Metal Oxide Fuzz

Design By Erik Vincent

REV B

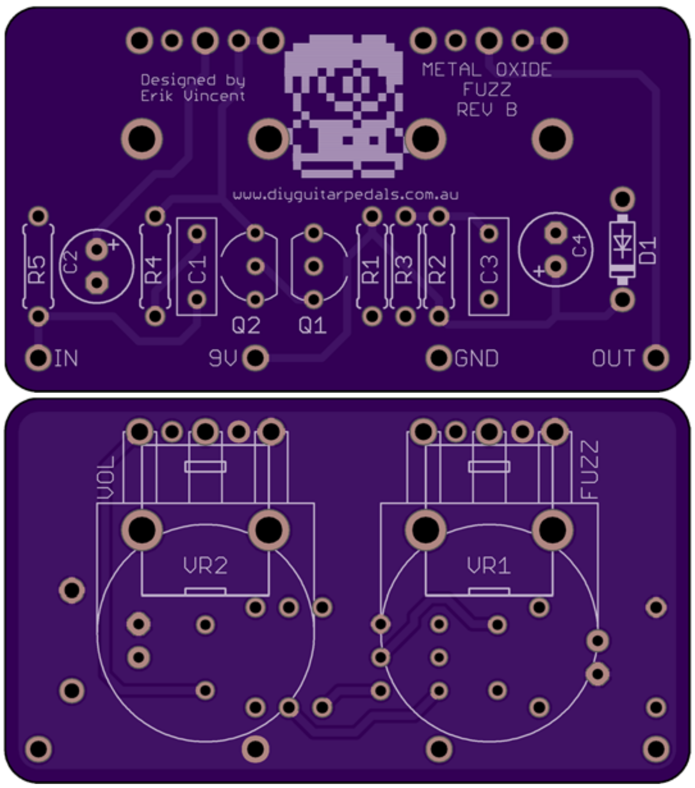
A new spin on an old classic; the metal oxide fuzz is a MOSFET fuzz face adaption!

Perfect for the first-time project of a newly budding guitar pedal enthusiast with its dozen piece part count. This pedal uses the standard 2 pot control of Volume and Fuzz. Using easy-to-find components, including silicon transistors and MOSFETs, this design still embodies the classic 2 stage amplifier with a feedback network path circuit of an original Fuzz Face. The layout is small enough to fit into a 1590B enclosure and still have plenty of room to work with. Build yours today!

- ✓ Simple construction / beginner friendly
- ✓ No sourcing of expensive and antiquated parts
- ✓ Unique MOSFET fuzz face adaption
- ✓ Negative ground (no charge pump required).

Bill of Materials, Stock Metal Oxide Fuzz, Rev B

Capacitor		Resistor	
C1	100nF (film)	**R1**	100K
C2	22µF (Electrolytic)	**R2**	1K
C3	100nF (film)	**R3**	5.6K
C4	47µF (Electrolytic)	**R4**	100K
		R5	1M
Diode			
D1	1N4007		
Transistor/MOSFET		**Potentiometer**	
Q1	2N5088	**Fuzz**	1kb (16mm or 9mm)
Q2	BS170	**Volume**	500ka (16mm or 9mm)

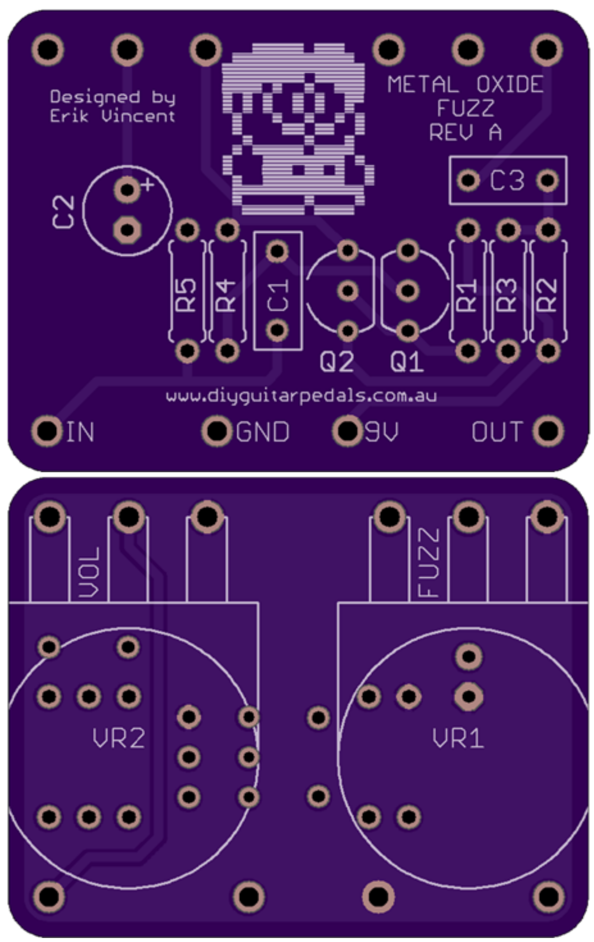


PCB Spacing
The Metal Oxide Fuzz PCB is spaced for 1590B sized enclosures or larger

Pot Spacing
The Metal Oxide Fuzz PCB mounted potentiometers are spaced for Alpha 16mm or 9mm potentiometers.

Bill of Materials, Stock Metal Oxide Fuzz, Rev A

Capacitor		Resistor	
C1	100nF (film)	**R1**	100K
C2	22µF (Electrolytic)	**R2**	1K
C3	100nF (film)	**R3**	5.6K
		R4	100K
Transistor/MOSFET		**R5**	1M
Q1	2N5088	**Potentiometer**	
Q2	BS170	**Fuzz**	1kb (16mm)
		Volume	500ka (16mm)



PCB Spacing

The Metal Oxide Fuzz PCB is spaced for 1590B sized enclosures or larger

Pot Spacing

The Metal Oxide Fuzz PCB mounted potentiometers are spaced for Alpha 16mm potentiometers.

Assembly.

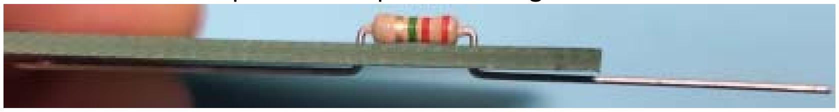
1. Soldering Order.

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

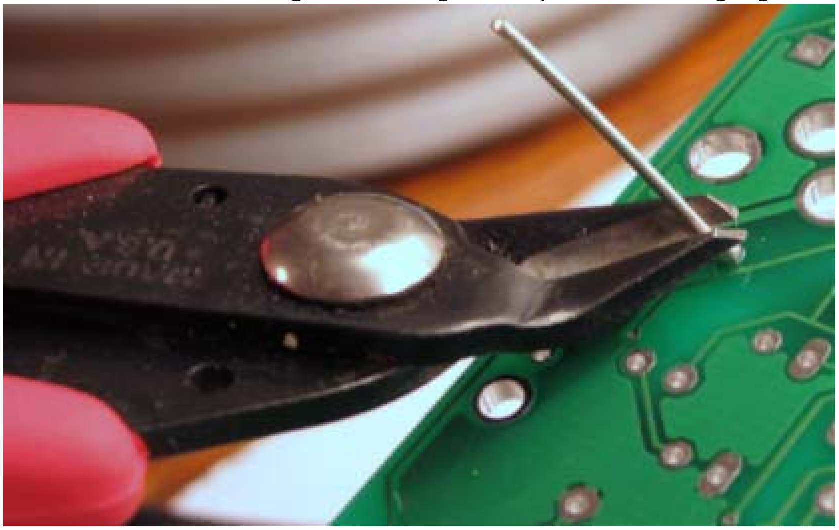
For the Metal Oxide Fuzz, the best order would be: resistors, transistors, film capacitors, electrolytic capacitors, wiring, and then potentiometers.

