DIY Guitar Pedals

Bulldozer

Design By Erik Vincent

The Bulldozer is a unique overdrive for bass or electric guitar.

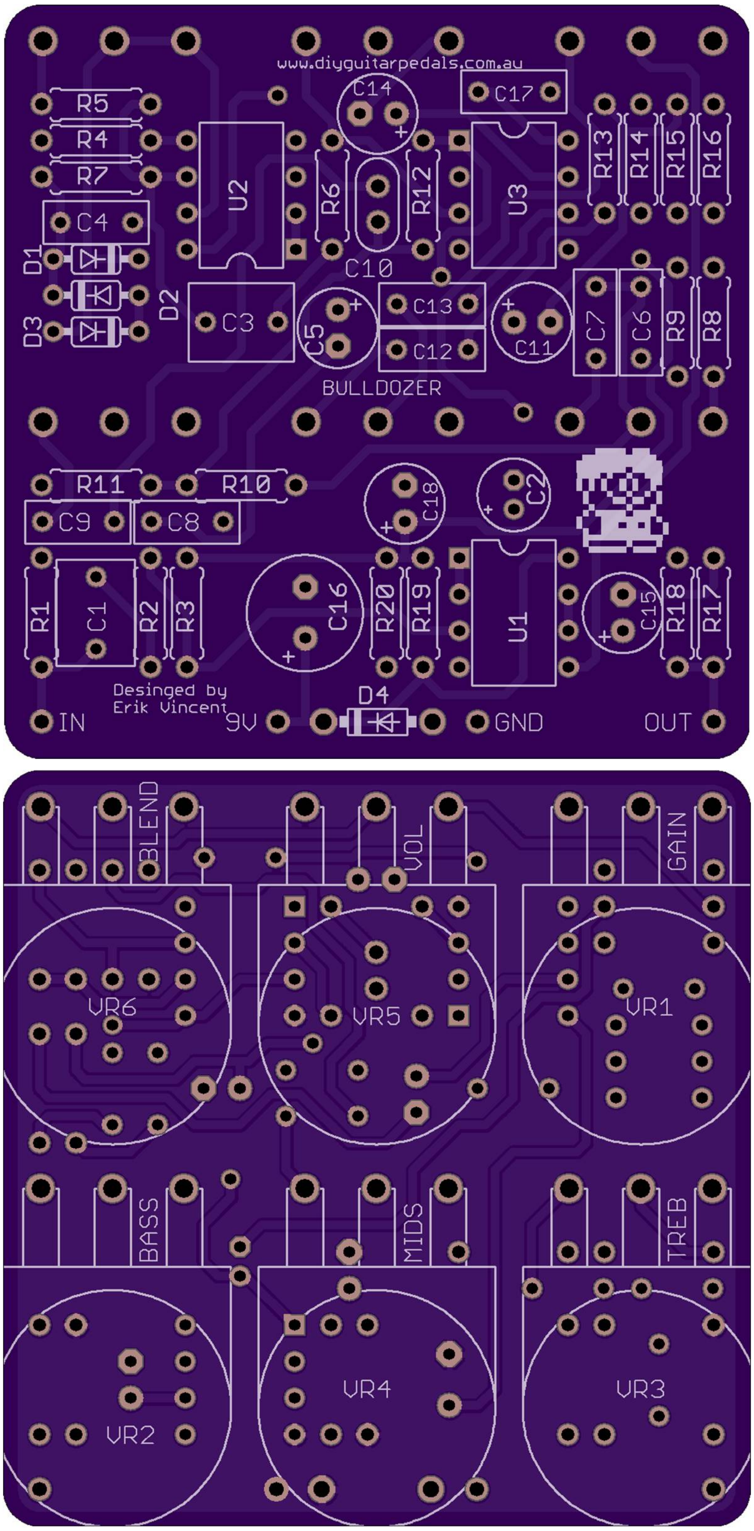
The preamp section of the circuit consists of an op-amp overdrive with asymmetrical soft clipping. This goes into a 3 EQ tone-stack to shape the gain stage sound. Finally, a clean blend is added to retain the low end of your signal.

Utilizing the blend feature you can control what part of your guitar signal you want to distort and what part will bypass the distortion circuit all together. Although this feature works well for both electric and bass guitars, it does have a specific benefit for bass players. Bypassing your bass frequencies from the distortion section of the circuit, will retain the low-end bass content of your bass guitars signal producing a crushing bass line.

The PCB is designed for a 125B enclosure but has been reportedly noted to fit in a cramped 1590B enclosure.

Bill of Materials, Stock Bulldozer

Capacitor		Resistor	
C1	1µF (film)	**R1**	1M
C2	1µF (Electrolytic)	**R2**	1K
C3	220nF (film)	**R3**	1M
C4	22nF (film)	**R4**	10K
C5	10µF (Electrolytic)	**R5**	33K
C6	22nF (film)	**R6**	3.3K
C7	22nF (film)	**R7**	33K
C8	10nF (film)	**R8**	10K
C9	10nF (film)	**R9**	10K
C10	47pF (ceramic)	**R10**	10K
C11	10µF (Electrolytic)	**R11**	3.3K
C12	22nF (film)	**R12**	1M
C13	22nF (film)	**R13**	2.2K
C14	10µF (Electrolytic)	**R14**	2.2K
C15	10µF (Electrolytic)	**R15**	220K
C16	100µF (Electrolytic)	**R16**	220K
C17	100nF (film)	**R17**	1K
C18	47µF (Electrolytic)	**R18**	100K
		R19	47K
Diode		**R20**	47K
D1	1N4148		
D2	1N4148		
D3	1N4148		
D4	1N4001	**Potentiometer**	
		Gain	1ma (16mm)
ICs		**Volume**	100ka (16mm)
U1	TL072	**Blend**	100kb (16mm)
U2	NJM4558D	**Bass**	100kb (16mm)
U3	TL072	**Mids**	100kb (16mm)
		Treble	100kb (16mm)



PCB Spacing
The Bulldozer PCB is spaced for 125B sized enclosures or larger

Pot Spacing
The Bulldozer PCB mounted potentiometers are spaced for Alpha 16mm potentiometers without dust covers

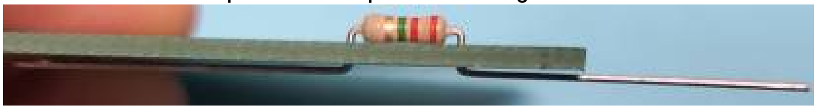
1. Soldering Order.

When soldering things to the PCB, the idea is to solder things on from lowest profile to tallest.

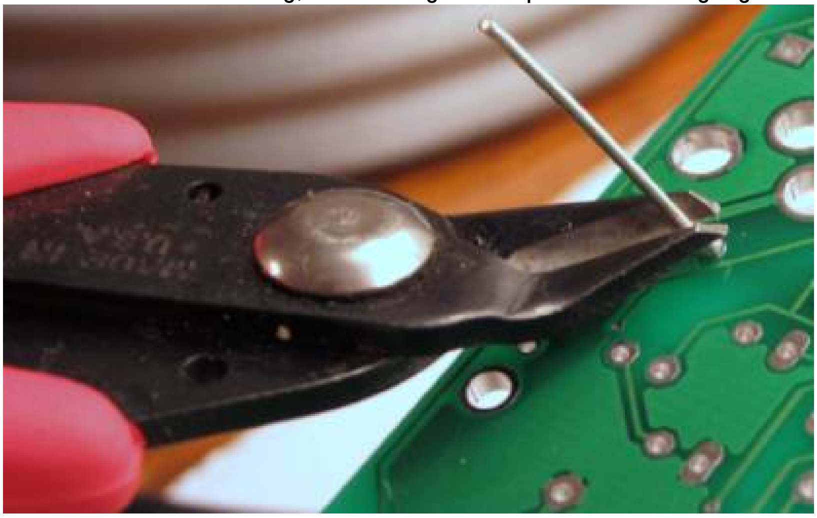
For the Rock Bottom, the best order would be: resistors, diodes, ceramic capacitors, IC sockets (if socketing), ICs (if not socketing), film capacitors, electrolytic capacitors, wiring, potentiometers.

1.1 Resistors.

Resistors are small passive components designed to create a resistance of passage of an electric current.



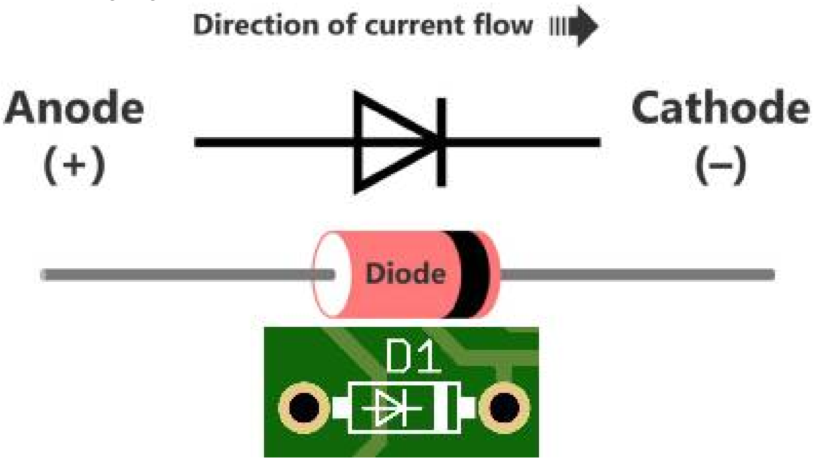
For this pedal we will be using 1/4 Watt resistors. These can either be 5% tolerance carbon resistors, or 1% tolerance metal film resistors. Orientation of “which way is up” doesn’t matter, so you can install them either way. After installation and soldering, do not forget to clip the remaining legs from the PCB.



1.2 Diodes.

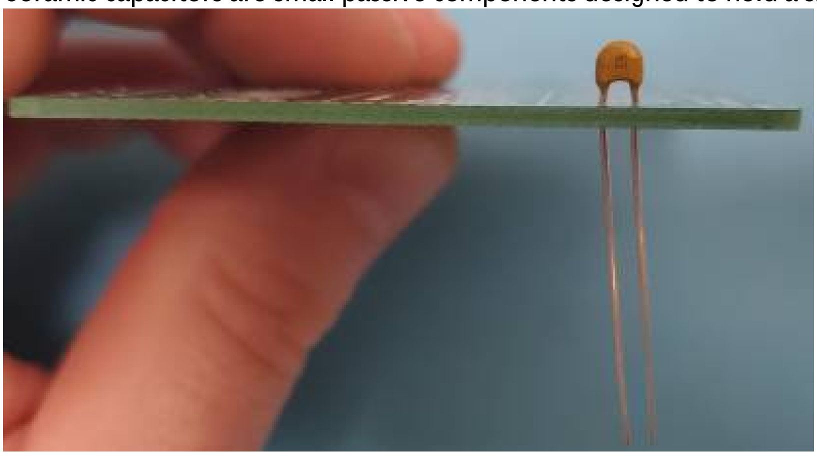
Diodes are semiconductor components typically designed to allow the flow electric current to go in one direction only.

The orientation of a diode does matter based on the cathode and anode of the diode in the circuit. Make sure the stripe on the diode lines up with the stripe on the PCB's silkscreen. After installation and soldering, do not forget to clip the remaining legs from the PCB.



1.3 Capacitors (ceramic).

Ceramic capacitors are small passive components designed to hold a small amount of charge in a circuit.

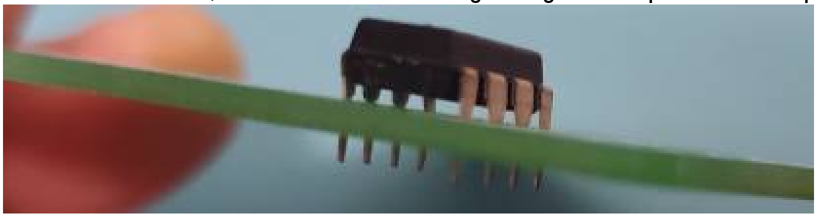


Orientation of "which way is up" doesn't matter, so you can install them either way. After installation and soldering, do not forget to clip the remaining legs from the PCB.

1.4 IC Sockets.
These are holders that allow easy installation and uninstallation of ICs.

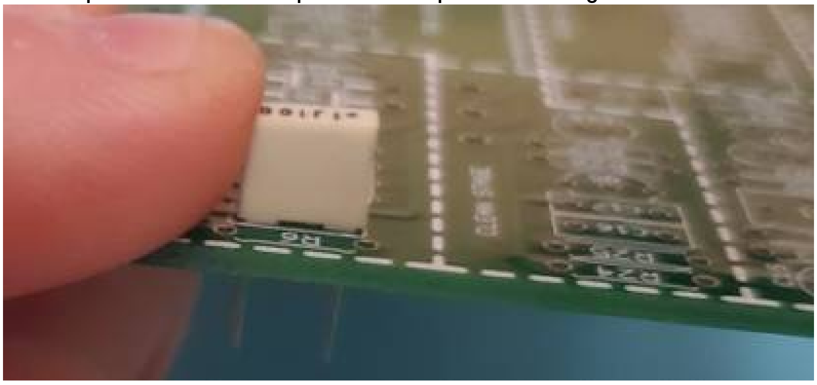
These devices will have a silk screen notch to indicate an orientation with the IC or socket for the IC. Just make sure the IC notches match.

1.5 Integrated Circuits.
Also known as ICs, these are small analog or digital components that provide specific electrical functions.



