“Tone Lube”

Distortion and Limiter Effect Circuit

Designed by: Michael Prosinski

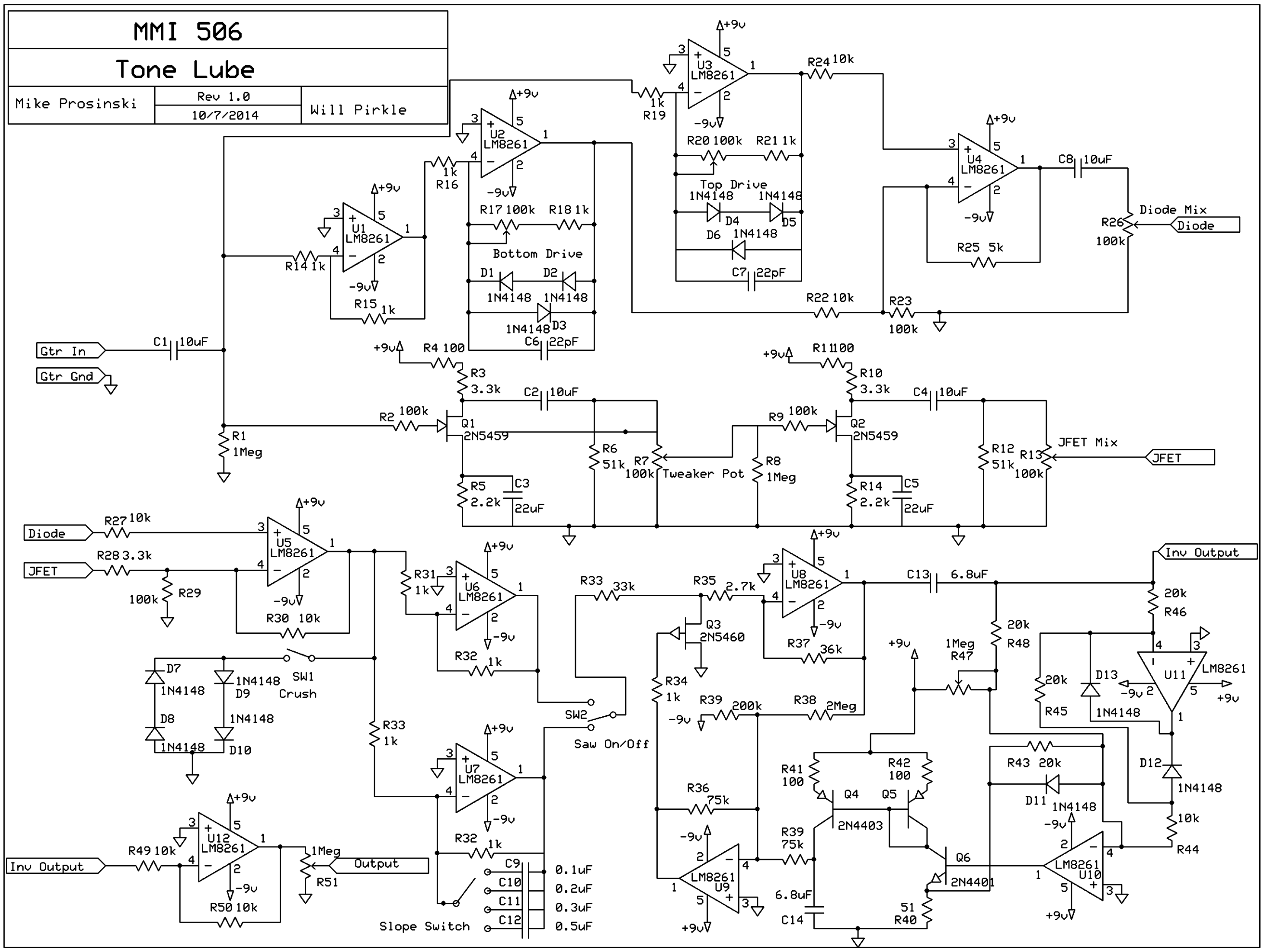
Completed for Advanced Audio Electronics: MMI 506