1.1 Resistors.

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

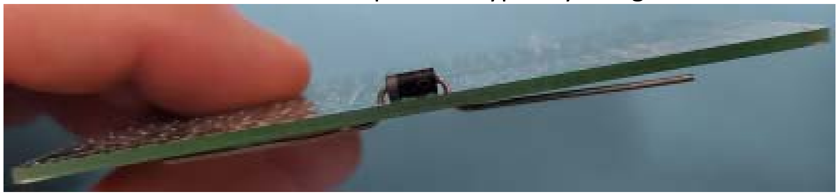


For this pedal we will be using 1/4 Watt resistors. These can either be 5% tolerance carbon resistors, or 1% tolerance metal film resistors. Orientation of "which way is up" doesn't matter, so you can install them either way. After installation and soldering, do not forget to clip the remaining legs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

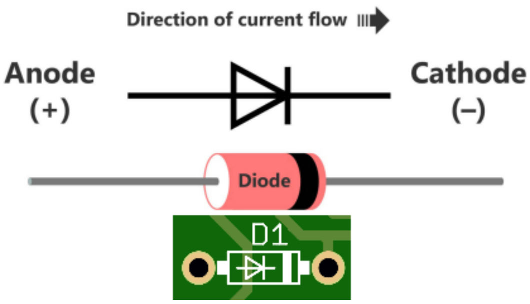


1.2 Diodes.

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

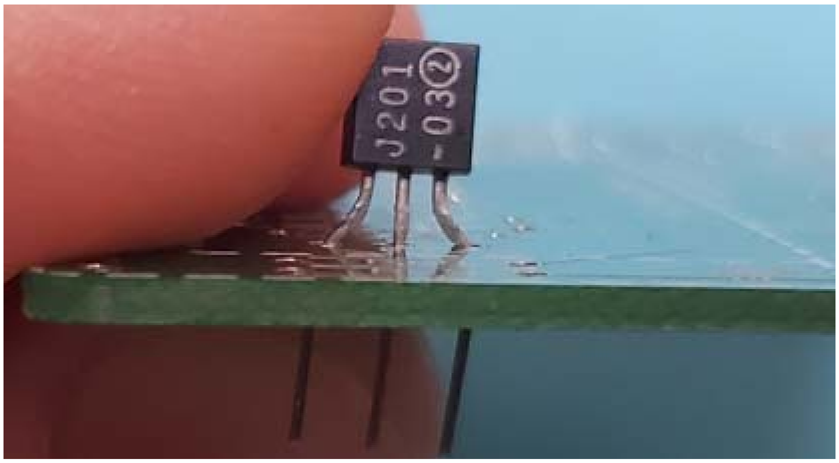


The orientation of a diode does matter based on the cathode and anode of the diode in the circuit. Make sure the stripe on the diode lines up with the stripe on the PCB's silkscreen. After installation and soldering, do not forget to clip the remaining legs from the PCB.

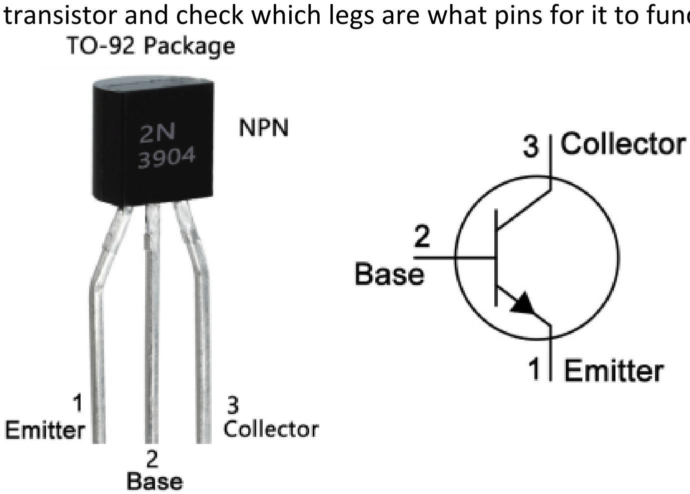


1.3 Transistors/FETs (silicon).

These semiconductor devices come in a few categories, such as BJT, JFET, MOSFET, and IGBT and are used for a variety of functions

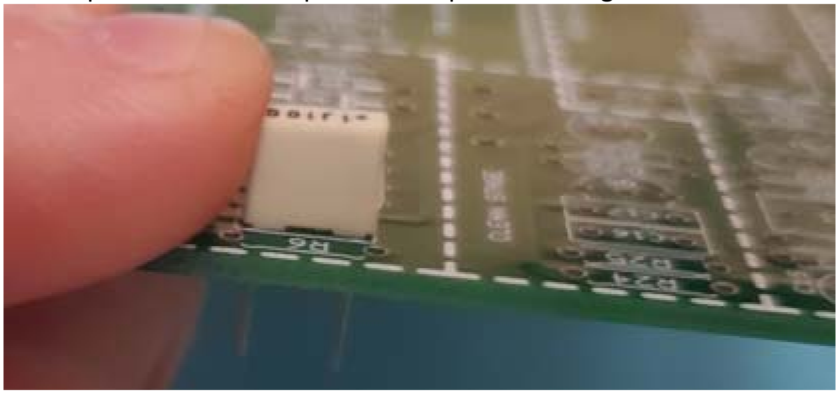


These devices typically only install one way, but pinouts can differ from different part numbers, so if using a different part number transistor than the one called out in the bill of materials will require that you check the datasheet of the transistor and check which legs are what pins for it to function properly.



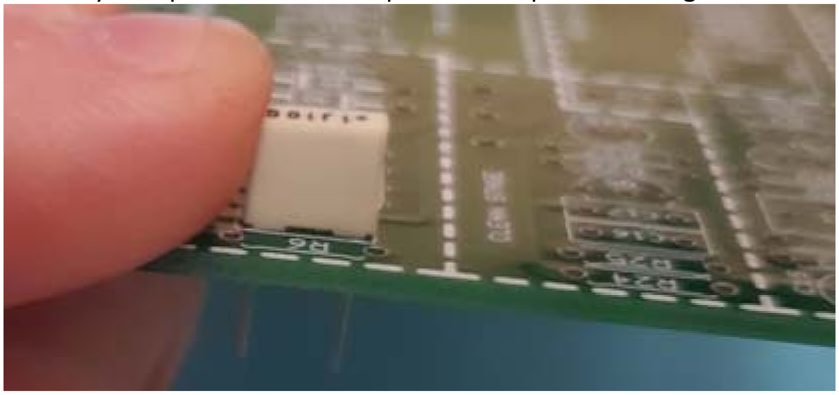
After installation and soldering, do not forget to clip the remaining legs from the PCB.

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

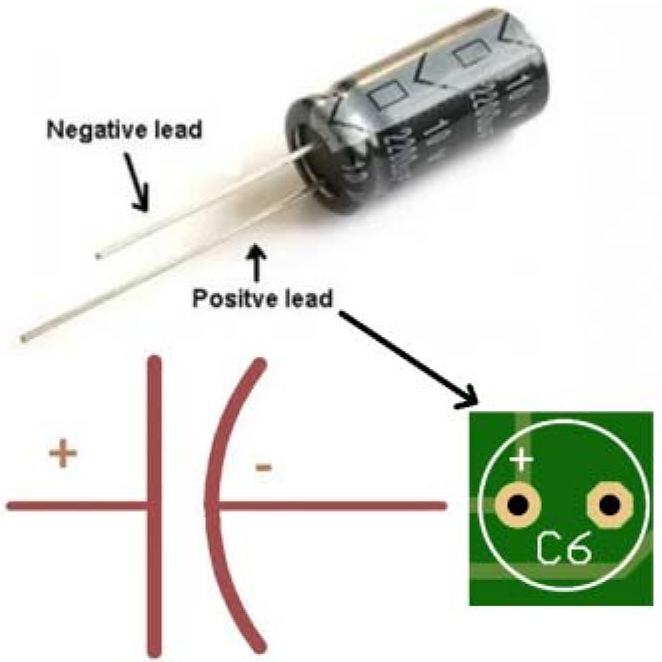


Orientation of “which way is up” doesn’t matter, so you can install them either way. After installation and soldering, do not forget to clip the remaining legs from the PCB.

1.5 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.

