Blues Crusher

Design By Erik Vincent

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

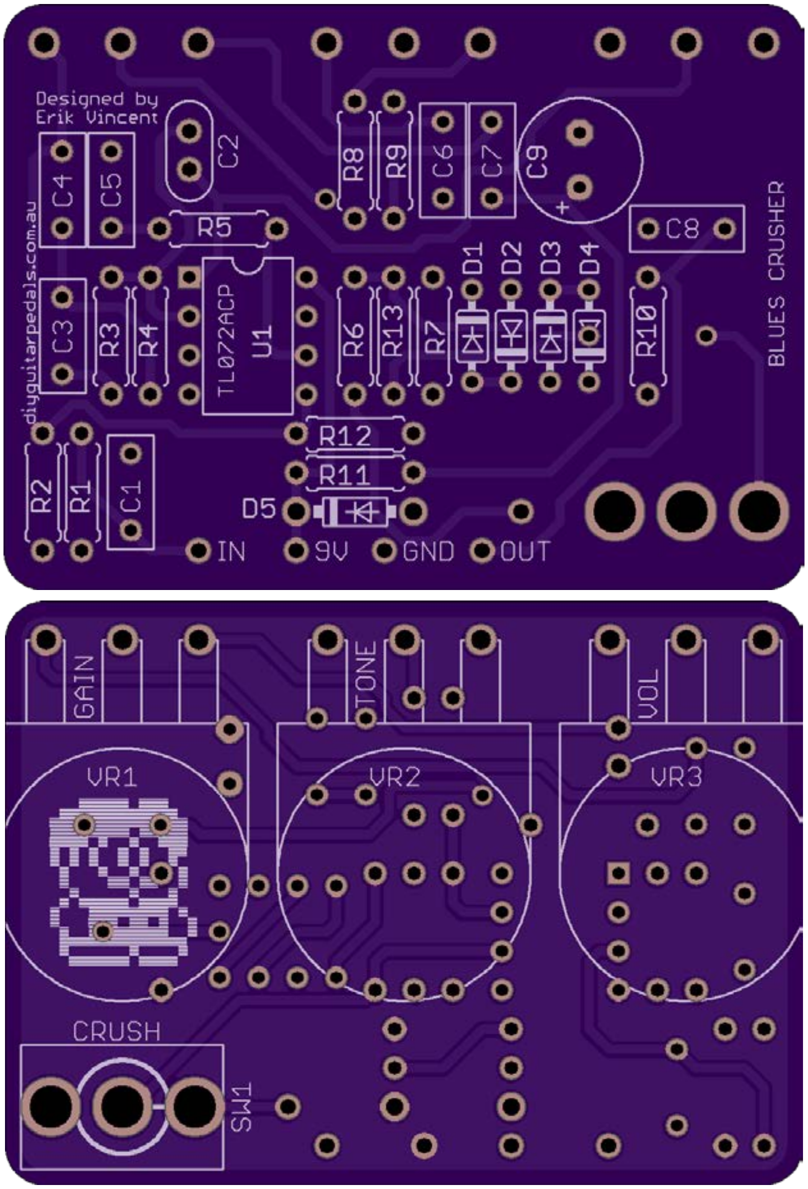
Want fuzz that Gilby Clarke used for all those years? This take on the Marshall Blues Breaker pedal will accomplish this. This pedal uses the standard 3 pot control of Volume, Tone, and Gain as well as a switch to add some harshness to the fuzz.

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)



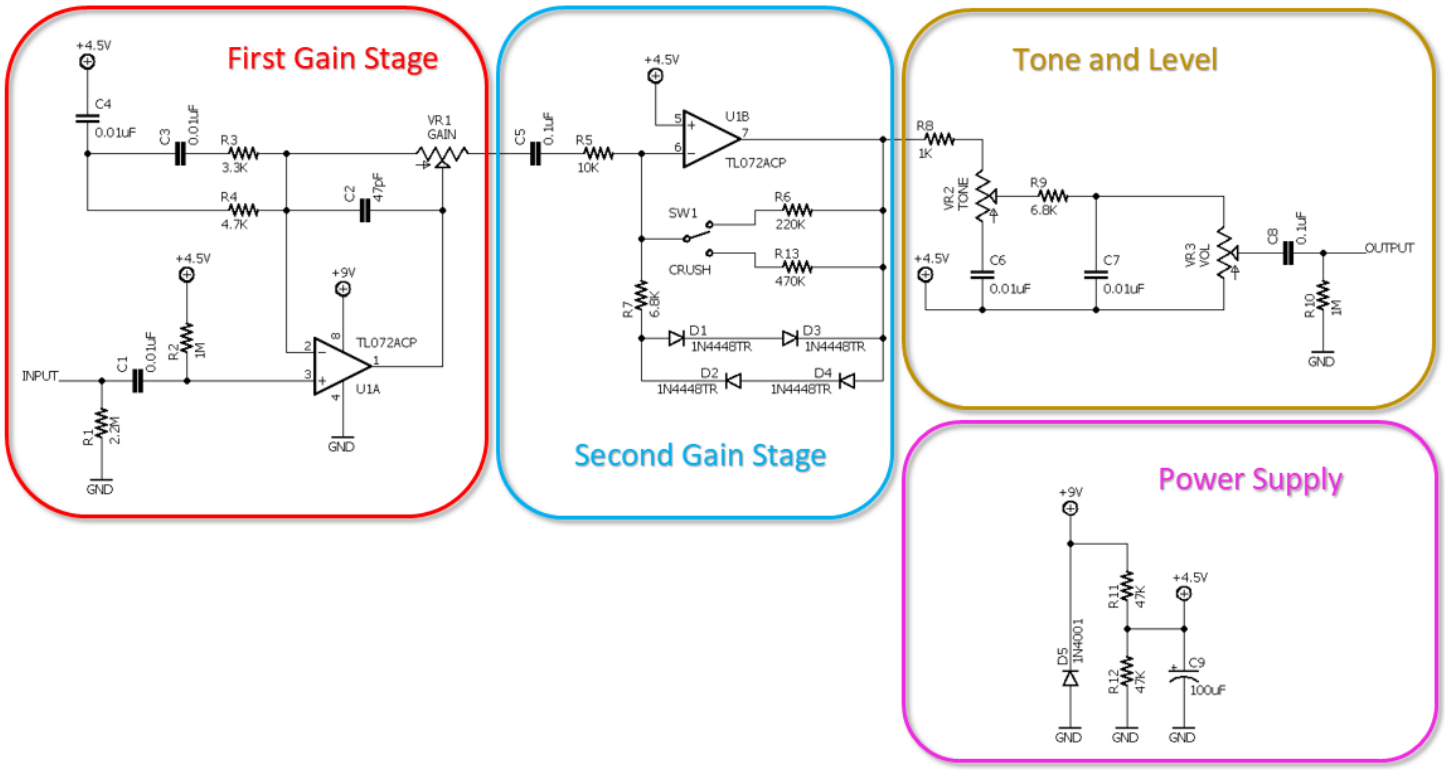
PCB Spacing
The Blues Crusher PCB is spaced for 1590B sized enclosures or larger