Orientation of “which way is up” will be indicated by a notch on the silkscreen on the PCB and a dot or bar on the actual IC itself. Do make sure they match.

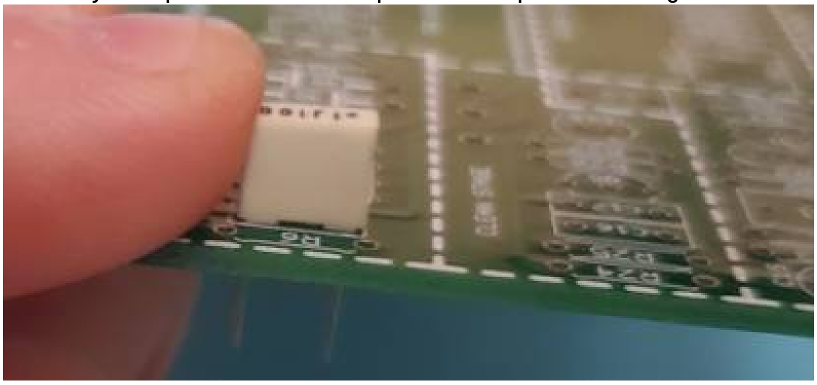
1.6 Capacitors (film).
Film capacitors are small passive components designed to hold a small amount of charge in a circuit.



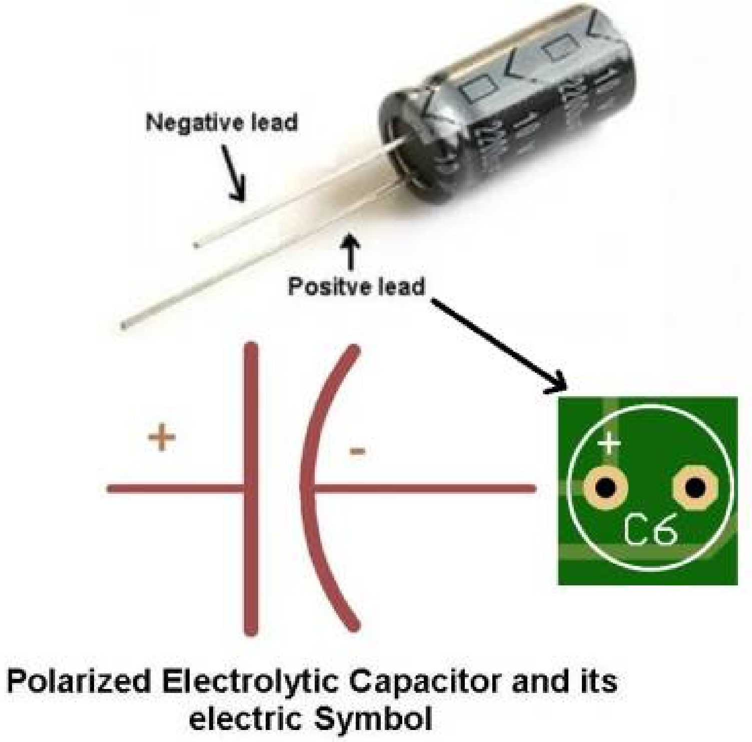
Orientation of “which way is up” doesn’t matter, so you can install them either way. After installation and soldering, do not forget to clip the remaining legs from the PCB.

1.7 Capacitors (electrolytic).

Electrolytic capacitors are small passive components designed to hold a small amount of charge in a circuit.



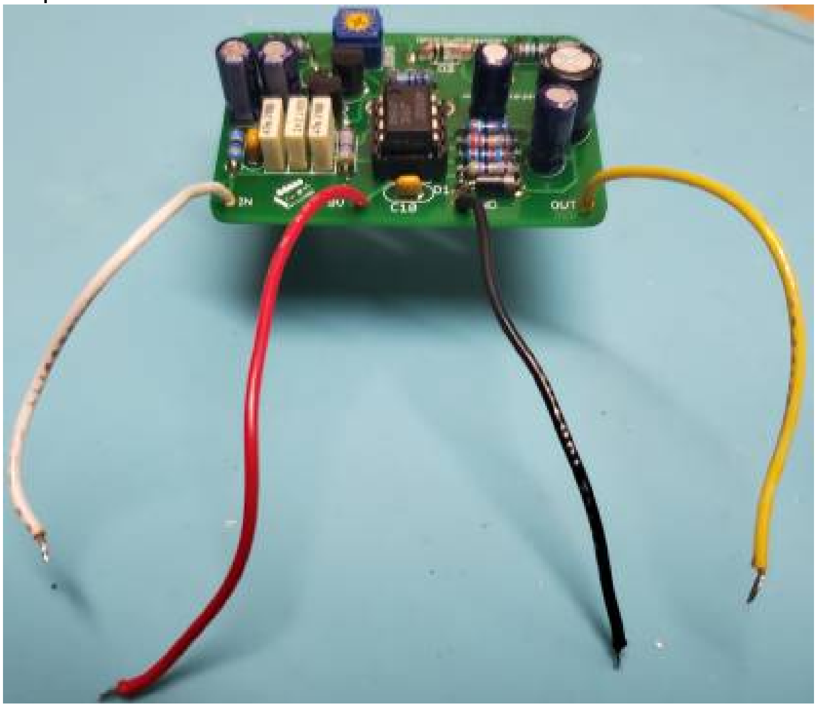
Electrolytic capacitors are typically polarized, so orientation will matter.



After installation and soldering, do not forget to clip the remaining legs from the PCB.

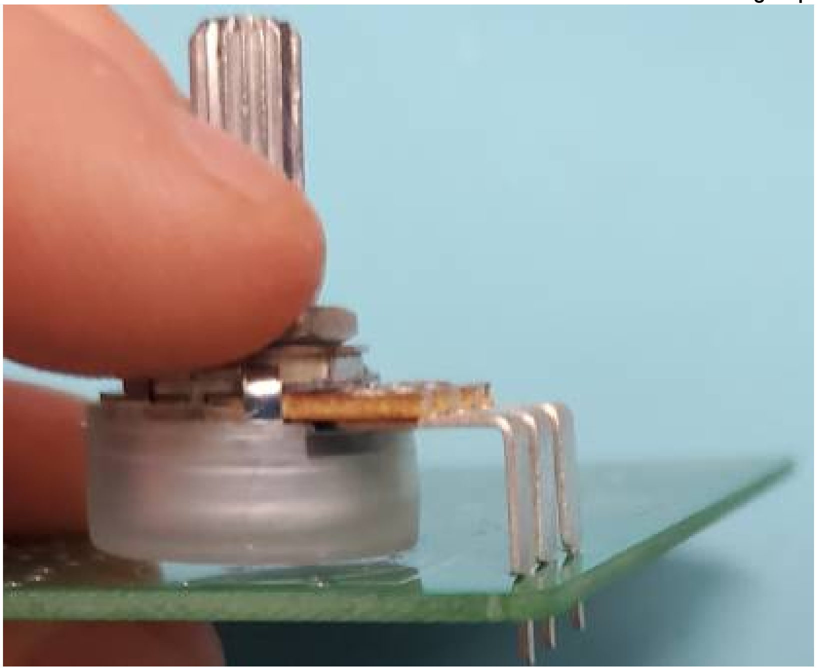
1.8 Wiring.

Wires used for the pedal are for delivering power over the hot and ground wires as well as signal for the input and output.



These can be installed at the very end, but in some situations, installing them before potentiometers are soldered in place can be advantageous. Colored wire doesn't change the properties, but using color codes for hot and ground wires, like red being hot, and black being ground, are common place. Typically, stranded hook-up wire, AWG 24 or 22 is used for this task. Using wire strippers, strip away about 1/8" (3mm) of the wire from either end and then using a soldering iron, tin the exposed tips with solder before installing into the PCB.

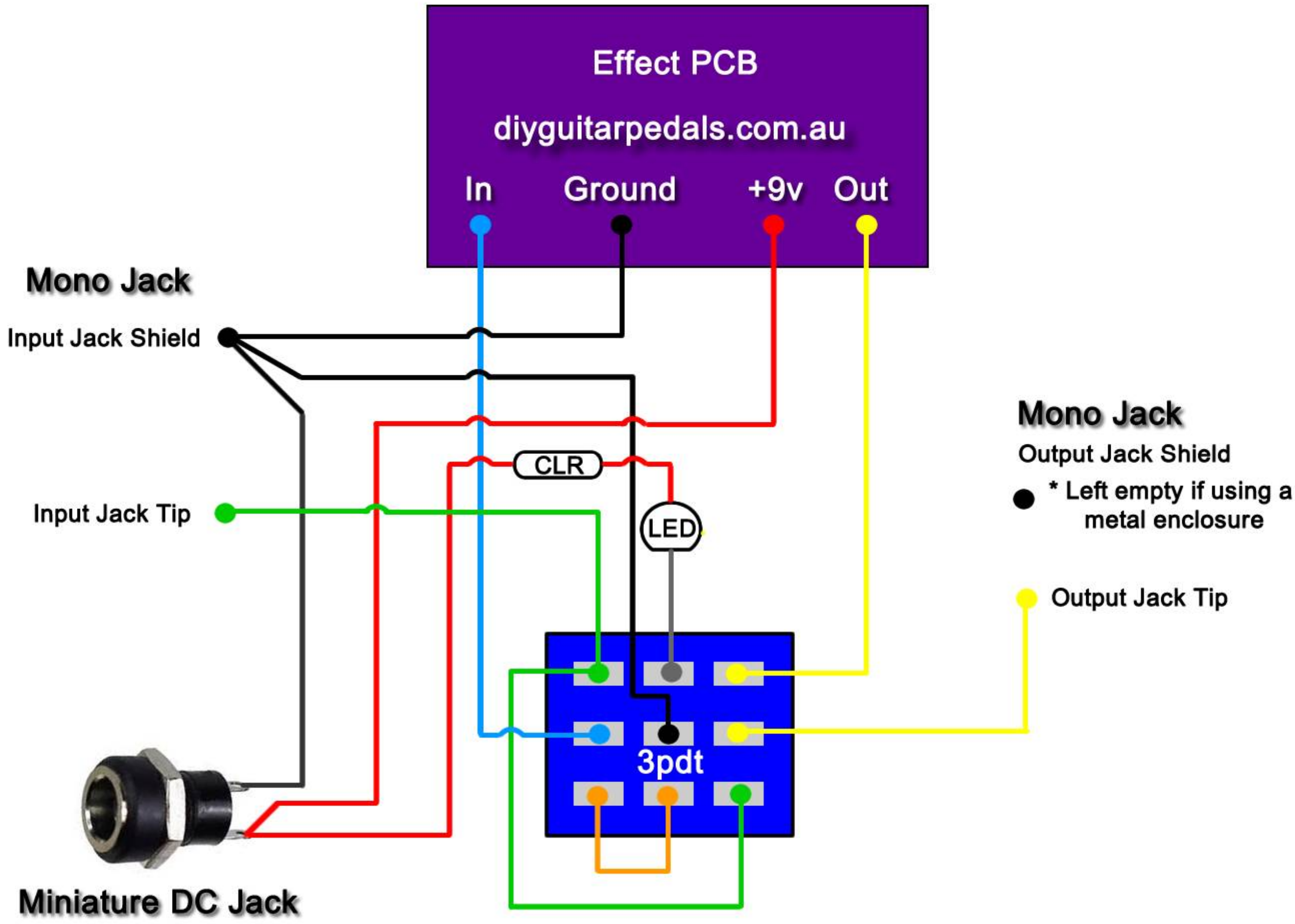
1.9 Potentiometers.
Potentiometers are variable resistors that are used for controlling aspects of the pedal.



This pedal can utilize 16mm pots. These are typically installed on the backside of the PCB and uses the included washer and jam-nut to mechanically secure the PCB to the enclosure via a strategically drilled hole on the enclosure. Orientation of potentiometer is preferred to line up the knob on the silk screen with the knob of the potentiometer.