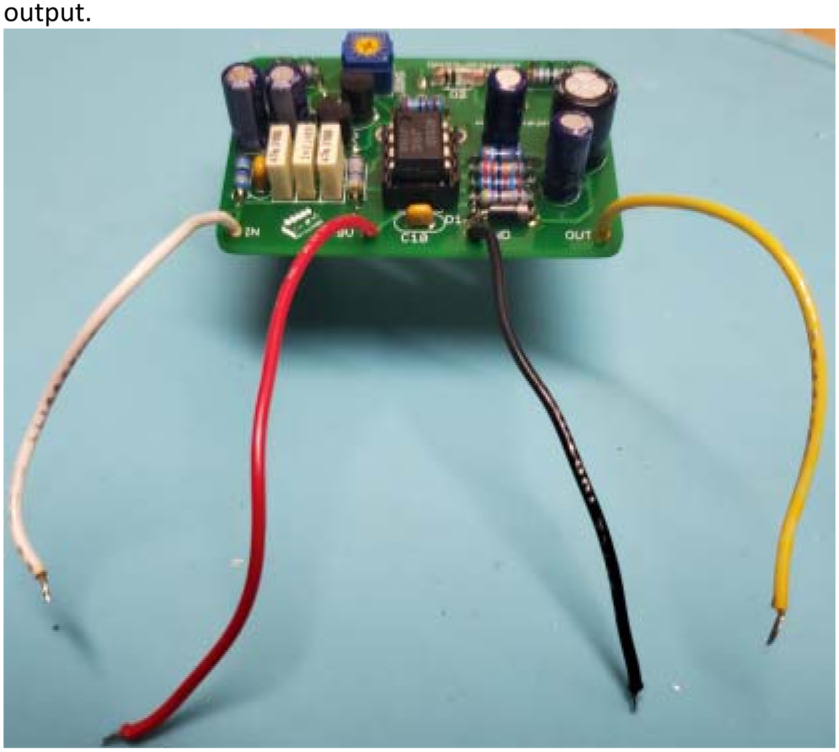


Polarized Electrolytic Capacitor and its electric Symbol

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

1.6 Wiring.

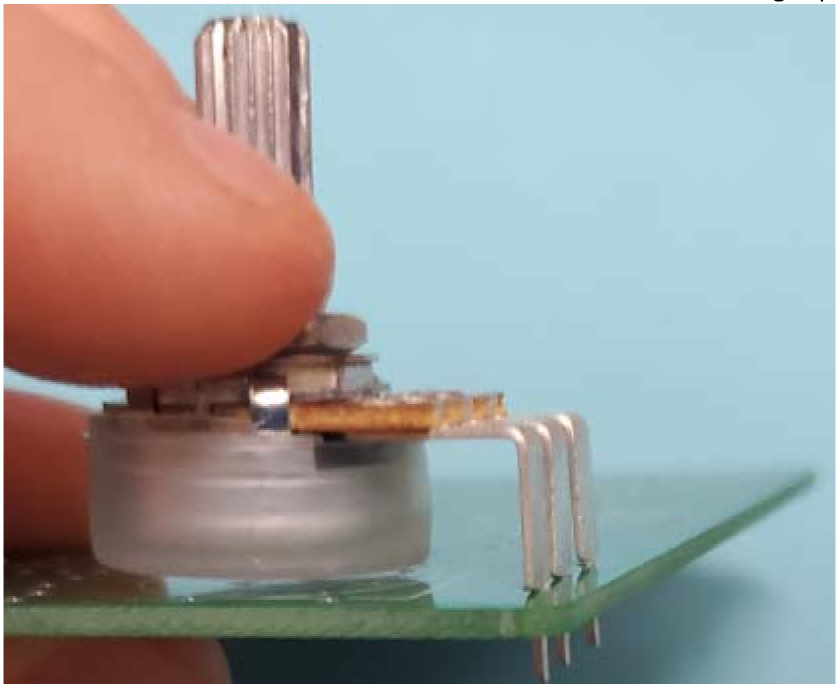
Wires used for the pedal are for delivering power over the hot and ground wires as well as signal for the input and output.



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.

1.7 Potentiometers.

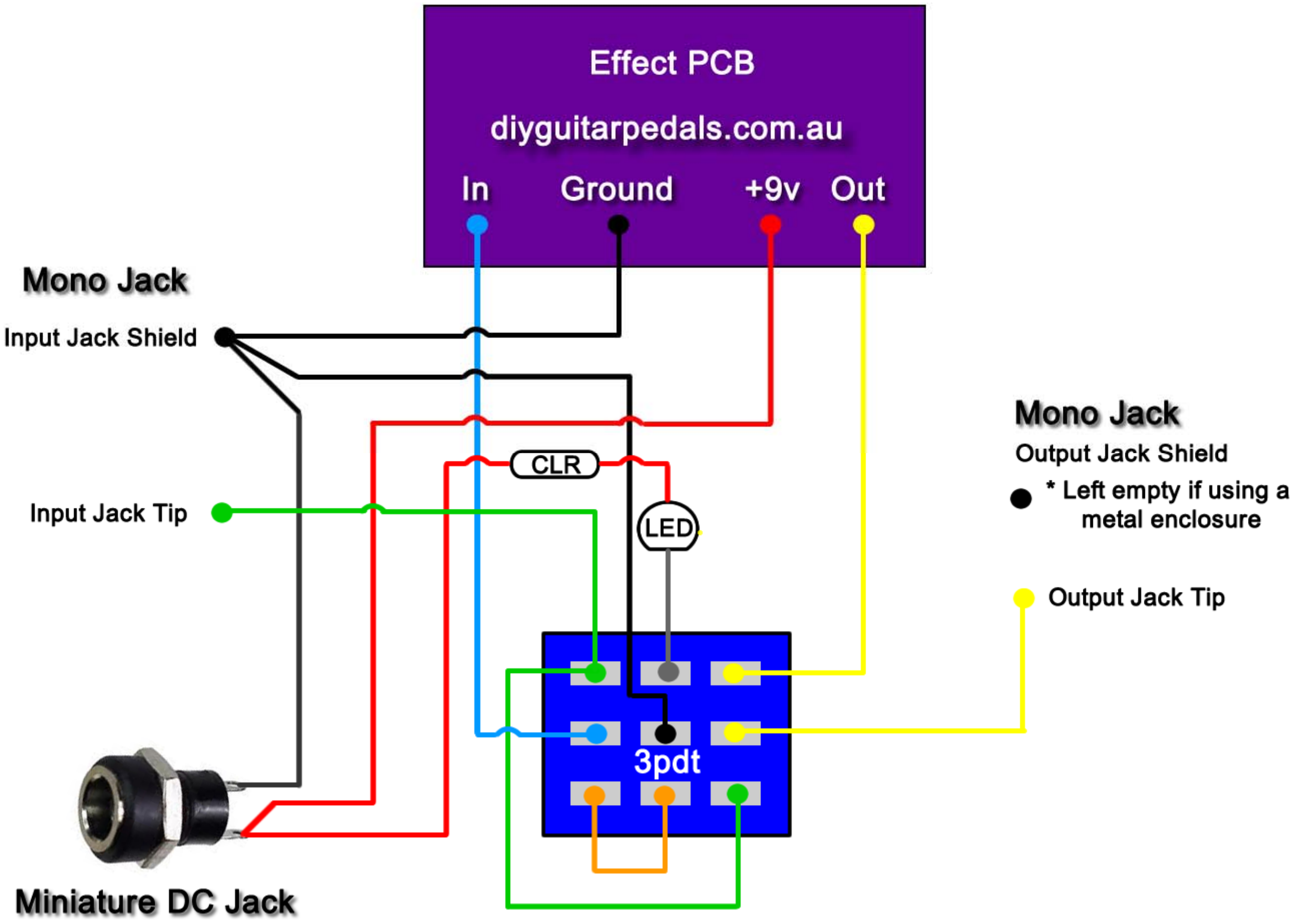
Potentiometers are variable resistors that are used for controlling aspects of the pedal.



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.

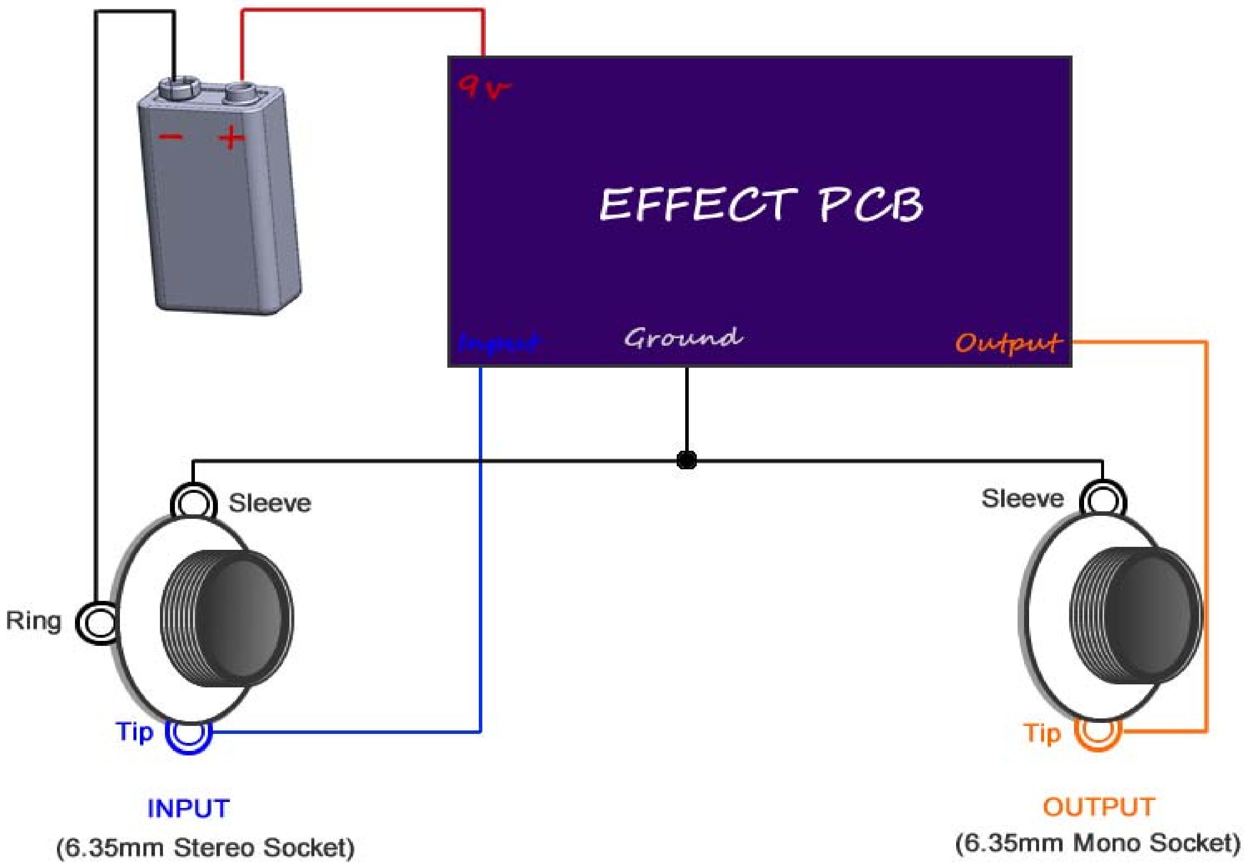
1.8 Off Board Wiring Diagram.