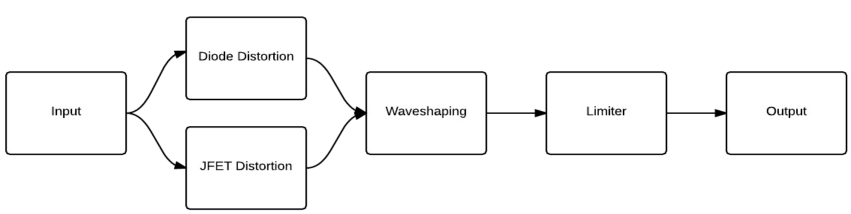
by Will Pirkle

October the 9th, 2014

Table of Contents

Schematic


MMI 506
Tone Lube
Mike Prosinski
Rev 1.0
10/7/2014
Will Pirkle
Gtr In
Gtr Gnd
Diode
JFET
Inv Output
Output
Diode Mix
JFET Mix
Top Drive
Bottom Drive
Tweaker Pot
Crush
Saw On/Off
Slope Switch


Input
Diode Distortion
JFET Distortion
Waveshaping
Limiter
Output

Theory of Operation

1. Overview

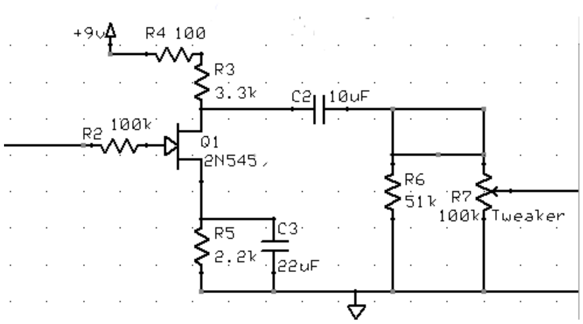
The Tone Lube distortion pedal is a tone enhancing circuit that utilizes the sounds of both diode and JFET distortion, coupled with an aggressive limiter, to create a sonically lubricated output. The circuit is divided into two parallel distortion stages, one for diode distortion and one for JFET distortion, followed by a tone shaping circuit, and finished with a limiter circuit.

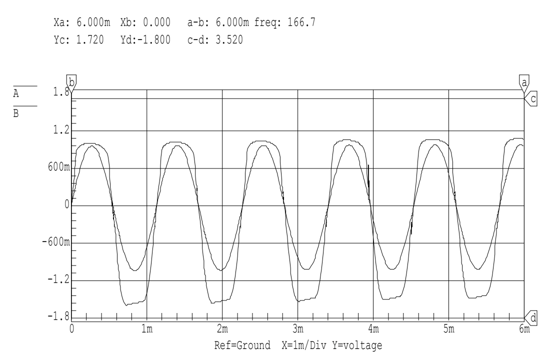
The circuit aims to provide enough flexibility to allow for the creation of unique distortion, letting the user design asymmetrical waveforms, both test-tube and square wave distortion, and both sinusoidal and triangular output waveforms.

The most significant contributors to the sound of the circuit are the effects of diode distortion, JFET amplifiers, and an integrator circuit. The output levels are controlled by both a master volume knob and the threshold of the limiter circuit that immediately precedes the output.

2. JFET Distortion

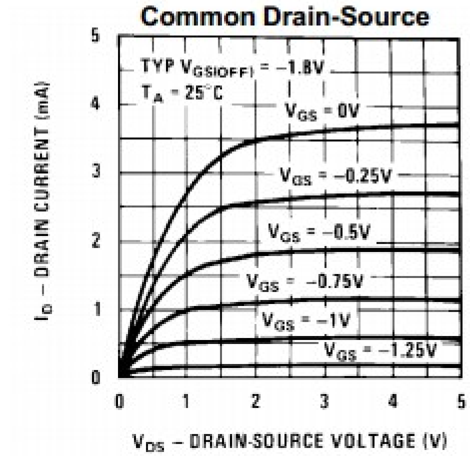
Two identical JFET amplifiers create one half of the initial input distortion. These overdriven JFETs produce a tube-like output signal with softly clipped test tube waveforms.



