Blues Crusher

Design By Erik Vincent

Sonically a hybrid fuzz and overdrive, the blues crusher is good balance between grit and soul.

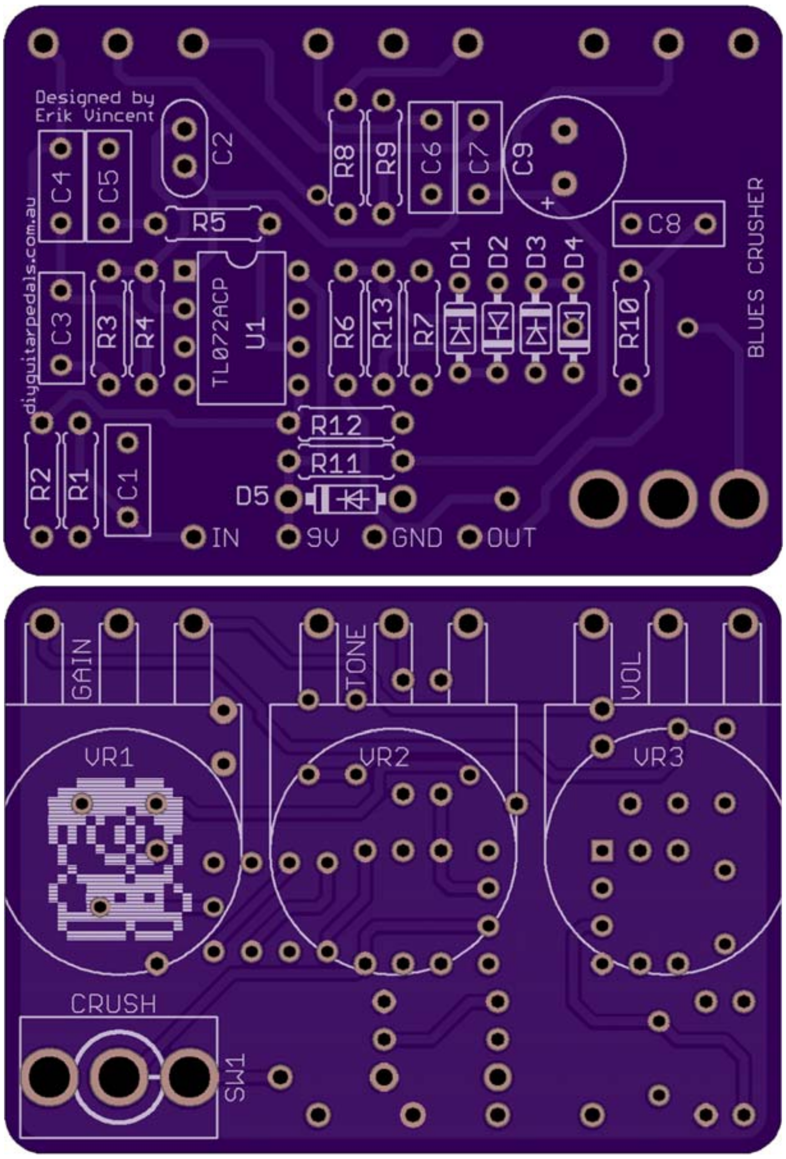
Want fuzz that Gilby Clarke used for all those years? This take on the Marshall Blues Breaker pedal will accomplish this. This pedal uses the standard 3 pot control of Volume, Tone, and Gain as well as a switch to add some harshness to the fuzz.

This project is at an easy level as there are only a few parts and is in a spacious layout that is easy to understand.

The PCB itself isn't too big and will fit snug into a 1590B enclosure very easily.

Bill of Materials, Stock Blues Crusher

Capacitor		Resistor	
C1	10nF (film)	**R1**	2.2M
C2	47pF (ceramic)	**R2**	1M
C3	10nF (film)	**R3**	3.3K
C4	10nF (film)	**R4**	4.7K
C5	100nF (film)	**R5**	10K
C6	10nF (film)	**R6**	220K
C7	10nF (film)	**R7**	6.8K
C8	100nF (film)	**R8**	1K
C9	100µF (Electrolytic)	**R9**	6.8K
		R10	1M
Diode		**R11**	47K
D1	1N4148 or 1N4448	**R12**	47K
D2	1N4148 or 1N4448	**R13**	470K or 1M for extra gain
D3	1N4148 or 1N4448		
D4	1N4148 or 1N4448	**Switch**	
D5	1N4001	**Crush**	SPDT Micro-switch (ON-ON)
ICs		**Potentiometer**	
U1	TL072	**Gain**	100kb (16mm)
		Tone	25kb (16mm)
		Volume	100ka (16mm)



PCB Spacing
The Blues Crusher PCB is spaced for 1590B sized enclosures or larger

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

Assembly.

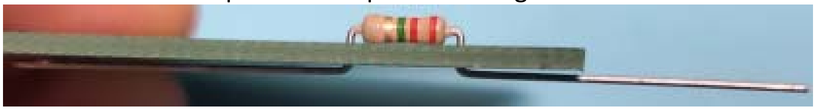
1. Soldering Order.

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

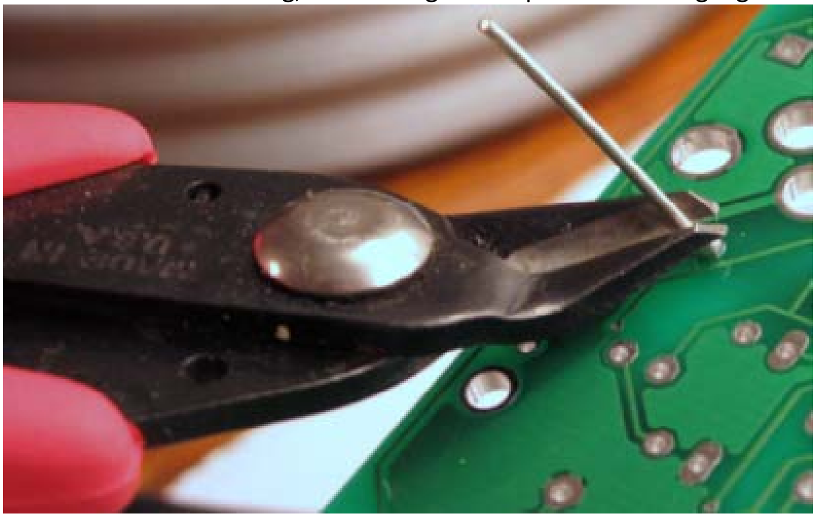
For the Blues Crusher, the best order would be: resistors, diodes, ceramic capacitors, IC sockets (if socketing), ICs (if not socketing), film capacitors, electrolytic capacitors, wiring, potentiometers, and then switches.

1.1 Resistors.

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

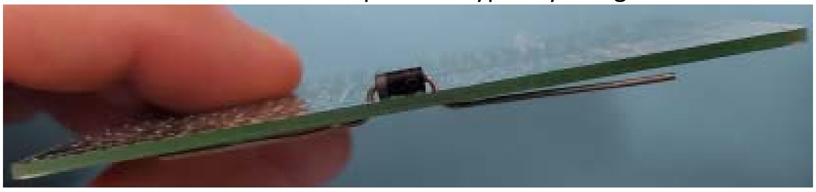


For this pedal we will be using 1/4 Watt resistors. These can either be 5% tolerance carbon resistors, or 1% tolerance metal film resistors. Orientation of “which way is up” doesn’t matter, so you can install them either way. After installation and soldering, do not forget to clip the remaining legs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

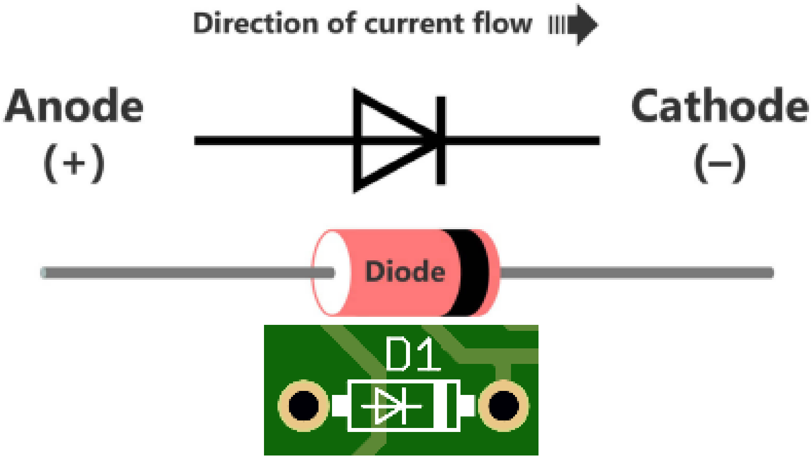


1.2 Diodes.

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

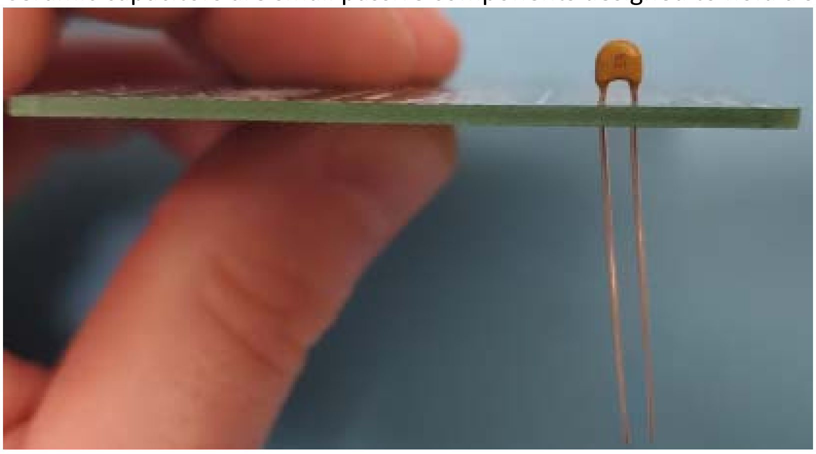


The orientation of a diode does matter based on the cathode and anode of the diode in the circuit. Make sure the stripe on the diode lines up with the stripe on the PCB's silkscreen. After installation and soldering, do not forget to clip the remaining legs from the PCB.



1.3 Capacitors (ceramic).

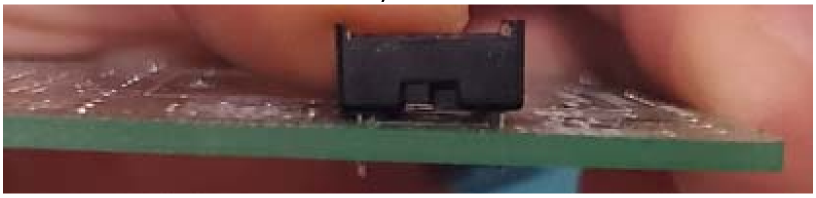
Ceramic capacitors are small passive components designed to hold a small amount of charge in a circuit.



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.