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


Effect PCB
diyguitarpedals.com.au
In
Ground
+9v
Out
Mono Jack
Input Jack Shield
Input Jack Tip
CLR
LED
3pdt
Mono Jack
Output Jack Shield
* Left empty if using a metal enclosure
Output Jack Tip
Miniature DC Jack

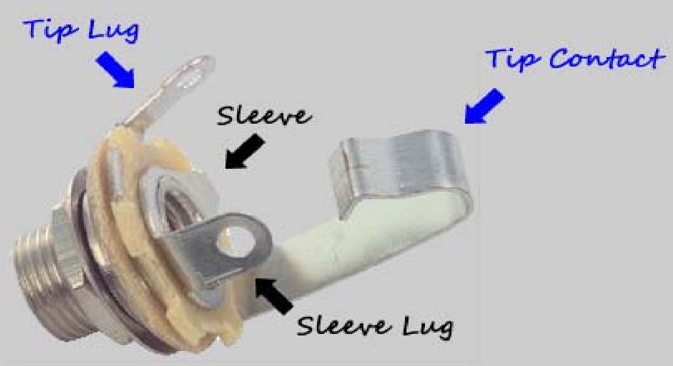
Testing Your Effect

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



Input and Output Sockets

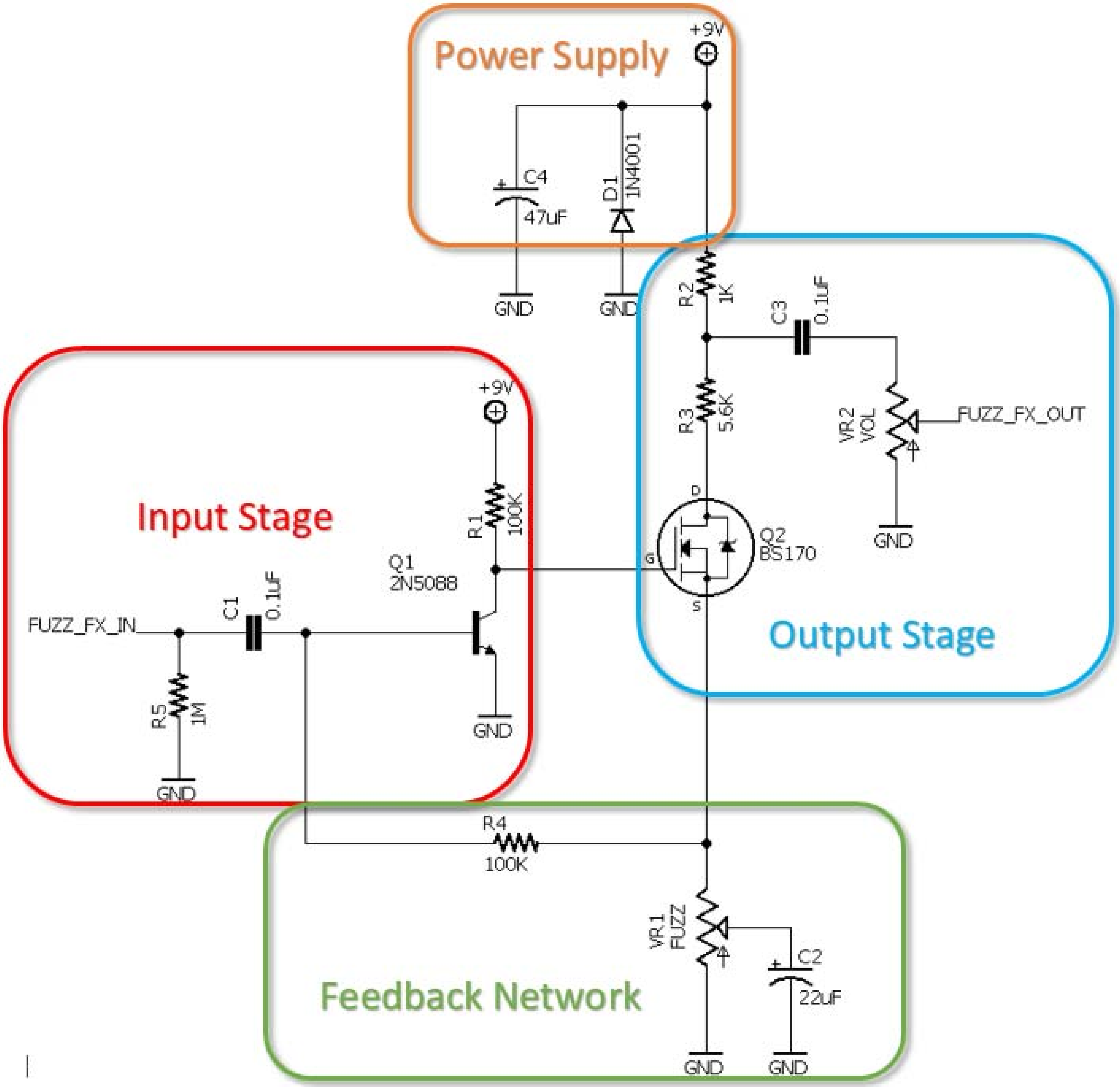
Pay close attention to the lugs of your sockets. Look at them side on so that you can distinguish the sockets individual layers. For instance the tip lug is connected to tip contact. The stereo jack looks the same as the socket below except it has an extra lug and contact for "Ring".



Metal Oxide Fuzz Circuit Analysis for modifying purposes.

2. Metal Oxide Fuzz Circuit.

The Metal Oxide Fuzz schematic can be broken down into some simpler blocks: Power Supply, Input Stage, Feedback Network, and Output Stage.

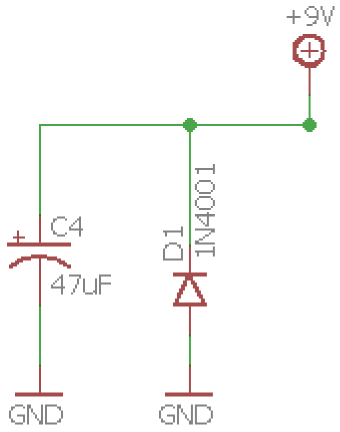


The circuit is designed around a BJT-MOSFET pair for gain. In Rev B, we added C4 and D1 to make the circuit a little more robust.

The input impedance on the Metal Oxide Fuzz is close to 3.5K Ω, which is very low and will load guitar pickups. A recommendation would be to put this pedal first on the pedal chain, just after the guitar.

3. Power Supply.

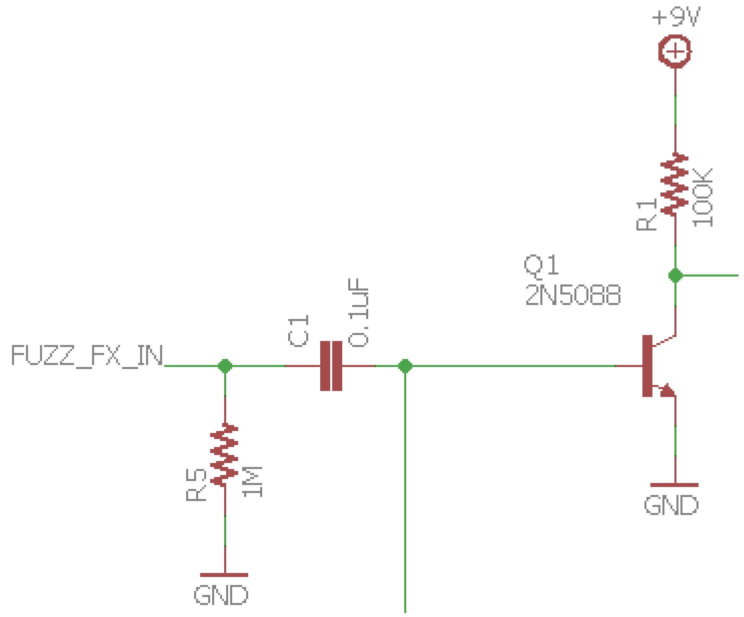
The Power Supply Stage provides the electrical power to all the circuitry, the whole power consumption is low and estimated around 1mA:



- The diode D1 protects the pedal against adapter reverse polarity connections.
- The electrolytic C4 is a simple bulk capacitor to keep the circuit from slumping in voltage.

3. Input Stage.

The input stage is a Common Emitter NPN amplifier. It provides a high voltage gain with low input impedance and high output impedance. It is not the ideal input stage for signal integrity but the best for simplicity and fast high gain.