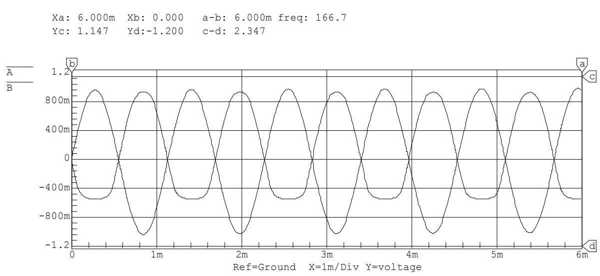


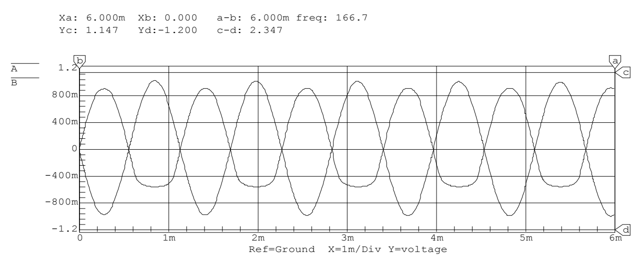
This inverting amp produces 16 dB of gain across a spectrum for 40Hz to 20kHz. The first stage has it's output set by a tweaker potentiometer. Keeping it low enough to maintain the test tube shaped distortion. The second stage has its output controlled by a gain knob that feeds the signal into a summing amp along with the output of the other primary distortion stage that makes use of diodes. Note the test tube distortion on the above graphic showing the input and output of a 1V sine wave send through the JFET amps.

Looking at the Data Sheet for the 2N5459 provides a little more clarity on what's happening. With a Vgs of around -1.25V the JFET operates almost entirely in the saturation region. The distortion circuit in the Tone Lube has a Vgs over just over -2 volts, making it a very non-linear amplifier. Also note that the image on the left with Vgs(off) for the 2N5459 is for a different model than the one used in the circuit with a Vgs(off) of -3.7 Volts. The circuit has a Vds of 3.5 Volts and an Id of around 1 mA. The results can be seen in the waveform on the previous page.



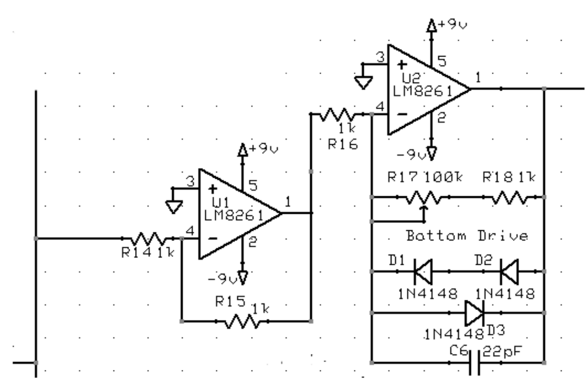
3. Diode Distortion

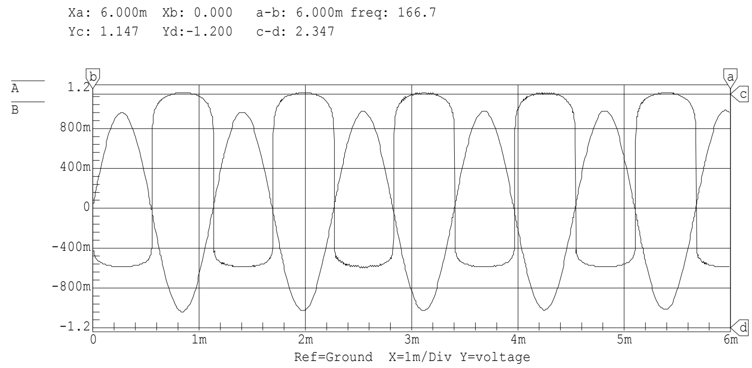




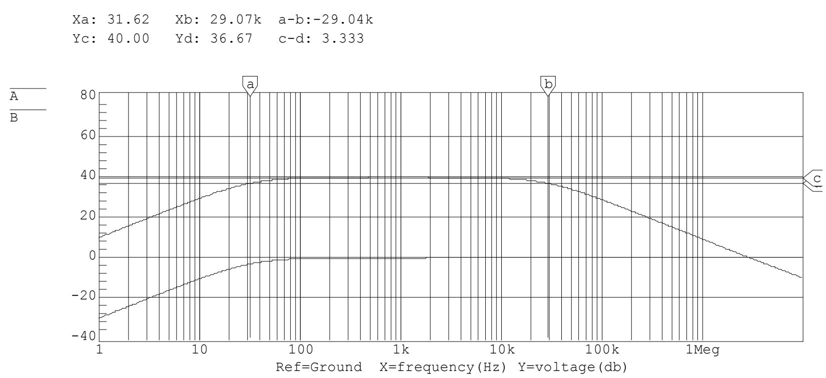
The two out of phase graphs here (with 0 gain) shows the input and output of the non-inverted and inverted inputs to the circuits respectively. These two near-identical circuits operate by using a variable gain op-amp with diodes in the feedback path to generate distortion on each of the two input waveforms. The only difference between them is that the two diodes in series operate of different parts of the waveforms due to the inputs being out of phase. In practice this allows the user to control the diode shaping of the waveform on both the top and bottom of the output wave by controlling the distortion level to the non-inverting and inverting inputs.