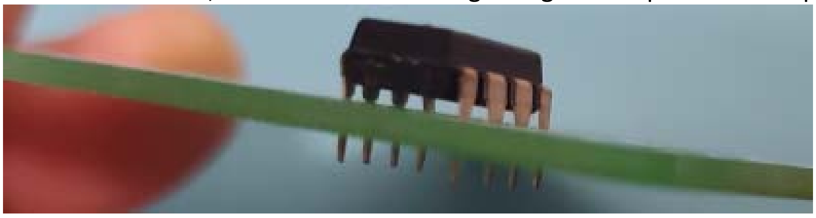
These are holders that allow easy installation and uninstallation of ICs.



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.

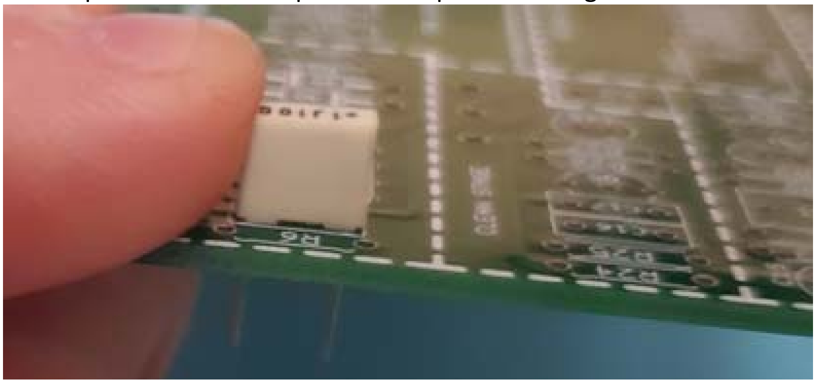
Also known as ICs, these are small analog or digital components that provide specific electrical functions.



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).

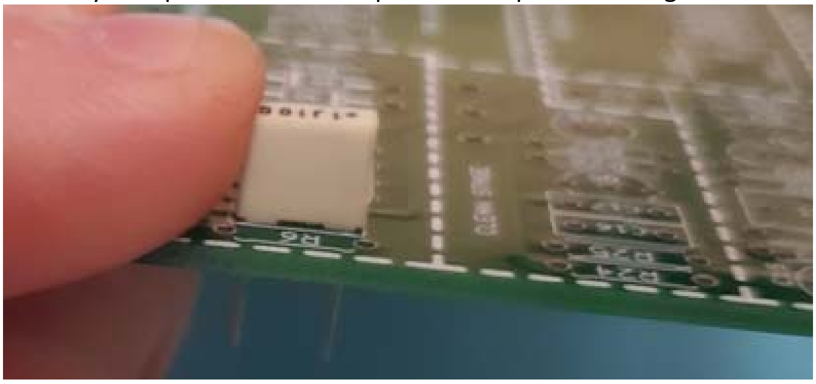
Film capacitors are small passive components designed to hold a small amount of charge in a circuit.



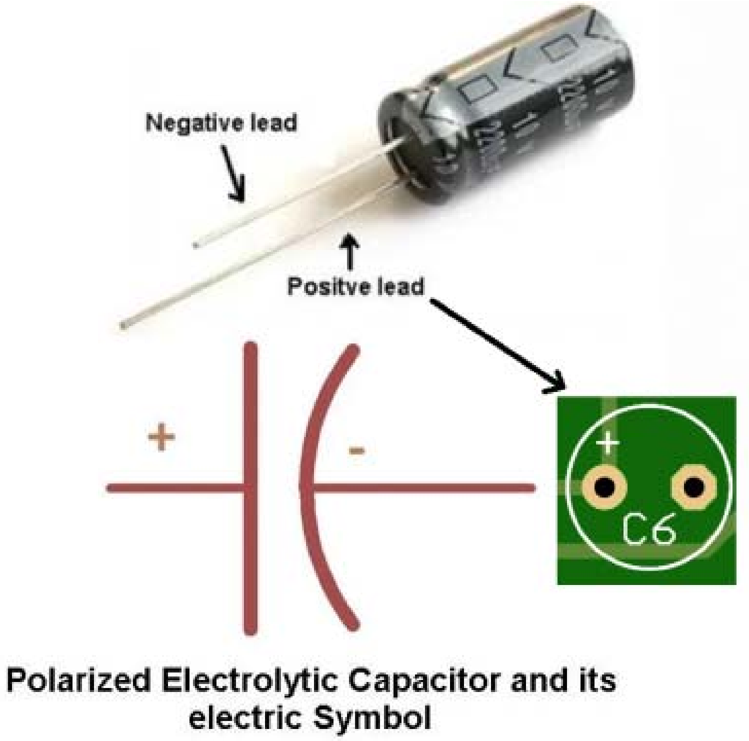
Orientation of “which way is up” doesn’t matter, so you can install them either way. After installation and soldering, do not forget to clip the remaining legs from the PCB.

1.7 Capacitors (electrolytic).

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

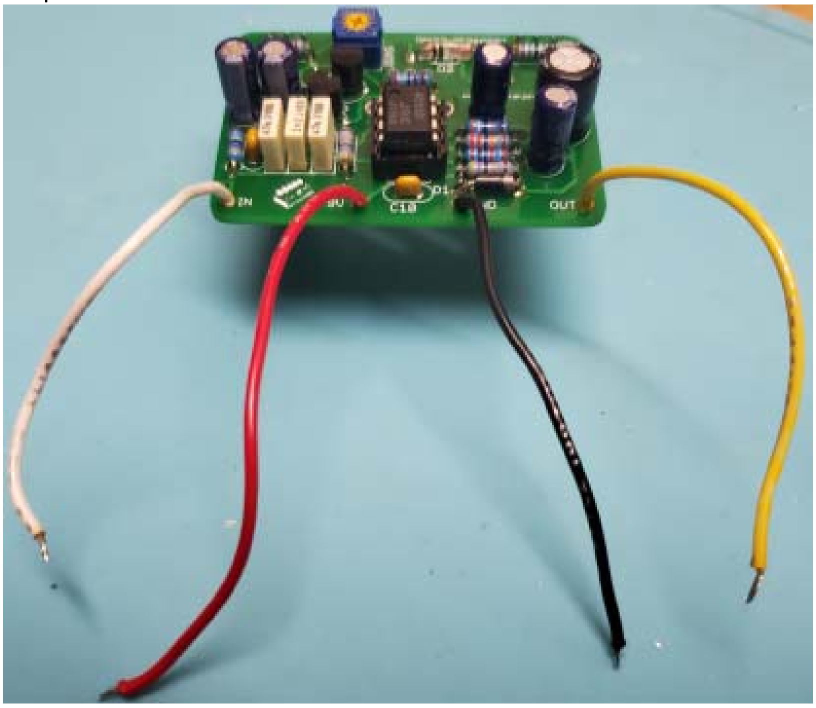


Electrolytic capacitors are typically polarized, so orientation will matter.



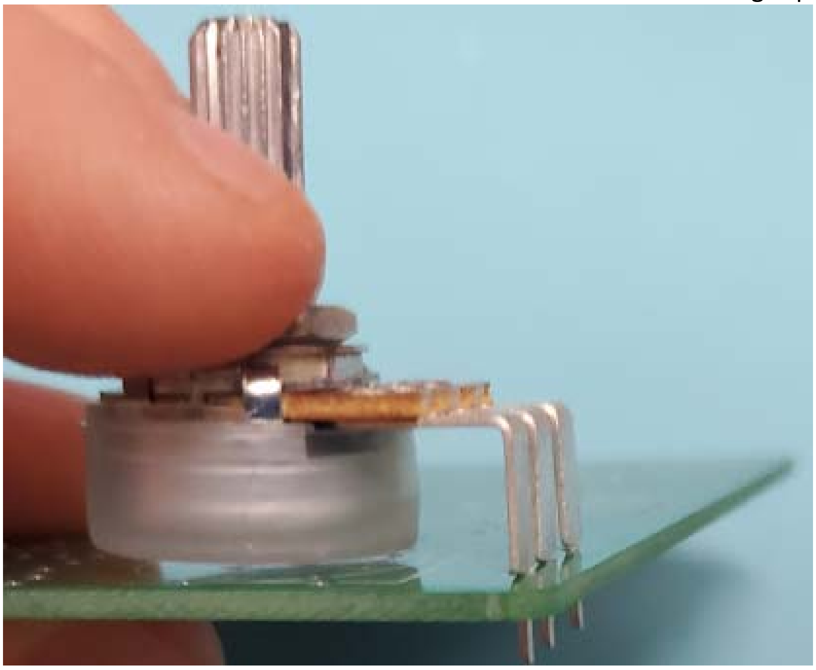
After installation and soldering, do not forget to clip the remaining legs from the PCB.

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.



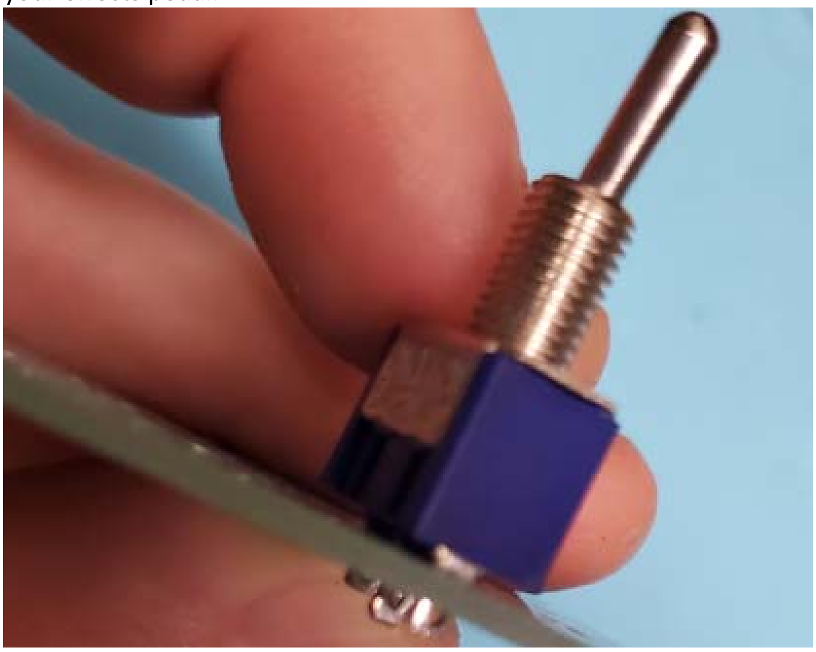
These can be installed at the very end, but in some situations, installing them before potentiometers are soldered in place can be advantageous. Colored wire doesn't change the properties, but using color codes for hot and ground wires, like red being hot, and black being ground, are common place. Typically, 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.