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

Blues Crusher Circuit Analysis for modifying purposes.

1. 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.

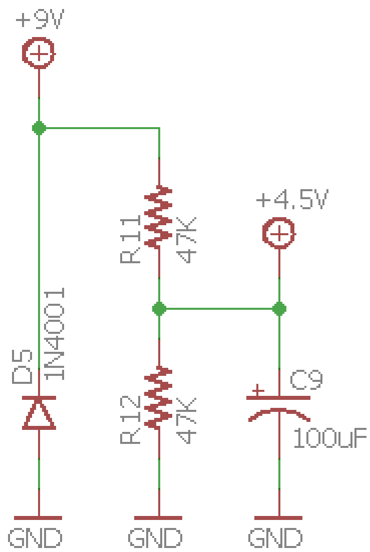


The circuit is designed around a dual op-amp gain and soft clipping topology with a passive tone and level control at the end.

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.

2. 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:

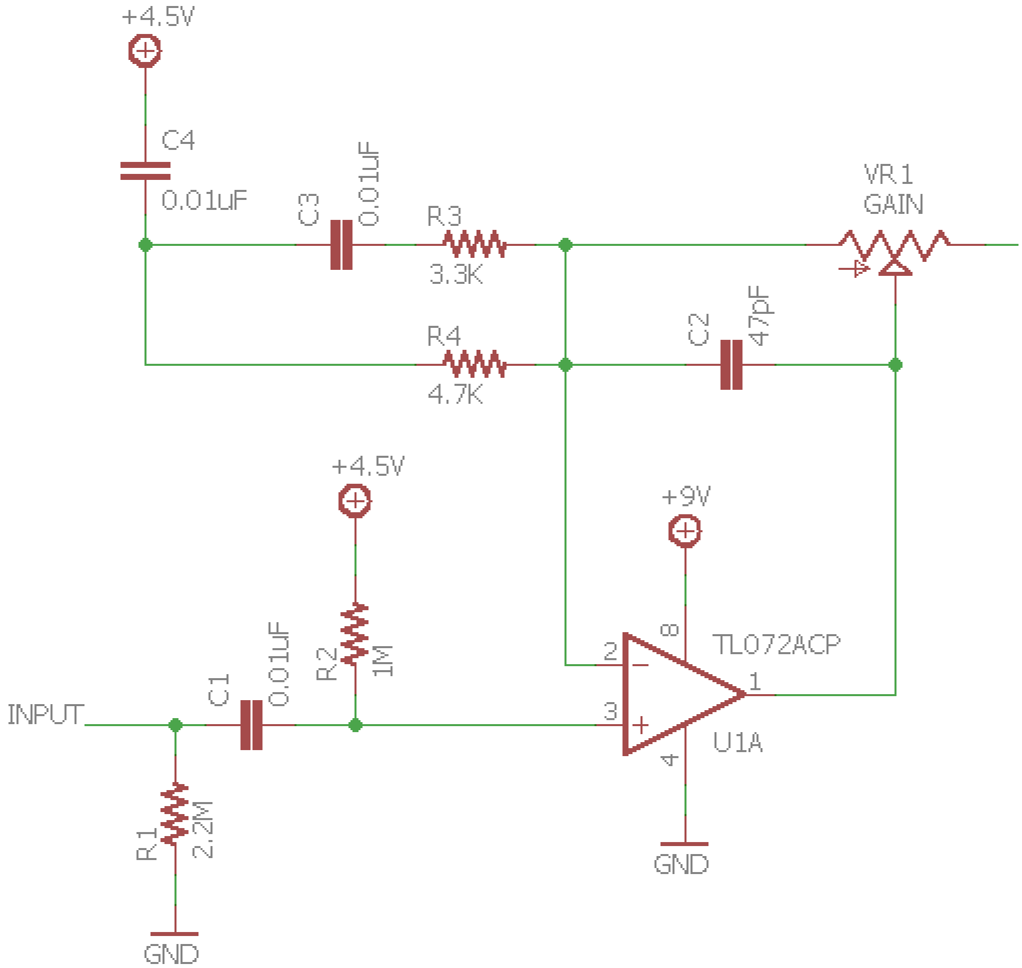


- The diode D5 protects the pedal against adapter reverse polarity connections.