- The 1MΩ R5 resistor from the input to ground is an anti-pop resistor, it will avoid abrupt pop sounds when the effect is engaged.
- The 100nF C1 capacitor is a film capacitor used to couple the input of the incoming guitar signal and the rest of the circuit.
- The Q1 transistor just needs to be a low-noise/high-gain transistor (β = 90-700).
- The 100KΩ R1 resistor is a simple pull up resistor for the Q1 transistor.

3.1 Input Impedance.

Is equal to the input impedance of a common emitter stage. It can be calculated as:

$$Zin = Qin + (1 / ((1 / R_5) + (1 / (\beta \cdot re))))$$

Assuming the β (gain) of the Q1 transistor is 100, which are typical of the 2N5088 in this circuit and that the emitter leg signal resistance is 25mV / 1mA or 25Ω. VT is the thermal voltage of a transistor, at room temperature the value is approximately 25mV. The minimum impedance for the 2N5088, per the datasheet, at 1kHz is 1,000.

$$Zin = 1{,}000 + (1 / ((1 / 1{,}000{,}000) + (1 / (100 \cdot 25))))$$
$$Zin = 1{,}000 + (1 / ((1 / 1{,}000{,}000) + (1 / 2{,}500)))$$
$$Zin = 1{,}000 + (1 / (0.000001 + 0.0004))$$
$$Zin = 1{,}000 + (1 / 0.000401)$$
$$Zin = 1{,}000 + 2{,}494$$
$$Zin = 3{,}493\Omega\ (3.5K)\ @\ 1\ kHz$$

For this math calculation the feedback network is ignored but in practice, it will lower the input impedance closer to 3.4KΩ. The Metal Oxide Fuzz has a very low input impedance that will change with the position of the R_{FUZZ} potentiometer. So the feedback network has a big impact on this parameter.

As a rule of thumb, Zin should be at least 1 MΩ. In other pedals with similar input stages like the one in the Big Muff Pi a series resistor is placed at the input in order to higher the impedance (at the cost of creating a voltage divider that reduces the available input signal).

The Metal Oxide Fuzz low input impedance will load the guitar pickups. This is the reason why they do not respond well when they are placed after other pedals, it is best to place it first, or before them, in the pedal chain. However, due to this property, it responds to the guitars volume knob very well.

3.2 Voltage Gain of the Input Stage.

In a Common Emitter transistor the voltage gain does require a bit of math to calculate and requires some assumed data beforehand.

- First, we need to assume our pedal is being powered by 9V.
- Second, we need to know the thermal voltage of the transistor, which is approximately 25mV (sometimes expressed at 26mV, depending on assumed temperature)
- Third, we need to know what the collector voltage for Q1 is at when no signal is going into the pedal. Typically, this is found to be at 2.54V when using 2N5088 transistors on this circuit. They can range from 2.5V – 2.7V depending on tolerances.

With this information, we can now calculate the gain of the first stage. First, we need to calculate the I_E, which is the DC emitter current. To calculate, we use the following formula:

$$I_E = (V_{CC} - V_C) / R_1 = (9V - 2.54V) / 100{,}000 = 0.0000646A = 0.0646mA$$

Next, we need to get the g_m, or measure of conductance of the transistor in this state. To calculate, we use the following formula:

$$g_m = I_E / V_T = 0.0646mA / 25mV = 0.002584$$

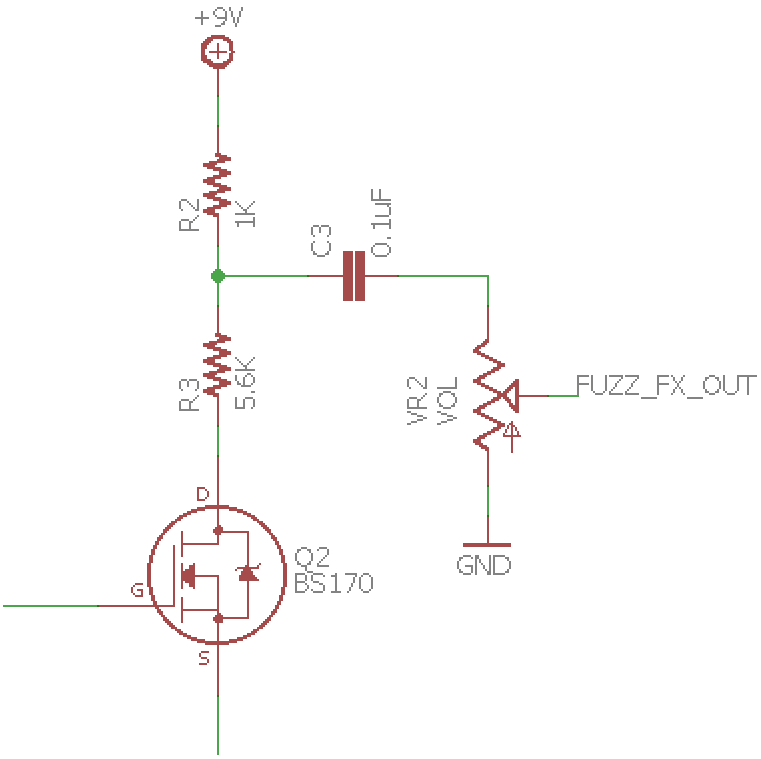
Lastly, we can now calculate voltage gain. To calculate, we use the following formula:

$$A_V = -g_m \cdot R_C = -g_m \cdot R_1 = 0.002584 \cdot 100K = 258.4\ (48.2dB)$$

In the real life, the input stage will not reach 48dB of gain, the feedback network will reduce this levels to 47 dB approx, assuming R4 is 100K and the 1K fuzz knob is maxed. It reduces the first stage gain to 36 dB when the 1K fuzz knob is at 0.

4. Output Stage.

The output stage is an Enhancement N-Channel MOSFET Common Source Amplifier coupled with a variable source degeneration resistor (RFUZZ=1KΩ).



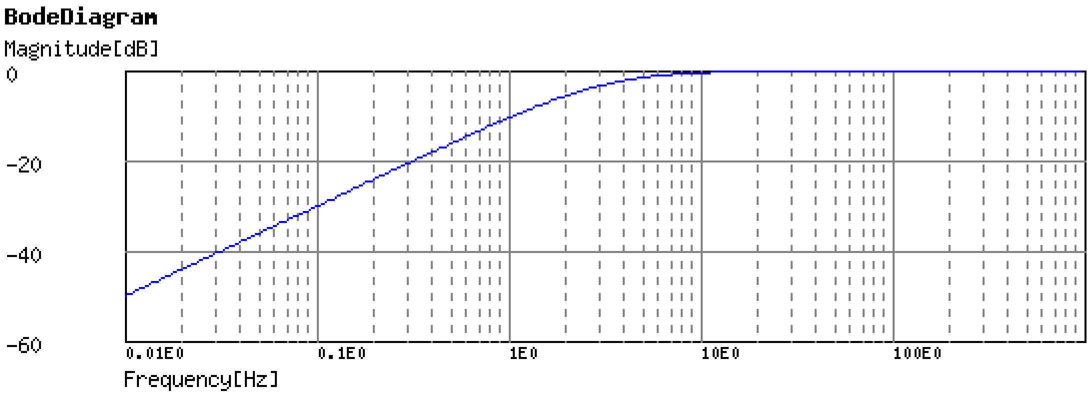
- The 1KΩ R2 resistor is the drain resistor for the Q2 MOSFET which help sets the voltage gain, bias points, and maximum drain current.
- The 5.6KΩ R3 resistor is the drain resistor for the Q2 MOSFET which help sets the voltage gain, bias points, and maximum drain current.
- The 100nF C3 capacitor is coupler capacitor to send the AC signal out to the volume potentiometer without any DC.
- The VR2 500K volume potentiometer is being used to control signal volume by sinking some of it to ground.
- The Q2 MOSFET is the core of this amplifier.