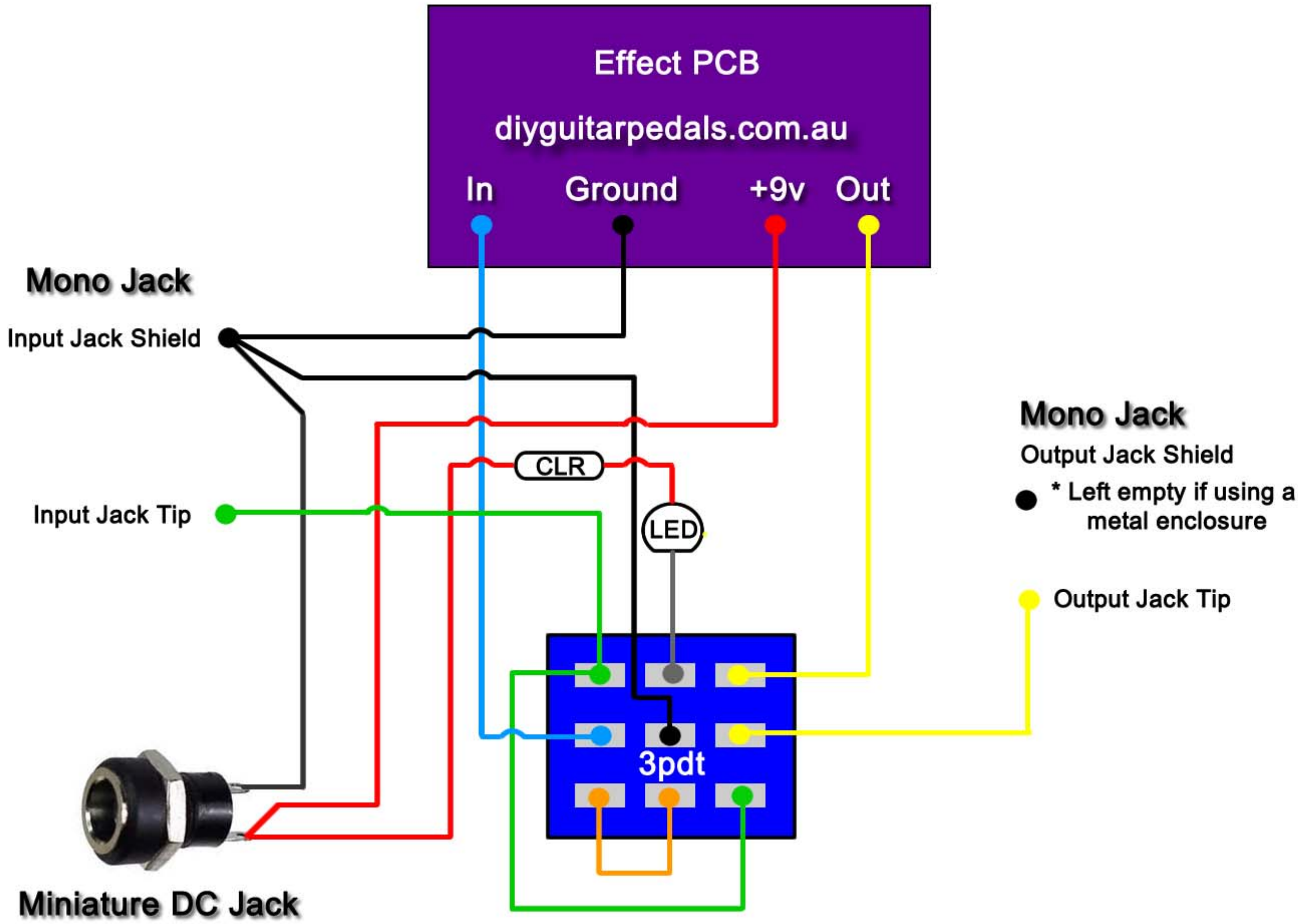
1.10 Switches.
Switches are mechanical devices that change the flow of electricity on a circuit, usually to provide different options to your effects pedal.



These are typically installed on the backside of the PCB and uses jam-nuts to set the “height” of the actuator and to mechanically secure the PCB to the enclosure via a strategically drilled hole on the enclosure. Orientation should not matter with most switches.

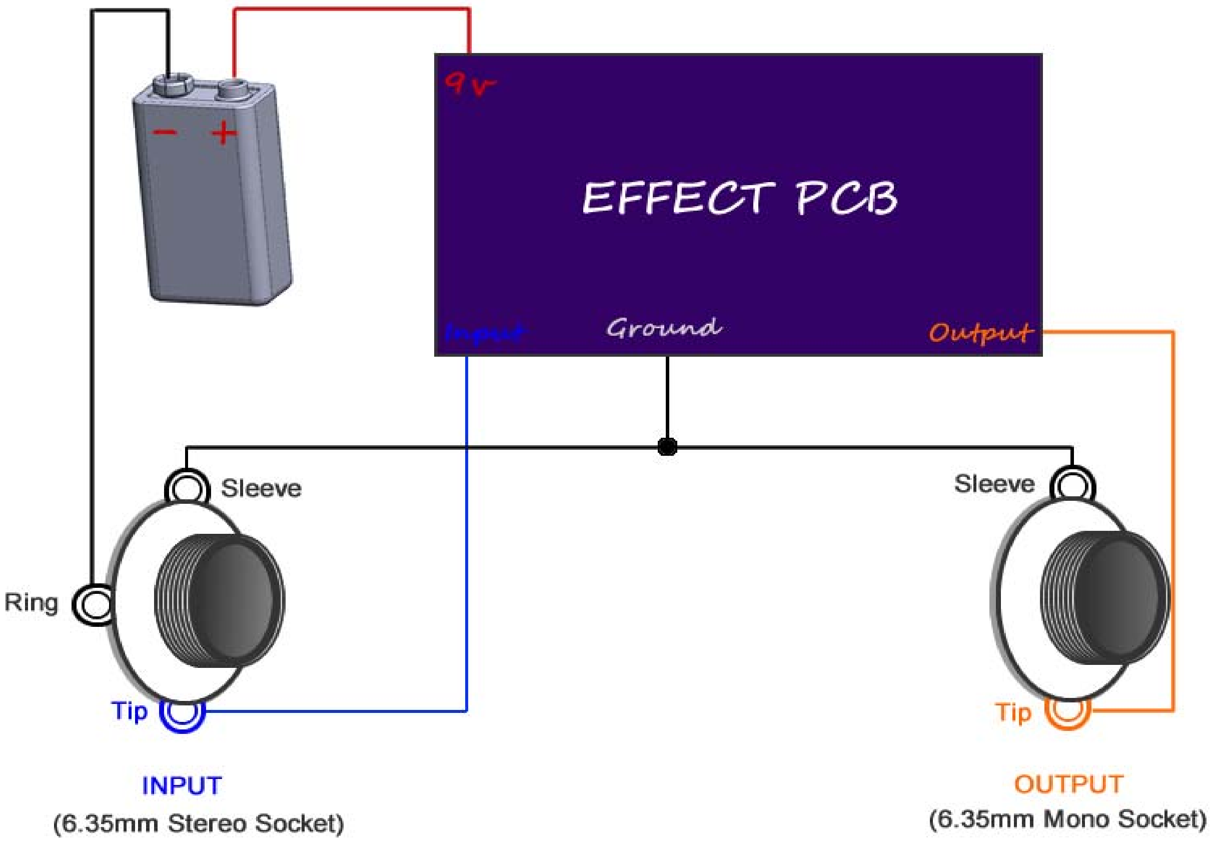
1.11 Off Board Wiring Diagram.

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



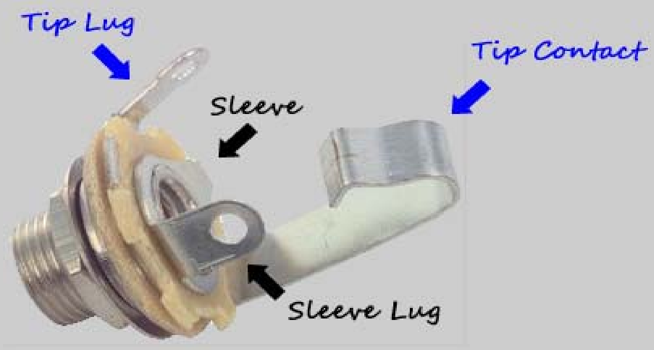
Testing Your Effect

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



Input and Output Sockets

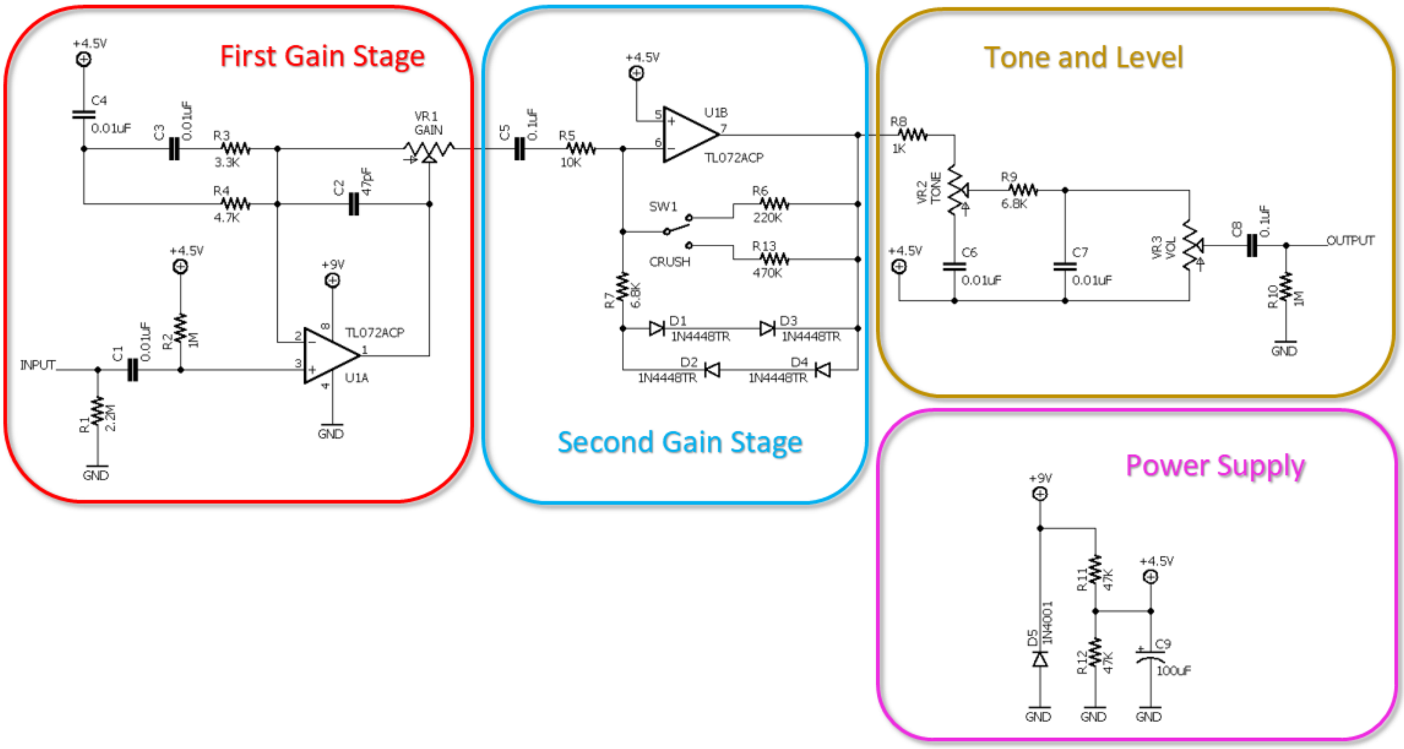
Pay close attention to the lugs of your sockets. Look at them side on so that you can distinguish the sockets individual layers. For instance the tip lug is connected to tip contact. The stereo jack looks the same as the socket below except it has an extra lug and contact for "Ring".