- 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.

3. 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):



The 2.2MΩ R1 resistor from the input to ground is an anti-pop resistor, it will avoid abrupt pop sounds when the effect is engaged.

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

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

$fc = 1 / (2\pi \cdot R_2 \cdot C_1)$

$fc = 1 / (2\pi \cdot 1M \cdot 10nF)$

$fc = 1 / (2\pi \cdot 1{,}000{,}000 \cdot 0.00000001)$

$fc = 16\ Hz$

3.1 Input Impedance.

The input impedance is defined by the formula:

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

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

$$Zin = (2.2M \parallel 1M) \parallel 1{,}000{,}000{,}000{,}000$$
$$Zin = (687{,}500) \parallel 1{,}000{,}000{,}000{,}000$$
$$Zin = 687{,}499.53\Omega$$

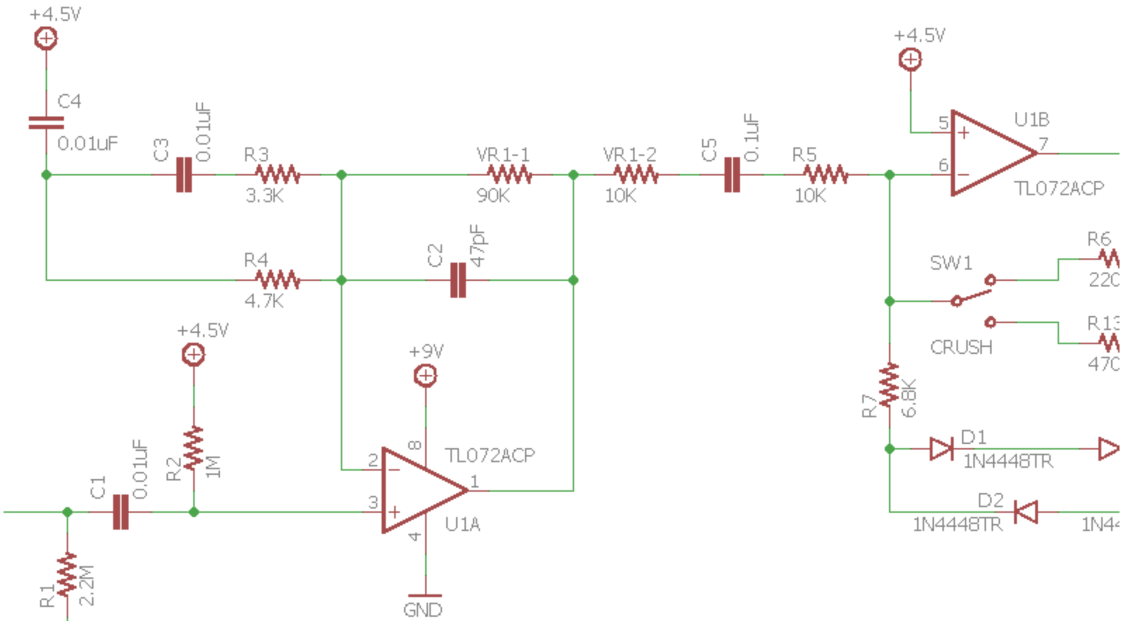
Therefore, the Blues Crusher input resistance is 687K, which isn't bad, but the closer to 1M it is, the better. Increasing R2 to 2.2M would bring the input resistance up to 1M, although that would also effect the input high pass filter.

3.2 Voltage Gain.

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

$$G_v = 1 + (R_{GAIN} / (R_3 \parallel R_4))$$
$$G_{vmin} = 1 + (0 / (3{,}300 \parallel 4{,}700)) = 1\ (0dB)$$
$$G_{vmax} = 1 + (100{,}000 / (3{,}300 \parallel 4{,}700)) = 52.58\ (34dB)$$

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.



3.3 Low Pass Filtering.

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.

Low pass Filter.

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:

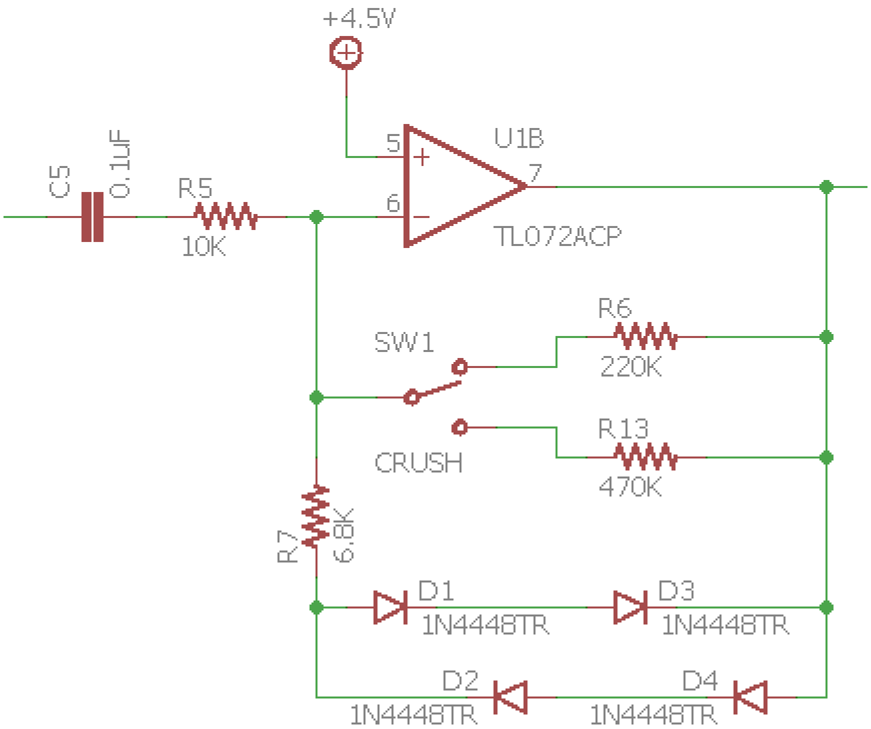
$$fc = 1 / (2\pi \cdot R_3 \cdot (1 / (1/C_3 + 1/C_4)))$$
$$fc = 1 / (2\pi \cdot 3{,}300 \cdot (1 / (1 / 0.00000001 + 1 / 0.00000001)))$$
$$fc = 1 / (2\pi \cdot 3{,}300 \cdot 0.000000005) = 9.65 \text{ kHz}$$

