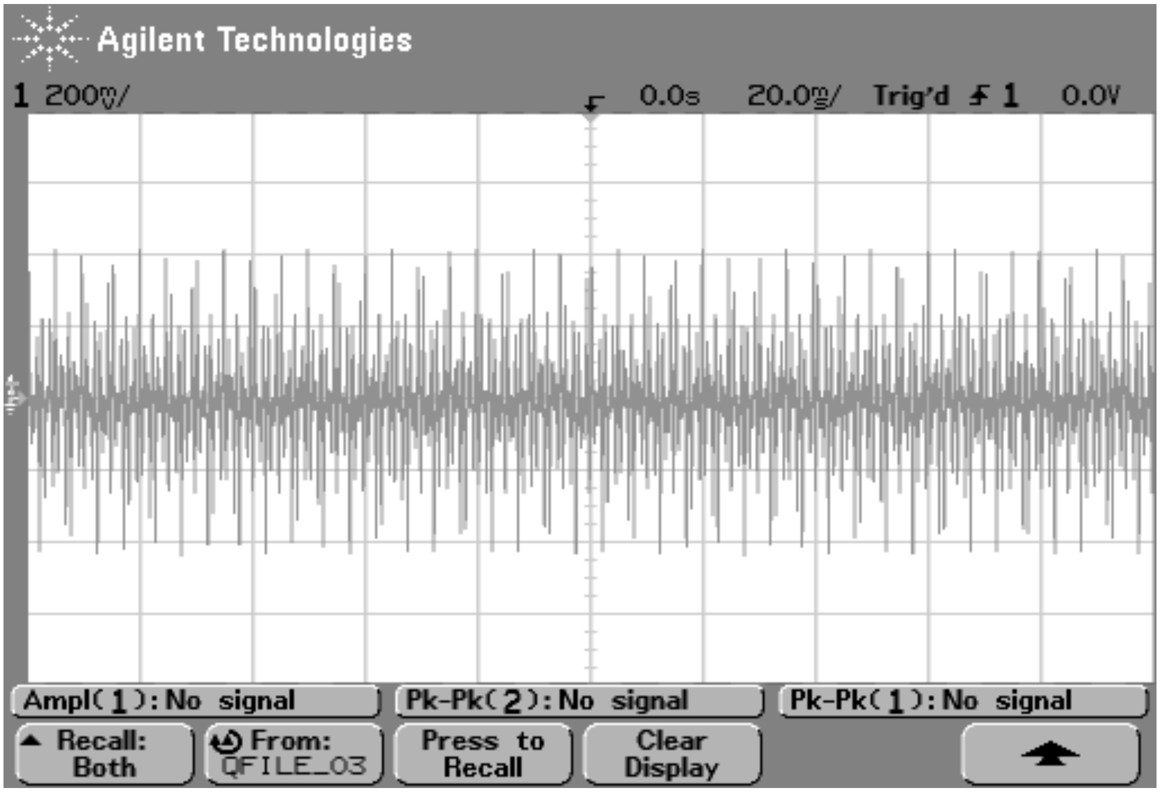

Figure 14: Output with freq pot at 5:00

Some spectra were taken, displaying the effect that the ring modulator has in the frequency domain. All screenshots have a vertical scaling of 10 dB/div.