Noting the diagram on the right, which includes the inverted to create the inverted input. We can see the inverting op-amp generated a gain between 1 and 101 with diodes and a capacitor in the feedback path to provide stabilization. This provides 0-40dB of gain with bandwidth between 30Hz and 20kHz.



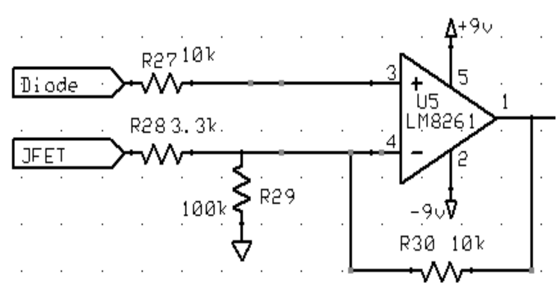


The output graphics represent a fully driven output waveform along with the magnitude response of that fully driven waveform. Note the delicious test-tube shaped output as well as the 40dB of gain produces across the full spectrum of a guitar or bass. Also take note of the distortion's asymmetrical output, which is what we expect as a byproduct of the feedback path having one diode limiting the voltage in one half of the waveform, and with two diodes in series operating on the other half.



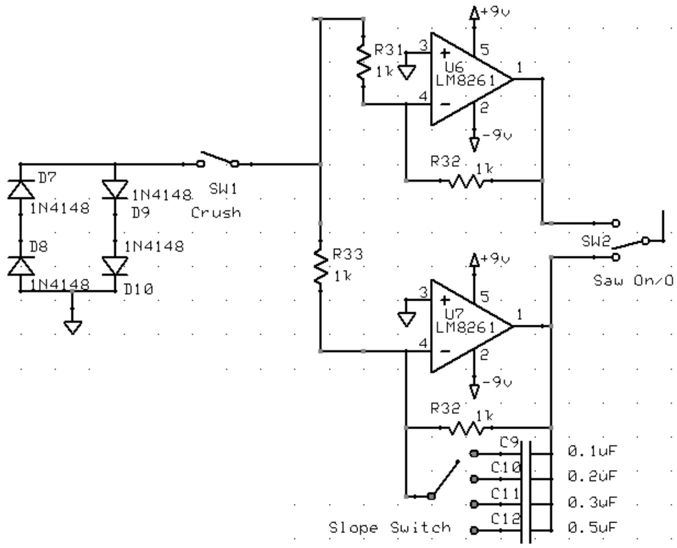
4. **Summation Stages**

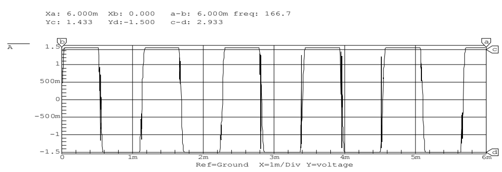
The two diode stages are summed through an op-amp circuit before both the diode and JFET stages are summed again. The levels on both the diode and JFET path are controlled by a potentiometer connected to ground, with the wiper feeding the paths labeled diode and JFET. Note the amp's gain of 3, which is done to feed the following stage.



5. **Waveshaping**

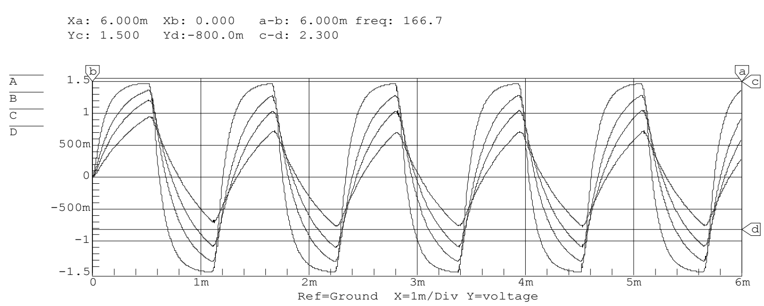
The waveshaping stage of the circuit has two important features. The first is a network of diodes to ground that can be engaged with a switch labeled "Crush". The net result will be a very square output.