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

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 provoke that high frequency notes will be attenuated before the clipping action, making everything under, more clipped and creating a frequency selective distortion. This cleans the distortion up and makes it more “overdriven” than distorted.

4. Second Gain Stage.

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



While C5 and R5 create an RC filter, C5 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.

4.1 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, and everything below it gets progressively less gain and less distortion. Bass notes are clipped least, so the distortion is frequency selective.

4.2 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.

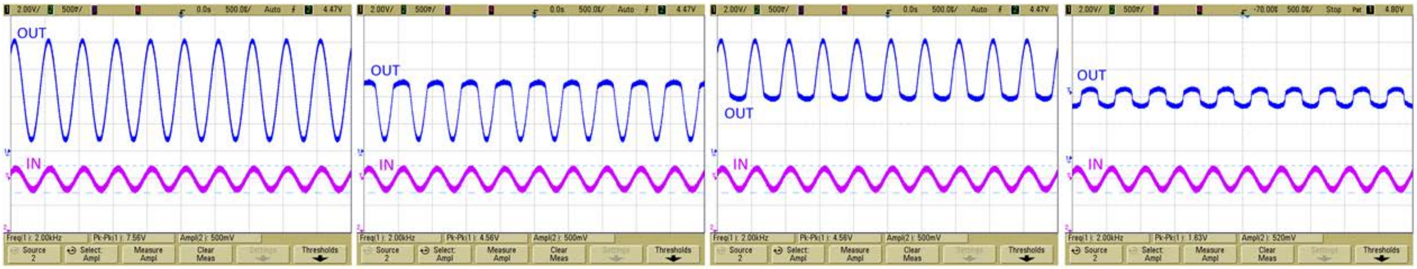
4.3 Clipping Diodes.

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.

Because of R7, the 6.8K resistor tames the soft clipping a little, making the clipping less harsh.

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), changing the gain of the inverting opamp from a high value (22 to 47) down to 1.

The diode D1+D3 will clip the positive semi-cycle signal and D2+D4 will clip the negative signal semi cycle:



D1 + D3 = Disconnected
D2 + D4 = Disconnected

D1 + D3 = Connected
D2 + D4 = Disconnected

D1 + D3 = Disconnected
D2 + D4 = Connected

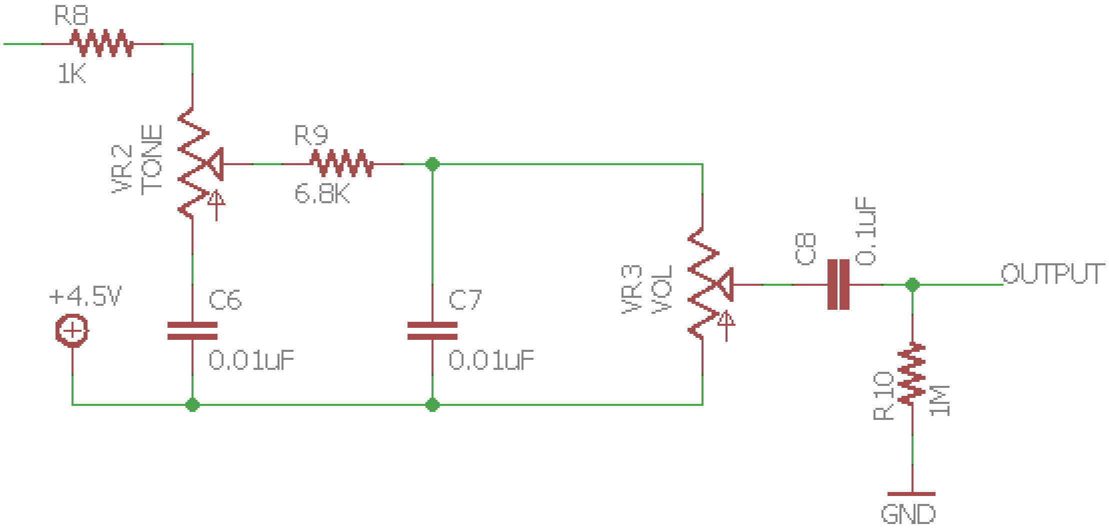
D1 + D3 = Connected
D2 + D4 = Connected

The oscilloscope image shown above depicts the difference between the pedal input signal (pink) and the output of the clipping stage (blue), removing any of the diode pairs D1+D3 or D2+D4 will result in an asymmetric clipping.

As a rule of thumb, the nominal output amplitude of most pickups is between 60 to 200 mV (single coils) and 200 to 600 mV (humbuckers and hot pickups), with hot pickups the picking transient can be as high as 2V peak.