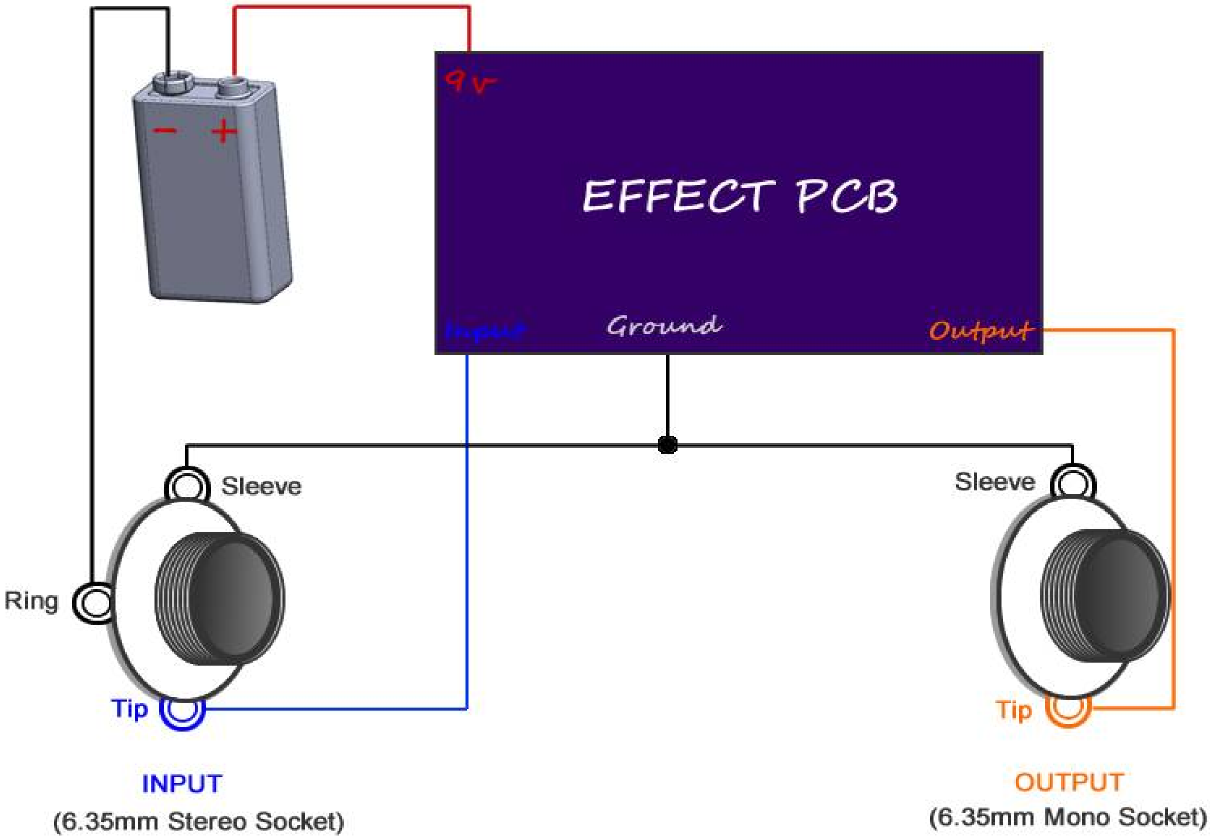
1.10 Off Board Wiring Diagram.

Potentiometers are variable resistors that are used for controlling aspects of the pedal. Using a non-switched miniature DC Jack and 2 Mono Jacks



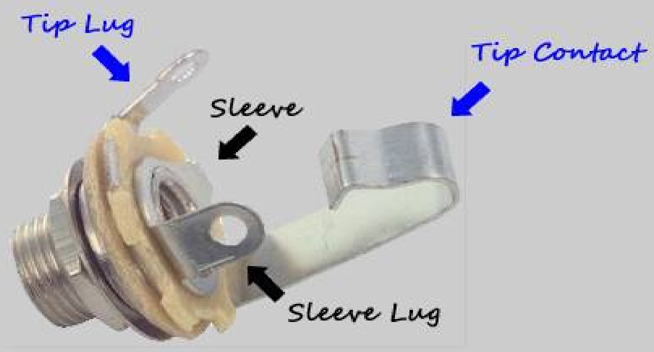
Testing Your Effect

Using aligator clips or soldering directly, wire your effect as in the following...



Input and Output Sockets

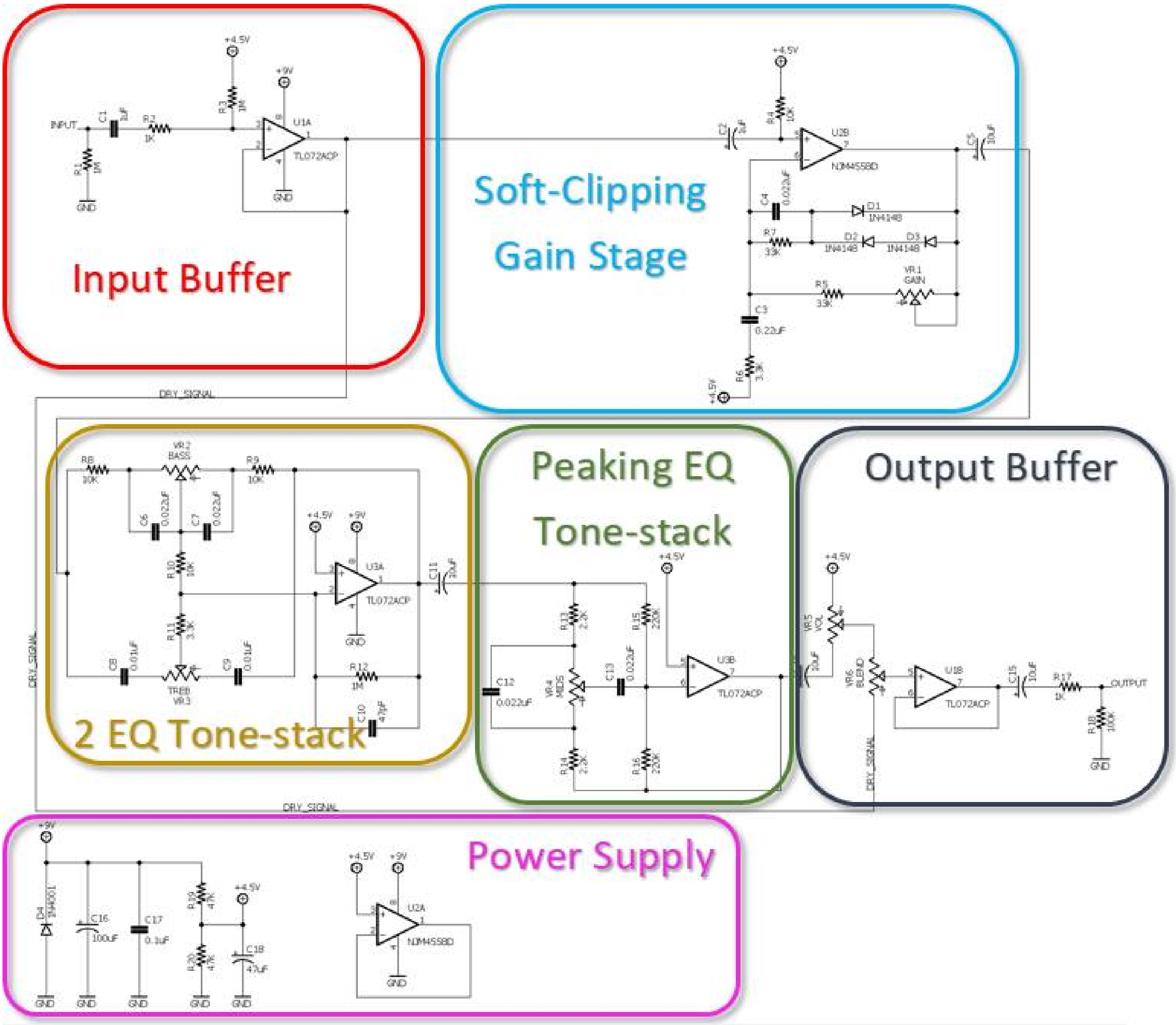
Pay close attention to the lugs of your sockets. Look at them side on so that you can distinguish the sockets individual layers. For instance the tip lug is connected to tip contact. The stereo jack looks the same as the socket below except it has an extra lug and contact for "Ring".



Bulldozer Circuit Analysis for modifying purposes.

2. Bulldozer Circuit.

The Bulldozer schematic can be broken down into some simpler blocks: Power Supply, Input Buffer, Soft-Clipping Gain Stage, 2 EQ Tone-stack, Peaking EQ Tone-stack, and Output Buffer.

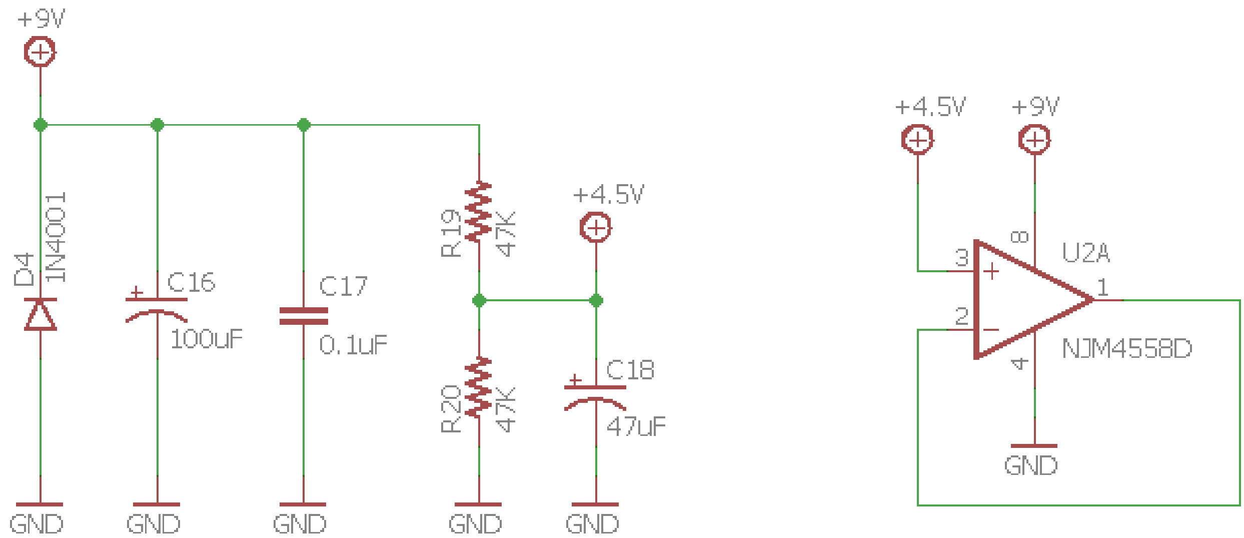


The circuit is designed around a dual op-amp gain and soft clipping topology with a passive tone and level control at the end.

The input impedance on the Bulldozer is close to 687K Ω, allowing the pedal to not overload the pickups on the guitar or to tone suck, but as a rule of thumb, increasing to 1M would be ideal.

3. Power Supply.

The Power Supply Stage provides the electrical power and bias voltage to all the circuitry, the whole power consumption is estimated around 32mA:



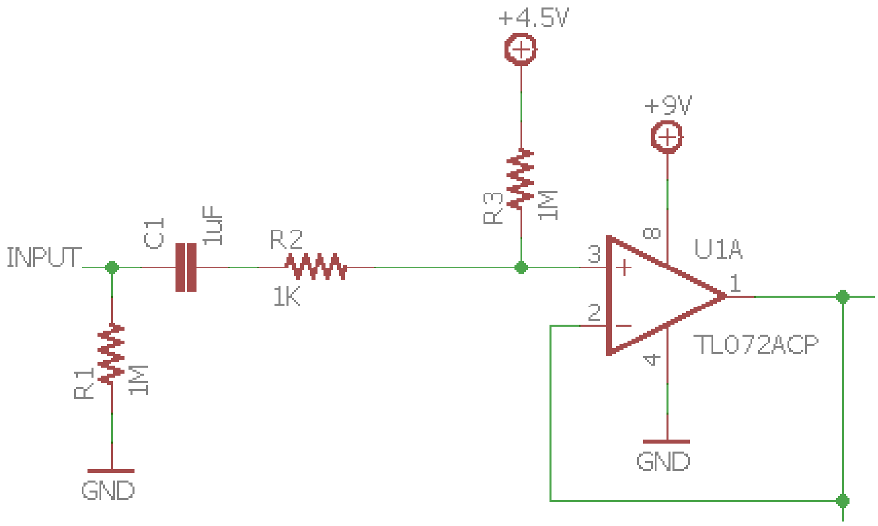
- The diode D4 protects the pedal against reverse polarity.

- The resistor voltage divider composed by R19 and R20 generates 4.5V to be used as a bias voltage/virtual ground. The resistors junction (+4.5V) is decoupled to ground with a large value electrolytic capacitor C18 47uF.

- C16 is a large 100uF bulk decoupling capacitor while C17 is a small 100nF capacitor for decoupling. Having the extra 100nF is valuable due to film capacitors ability to handle higher frequency noise better than electrolytic.

4. Input Buffer Stage.

The input buffer stage is made of a non-inverting op-amp amplifier used as a unity gain buffer with minimal tone-shaping and high input impedance that preserves signal quality eliminating tone sucking (high-frequency loss). The buffer is used to split the dry signal away from what will become the wet signal.



The 1MΩ R1 resistor from the input to ground is an anti-pop resistor, it will avoid abrupt pop sounds when the effect is engaged.