This will sound awful. However, the point of the crush switch is for it to be used in tandem with the integrator circuit which follows.

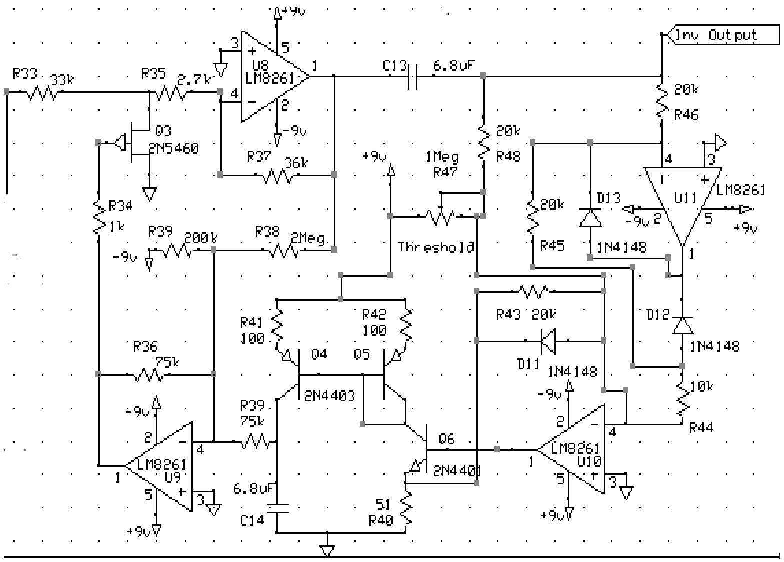
The integrator, which can be used with and without the crush setting selected, allows the user to shape their output to more closely resemble sawtooth or triangle waves. By switching between more highly reactive capacitors, the user can shape the output more and more heavily.



The result (shown above) is a waveform that starts as a sawtooth and moves more and more towards a triangle output as the user switches to higher value capacitors. By the nature of the integrator circuit, which is essentially a lowpass filter, the effect is more intense at higher frequencies. The above example at 880Hz is in the upper register of a guitar's playing range and illustrates the effect quite nicely, while notes on the lower end of the spectrum will have a poorer response to the waveshaping.

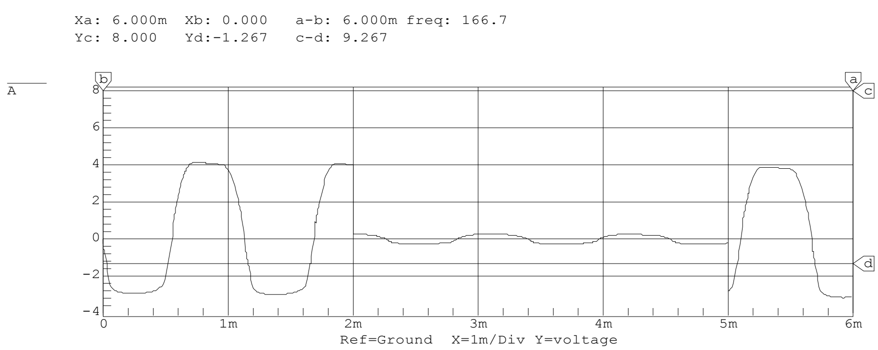
Note the unity gain amp and the switch to allow choosing between shaped and unshaped signal. The enables either test tube or square waves output either integrated or not.

6. **Limiter**



The final stage of processing is an adaptation of the Leach limiter redesigned to run on a +/-9V power supply. The limiter uses the 2N5460 as a variable resistor in a voltage divider to limit the output signal.

The circuit takes advantage of an inverting peak detector and a full-wave rectifier to feed a current mirror and a unity gain op-amp which sets the voltage on the gate of the JFET. Take note of the potentiometer R47 which sets the DC offset on the rectifier circuit and consequently the threshold of the limiter. This represents the only control the user has over the processing of the limiter.