4.1 Output EQ Curve.

In regards to the output capacitor of C3, changing the volume pot from a 500K resistance pot to a 100K resistance pot changes the high pass filter response. For example, changing C3 from 100nF to 10nF and changing the pot to 100K will give a much higher cut-off, making the sound brighter.

$$fc = 1 / (2\pi RC)$$
$$fc = 1 / (2\pi \cdot R_{volMAX} \cdot C_3)$$
$$fc = 1 / (2\pi \cdot 500K \cdot 0.1uF)$$
$$fc = 1 / (2\pi \cdot 500{,}000 \cdot 0.0000001)$$
$$fc = 3.2\ Hz$$

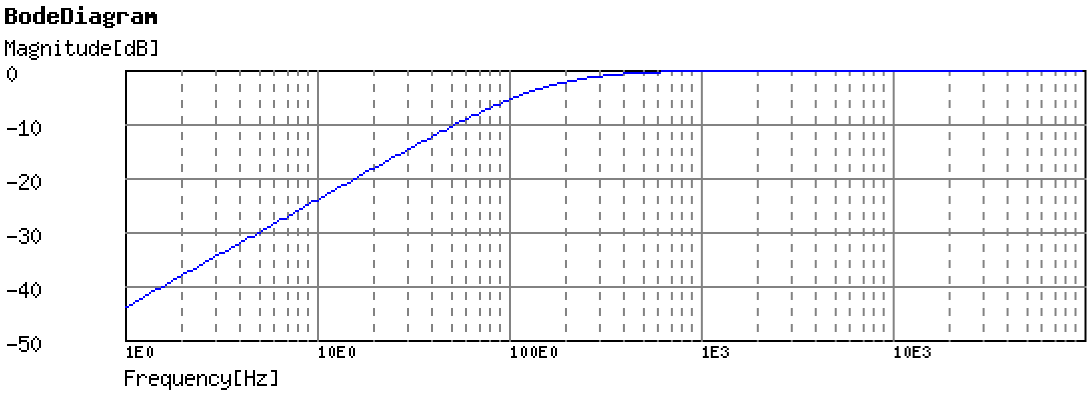
This basically starts cutting out the low frequencies below 3.2Hz, which basically is just cutting out DC noise from leaving the pedal and going into the next, which is a good thing. However, all the bass and sub frequency bass will leave the pedal if above 3.2Hz



So, using a 100K volume pot and 10nF C3 cap:

$$fc = 1/(2\pi RC)$$
$$fc = 1/(2\pi \cdot R_{volMAX} \cdot C_3)$$
$$fc = 1/(2\pi \cdot 100K \cdot 0.01uF)$$
$$fc = 1/(2\pi \cdot 100{,}000 \cdot 0.00000001)$$
$$fc = 160\ Hz$$

Now, frequencies get cut under 160Hz, still protecting the next pedal from low frequency DC noise, but also cuts a lot of the bass out of the exit of the pedal.



4.2 Output Impedance.

The value of the output impedance can be calculated using the formula:

$$Z_{out} = R_{vol} \text{ Parallel to } R_2$$
$$Z_{out} = 500K \text{ Parallel to } 1{,}000\ \Omega = 998\Omega$$

The output impedance is affected by the feedback network and has a real value of 1.88KΩ (measured at 1 KHz with RVOL=500KΩ). This value varies with the volume control level and the fuzz control position. It is, however, well-under 10KΩ of resistance in most situations, so it still is on the upper end of ideal.

4.3 Total Voltage Gain.

The source degeneration resistor RFUZZ creates a local negative feedback, making the second amplifier stage more stable and immune to gain variations due to temperature, bias current and transistor intrinsic properties.

With this source resistance added, the Common Source NPN major parameters (ignoring by the moment the feedback network) can be determined by the ratio between the drain resistors (R2 + R3) to and the source resistor (the portion of RFUZZ not shorted to ground through the 22uF cap).

$$A_V = R_C / R_E = (R_2 + R_3) / R_{FUZZ}$$

$$A_{Vmin} = (1K + 5.6K) / 1K = 6.6\ (16dB)$$

The voltage gain (AV) can go from 6.6 to as high as the transistor's basic internal gain (when RFUZZ is maxed out).

If we take into consideration the feedback network, once again the second stage will not reach values as 16dB. In this case, the total voltage gain measured at Q2 source is around 19.5dB. Remember that the input stage had a gain of 18.6 dB, that leaves the second stage a total amount of 1dB of gain (19.5-18.6=0.9dB). The general amount of gain is considerably reduced due to the feedback network.

But the output of the pedal is not directly taken from Q2 source, there is a voltage divider created by R2 and R3 (the power supply is effectively at AC ground). This divider reduces the gain by a factor of R2 / (R2 + R3) = 1000 / (1000 + 5600) = 0.1515 (-16.4dB), so the real gain of the output stage is:

$G_{VTOTAL} = GV_{PEDAL}$ - Attenuation of R2 / (R2 + R3) = 19.5 – 16.4 = 3.1dB

This voltage divider created by R2 and R3 will greatly reduce the output level. The value usually does not get as low as 3.1dB, the series resistor of the battery should be taken into consideration and will raise the output level.

It might look funny but it has a reason: the output signal is not much larger than the input signal to keep the huge amount of signal available from over-driving the input of the pedal or amplifier following it. The fuzz is not designed to overdrive the following system by level.

Metal Oxide Fuzz sounds different with different batteries and with the same battery as it gets run down. The internal series resistance of the battery is added to the 1K Ω R2 resistor, modifying the value by a significant amount.

Any impedance between C2 source and ground (RFUZZ) will reduce the gain of the output stage, it is a form of local negative feedback. Increasing this impedance will reduce the gain. If we are looking for high gain it is a common practice to have part or all of the source resistor grounded with a bypass capacitor.

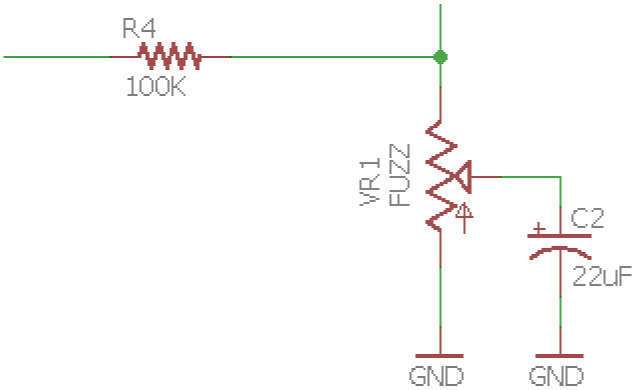
Capacitors present an impedance that decreases with frequency, the bias (DC) points will remain the same but high guitar (AC) signals will get higher voltage gain. In terms of design, the bypass capacitor C2 should have a reactance, at the lowest frequency you are interested to amplify, less than the value of RFUZZ. We can use the formula:

$$f_c = 1 / (2\pi RC) = 1 / (2\pi \cdot R_{pot1} \cdot C_2) = 1 / (2\pi \cdot 1K \cdot 22uF) = 7.2Hz$$

All the frequencies over 7.2Hz get full amplification. The 22uF is so big that almost all the frequencies get full amplification.

5. Feedback Network.

Amplifiers use current or voltage as input or outputs, you can check the amplifier classification. The Metal Oxide Fuzz has a negative feedback called shunt-series feedback (Current Controlled Current Source CCCS). Part of the output current is taken from Q2 drain and introduced as current in Q1 base, so the feedback resistor R4 is shunt connected with the input and in series connected with the output



Why using feedback?

In amplifier design the degenerative (negative) feedback is used to:

- Desensitize the gain: make the gain value less sensitive to transistors (i.e. component variation caused by temperature).
- Reduce nonlinear distortion: make the gain constant.
- Reduce the noise: minimizing the contribution to the output of unwanted electrical signals.
- Control the input/output impedance: raising or lowering their values.
- Extend the bandwidth of the amplifier.

The properties above are obtained at the expense of a reduction of gain. As a rule of thumb with more feedback, there is less global gain, following the formula:

$$A_{FB} = A_{OL} / (1 + B_{FB}A_{OL})$$

Where

AFB = Total current gain of the amp in the closed loop.

AOL = Current gain of the amp in open loop

B = Feedback constant (not to be confused with the transistors β parameter).

When the fuzz control increases the attack, the 22uF C2 cap will gradually shunt the negative feedback to the ground, thus letting the circuit operate with more gain (right image below).

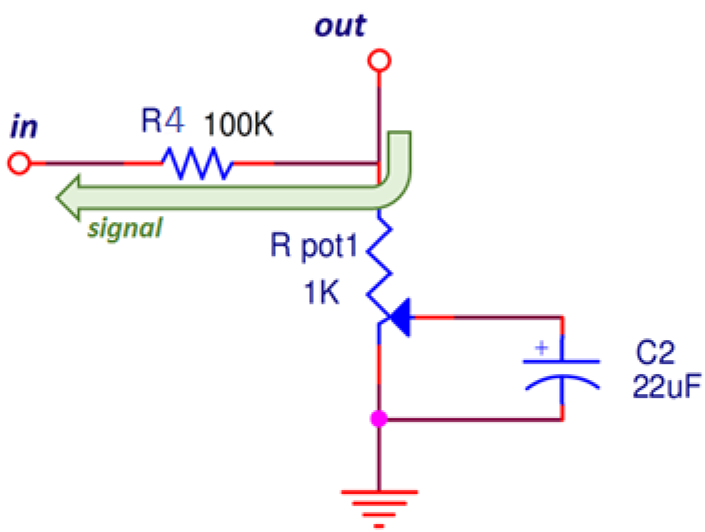
Where

- AFB = Total current gain of the amp in the closed loop.
- AOL = Current gain of the amp in open loop
- B = Feedback constant (not to be confused with the transistors β parameter).