Blues Crusher Circuit Analysis for modifying purposes.

2. Blues Crusher Circuit.

The Blues Crusher schematic can be broken down into some simpler blocks: Power Supply, First Gain Stage, Second Gain Stage, and Tone Level Control.

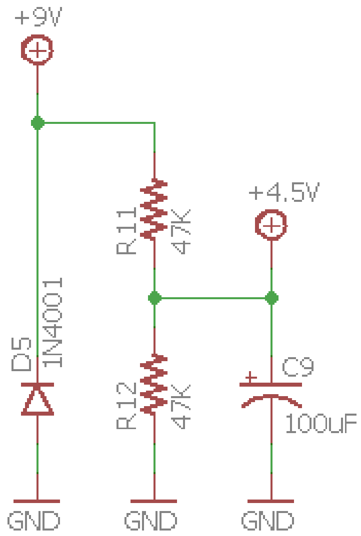


The circuit is designed around a dual op-amp gain and soft clipping topology with a passive tone and level control at the end.

The input impedance on the Blues Crusher 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 low and estimated around 5mA:

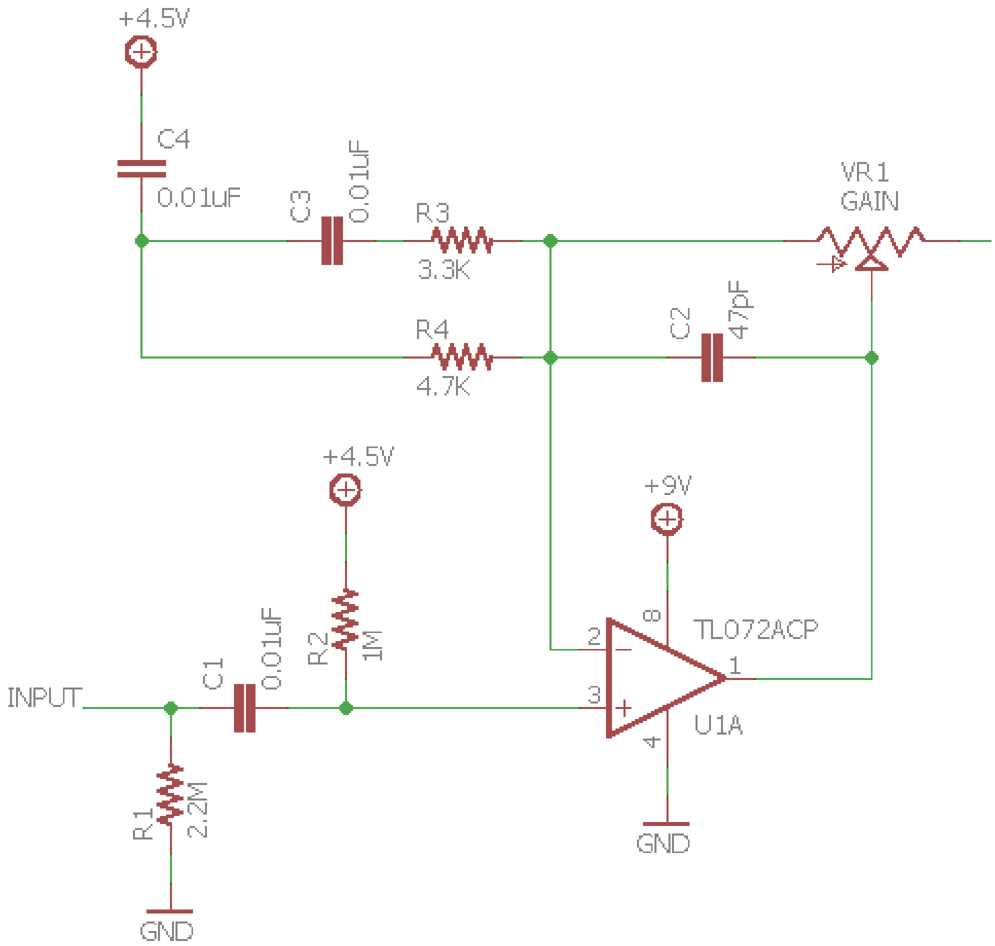


- The diode D5 protects the pedal against adapter reverse polarity connections.

- The resistor voltage divider composed by R11 and R12 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 C9 100uF.

4. First Gain Stage.

The first gain stage is made of a non-inverting op-amp amplifier with variable voltage gain and some filters to shape the gain response and high input impedance that preserves signal quality eliminating tone sucking (high-frequency loss):



- R1 is a 2.2MΩ resistor from the input to ground is an anti-pop/bleeder resistor, it will avoid abrupt pop sounds when the effect is engaged.
- C1 is an input coupling capacitor to block DC signal
- R2 is a bias resistor for U1A op-amp
- C2 is a small capacitor used to filter out high-frequencies from the negative feedback loop of the U1A op-amp
- R3 and R4 form the resistance to ground/virtual ground path for the U1A op-amp's negative feedback loop, which in turn sets the gain amount that leaves the op-amp.
- C3 and C4 form the capacitance to ground/virtual ground path for AC signals in the U1A op-amp's negative feedback loop.
- VR1, or Gain potentiometer, is what variably changes and sets the gain for the first stage along with R3 and R4.

4.1 Input Impedance.

The input impedance is defined by the formula:

$Zin = (R_1 \,||\, R_2) \,||\, Zin_{TL072}$

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

$Zin = (2.2M \,||\, 1M) \,||\, 1{,}000{,}000{,}000{,}000$

$Zin = (687{,}500) \,||\, 1{,}000{,}000{,}000{,}000$

$Zin = 687{,}499.53\Omega$

Therefore, the Blues Crusher input resistance is 687K, which isn't bad, but the closer to 1M it is, the better. Increasing R2 to 2.2M would bring the input resistance up to 1M, although that would also effect the input high pass filter.

4.2 Voltage Gain.

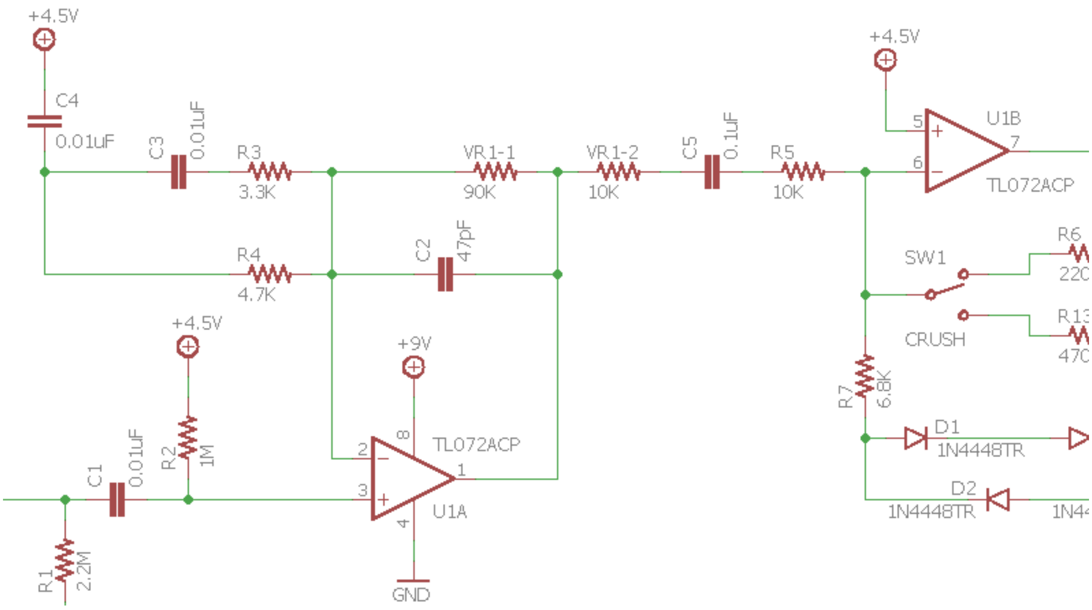
The voltage gain is trimmed with the gain knob, so in a non-inverting topology this can be calculated as:

$G_v = 1 + (R_{GAIN} / (R_3 \,||\, R_4))$

$G_{vmin} = 1 + (0 / (3{,}300 + 4{,}700)) = 1\ (0dB)$

$G_{vmax} = 1 + (100{,}000 / (3{,}300 + 4{,}700)) = 11\ (20dB)$

Also note that as the Gain pot, VR1, is increased, the gain on the first stage is increased by the formula you see above, the signal leaving the first stage is getting less resistance going into the input of the second gain stage, which in turn gives more of the signal to be amplified in the next stage. This too, will increase the overall gain of the pedal.



4.3 EQ Shaping.

It is usual to find a combination of low pass and high pass filters before or within the gain stage in overdrive pedals. The overdriven distortion makes the original guitar signal more harmonically complex, this means that more amounts of distortion are being added, it can be more difficult to give each sound its own space in the band mix. Artificially band-limiting a distorted signal, using both high and low-pass filters, can help it sit more comfortably in a mix, by preventing its spectrum from spreading over too wide an area. In the case of this pedal, the primary filtering are just low pass filters, along with a high pass input filter

High Pass Input Filter.

The 10nF C1 input capacitor blocks DC and provides simple high pass filtering. C1 and R2 create a high pass filter.

$$fc = 1 / (2\pi RC)$$
$$fc = 1 / (2\pi \cdot R_2 \cdot C_1)$$
$$fc = 1 / (2\pi \cdot 1M \cdot 10nF)$$
$$fc = 1 / (2\pi \cdot 1{,}000{,}000 \cdot 0.00000001)$$
$$fc = 16\ Hz$$

Low Pass Filters.

The small 47pF capacitor C2 across the feedback resistor works as a low pass filter, softening the corners of the guitar waveform and mellowing out the high end before the clipping.