The 1uF C1 input capacitor blocks DC and provides simple high pass filtering. C1 and R2/R3 create a high pass filter. Because R3 is larger, it will overtake the resistor R2 in the filter, so to calculate the cut-off, it is best to just use R3.

$$fc = 1 / (2\pi RC)$$
$$fc = 1 / (2\pi \cdot R_3 \cdot C_1)$$
$$fc = 1 / (2\pi \cdot 1M \cdot 1uF)$$
$$fc = 1 / (2\pi \cdot 1{,}000{,}000 \cdot 0.000001)$$
$$fc = 0.16\ Hz$$

4.1 Input Impedance.

The input impedance is defined by the formula:

$$Zin = (R_1 \parallel R_3) \parallel (R_2 + Z_{inTL072})$$

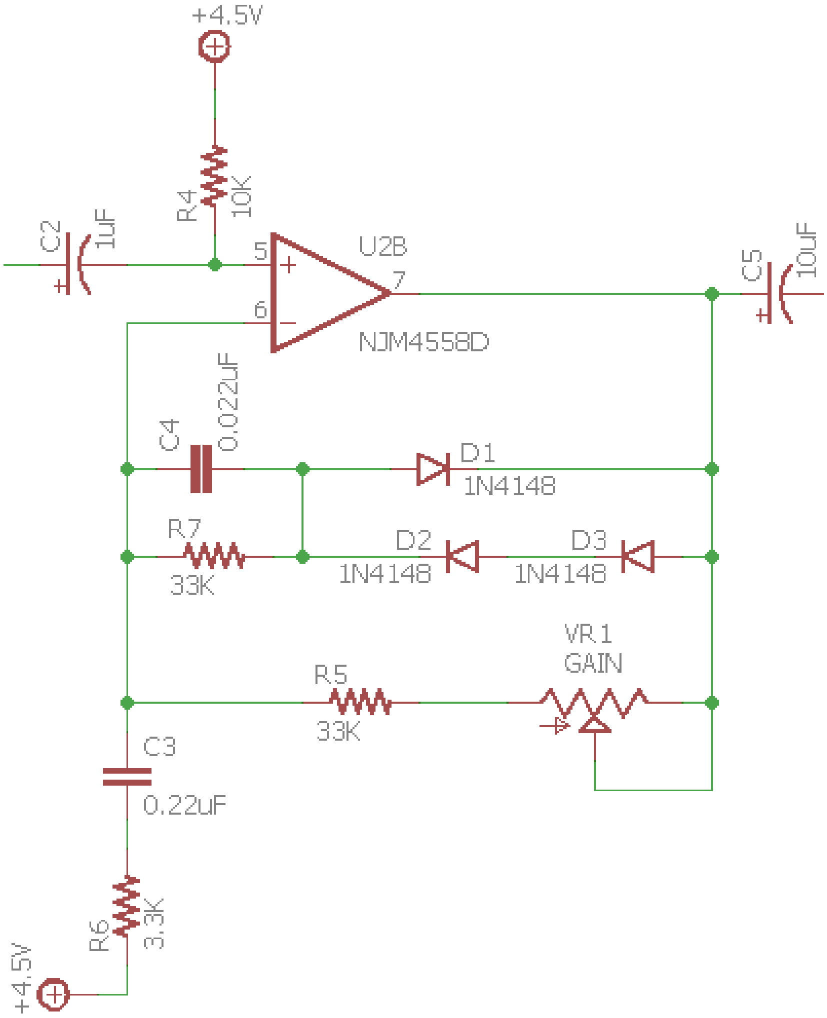
If you look up the datasheet for the TL072, under the electrical characteristics, the input resistance is 10^{12}

$$Zin = (1M \parallel 1M) \parallel (1{,}000 + 1{,}000{,}000{,}000{,}000)$$
$$Zin = 500{,}000 \parallel 1{,}000{,}000{,}001{,}000$$
$$Zin = 499{,}999\Omega$$

Therefore, the Bulldozer input resistance is 499.9K, which isn't bad, but the closer to 1M it is, the better. Increasing R1 and R3 to 2.2M would bring the input resistance up to 1M, although that would also effect the input high pass filter.

5. Soft Clipping Gain Stage.

The soft-clipping gain stage is made of a non-inverting op-amp with some filtering and asymmetric soft-clipping diodes:



5.1 High Pass Filter prior to op-amp

While C2 and R4 create an RC filter, C2 also provides the role of a coupling capacitor from the previous gain stage. This rejects any DC signal that might have been created from that stage and prevents it from entering this stage. C2 along with R4 create a high-pass filter calculated as:

$$fc = 1 / (2\pi RC)$$
$$fc = 1 / (2\pi \cdot R_4 \cdot C_2)$$
$$fc = 1 / (2\pi \cdot 10K \cdot 1uF)$$
$$fc = 1 / (2\pi \cdot 10{,}000 \cdot 0.000001)$$
$$fc = 16\ Hz$$

This is important as we only want to really deal with frequencies above a certain level before the op-amp gain stage. If the signal is too muddy, decreasing the capacitance of C2, or the resistance of R4 will cut out more of the bass before passing it through the op-amp for gain and soft-clipping distortion. Don't worry about general loss of bass in the signal, as the dry signal from the input buffer stage is preserved.

5.2 High Pass Filter in the Feedback Loop

The resistor R6 and capacitor C3 from the (-) input to ground act as an active high pass filter, attenuating frequencies below the fc cut-off frequency:

$$fc = 1 / (2\pi \cdot R_6 \cdot C_3)$$
$$fc = 1 / (2\pi \cdot 3{,}300 \cdot 0.00000022) = 219 \text{ Hz}$$

Harmonics above 219 Hz get the full gain of the clipping stage, and everything below it gets progressively less gain and less distortion. Bass notes are clipped least, so the distortion is frequency selective.

4.3 Voltage Gain.

The voltage gain for this stage varies depending on frequencies, but when ignoring R7, C3, C4, along with the diodes, it can be calculated as.

$$G_{vmin} = 1 + (R_5 / R_6)$$
$$G_{vmin} = 1 + (33{,}000 / 3{,}300) = 11 \ (20.8dB)$$

$$G_{vmax} = 1 + ((R_5 + VR_1) / R_6)$$
$$G_{vmax} = 1 + ((33{,}000 + 1{,}000{,}000) / 3{,}300) = 314 \ (50dB)$$

However, the voltage gain of this stage will not reach these values. As will be seen in the next point, the gain will be limited by the clipping diodes action.

5.4 Clipping Diodes.

When the voltage difference (positive or negative) between the op-amp output and the (-) input is bigger than the diodes forward voltage VF the diode will turn on.

As the diode turns on forward biased, the equivalent resistance of the diode goes from an open circuit to a very low value (few ohms). On soft-clipping circuits, like the Ibanez Tubescreamer, this would short the op-amp's inverting pin to the output pin, changing the gain of the inverting op-amp from a high value (11 to 314) down to 1, essentially bringing it to unity.

However, in this circuit, the series resistor R7 won't let the diodes short out those two pins on the op-amp, retaining some gain. So, when the signal clips, the gain calculations would look like this:

$$G_{vmin} = 1 + ((R_5 \parallel R_7) / R_6)$$
$$G_{vmin} = 1 + ((33{,}000 \parallel 33{,}000) / 3{,}300)$$
$$G_{vmin} = 1 + (16{,}500 / 3{,}300) = 6 \ (15.5dB)$$

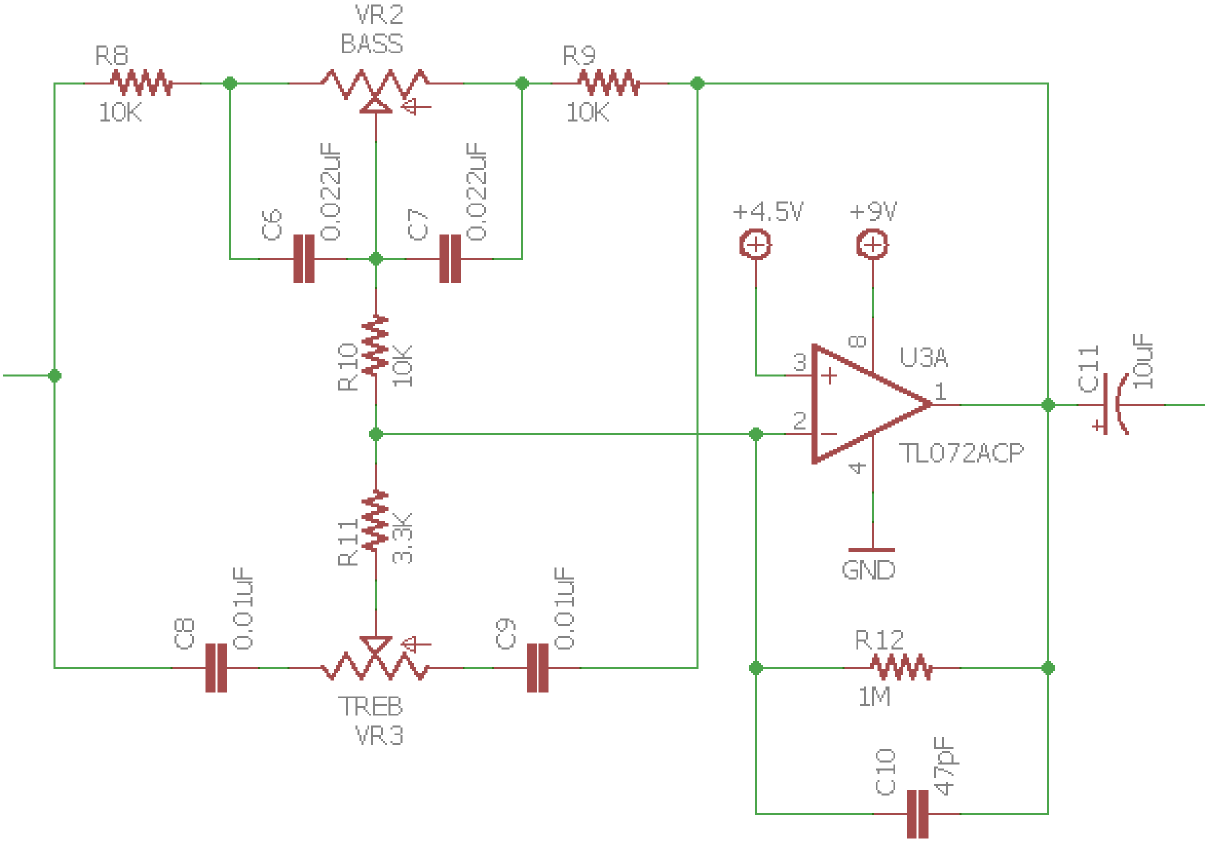
$$G_{vmax} = 1 + (((R_5 + VR_1) \parallel R_7) / R_6)$$
$$G_{vmax} = 1 + (((33{,}000 + 1{,}000{,}000) \parallel 33{,}000) / 3{,}300)$$
$$G_{vmax} = 1 + (31{,}978 / 3{,}300) = 10.7 \ (20.5dB)$$

Furthermore, as the diodes are asymmetric, the clipping will be lop-sided, clipping more on one side than the other.

Lastly, the capacitor C4 across the resistor R7 will start to dominate the impedance (going down) at the frequency where (1 / (2π x C4)) = R7. This works as a low pass filter. There will be more gain below that frequency and less gain above that frequency. Increasing C4 allows reduces more of the high-end from getting any gain. Decreasing C4 allows more high-end.

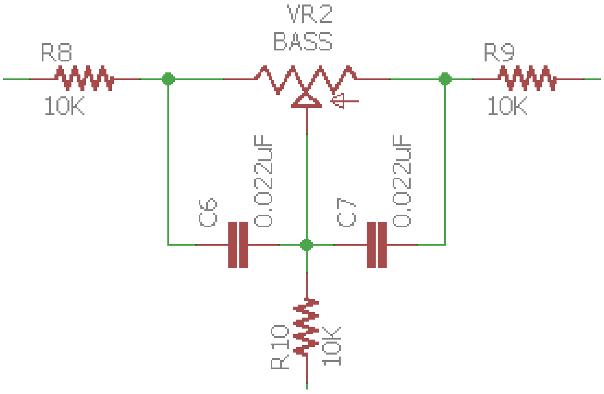
6. 2-EQ Tone Stack.

The Bulldozer uses an active Baxandall, 2-EQ tonestack to first manipulate the bass and treble frequencies of the now gained and soft-clipped signal.

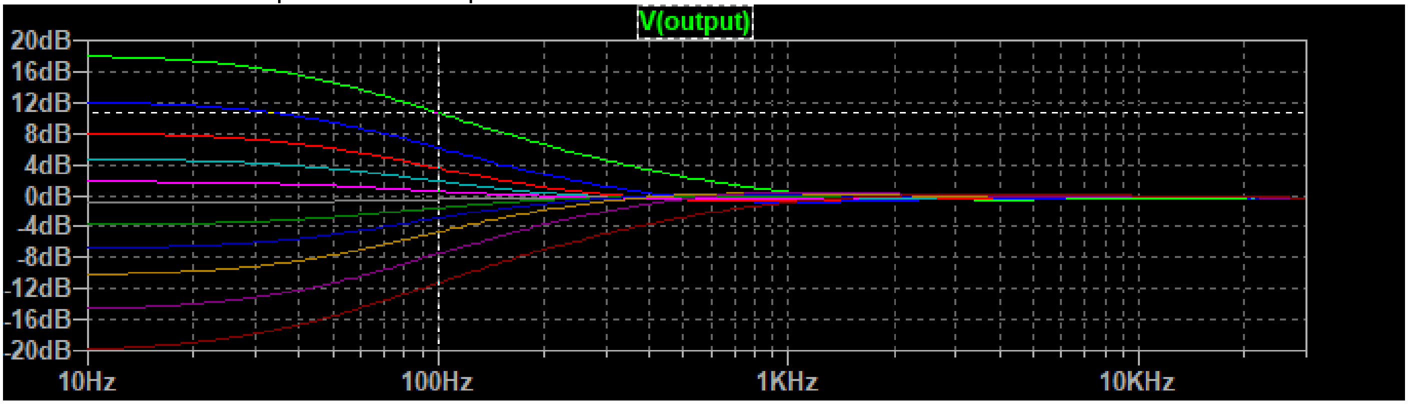


Because the tone stack feeds into both sides of the op-amp U3A's negative feedback loop, this allows the two RC filters to actively cut AND boost the signal. R12 ultimately controls the center point of level controls and works with C10 as a general filter. Lowering the resistance of R12 will make it so that if both bass and treble knobs are at noon, the flat response will no longer be at unity, but will in fact cut. C10 effects the highs. The larger the capacitance, the more highs it will cut off. Once it reaches 1nF, it will greatly affect the high frequencies and treble knob response.