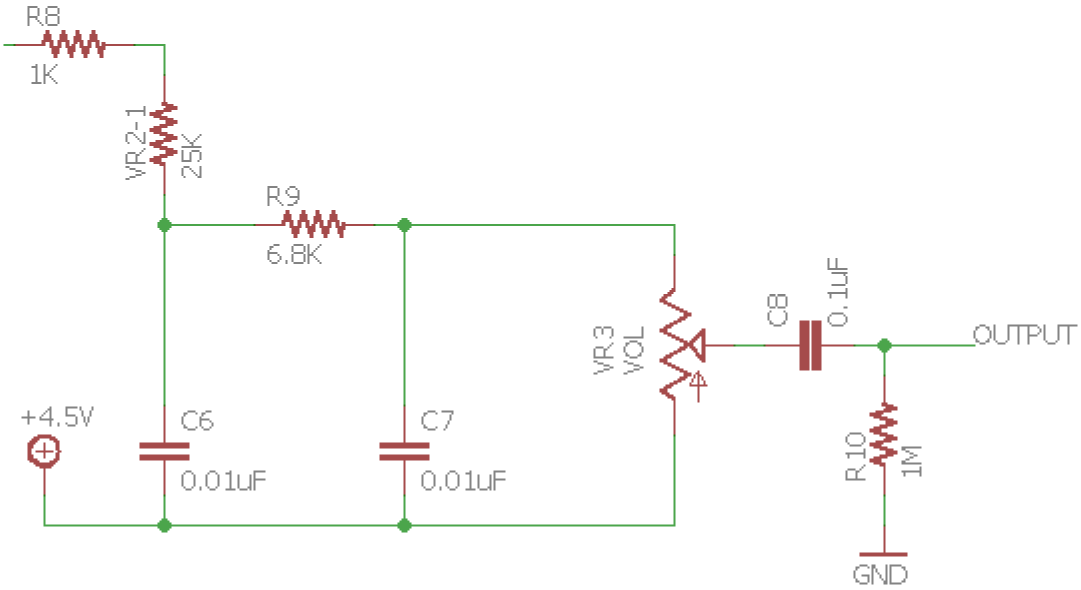
5. Tone Level Stage.

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.



C8 and R10 form a high pass filter cutting out DC harmonics around the 1.6 Hz frequencies.

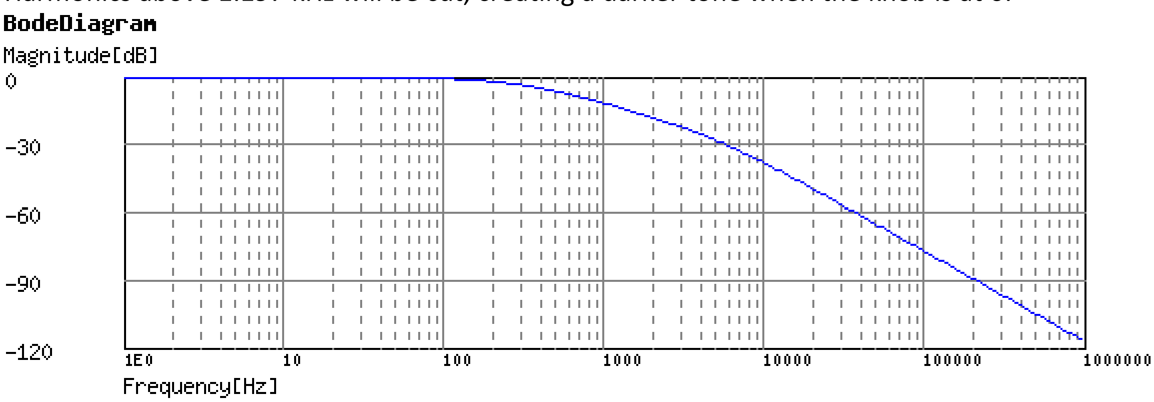
5.1 Tone Frequency Response.



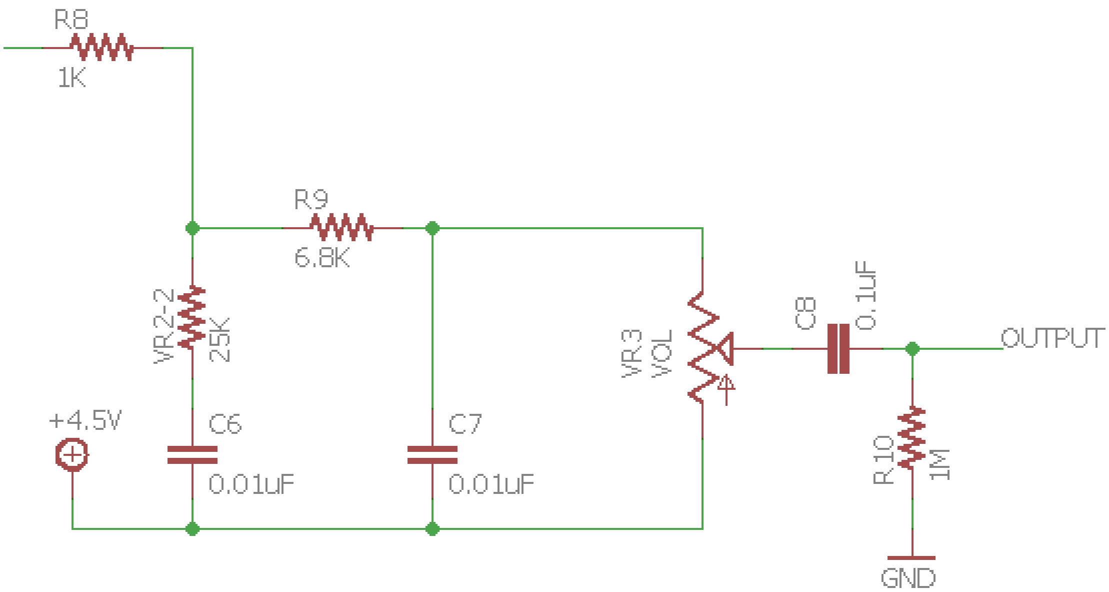
If the tone knob is dialed all the way down to a 0, the schematic for the tone section could be represented schematically by the circuit above. This means we have a low-pass filter of R8+VR2-1 and C6 along with R8+VR2-1+R9 and C7. As this is a second order low-pass filter, the cut off could be calculated as:

$$fc = 1 / (2\pi \cdot \sqrt{((R_8 + VR_{2\text{-}1}) \cdot C_6 \cdot R_9 \cdot C_7)})$$
$$fc = 1 / (2\pi \cdot \sqrt{((1{,}000 + 25{,}000) \cdot 0.00000001 \cdot 6{,}800 \cdot 0.00000001)})$$
$$fc = 1 / (2\pi \cdot \sqrt{(26{,}000 \cdot 0.00000001 \cdot 6{,}800 \cdot 0.00000001)})$$
$$fc = 1 / (2\pi \cdot \sqrt{(0.00000001768)})$$
$$fc = 1 / (2\pi \cdot 0.000132966161110887573)$$
$$fc = 1 / 0.00083545102983136173844872218395 = 1{,}197 \text{ Hz}$$

Harmonics above 1.197 kHz will be cut, creating a darker tone when the knob is at 0.



As the tone knob goes from 0 to 10, less and less of the signal goes towards the C6 capacitor, practically changing the second order low-pass filter to a single order between R8 + R9 and C7.



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.

6. Modifications

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

6.1 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

6.2 Capacitors

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 tonestack.

6.3 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". Using red, green, yellow, or blue LEDs in place of diodes can also work. If less clipping is desired, shunting D3 and D4 and therefore, only populating D1 and D2 can effectively clip less. Also, creating levels of asymmetrical clipping may be desired for a "less compressed" feel by shunting only D4, but populating D1, D2, and D3.

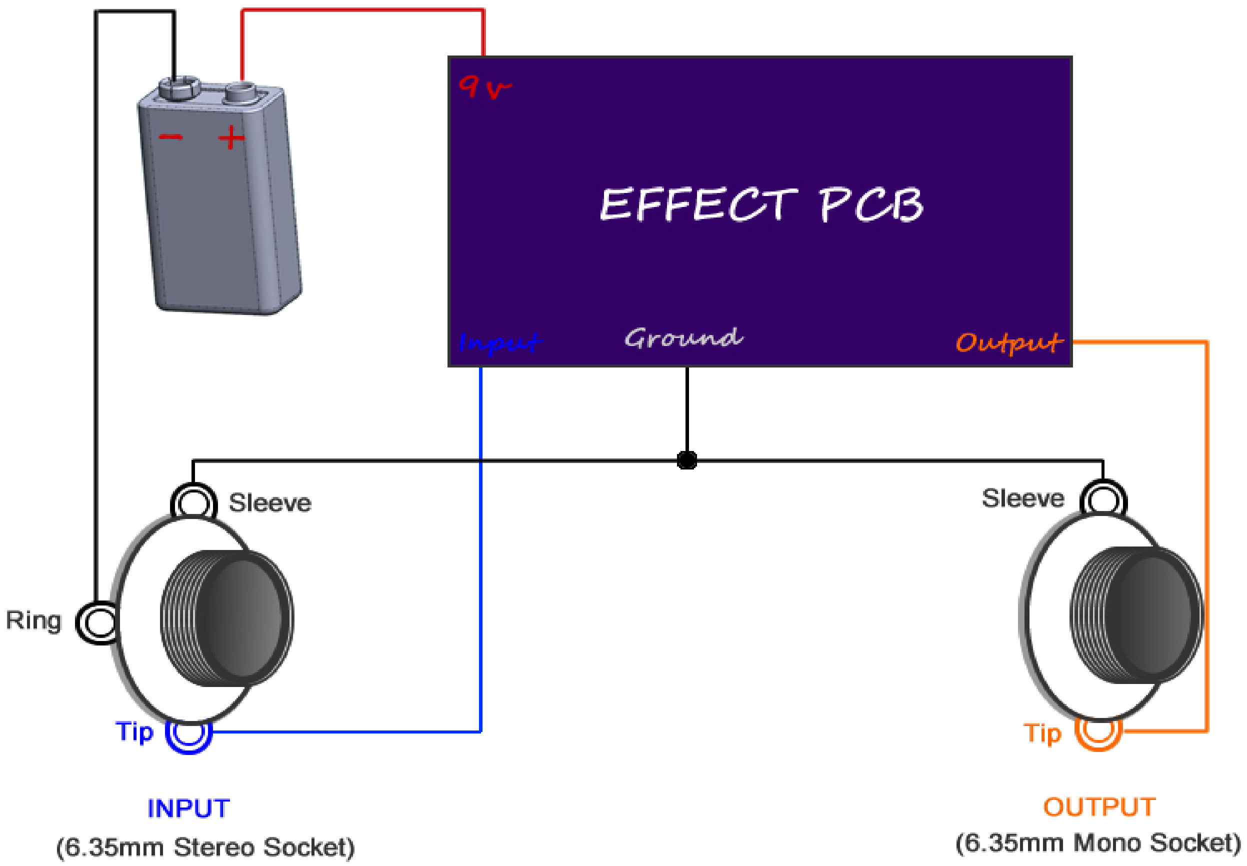
If no soft clipping is desired, simply not populating any of the diodes will accomplish this. However, the dual gain structures of the op-amps will still overdrive the guitar amplifier in front of it due to op-amp clipping.