The cut-off frequency of the filter is defined by the formula:

$$fc = 1 / (2\pi \cdot R_{GAIN} \cdot C_2)$$
$$fc = 1 / (2\pi \cdot 100{,}000 \cdot 0.000000000047) = 33.88\ \text{kHz}$$

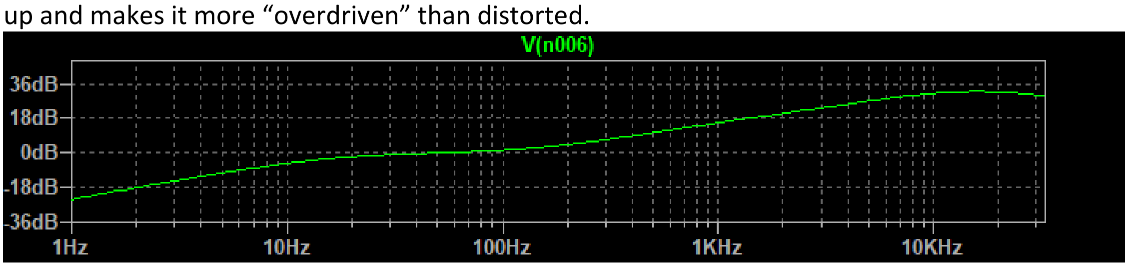
The gain potentiometer will shift the fc frequency, making the action of the 47pF more dramatic when the distortion control is maxed out at 100K, bringing the cut-off minimum frequency to the audible frequencies (34 KHz) and then softening the distortion. When the distortion knob is not maxed out, the fc goes higher being less noticeable.

There are two parallel RC networks formed by R4 and C4 and R3 with series capacitors C3 and C4 from the (-) input to virtual ground (bias). They are an active low pass filter, placing two poles and attenuating frequencies below the cut-off frequencies:

$$fc = 1 / (2\pi \cdot R_3 \cdot (1 / (1/C_3 + 1/C_4)))$$
$$fc = 1 / (2\pi \cdot 3{,}300 \cdot (1 / (1 / 0.00000001 + 1 / 0.00000001)))$$
$$fc = 1 / (2\pi \cdot 3{,}300 \cdot 0.000000005) = 9.65\ \text{kHz}$$

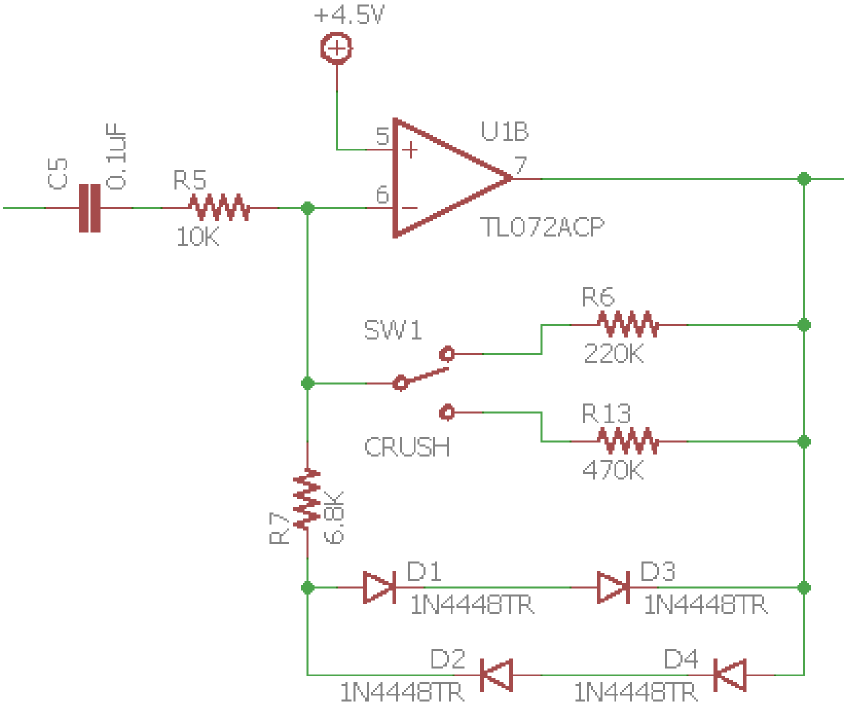
$$fc = 1 / (2\pi \cdot R_4 \cdot C_4)$$
$$fc = 1 / (2\pi \cdot 4{,}700 \cdot 0.00000001) = 3.4\ \text{kHz}$$

Harmonics above 3.4 kHz will have an attenuation 20dB/dec and lower harmonics above 9.65 kHz will be severely muted at 40dB/dec. This filtering provokes that high frequency notes will be attenuated before the clipping action. This makes everything under those frequencies more clipped and creates a frequency selective distortion. This cleans the distortion up and makes it more “overdriven” than distorted.



5. Second Gain Stage.

The second gain stage is made of an inverting op-amp with some filtering and soft-clipping diodes:



- C5 is a coupling capacitor, removing DC signal from the previous stage.
- R5 is a current limiting resistor that adds a small amount of input impedance to the U1B op-amp, creates a small RC filter with C5 and the negative feedback loop of U1B, but most importantly sets the gain for the output of the U1B op-amp
- R6 and R13 form potential resistance values for the negative feedback loop of this gain stage, ultimately allowing a user to switch between 2 values of extra gain. The 220KΩ resistor path will have less output gain than the larger 470KΩ path.
- R7 is a resistor designed to help reduce signal getting to the soft-clipping diodes, making the soft-clipping more tame.
- D1, D2, D3, and D4 are small silicon diodes used for soft-clipping in the U1B op-amp's soft clipping section
- The switch SW1, is a Single Pole, Double-Throw (SPDT), ON-ON switch designed to switch between R6 and R13 for setting the gain of this stage.

5.1 High Pass Filter in the Feedback Loop

The series resistor R5 and capacitor C5 from the (-) input to ground act as an active high pass filter, attenuating frequencies below the fc cut-off frequency:

$$fc = 1 / (2\pi \cdot R_5 \cdot C_5)$$
$$fc = 1 / (2\pi \cdot 10{,}000 \cdot 0.0000001) = 159.2 \text{ Hz}$$

Harmonics above 159.2 Hz get the full gain of the distortion stage. Everything below gets progressively less gain and less distortion. Bass notes are clipped least, so the distortion is frequency selective.

5.2 Voltage Gain.

The voltage gain for this stage is only varying from the Crush switch. For these calculations, we are not considering yet the diodes D1, D2, D3, and D4.

$$G_{vmin} = (R_6 / R_5)$$
$$G_{vmin} = (220{,}000 / 10{,}000) = 22\ (28.85dB)$$

$$G_{vmax} = (R_{13} / R_5)$$
$$G_{vmax} = (470{,}000 / 10{,}000) = 47\ (33.44dB)$$

Imagine changing R13 to an even higher resistor, such as 1M. When selecting the crush switch, even more gain can be heard. See below:

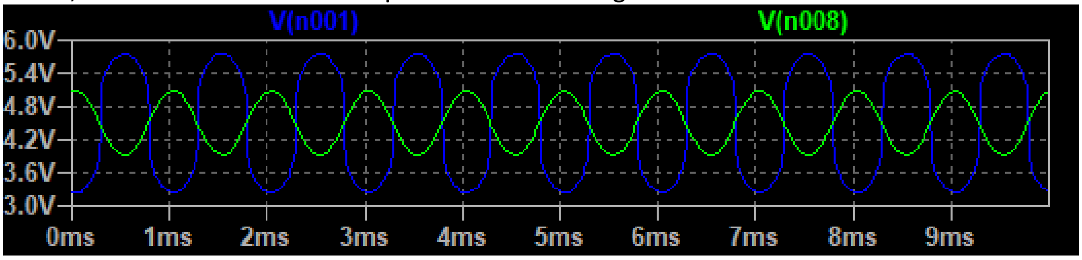
$$G_{vmax} = (R_{13} / R_5)$$
$$G_{vmax} = (1{,}000{,}000 / 10{,}000) = 100\ (40dB)$$

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.

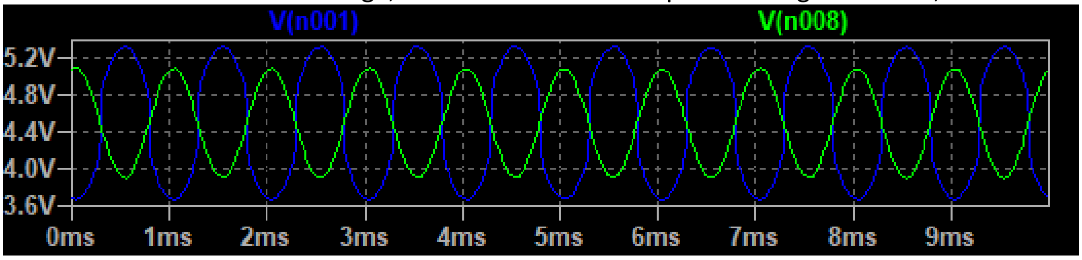
5.3 Clipping Diodes.

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.

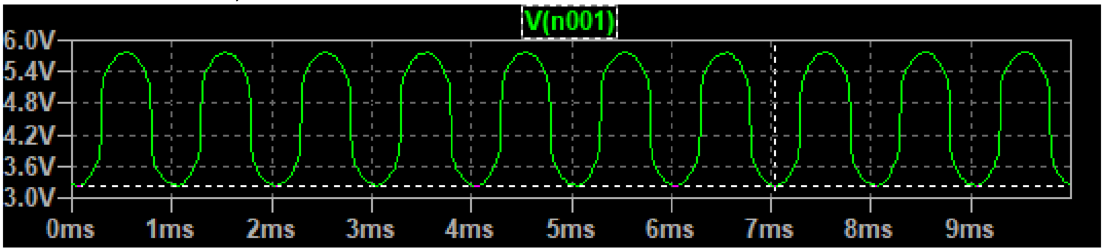
Below is a signal entering this gain stage, in green, while the blue signal is the signal leaving this gain stage with the 220K feedback path enabled by the switch. Because the clipping diodes D1 and D3 are in series, as well as D2 and D4 being in series, the blue curve starts to clip at a forward voltage of around 2.5V



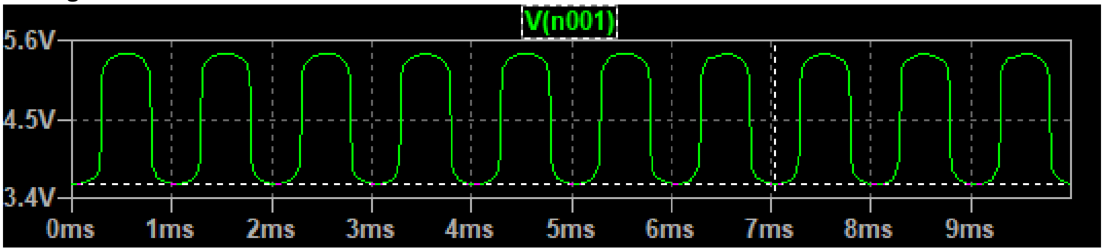
If we were to remove D1 and D2 and replace them with a wire to shunt their connections, D3 and D4, by themselves, will have a lower forward voltage, and therefore will compress the signal further, at around 1.7V