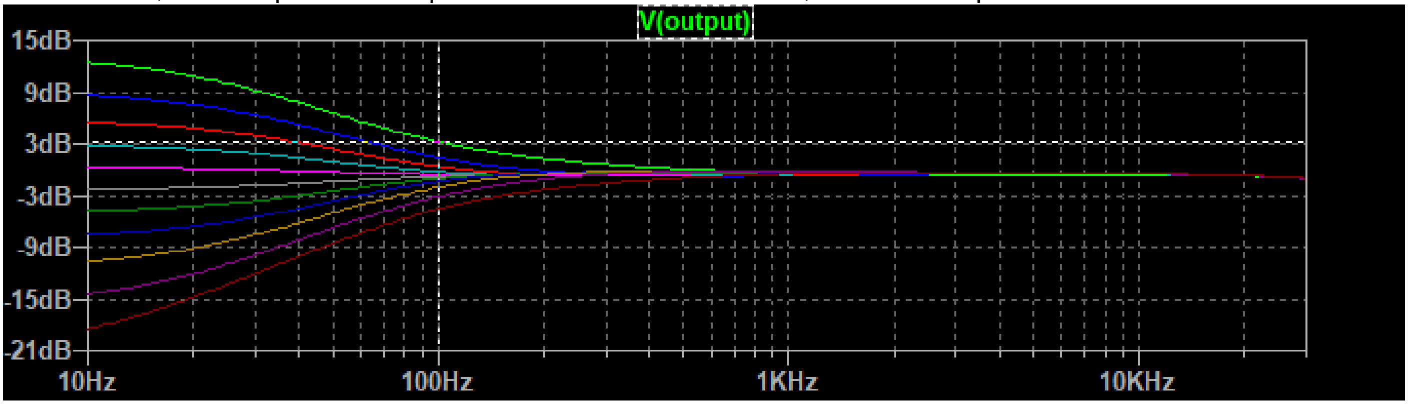
6.1 Bass Frequency Response



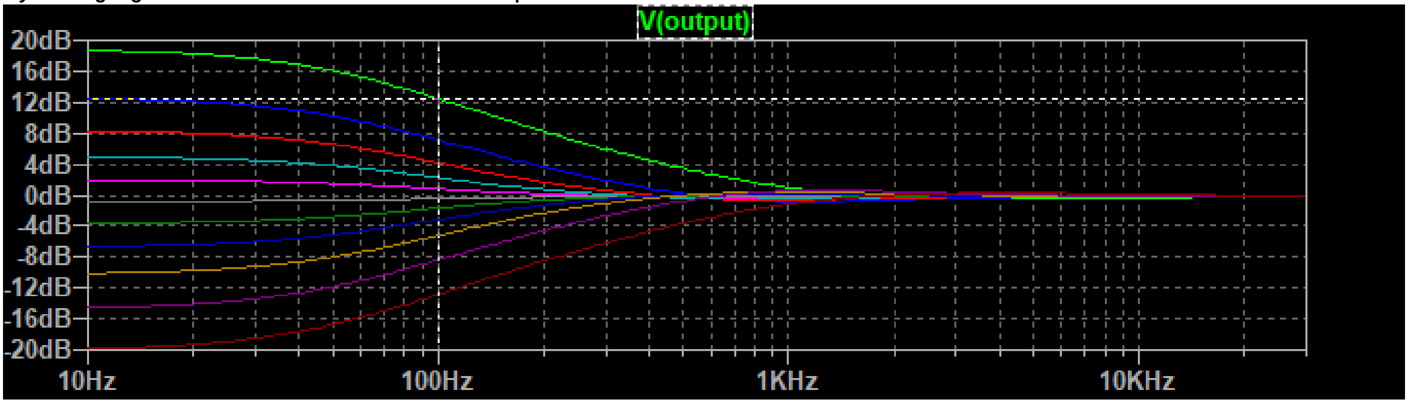
The bass knob has a response that sweeps the 100 Hz mark around +/-10db and levels out at around 1.2kHz



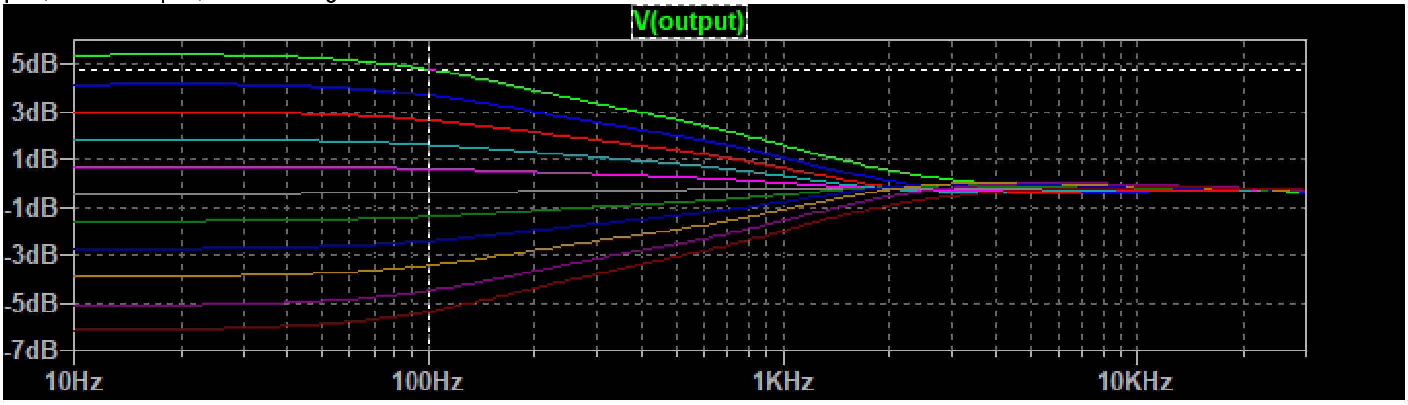
By changing the value of R10, the sweep of responses will change. For example, by changing R10 from a 10K resistor to a 100K resistor, the sweep of the bass pot becomes more bass focused, but also a drop in amount of cut/boost:



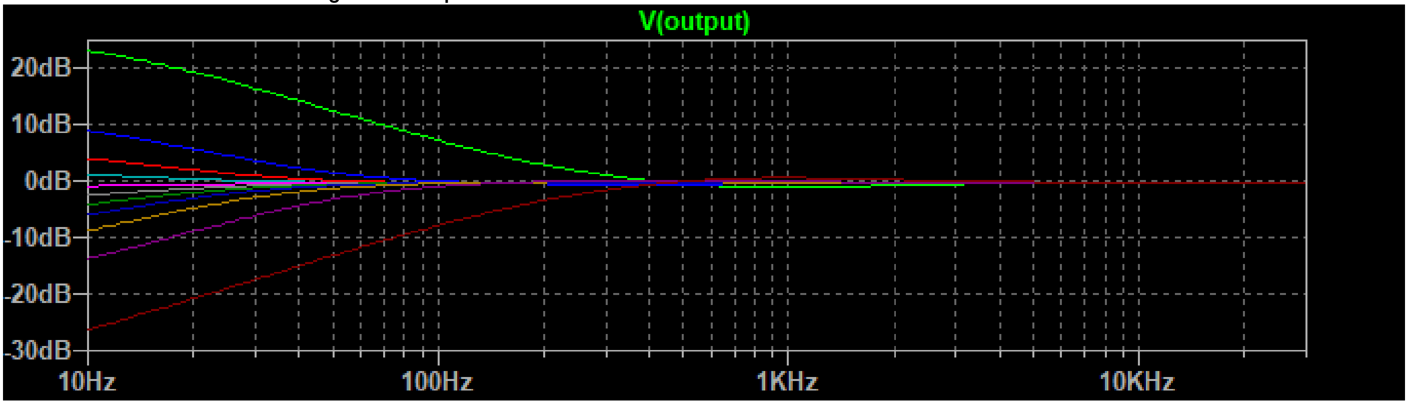
By changing R10 from a 10K resistor to a 1K pushes the focus of the bass knob closer to the 1.2 kHz area:



Another portion of the sweep is the potentiometer itself. If changing the value of the bass pot from a 100k pot to a 10k pot, for example, but leaving all other values stock results in much less cut and boost to the bass:

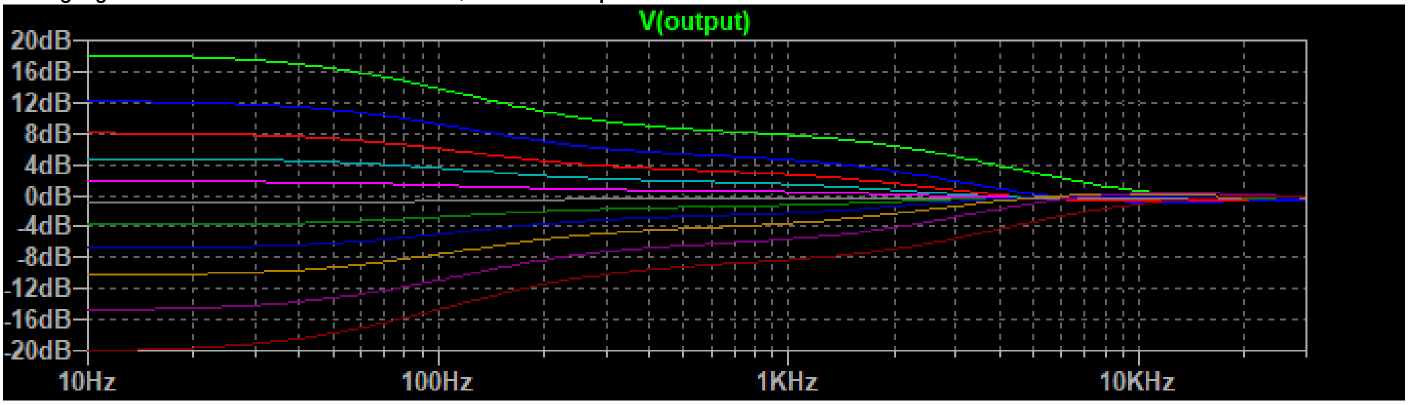


And if the potentiometer for the bass were to be increased to 1M, there will be much more boost and cut to the bass at the extreme ends of the range on the potentiometer:

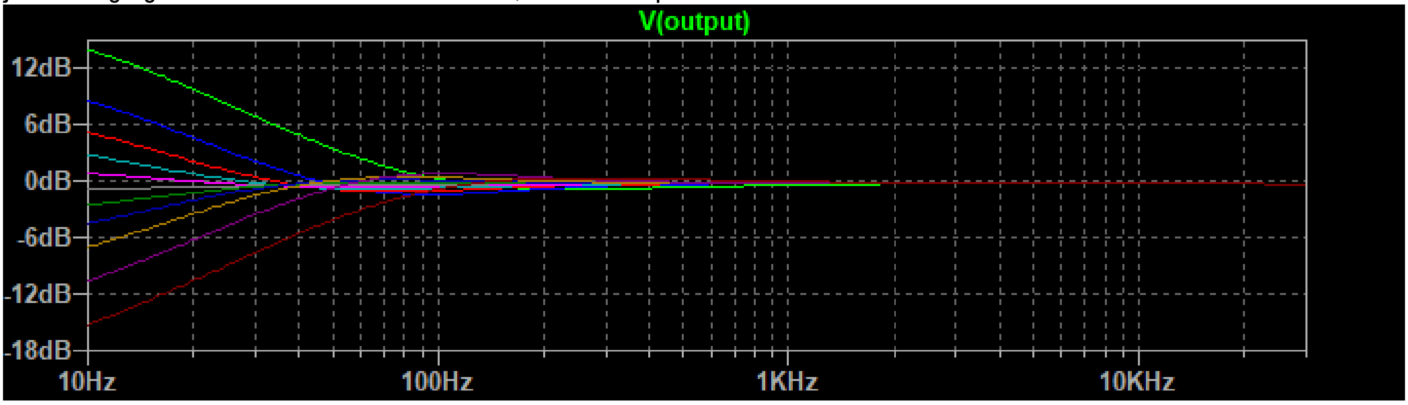


The values of R8 and C6 effect the boost side of the frequency curve while C7 and R9 effect the cut side of the frequency curve. Increasing the resistance of R8 and R9 reduces how much cutting or boosting will occur, similar to reducing the potentiometer value. Decreasing the resistance increases the amount of cutting or boosting that will occur, similar to increasing the potentiometer value.