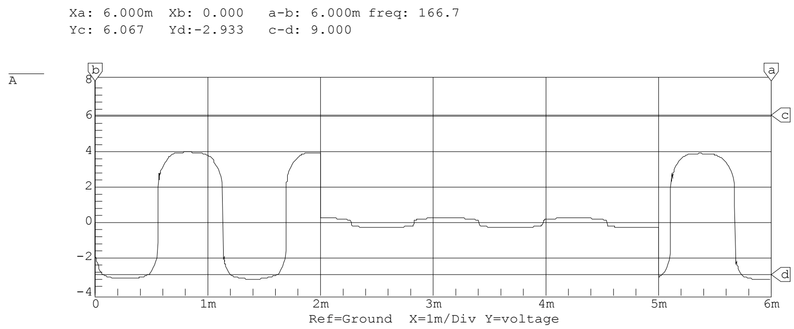


Above is an image of distorted input, with the limiter engaging at it's lowest threshold between 2 and 5 milliseconds. The net gain reduction between the highest and lowest threshold in this case is 23dB. This squishing of dynamic range also does a good job of eliminating any residual DC offset on the signal as a result of the asymmetrical clipping beforehand. This can also be observed in the above image.

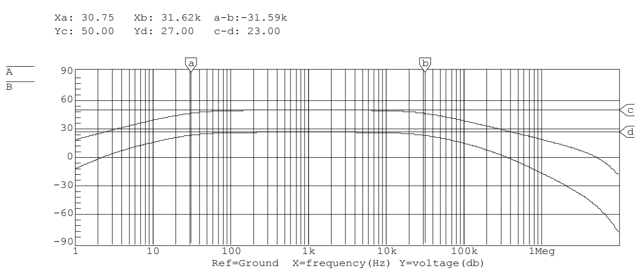
The final stage is not pictured, and consists of an inverting unity gain op-amp designed to invert the signal so phase remains consistent between input and output. There is also a potentiometer tied to ground functioning as a master volume knob.

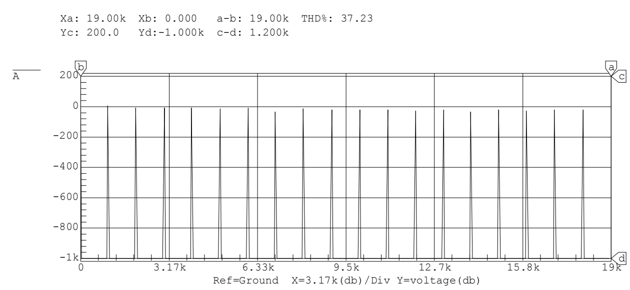
Output Measurements and Simulations

Too Much Drive – Full Distortion and maximum blend on both stages, no waveshaping



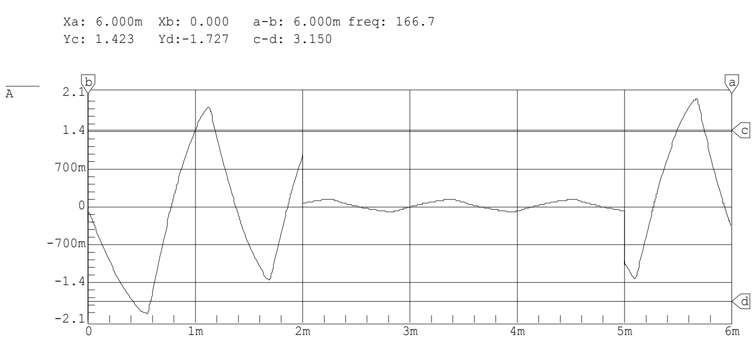
With all the distortion the circuit can muster, there is more than enough drive. The output waveform has the distinctive test tube shape. The limiter engages at 2ms leaving the shape but reducing the dynamic range considerably.



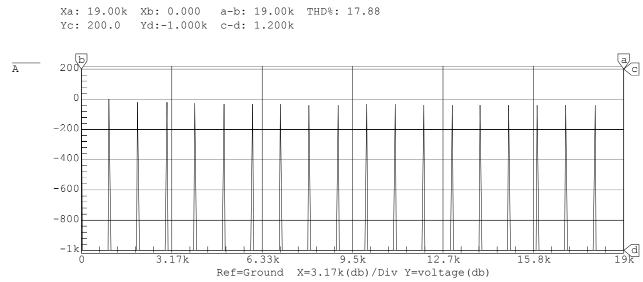


In the Magnitude Response, we see the input and the output of the limiter circuit, with a full guitar/bass bandwidth of 30Hz-20kHz and 50dB of gain, with 27dB of gain accounting for the -23dB of the limiter. In the Transient Response we see over 37% THD, which is solid considering distortion is definitely the goal here.