The function of the R7 resistor is the tame the soft-clipping even further by rounding the curved tops more as the resistance increases, as seen below:



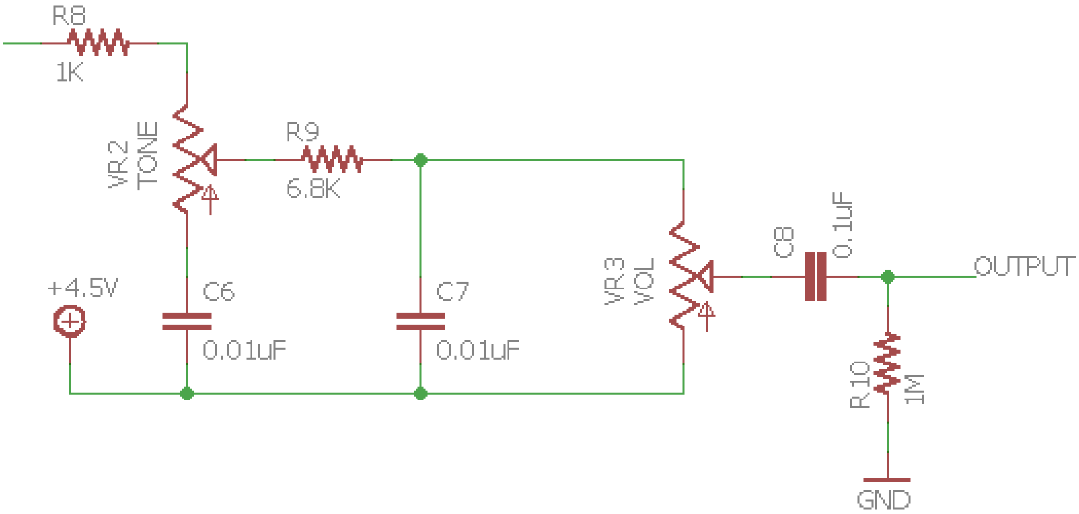
However, as the resistor drops in value, the harshness returns, squaring more of the waveform, as seen below with R7 having a resistance of near 0.



Increasing the resistance beyond 10K for R7 seems to almost have no effect to the waveforms already natural curve.

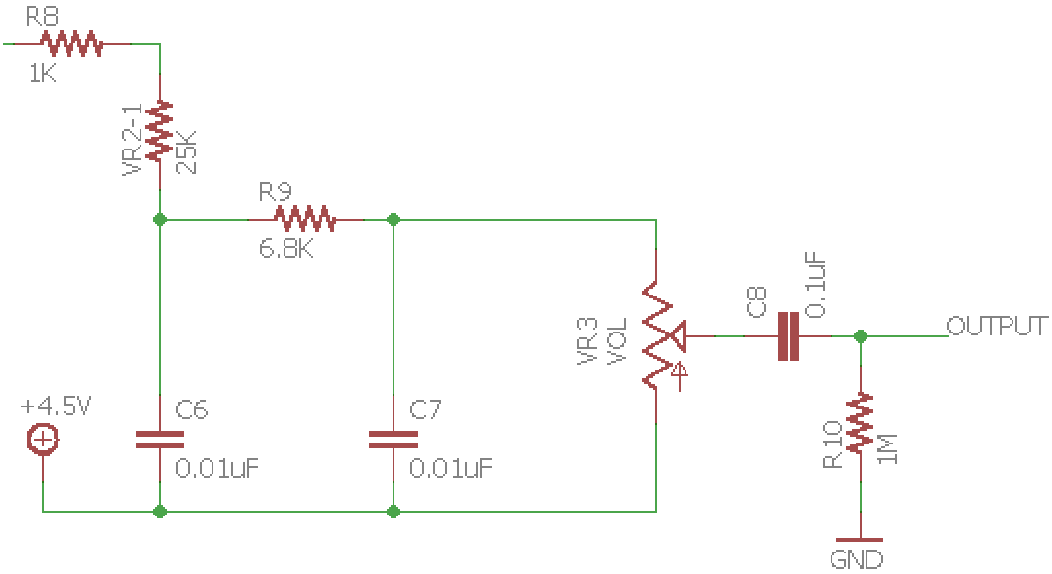
6. Tone Level Stage.

The Blues Crusher uses two series RC networks formed by R8+VR2 and C6 along with R8+VR2+R9 and C7 going down to bias, aka virtual-ground. This is creates a second order low-pass filter. From there it goes to a volume potentiometer to virtual ground and out a coupling capacitor with a low pass filter.



- R8 is a 1KΩ resistor to set the minimum resistance value of the upcoming RC filters for the tone knob.
- R9 is a resistor that along with the series resistance of R8 and what is left on the top half of the Tone knob's resistance form a second stage of RC filters for the tone section with capacitor C7.
- C6 is the capacitor going to virtual ground (4.5V bias) used as part of the first stage of RC filters in the tone section.
- C7 is the capacitor going to virtual ground (4.5V bias) used as part of the second stage of RC filters in the tone section.
- The volume knob is a simple potentiometer sending the audio signal to virtual ground (4.5V bias) to reduce volume.
- C8 is a coupling output capacitor to remove any DC signal from the output leaving the volume potentiometer that came from the tone-stack section. It also forms a high-pass RC filter with R10 that cuts out frequencies of around 1.6 Hz and below.

6.1 Tone Frequency Response.



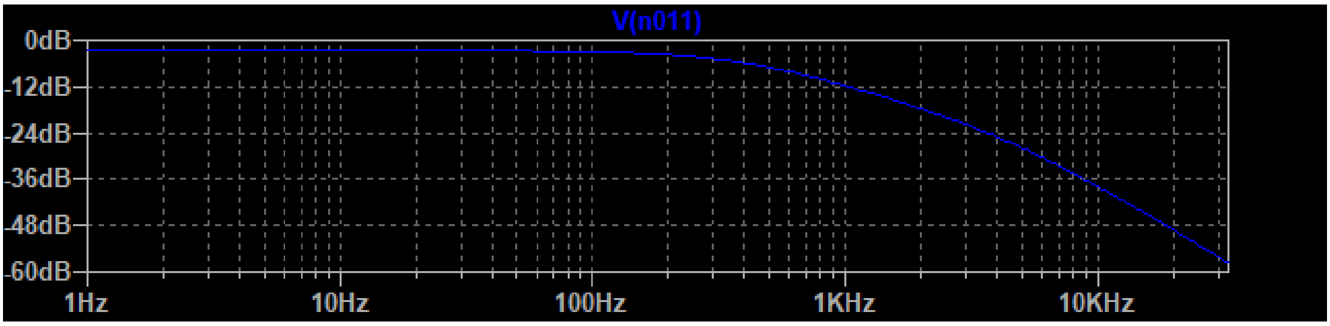
If the tone knob is dialed all the way down to a 0, the schematic for the tone section could be represented schematically by the circuit above. This makes two low pass filters cascaded into each other. The first one is formed with the series resistance of R8 and VR2-1 and capacitor C6, which is calculated as:

$$fc = 1 / (2\pi RC)$$
$$fc = 1 / (2\pi \cdot (R_8 + VR_{2\text{-}1}) \cdot C_6)$$
$$fc = 1 / (2\pi \cdot 26{,}000 \cdot 0.00000001)$$
$$fc = 612\ Hz$$

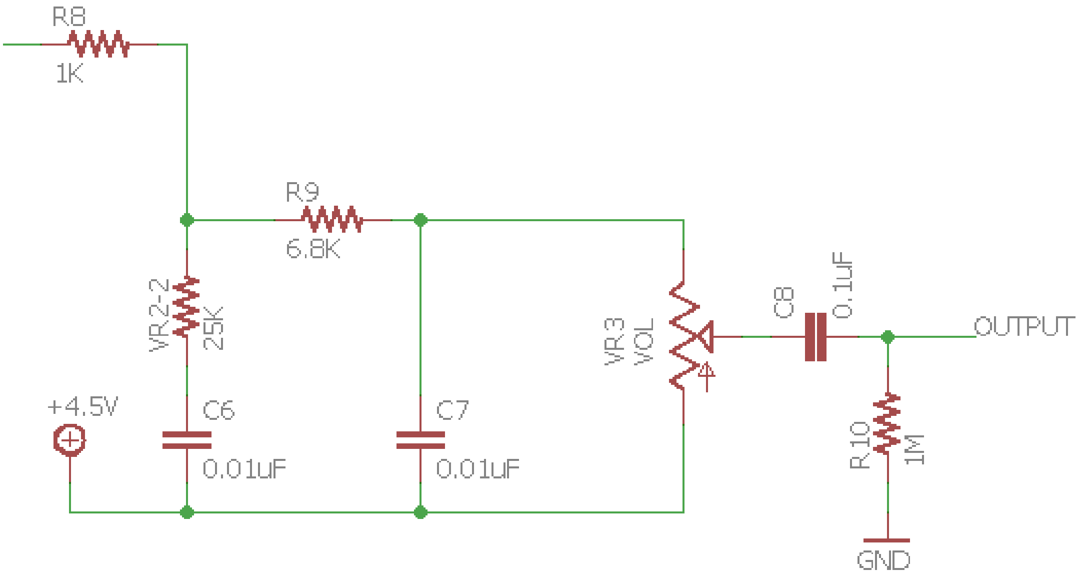
The second one is formed with the series resistance of R8, VR2-1, and R9, along with capacitor C7, which is calculated as:

$$fc = 1 / (2\pi RC)$$
$$fc = 1 / (2\pi \cdot (R_8 + VR_{2\text{-}1} + R_9) \cdot C_6)$$
$$fc = 1 / (2\pi \cdot 32{,}800 \cdot 0.00000001)$$
$$fc = 485\ Hz$$

Harmonics above 485 Hz will be cut from the second filter, and further cut at 612 Hz from the first, creating a darker tone when the knob is at 0.



As the tone knob goes from 0 to 10, this changes the look of the two RC filters as seen in the schematic below once the tone knob is at 10.