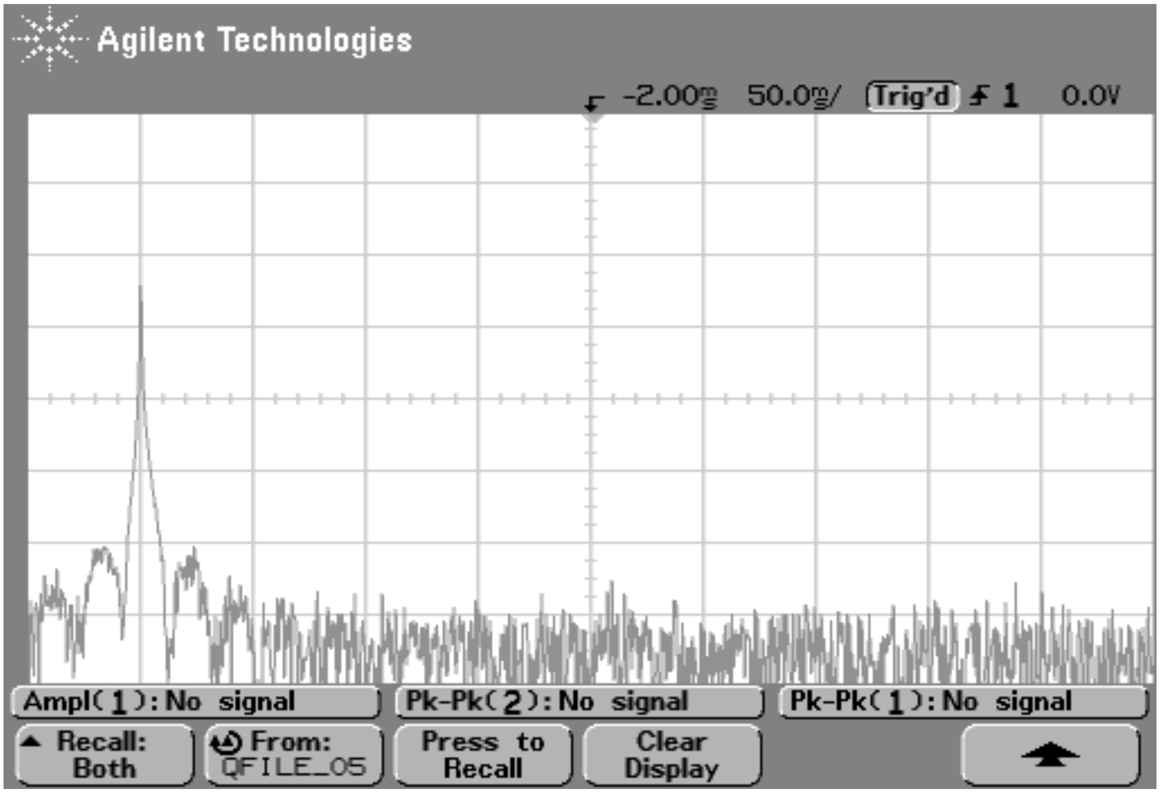

Figure 15: Spectrum of 200 Hz input signal

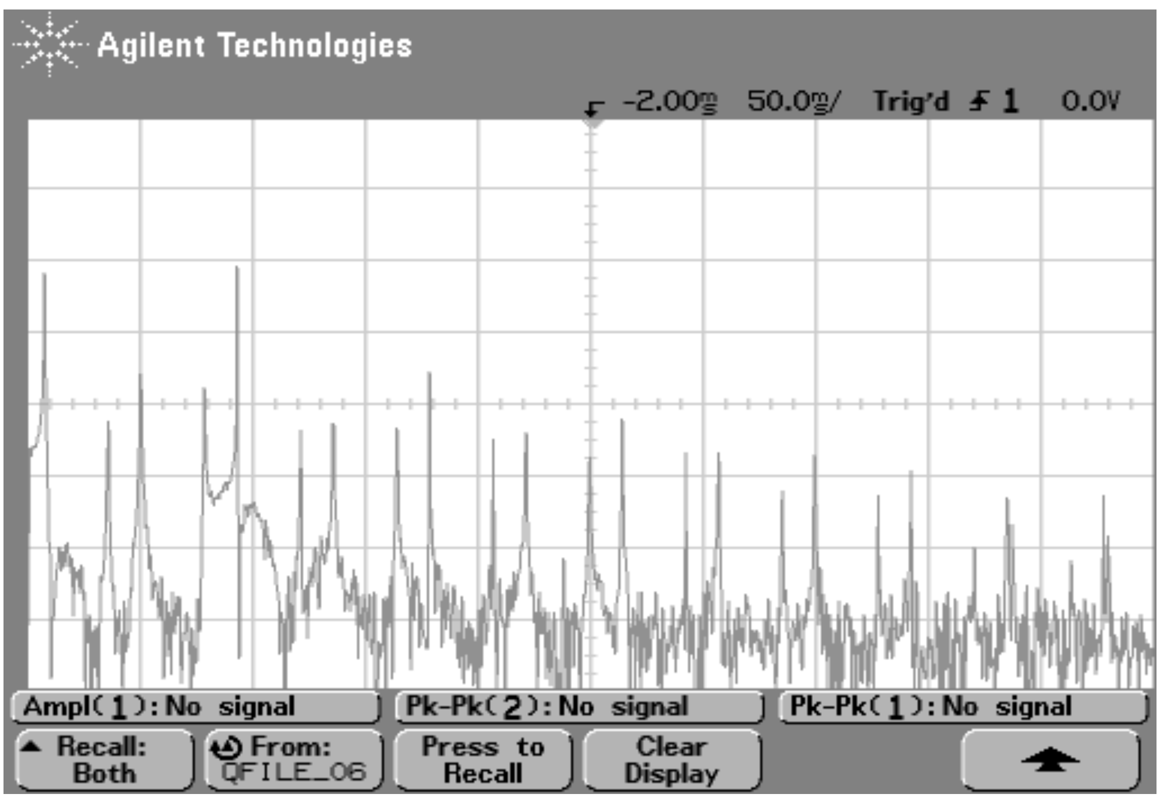

Figure 16: Spectrum (2 kHz span) with freq. pot at 12:00

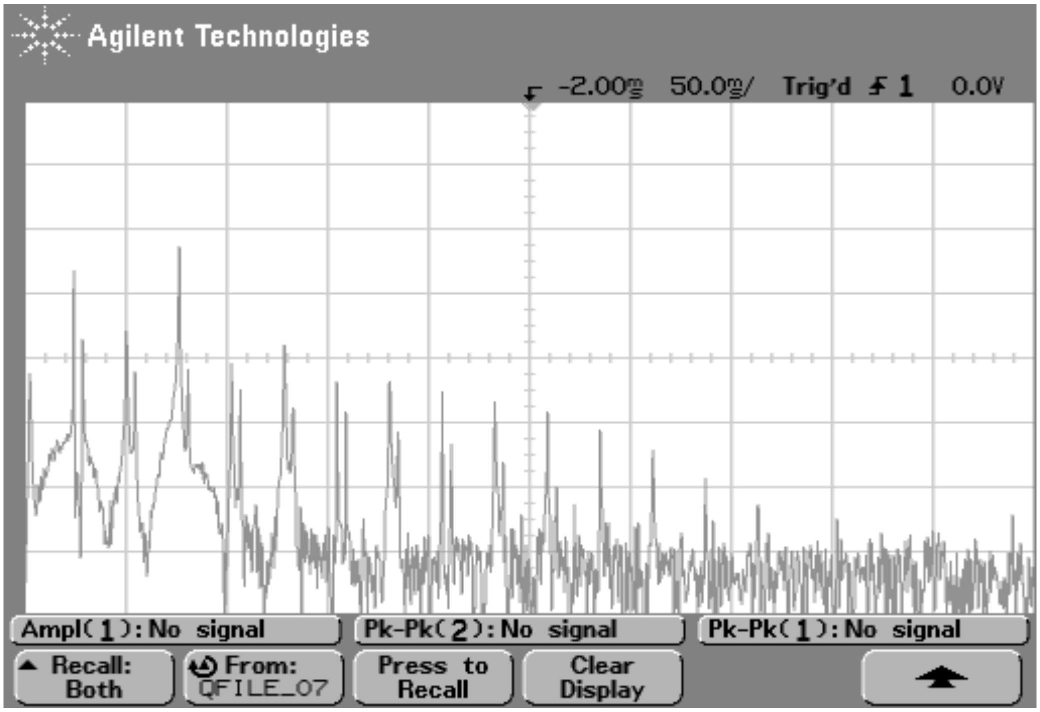

Figure 17: Spectrum (2 kHz span) with freq. pot at 7:00

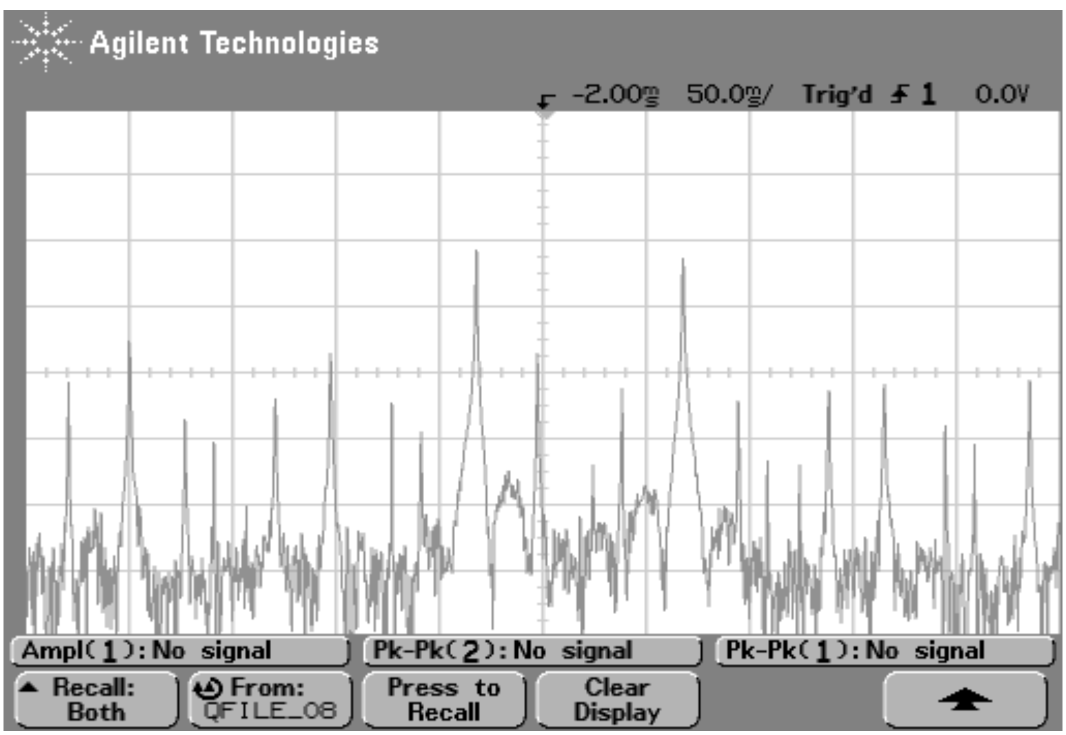

Figure 18: Spectrum (2 kHz span) with freq. pot at 5:00

Conclusion

Although there is still an issue with oscillator bleed-through, the pedal works well overall. I'm glad I got the opportunity to build it, and I'm looking forward to adding a few features this summer. I am hoping to put a variable low-pass filter on the ring-modulated signal, while leaving the clean signal full-frequency. This could tame the harshness of some of the upper harmonics and make this pedal more usable in a normal setting. I'm also planning to tweak component values to match the volume of the pedal with the bypassed guitar volume. Hopefully this can serve as a good starting point to turn this into a really great ring-mod pedal. I'd like to thank Prof. Errede and John Alsterda for their help with this project.