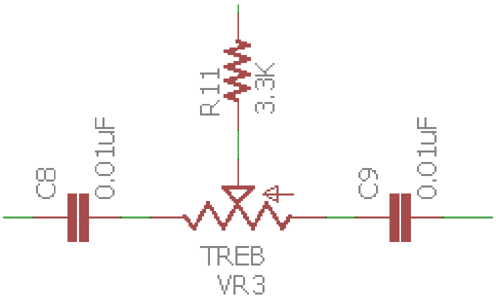
Decreasing the capacitance of C6 or C7 will effect where the frequency cut/boost point is located. For example, by just changing C6 and C7 from 22nF to 2.2nF, the center point shifted from 1.2 kHz to 12 kHz:



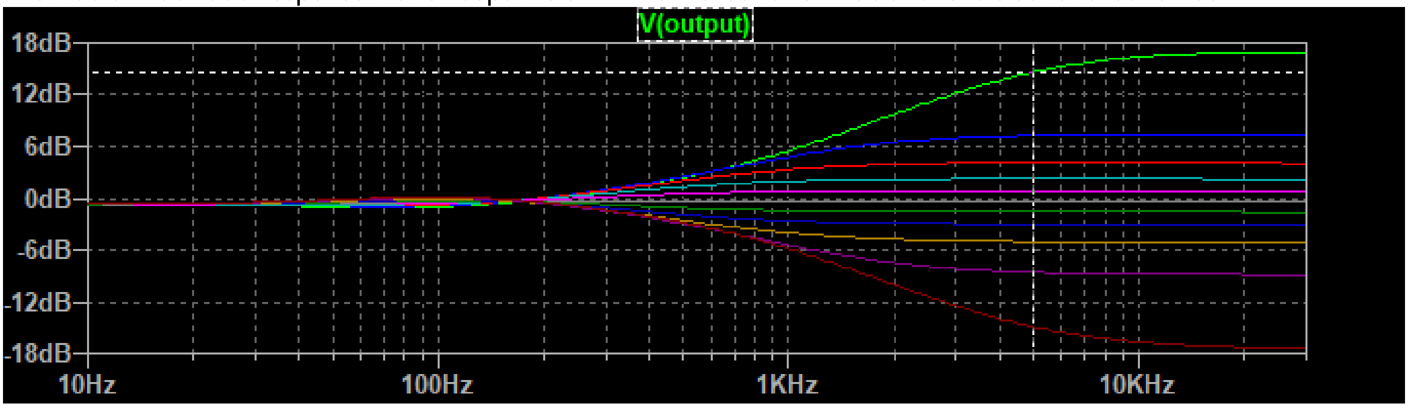
Increasing the capacitance of C6 or C7 will also effect where the frequency cut/boost point is located. For example, by just changing C6 and C7 from 22nF to 220nF, the center point shifted from 1.2 kHz to 120 Hz:



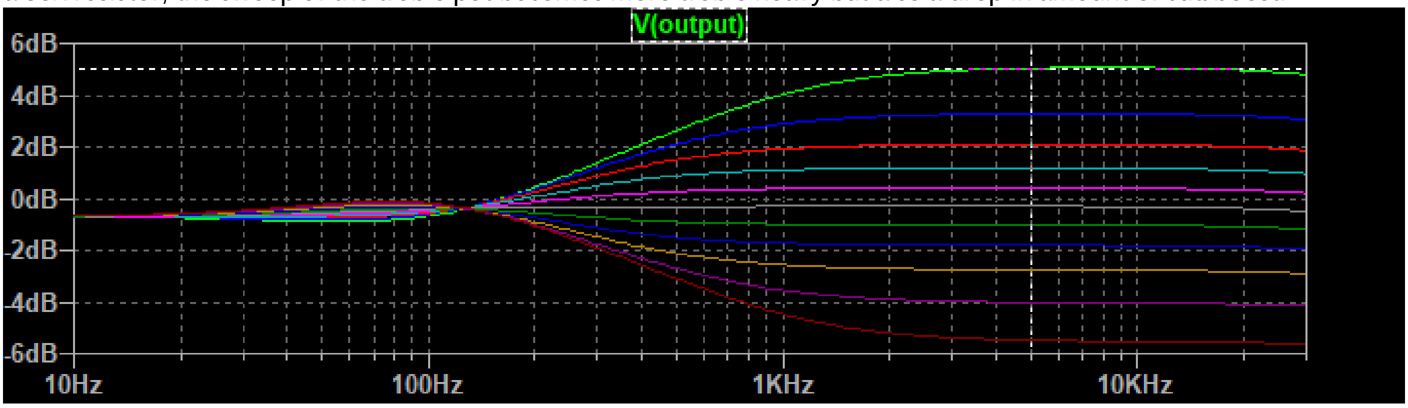
6.2 Treble Frequency Response



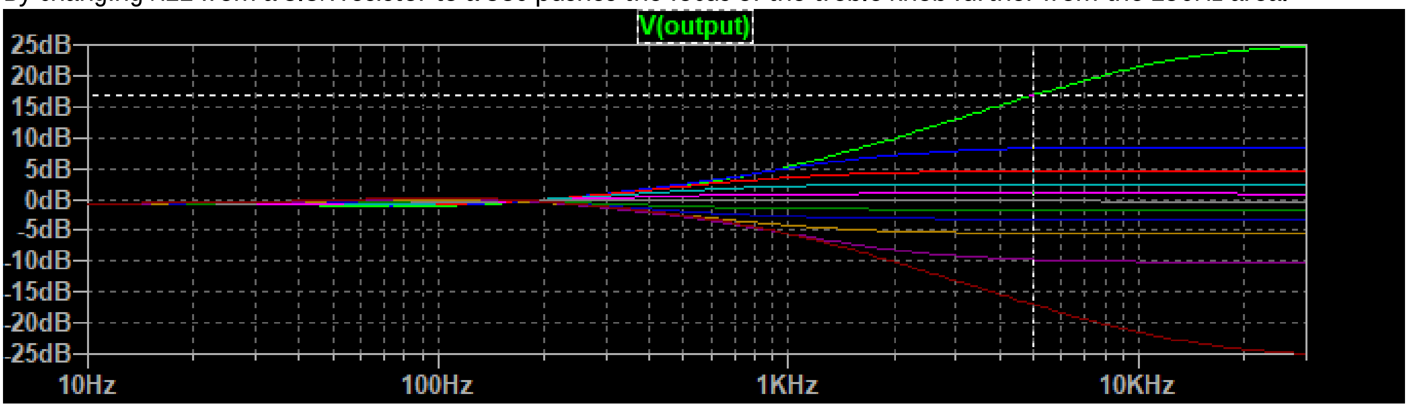
The treble knob has a response that sweeps the 5 kHz mark around +/-14db and levels out at around 150 Hz



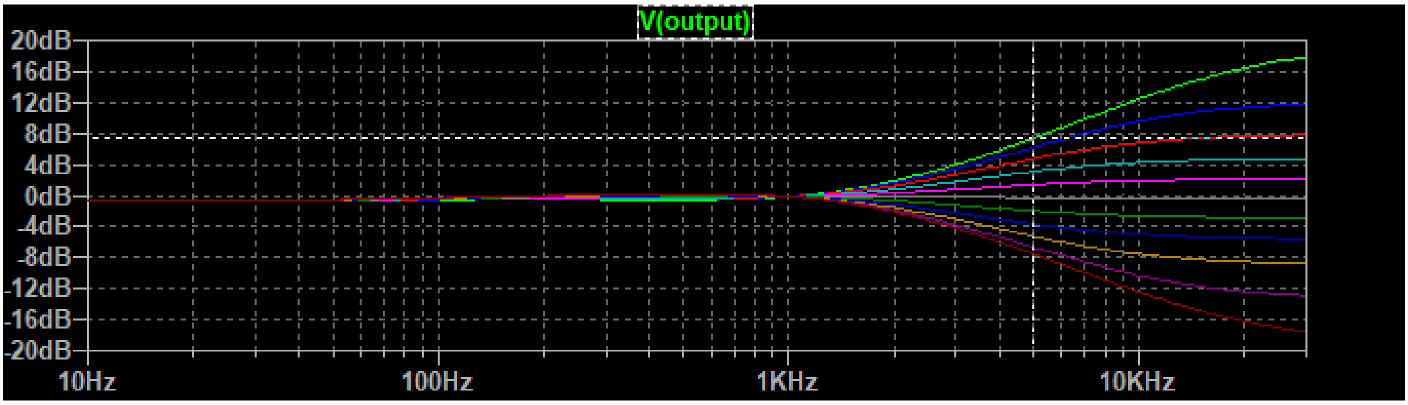
By changing the value of R11, the sweep of responses will change. For example, by changing R11 from a 3.3K resistor to a 33K resistor, the sweep of the treble pot becomes more treble heavy but also a drop in amount of cut/boost:



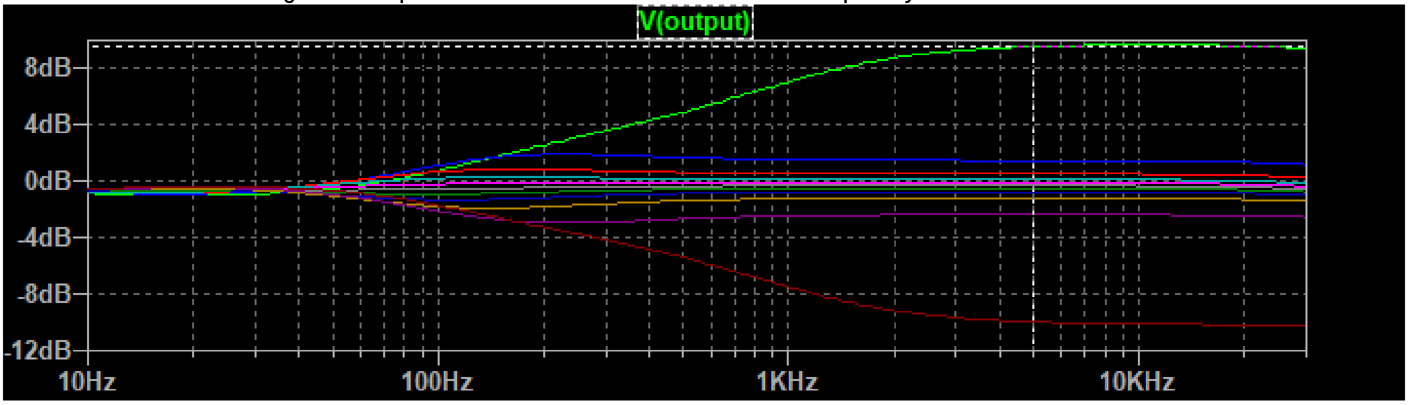
By changing R11 from a 3.3K resistor to a 330 pushes the focus of the treble knob further from the 150Hz area.



Another portion of the sweep is the potentiometer itself. If changing the value of the treble pot from a 100k pot to a 10k pot, for example, but leaving all other values stock results a shifted frequency of where the treble cut/boost occurs:

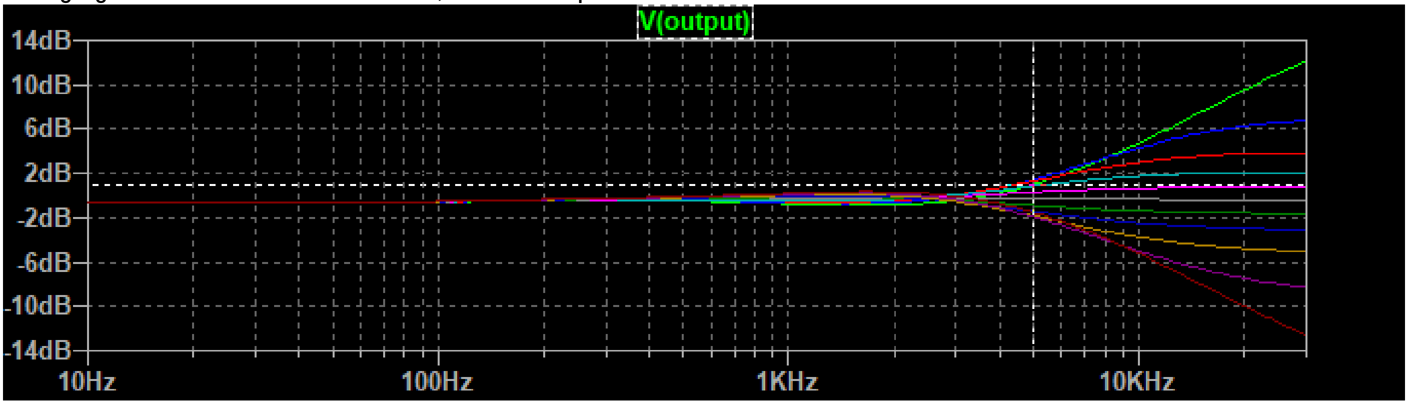


And if the potentiometer for the treble were to be increased to 1M, there will be less boost and cut to the treble at the extreme ends of the range on the potentiometer as well as a shifted frequency cut to where the cut/boost occurs:

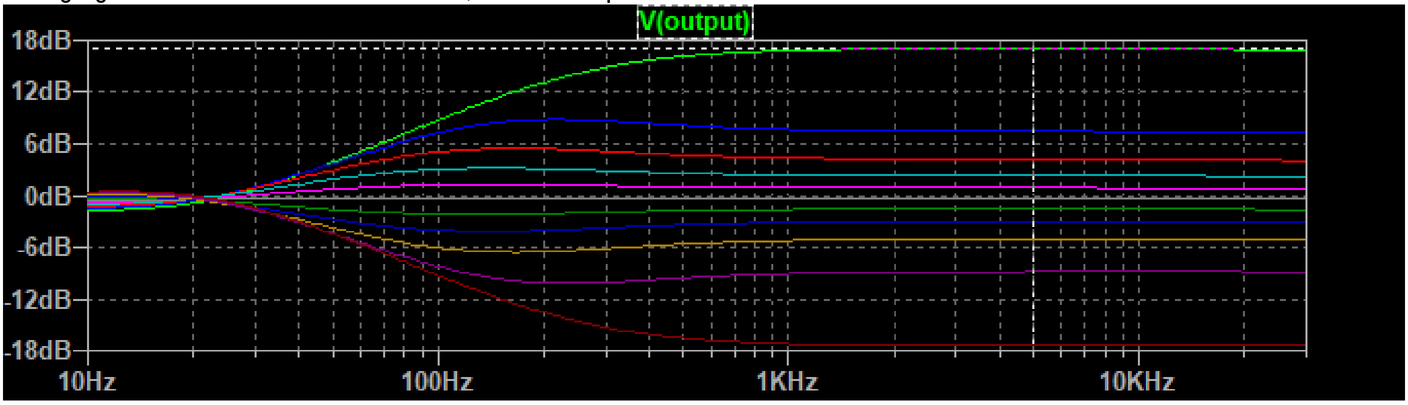


The values C8 along with the treble potentiometer effect the boost side of the treble, while C9 along with the treble potentiometer effect the cut side of the treble.