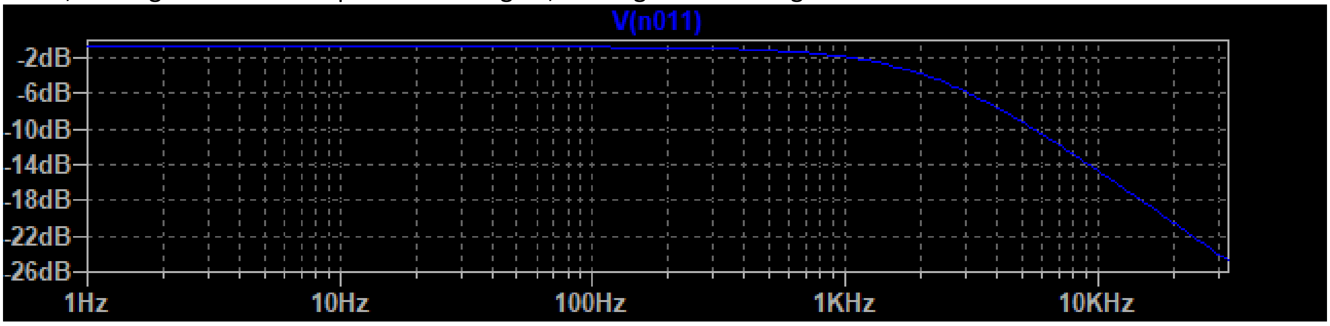


This means we have a low-pass filter of R8+VR2-1+VR2-2 and C6 along with R8+VR2-1+R9 and C7. Their cut offs could be calculated as:

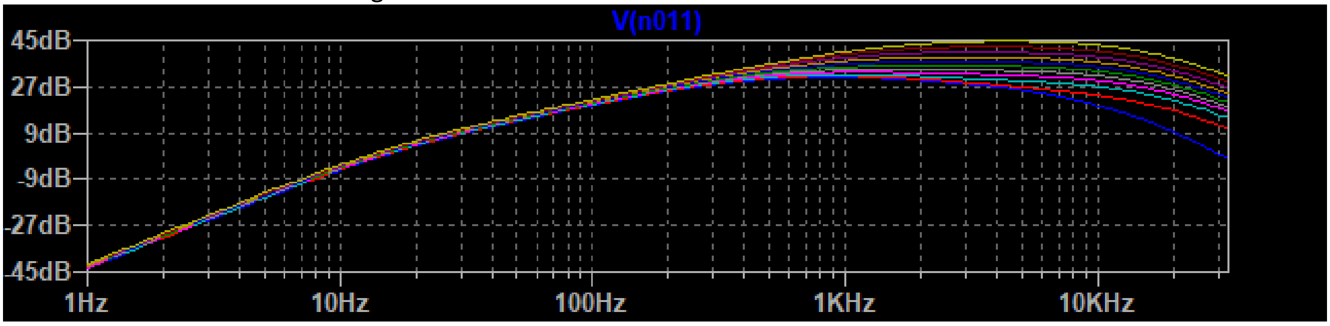
$$fc = 1 / (2\pi \cdot (R_8 + VR_{2\text{-}2}) \cdot C_6)$$
$$fc = 1 / (2\pi \cdot (1{,}000 + 25{,}000) \cdot 0.00000001)$$
$$fc = 1 / (2\pi \cdot 26{,}000 \cdot 0.00000001) = 612 \text{ Hz}$$

$$fc = 1 / (2\pi \cdot (R_8 + R_9) \cdot C_7)$$
$$fc = 1 / (2\pi \cdot (1{,}000 + 6{,}800) \cdot 0.00000001)$$
$$fc = 1 / (2\pi \cdot 7{,}800 \cdot 0.00000001) = 2 \text{ kHz}$$

Now the harmonics are being cut from above 612 Hz, but doubly so with the second filter attenuating frequencies above 2 kHz, leaving more of the top end in the signal, making the tone brighter.



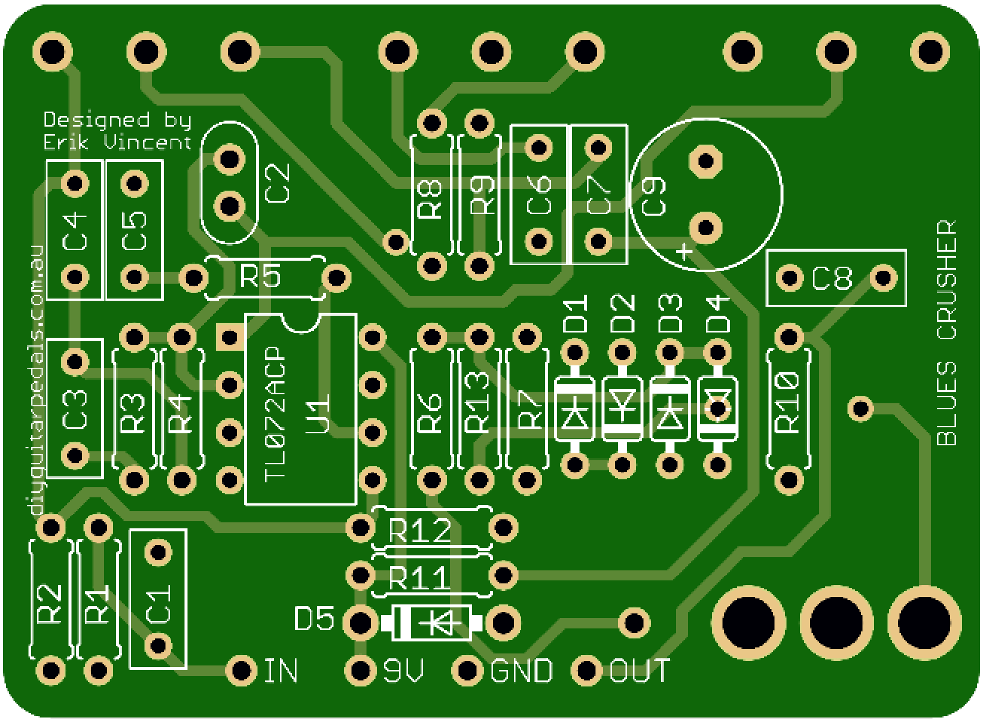
Summed with the tone responses of the previous sections, the overall tone-sweep cuts out a low of the lows and allows the tone section to effect the highs.

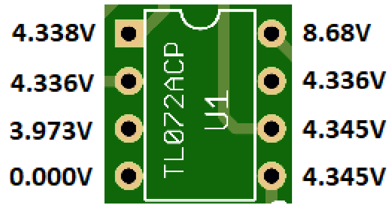


7. Voltage Readouts.

Below are the voltage readouts of the ICs onboard, assuming 9V Power Supply.

IC read-outs





KNOBS

- VOL: MAX
- TONE: MAX
- GAIN: MAX
- CRUSH SWITCH: OFF

8. Modifications

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

8.1 Resistors

The first resistors that are an obvious choice are the ones tied to the Crush switch, which effects the clipping stage directly. On the stock Blues Crusher, the choice is R6, which is what the Blues Breaker from Marshall originally came with, but by roughly doubling the value to 470K (via the switch and R13), it can add a bit more harsher clipping effect making the pedal more distortion than overdrive or fuzz. So R6 could go to a lower resistance for tamer tastes and R13 can be raised to a higher value for more distorted tastes.

Increasing R2 to 2.2M will improve input impedance, but to keep a similar input filter for DC noise rejection, decrease C1 from 10nF to 4.7nF

8.2 Capacitors

Increasing C1 from 10nF to 47nF is a modification for using the Blues Crusher for more rhythm style playing and for bass as it lets in more bass frequencies, but not enough to make it too muddy.

Changing the values of C6 and C7, as noted directly on the schematic, will give more bottom end for tone control by increasing them to a larger value. To allow for more bass, increase the values to around 220nF whereas if the tone isn't bright enough, decrease the values to 1nF

On the first gain stage, changing values of C2, C3, and C4 can also affect tone. Increasing C2 from 47pF to 100pF, for example, will remove even more harshness on the top end of the overdrive/distortion leaving the first gain stage. Increasing C3 and C4 values from 10nF to 22nF or higher will also decrease the higher frequencies from being overdrive and clipped. This may be desirable for a baritone guitar or bass.

Increasing the value of C7 will add more bass at the tone stack while decreasing the value of C7 will brighten the whole pedal's tone stack.

8.3 Diodes

Changing diodes in the second stage will also affect the sound of the distortion/overdrive from the soft clipping diodes. There are several configurations that can be used here. Using germanium diodes, such as the 1N34A or a series 1N34A with a 1N4001 can make a more "old school fuzz", but due to the lower forward voltage of Germanium diodes, there will be a bit of a volume drop. Using LEDs, which have higher forward voltages, the pedal will distort more, but be less compressed.

If no soft clipping is desired, simply not populating any of the diodes will accomplish this. This will increase the total volume output, and with the gain maxed, will distort rather heavily.

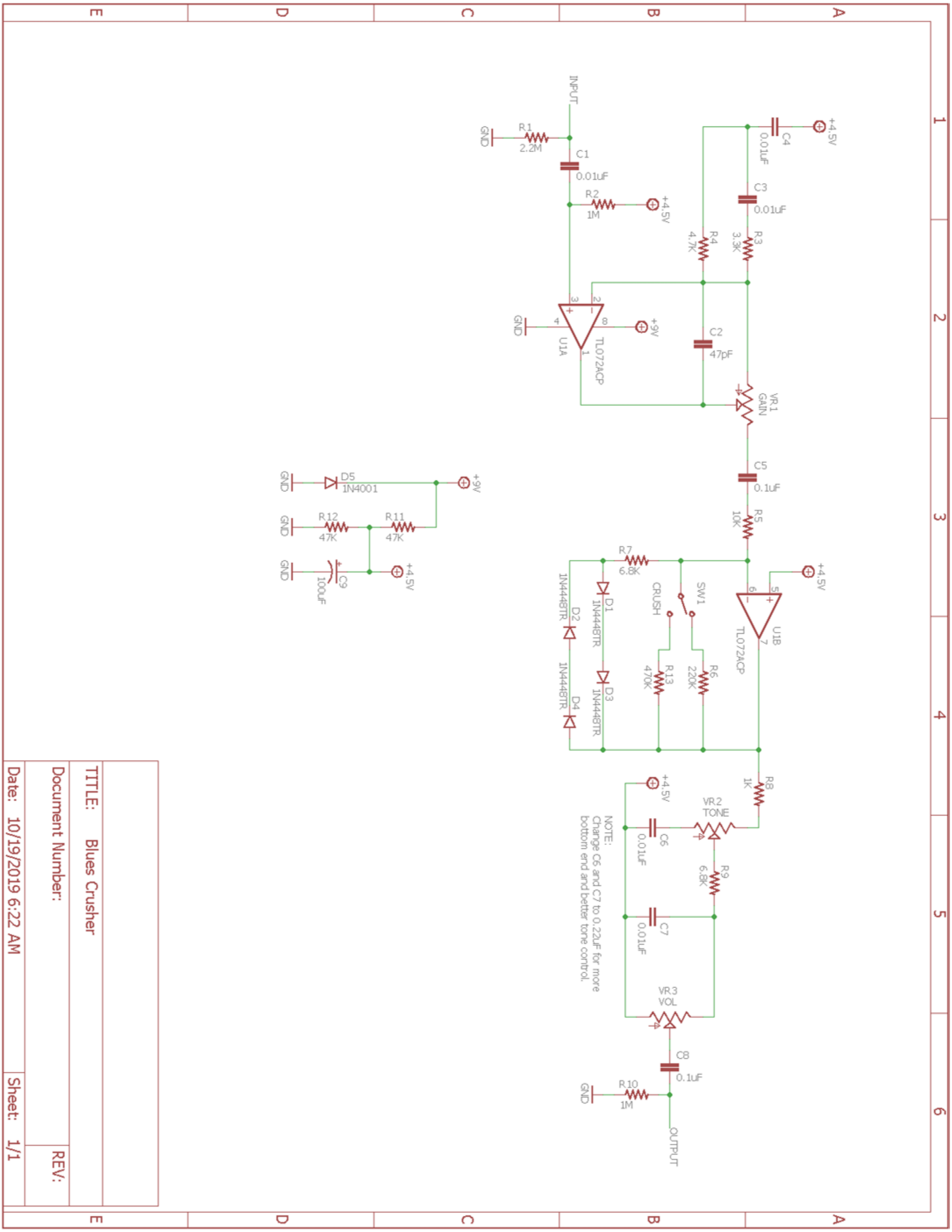
8.4 Op-Amps

Changing the dual op-amp will have some subtle affect to the soft clipping that occurs in the circuit. Using M5218A's or 4558's will be a little harsher on that clipping. An LM833N is another classic substitute for the op-amp, as found in JHS's Morning Glory pedal.