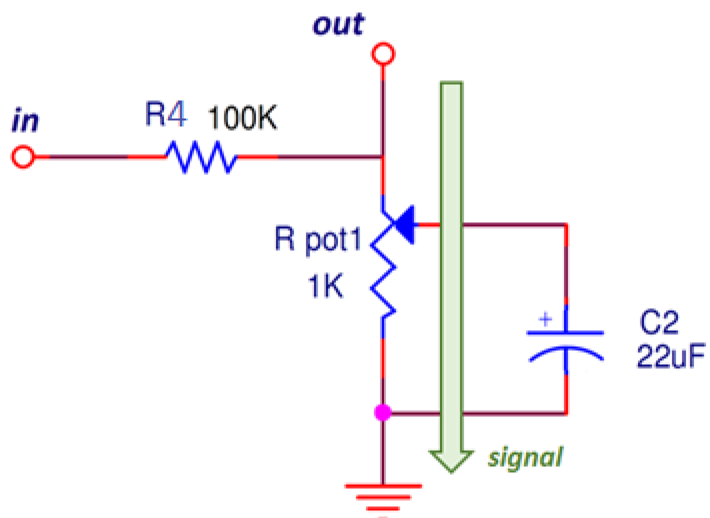
How does the feedback work in the Metal Oxide Fuzz?

The job of the feedback network is basically to reduce the huge gain of the Metal Oxide Fuzz stages, making the whole circuit more stable and independent from problematic transistors:

- When the fuzz control (1KΩ pot) is set to minimum, a big amount of signal is sent back to the input, creating a big feedback loop and reducing the total pedal gain (left image below).
- When the fuzz control increases the attack, the 22uF C2 cap will gradually shunt the negative feedback to the ground, thus letting the circuit operate with more gain (right image below).



max feedback = min gain

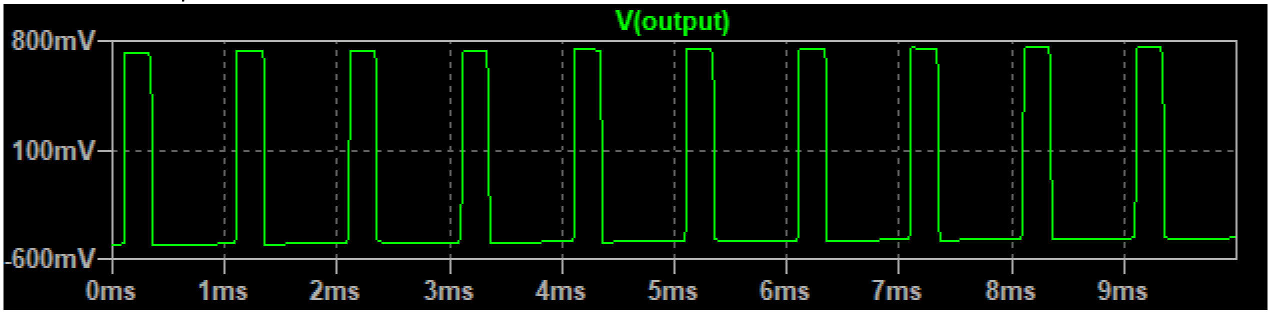


min feedback = max gain

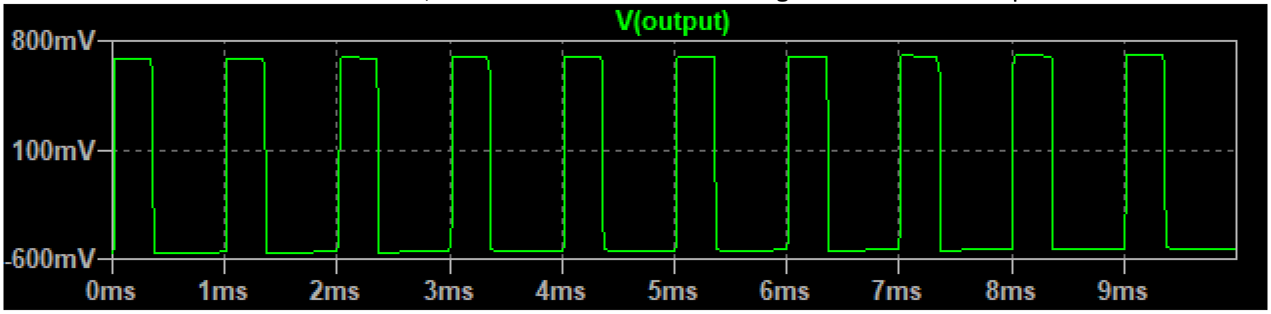
5.1 Gating the Fuzz.

When increasing the resistance of the feedback network, the reduction of noise and nonlinear distortion begins to act like a crude noise-gate.

Here is the output waveform with stock build and fuzz and volume maxed:

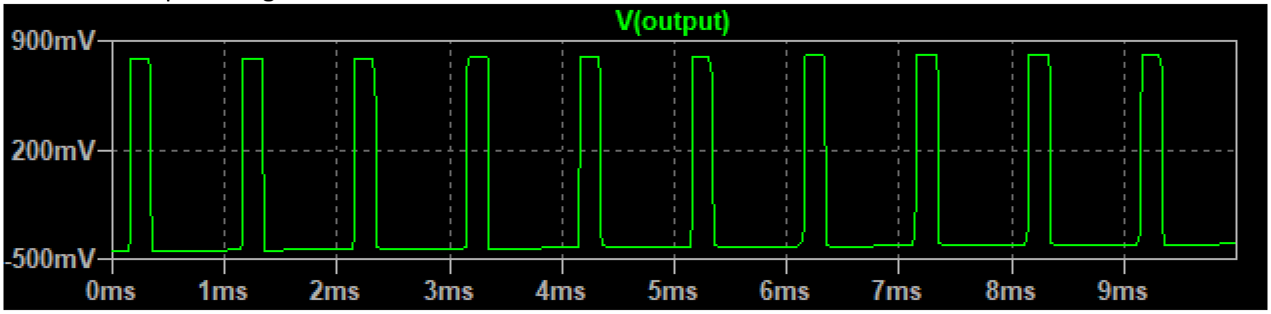


As the R4 resistor is lowered to 22K, the waveform starts to change as seen with the positive 800mV side.



A resistor value much lower than 22K will cause the volume to drop, so it isn't advised.

If the R4 resistor is increased, for example 470K, a gating effect will begin to occur to create a bit of a "Velcro" sound with a bit of sputtering.



As the resistor reaches towards 1M, the sputtering becomes more apparent, which typically isn't desirable.

6. Metal Oxide Fuzz Frequency Response.

The FF frequency response is shaped by the three capacitors C1, C2 and C3:

- C1: The 100nF input cap creates a high pass filter together with the input pedal impedance (5KΩ approx.), removing dangerous DC levels, hum and overloading bass.

  $$fc = 1 / (2\pi RC) = 1 / (2\pi \cdot Z_{in} \cdot C_1) = 1 / (2\pi \cdot 41K \cdot 0.1uF) = 33.8\ Hz$$

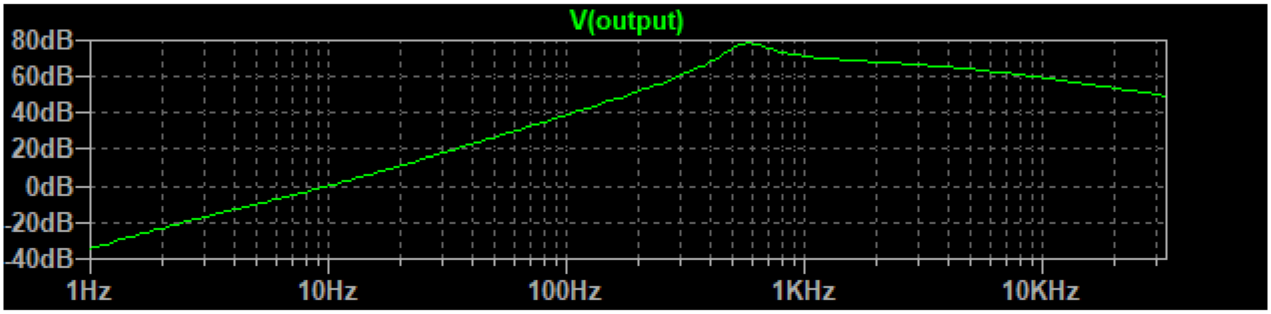
  All harmonics below 33.8 Hz will have 6dB/oct of attenuation

- C2: Shunts part of the signal to ground, but its value is so high (22uF) that in the worst case only signals below 7Hz (and the audio spectrum) will be affected, so the contribution for the general frequency response can be discarded.
- C3: The output cap creates also a high pass filter, removing the excess of bass that the Metal Oxide Fuzz delivers:

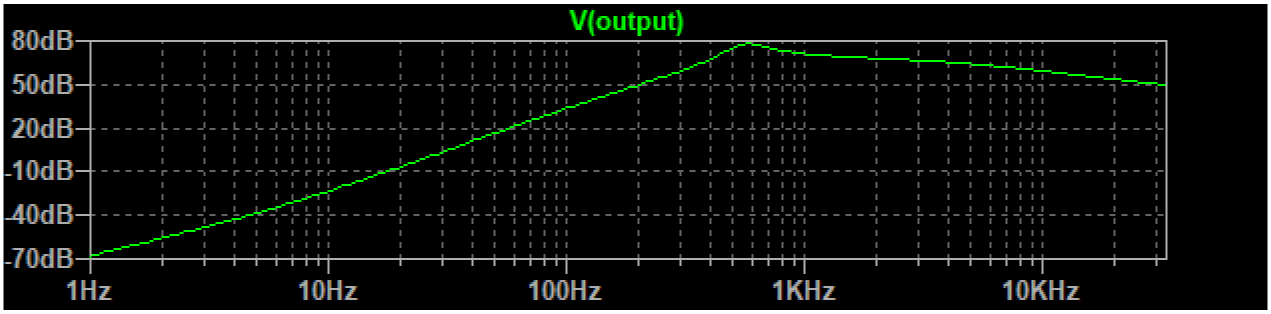
  $$fc = 1 / (2\pi RC) = 1 / (2\pi \cdot R_{vol} \cdot C_3) = 1 / (2\pi \cdot 500K \cdot 0.1uF) = 3.1\ Hz$$

  All harmonics below 31 Hz will have 6dB/oct of attenuation. If the level goes down, the 500KΩ resistor will be reduced and the filter will remove more bass.