Triangluar Drive – Full Distortion and maximum blend on both stages, waveshaping

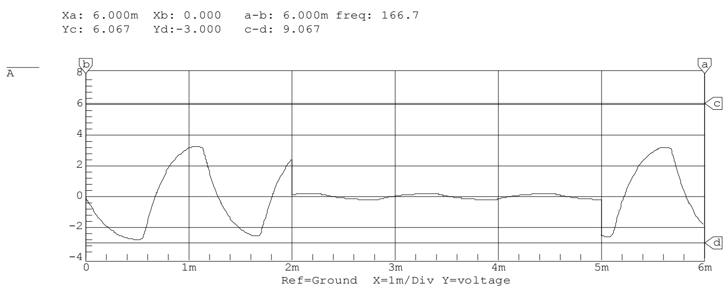


With the highest value capacitor selected in the integrator, the resultant waveform is very triangular. Note the remnants of the sawtooth shape in the signal, a function of the capacitor's charging and discharging, which is this instance we seek to slow down so as to be more linear.



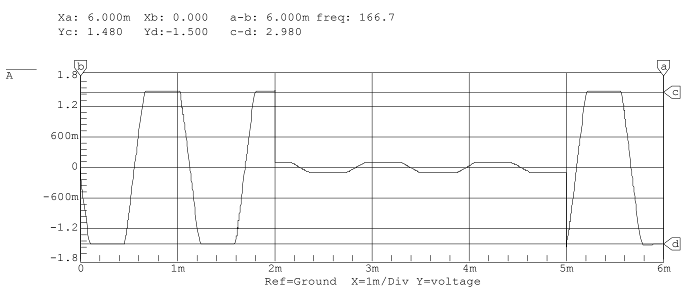
There is a significantly smaller bandwidth because of the lowpass filter generated by the integrator. However, for a small frequency range between 41Hz and 240Hz there is the full 50dB of gain before the limiter. The THD in this situation is also lowered to around 18%.

Saw Drive – Full Distortion and maximum blend on both stages, light waveshaping



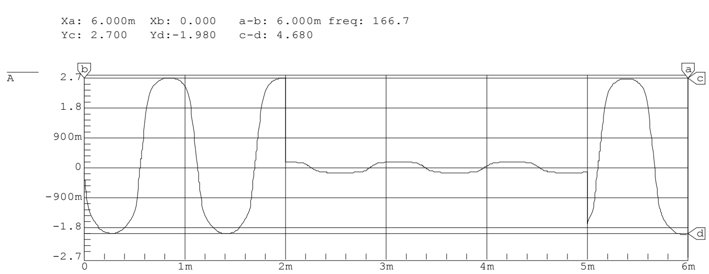
With a lower capacitor selected on the integrator, the signal because more sawtooth shaped than triangularly shaped. This is because the integrator is taking advantage of more of the non-linearity of the capacitor's charging/discharging time.

Trapezoid Drive – No Distortion, crush, no waveshaping



By not driving the diode stage and shunting the entire JFET stage to ground, we can get clean input into the waveshaping stage and use that to clip the tops of the input signal making trapezoidal waves.

Finger Time – Light Distortion, no waveshaping



With only the top of the diode circuit driving and the other one off, the output is slightly tube shaped, but with narrower peaks on the top than the bottom of the waveform. I call the output finger waveforms.

Future Design Ideas and Improvements

Some things that could really improve this design, as well as some considerations that should be taken before its construction.

- This design needs a 9V and -9V supply to operate. Half supplying this circuit so it works with only one 9V battery would be nice. Though it would up the component count.
- Currently there is no way of modifying the gain of the JFET stage, only the output volume from it. Another amp could be inserted before that stage to make things more flexible.
- Add a tone control, because it would be nice to able to control this, though I suppose there are other options for doing so in another circuit in the chain.
- Attack and release controls on the limiter. Though the circuit is already full of controls, allowing the limiter to be more controllable would be a nice feature.
- Experiment with more feedback in this circuit. There are plenty of avenues for interesting feedback connections to be made. Currently this only exists in individual op amps.
- Consider converting the limiter into a compressor for greater dynamic control instead of only limiting the output