6.4 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.

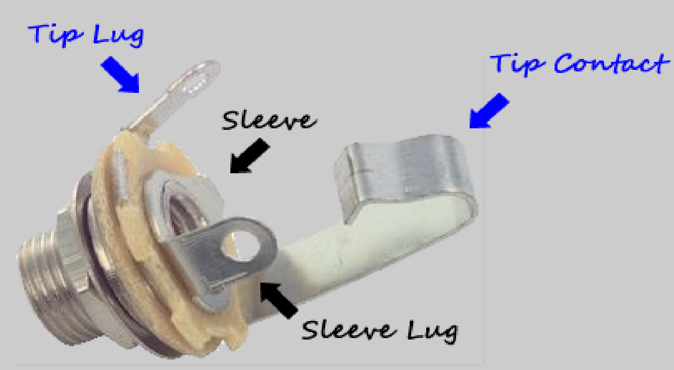
Testing Your Effect

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



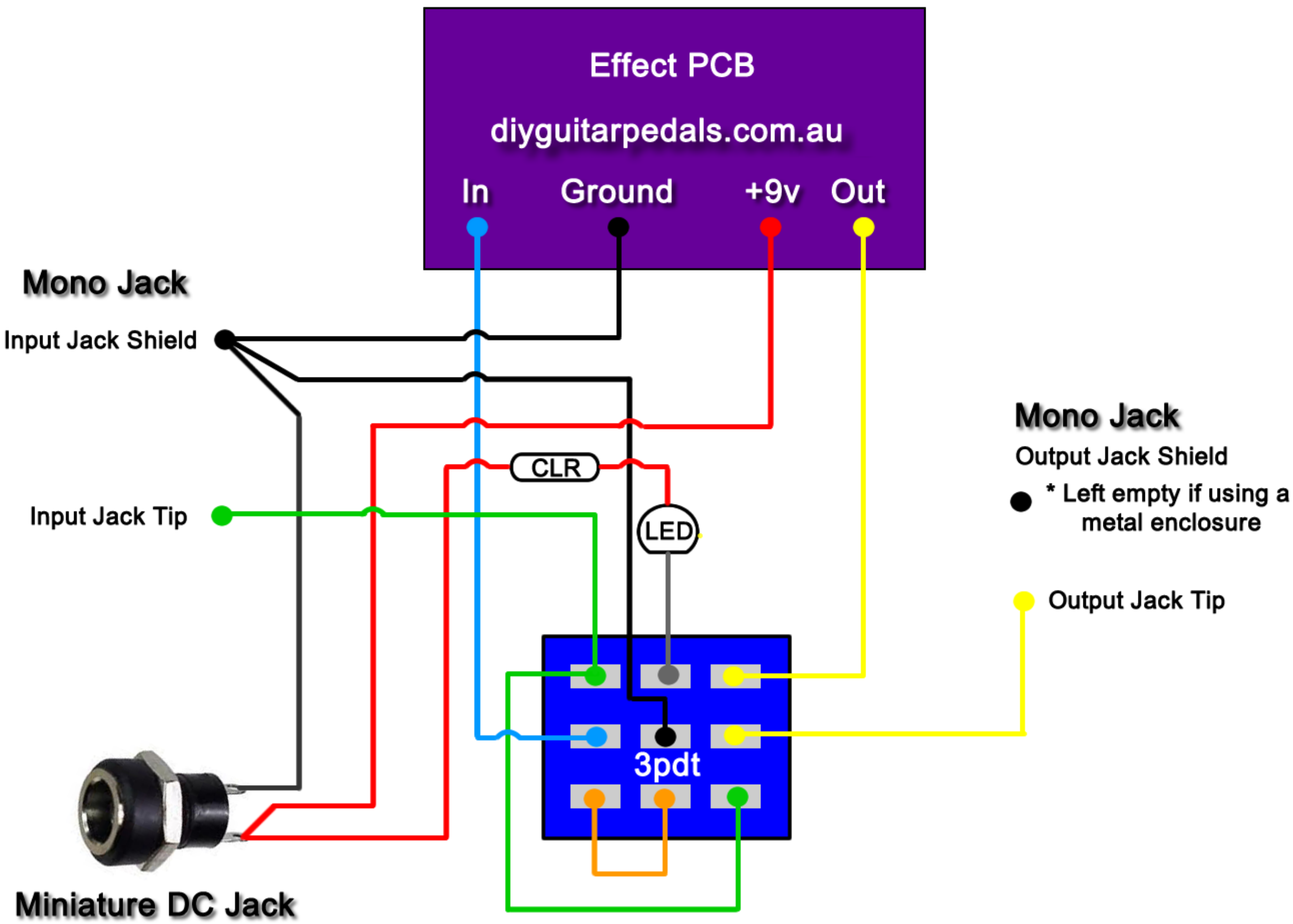
Input and Output Sockets

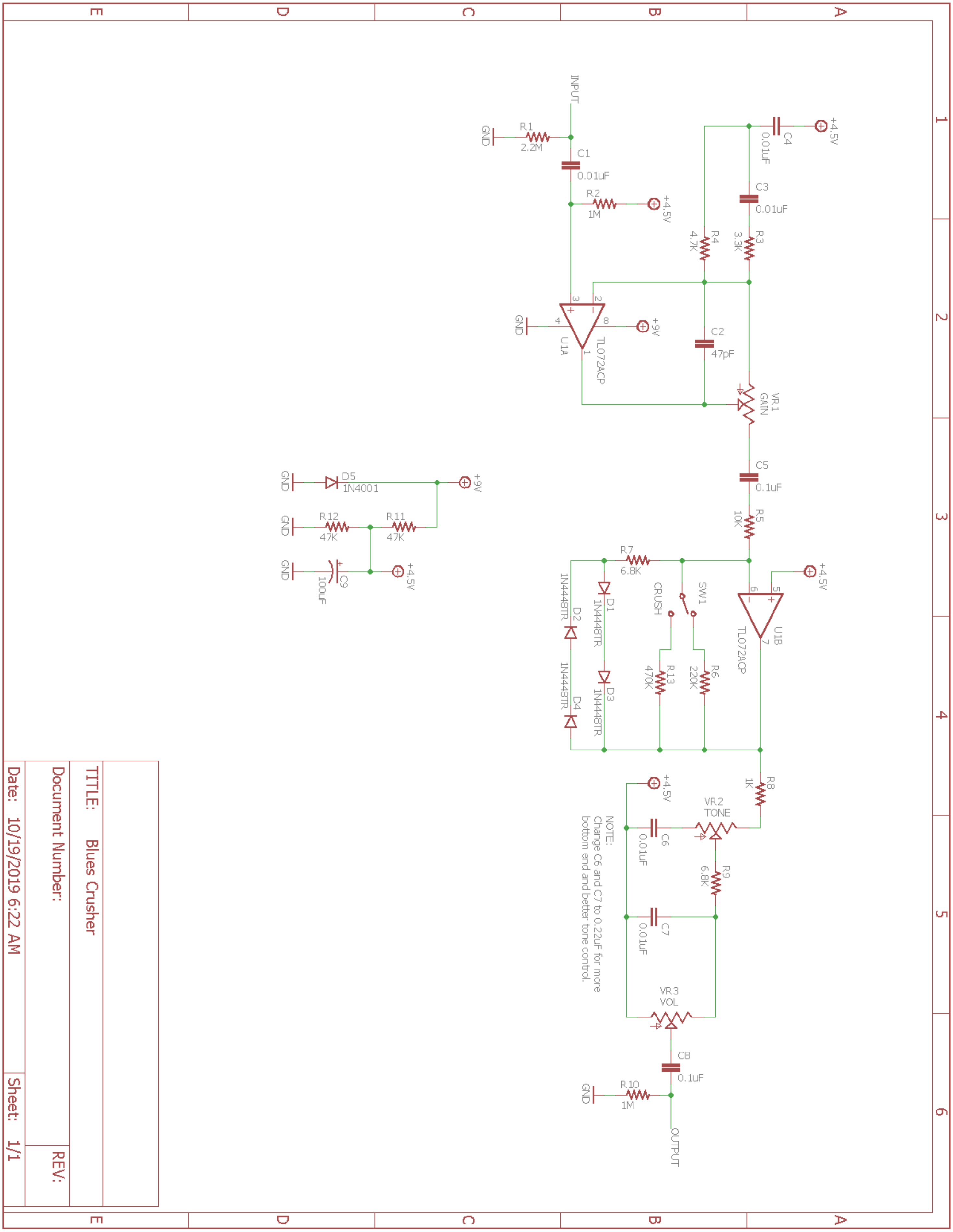
Pay close attention to the lugs of your sockets. Look at them side on so that you can distinguish the sockets individual layers. For instance the tip lug is connected to tip contact. The stereo jack looks the same as the socket below except it has an extra lug and contact for "Ring".

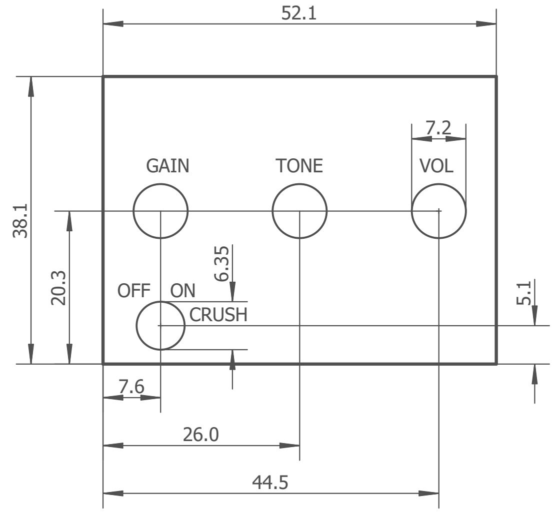


Off Board Wiring Diagram

Using a non-switched Miniature DC Jacks and 2 Mono Jacks




INPUT
R1 2.2M
GND
C1 0.01uF
R2 1M
+4.5V
C4 0.01uF
C3 0.01uF
R3 3.3K
R4 4.7K
C2 47pF
U1A TL072ACP
+9V
VR1 GAIN
C5 0.1uF
R5 10K
R7 6.8K
SW1 CRUSH
R6 220K
R13 470K
D1 1N4448TR
D2 1N4448TR
D3 1N4448TR
D4 1N4448TR
U1B TL072ACP
R8 1K
VR2 TONE
C6 0.01uF
R9 6.8K
C7 0.01uF
VR3 VOL
C8 0.1uF
R10 1M
OUTPUT
NOTE: Change C6 and C7 to 0.22uF for more bottom end and better tone control.
D5 1N4001
R11 47K
R12 47K
C9 100uF
TITLE: Blues Crusher
Document Number:
REV:
Date: 10/19/2019 6:22 AM
Sheet: 1/1


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