8.5 Potentiometers

Changing the gain potentiometer to a higher value can also give this pedal a bit more of a push. Increasing the value from a 100K potentiometer to a 500K potentiometer will drive the effect harder at max than before, but as the gain knob is approaching 0, it will have less gain than if it still were a 100K pot.

9. Schematic


INPUT
R1 2.2M
GND
C1 0.01uF
R2 1M
+4.5V
C4 0.01uF
C3 0.01uF
R4 4.7K
R3 3.3K
U1A TL072ACP
+9V
C2 47pF
VR1 GAIN
C5 0.1uF
R5 10K
R7 6.8K
SW1 CRUSH
U1B TL072ACP
D1 1N4448TR
D2 1N4448TR
D3 1N4448TR
D4 1N4448TR
R13 470K
R6 220K
R8 1K
VR2 TONE
C6 0.01uF
R9 6.8K
C7 0.01uF
VR3 VOL
C8 0.1uF
R10 1M
OUTPUT
D5 1N4001
R12 47K
R11 47K
C9 100uF
NOTE: Change C6 and C7 to 0.22uF for more bottom end and better tone control.
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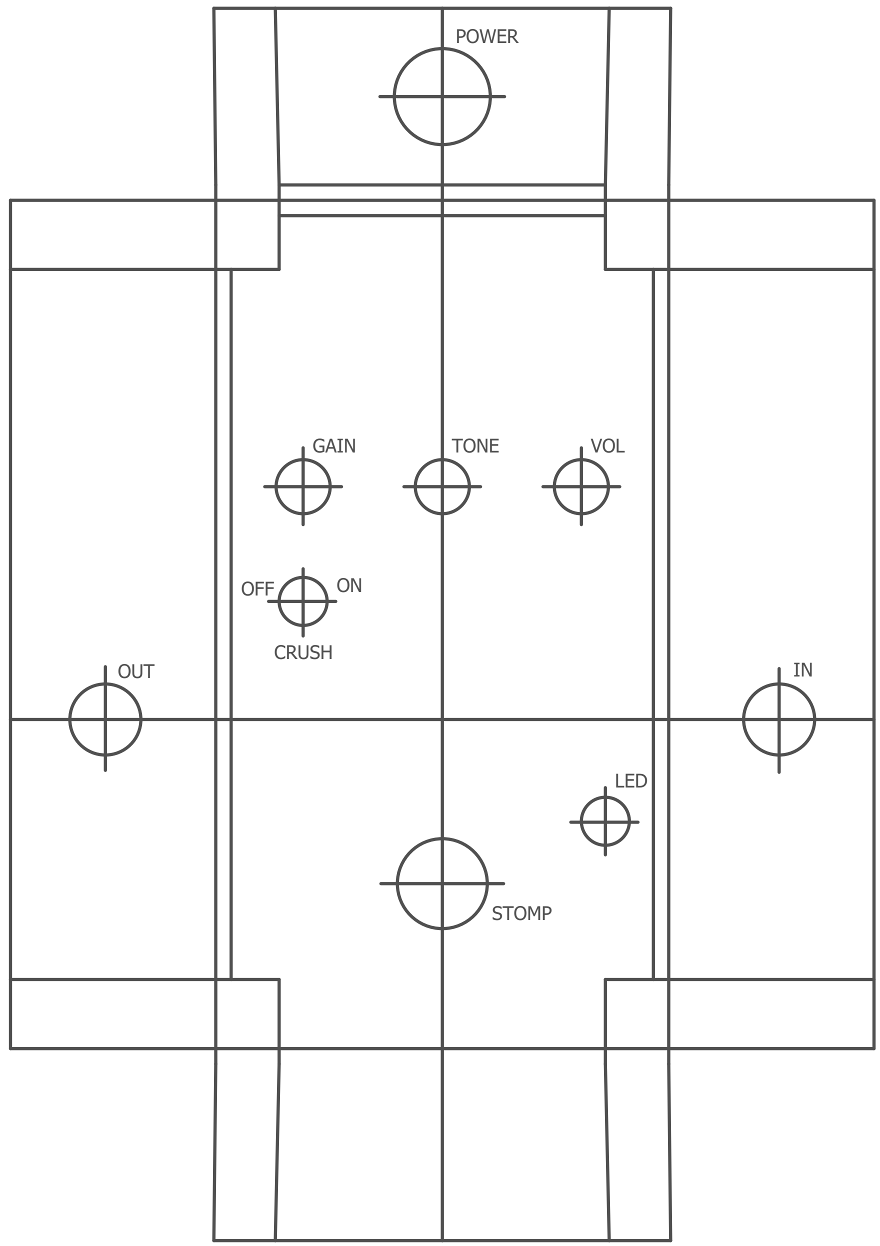
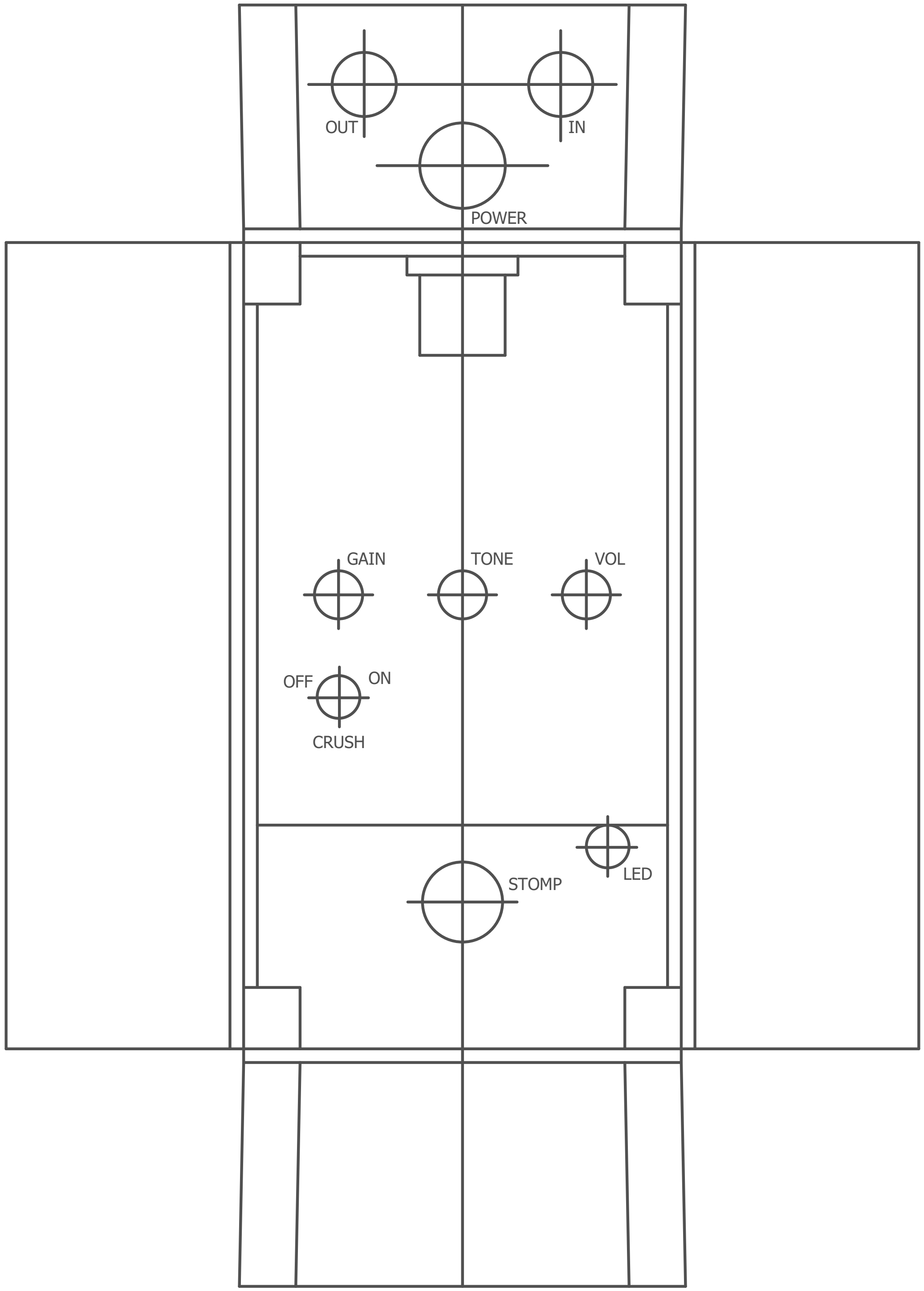
Sheet: 1/1


POWER
GAIN
TONE
VOL
OFF
ON
CRUSH
OUT
IN
LED
STOMP



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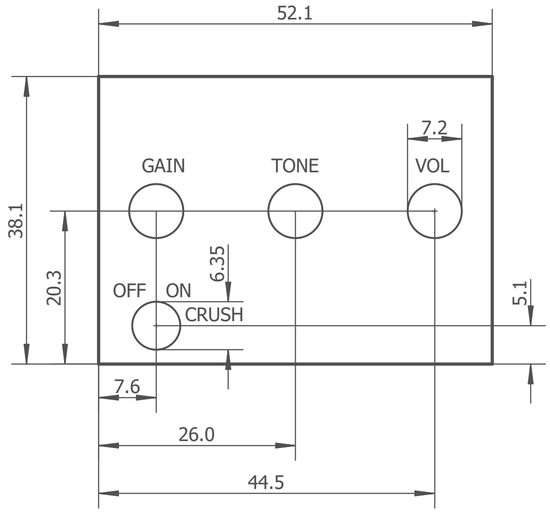
52.1
7.2
GAIN
TONE
VOL
38.1
20.3
6.35
OFF
ON
CRUSH
5.1
7.6
26.0
44.5