Decreasing the capacitance of C8 or C9 will effect where the frequency cut/boost point is located. For example, by just changing C8 and C9 from 10nF to 1nF, the center point shifted from 200 Hz to 2 kHz:

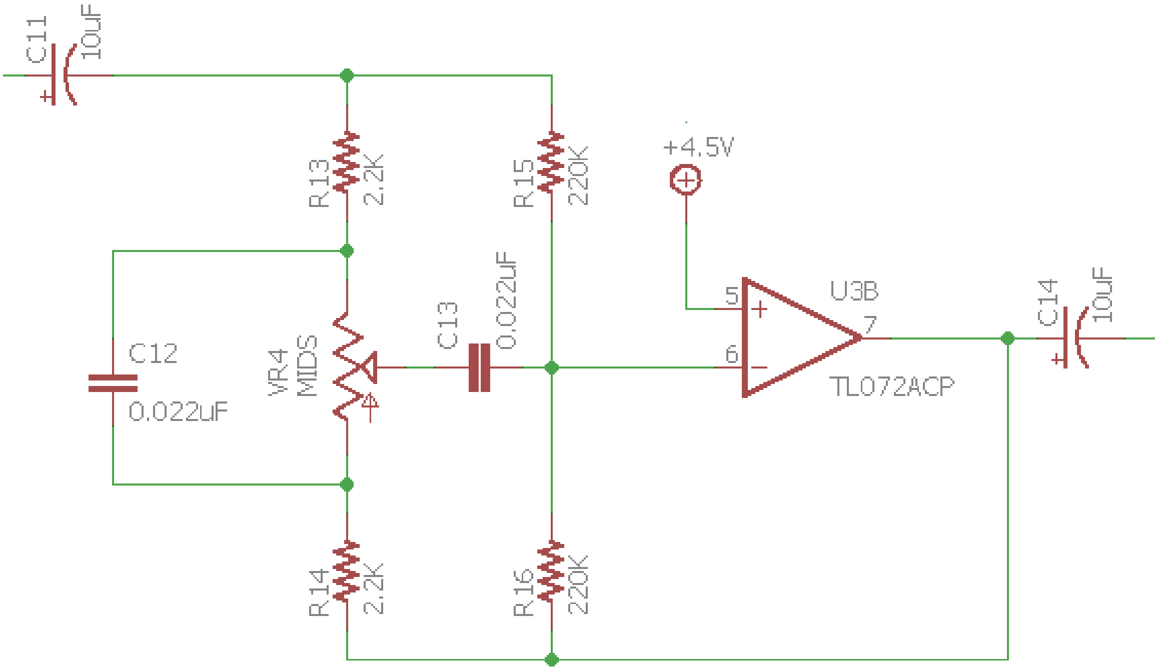


Increasing the capacitance of C8 or C9 will effect where the frequency cut/boost point is located. For example, by just changing C8 and C9 from 10nF to 100nF, the center point shifted from 200 Hz to 20 Hz:



7. Peaking EQ Tone Stack.

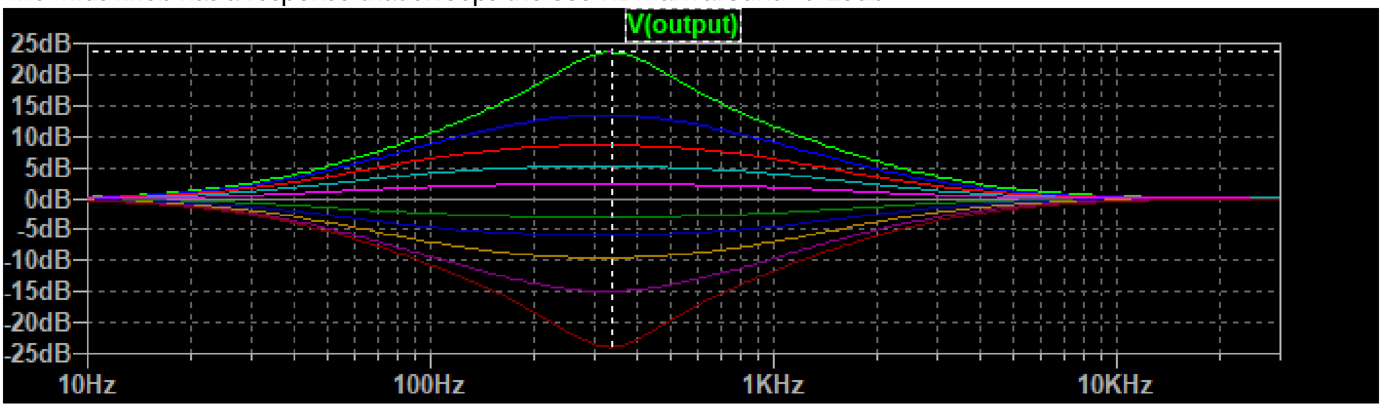
The Bulldozer uses an active Peaking EQ tone stack to effect the EQ bands between the previous baxandall tonestack.



Because the tone stack feeds into both sides of the op-amp U3B's negative feedback loop, this allows the two RC filters to actively cut AND boost the signal.

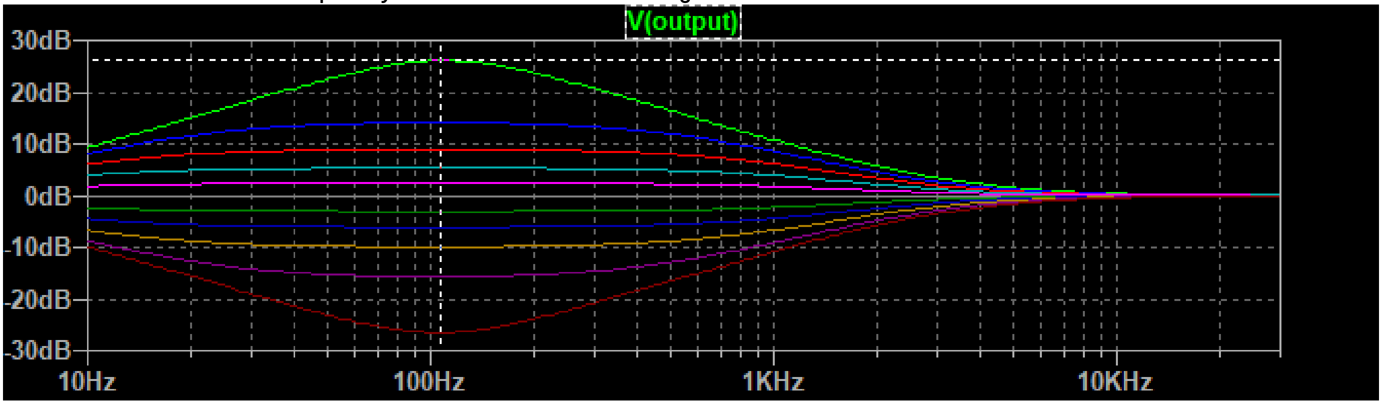
7.1 Mids Frequency Response

The mids knob has a response that sweeps the 335 Hz mark around +/-25db

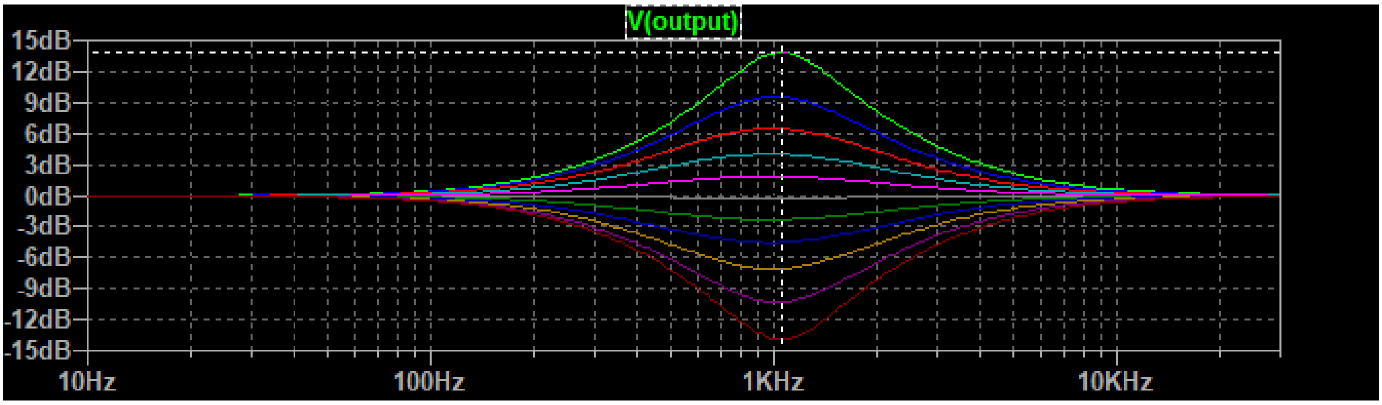


Because the potentiometer is more or less a ratio creator, changing the potentiometer value will only slightly effect the peaking effect. Increasing the potentiometer from 100K to 1M only increases the furthest extents of the potentiometer to cut or boost a little bit more, and slightly shifts the center point from 335 Hz to about 320 Hz, while decreasing the potentiometer to 10K reduces the boost and cut to 14dB and shifts the center point over to 398 Hz.

Changing C13 will have the most effect by shifting the center point around. Increasing the capacitance from 22nF to 220nF shifts the center frequency over to 107 Hz with a slight bit more boost and cut as well:



While decreasing the capacitance from 22nF to 2.2nF will push the center point to about 1.04 kHz, but also reduce the total boost and cut:



7.2 Design Formulas for Peaking Equalizers

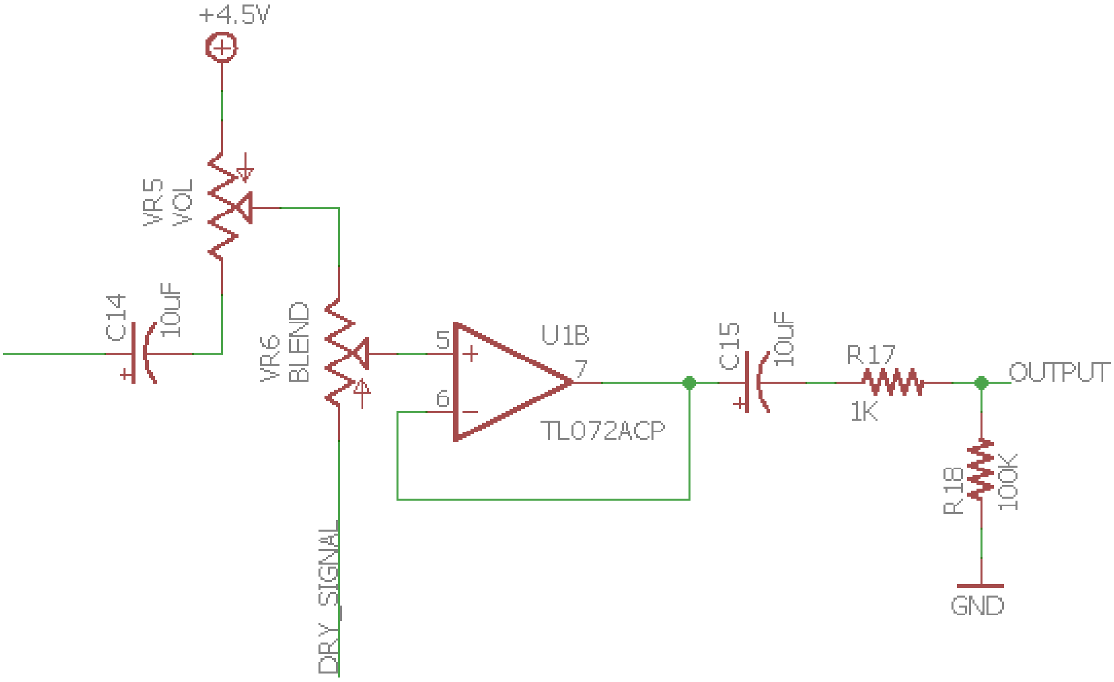
Where Baxandall tone stacks usually are easier to design with simulators, Peaking Equalizers are a little easier to work through the math of. This does assume R13 and R14 are the same resistance (so to boost and cut equally) as well as R15 and R16 are as well.