Appendix

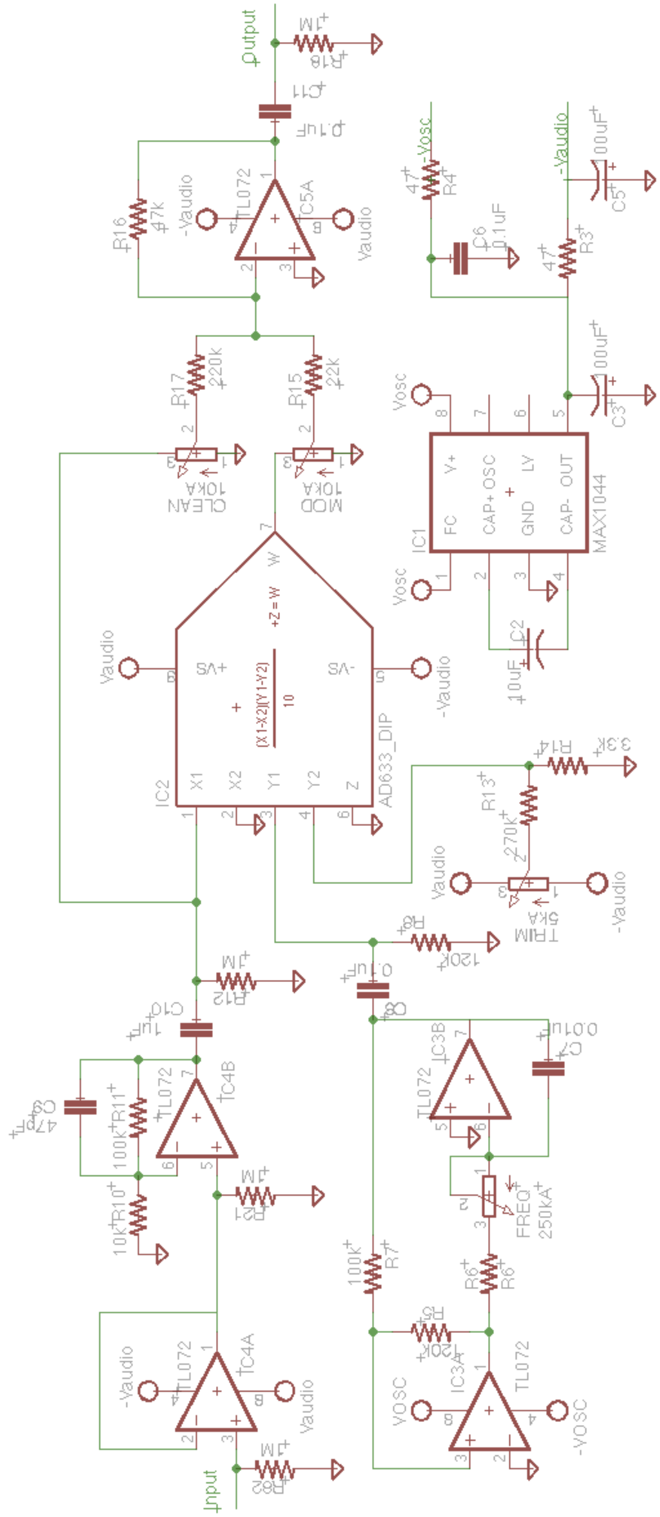

Figure 19: Complete schematic

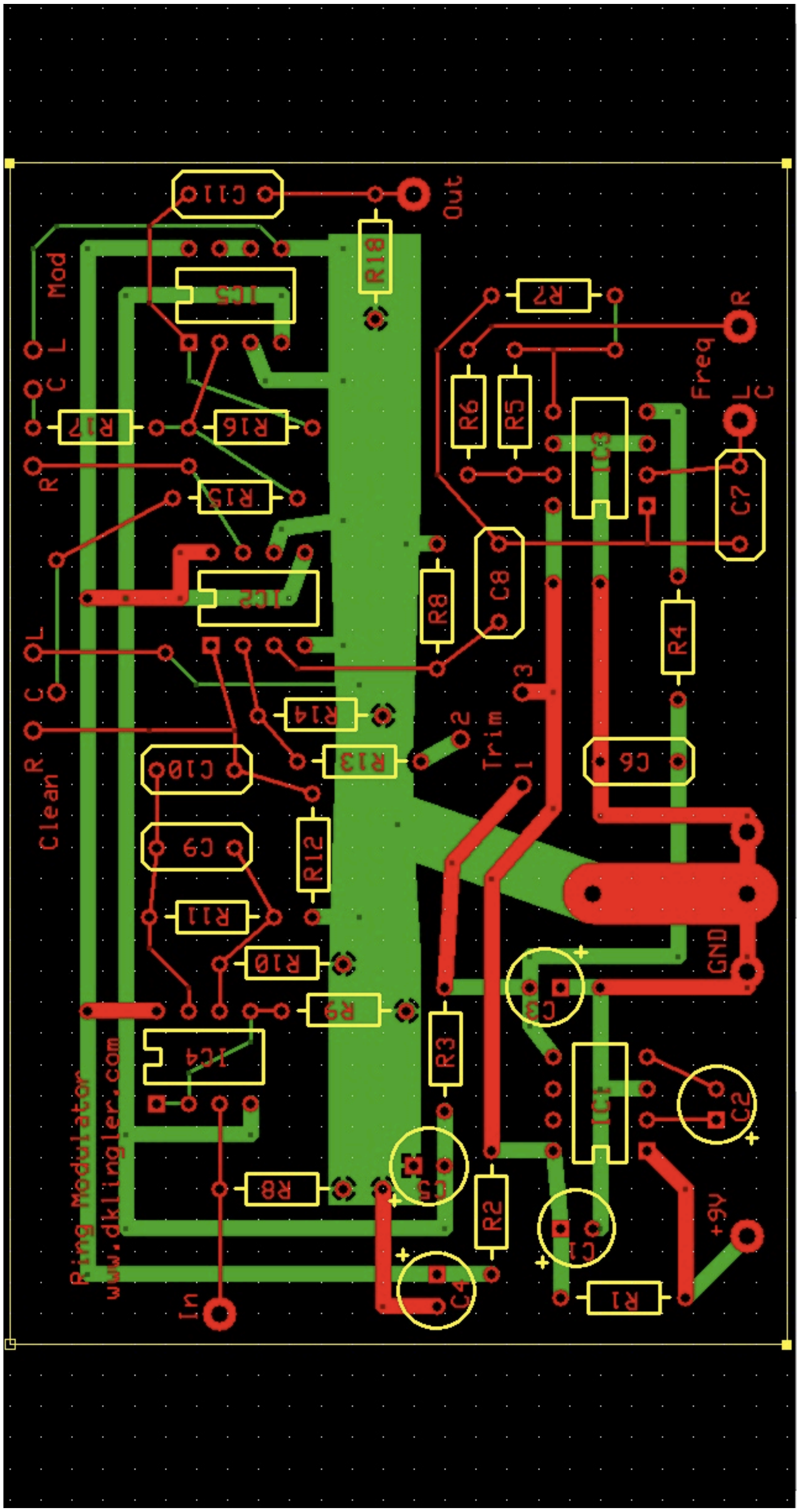

Figure 20: Complete layout