There are three factors to calculate for:

1. Little Omega – This is needed in the next equation:
   Square Root of (2 x R13 + VR4) / (R13 x VR4 x R15 x C12 x C13)
   (2 x 2,200 + 100,000) / (2,200 x 100,000 x 220,000 x 0.000000022 x 0.000000022)
   104,400 / 0.0234256
   Square Root of 4,456,662.796257086
   roughly: 2,111
2. Frequency – This is the center point in which it cuts or boosts:
   ω / (2 x π)
   2,111 / 6.2831853 = 335.97 Hz
3. Amplitude – This is how many dB this frequency will be cut or boosted:
   ((2 x R13 x VR4 x C12) + (R15 x (R13 + VR4) x C13) / ((2 x R13 x VR4 x C12) + (R13 x (R15 + VR4) x C13)
   ((2 x 2,200 x 100,000 x 0.000000022) + (220,000 x (2,200 + 100,000) x 0.000000022) / ((2 x 2,200 x 100,000 x 0.000000022) + (2,200 x (220,000 + 100,000) x 0.000000022)
   (9.68 + 494.648) / (9.68 + 15.488)
   504.328 / 25.168 = 20dB (However, this is based on an “ideal op-amp” and so the op-amps characteristics will slightly raise or drop this value.

8. Output Buffer.

Here, we have the volume knob being sent to virtual ground/bias voltage to control the wet signal volume a blend knob reintroduces the dry signal. This goes into a non-inverting op-amp being used as a unity gain buffer. Leaving the op-amp is a slight RC filter to reduce the output impedance to a good level.



8.1 Output Impedance.

The output resistor network composed by R17 and R18 will limit the output current; even if the output jack is connected to ground the op-amp will see a load of at least 1000Ω, limiting the output current and protecting the operational amplifier. The TL072 op-amp has an internal output resistance of around 100Ω. The output impedance is defined by the formula:

$$Zout = R_{18} \,||\, (R_{17} + Zout_{2TL072\ op\text{-}amp})$$
$$Zout = 100K \,||\, (1K + 100)$$
$$Zout = 100{,}000 \,||\, (1{,}100)$$
$$Zout = 1{,}088\Omega$$

Therefore, the Bulldozer output resistance is 1K, which is good, keeping signal fidelity. As a rule of thumb, it is good practice to keep output resistance of a pedal below 10K.

8.2 High Pass Filter.

The output capacitor C15 acts like a high pass filter together with R17 and R18. Being R18 > R17, the cut-off frequency is:

$$fc = 1 / (2\pi RC)$$

$$fc = 1 / (2\pi \cdot R_{18} \cdot C_{15})$$
$$fc = 1 / (2\pi \cdot 100K \cdot 10uF)$$
$$fc = 1 / (2\pi \cdot 100{,}000 \cdot 0.000010)$$
$$fc = 0.16\ Hz$$

With a cut of 0.16Hz it will block DC and any super low-frequency parasitic oscillation.

9. Modifications

Following is a couple of worthwhile modifications that can be applied to the Bulldozer.

9.1 Resistors

Changing the values of R5 and the gain potentiometer will influence the general gain of the clipping section. Increasing R5 will increase the gain while reducing the size of the gain pot will drop the general over-all gain. Reducing the value of R7 will allow more soft-clipping to occur, while increasing it will continue to soften the clipping section.

R10 changes some of the bass response while R11 changes the treble. R8 changes the bass response to boost side while R9 changes the bass response to the cut side. See section 5 as how these resistors ultimately change the tone stack.

R13 and R15 changes the response to the boost side of the mids control while R14 and R16 changes the response to the cut side of the mids control. See section 6 as to how these resistors ultimate change the tone stack.

Increasing R1 and R3 to 2.2M will improve input impedance, but to keep a similar input filter for DC noise rejection, decrease C1 from 1µF to 470nF.

9.2 Capacitors

In the clipping section, increasing C4 allows reduces more of the high-end from getting any gain. Decreasing C4 allows more high-end, making the soft-clipping frequency dependent.

C6 changes the bass response to boost side while C7 changes the bass response to the cut side. C8 changes the treble response to boost side while C9 changes the treble response to the cut side. See section 5 as how these capacitors ultimately change the tone stack.

C12 and C13 changes the response to the mids control. See section 6 as to how these resistors ultimate change the tone stack.

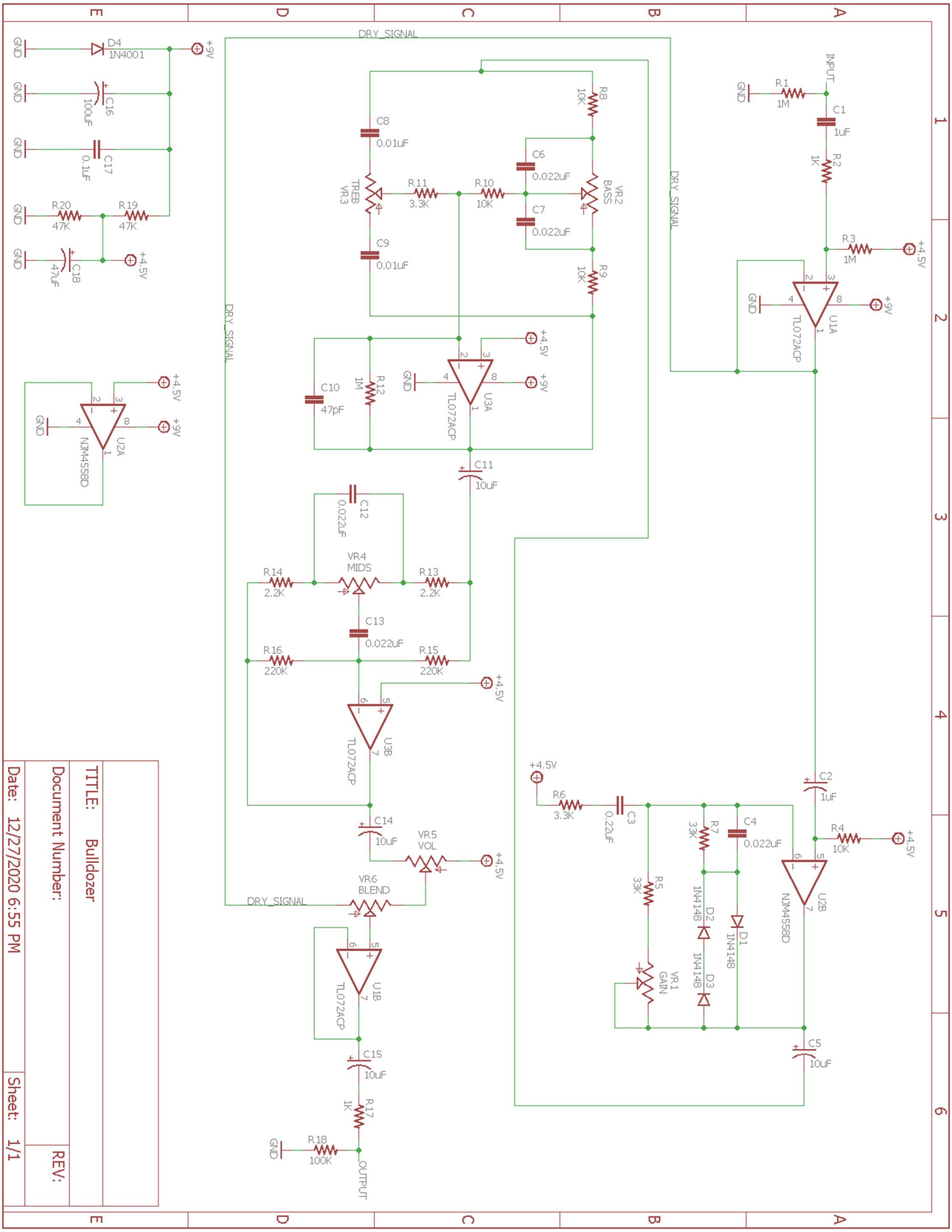
9.3 Diodes

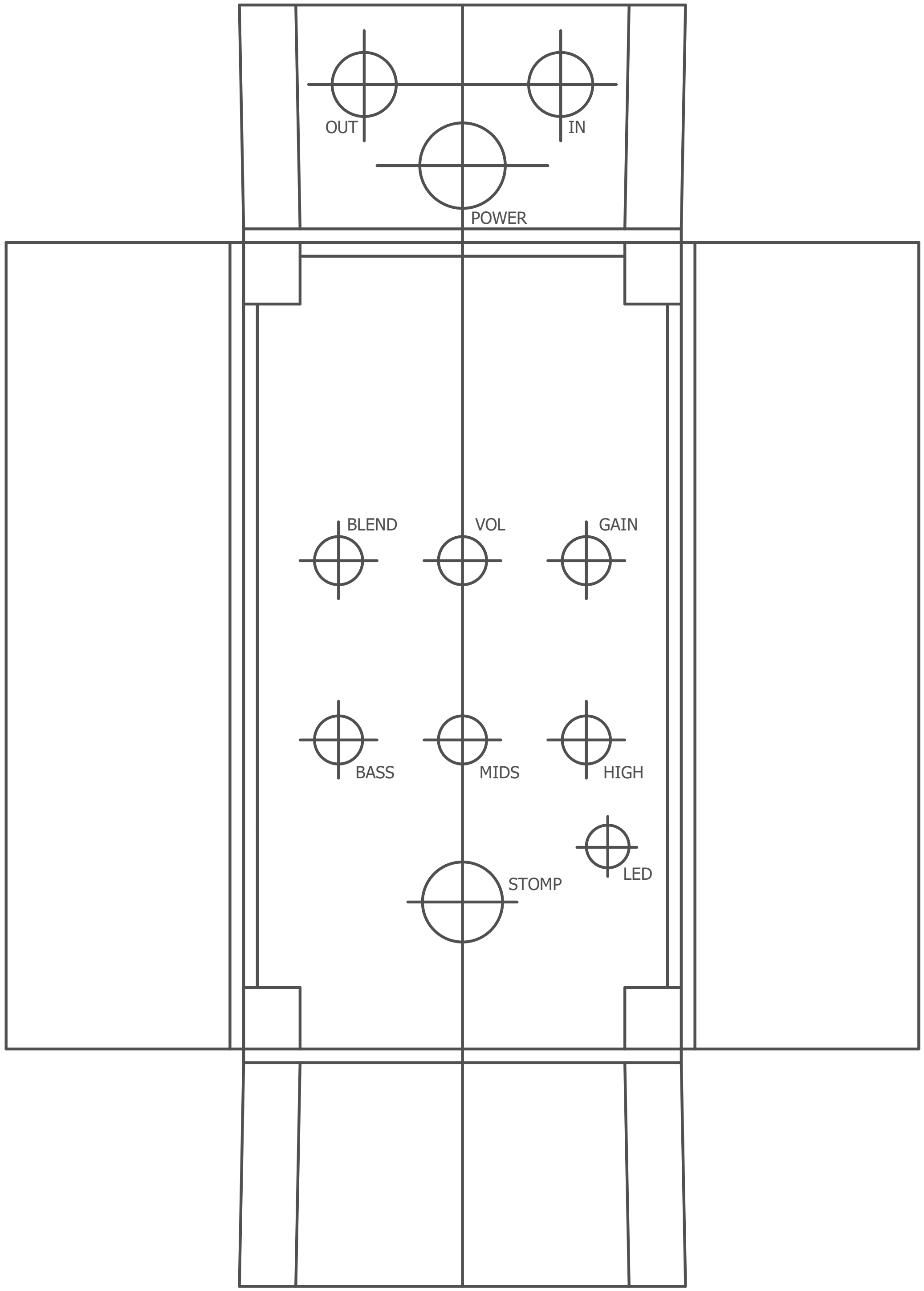
Changing diodes in the clipping stage can affect the clipping tone. To go from asymmetric clipping to symmetric, shunt diode D3. Changing the diode types to LEDs will also effect the amount of clipping based off the change in forward voltage. If no soft clipping is desired, simply not populating any of the diodes will accomplish this.

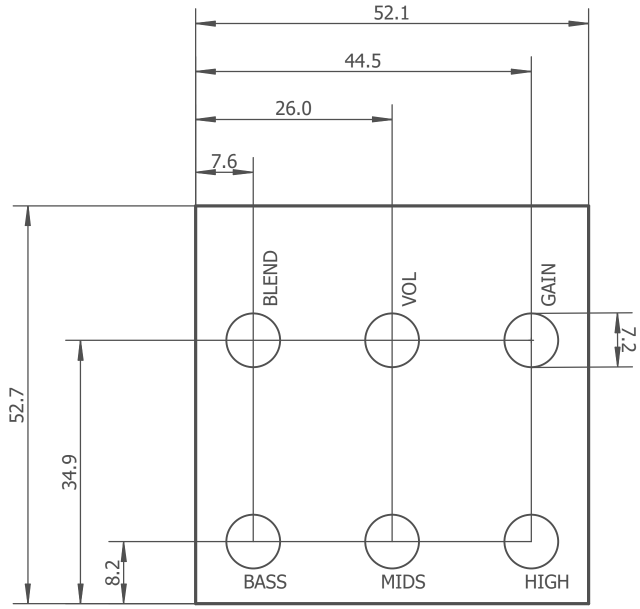
9.4 Op-Amps

Changing the dual op-amp will have some subtle affect to the soft clipping that occurs in the circuit, primarily in the soft-clipping gain stage. Using a TL072, or any other JFET style op-amp will have a slightly sharper sound.

10. Schematic




OUT
IN
POWER
BLEND
VOL
GAIN
BASS
MIDS
HIGH
LED
STOMP


52.1
44.5
26.0
7.6
BLEND
VOL
GAIN
7.2
52.7
34.9
8.2
BASS
MIDS
HIGH