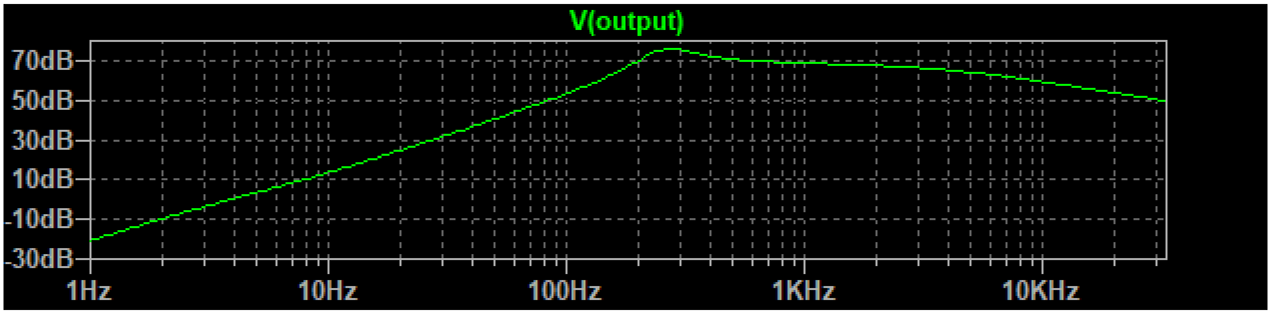
  The stock build EQ curve would look like this at the output with the Fuzz and Vol maxed:



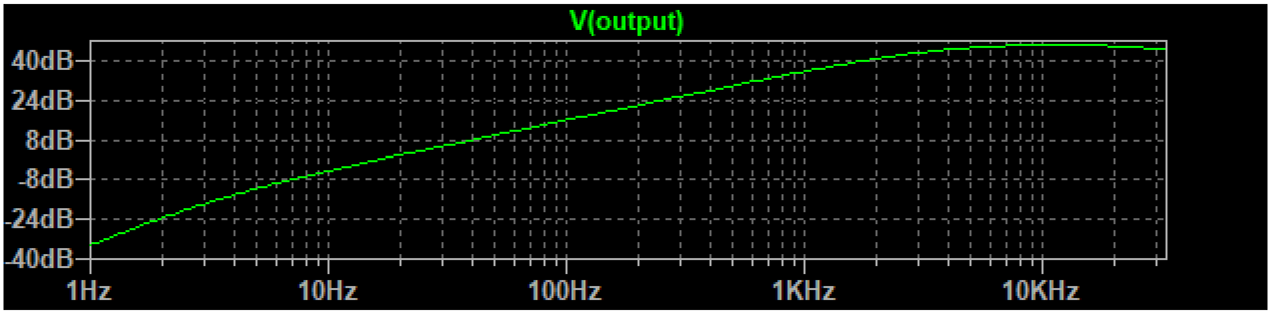
With the Volume pot changed to 100K and the output capacitor changed to 10nF



Stock build but with the input capacitor raised to 470nF

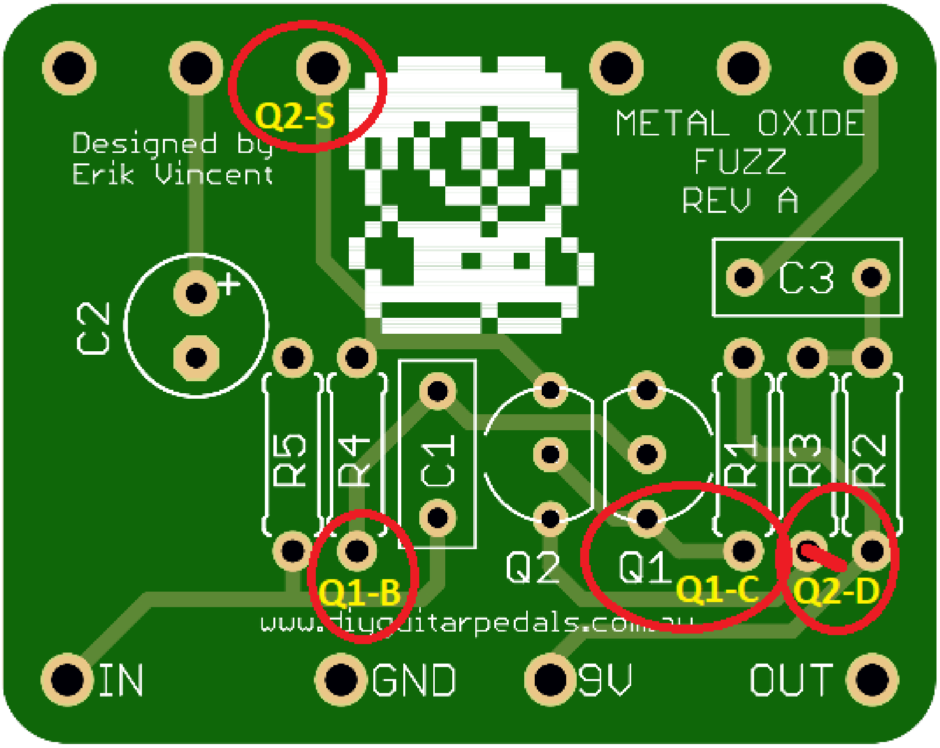


And with the stock build, with the volume maxed, but the fuzz set to zero. Here you see the bass get more cut.



7. Voltage Readouts

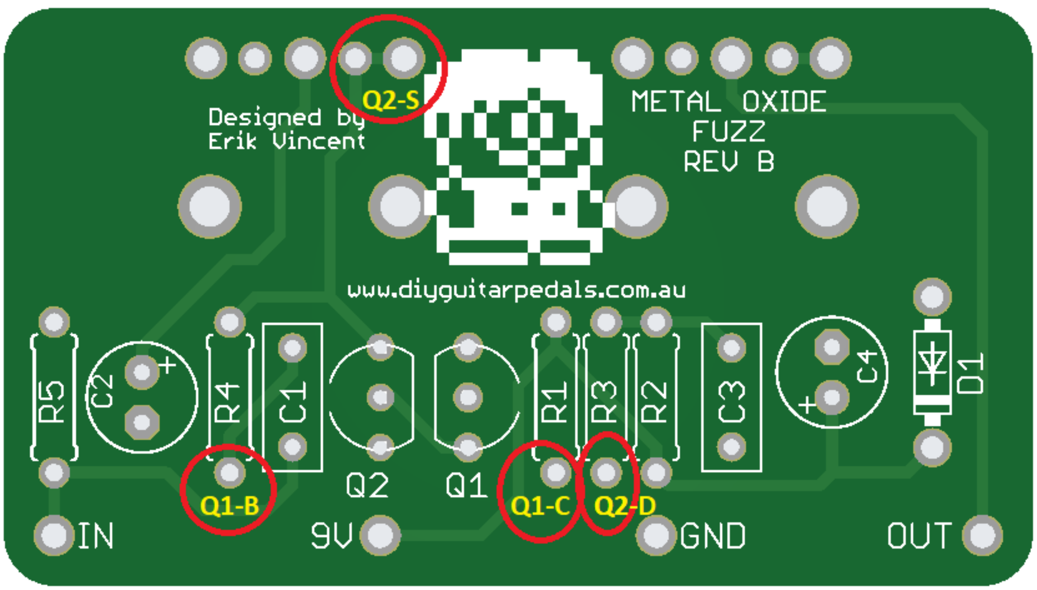
Below are the voltage readouts for the Metal Oxide Fuzz, assuming 9V Power Supply.



Q1 - C: 2.671V
Q1 - B: 0.528V
Q1 - E: 0.000V (GROUND)

Q2 - D: 5.264V
Q2 - G: 2.671V (Q1 COLLECTOR)
Q2 - S: 0.536V

SET FUZZ AND VOL TO MAX



Q1 - C: 2.671V
Q1 - B: 0.528V
Q1 - E: 0.000V (GND)

Q2 - D: 5.264V
Q2 - G: 2.671V (Q1 COLLECTOR)
Q2 0 S: 0.536V

SET FUZZ AND VOL TO MAX

KNOBS

- VOL: MAX
- FUZZ: MAX

8. Modifications

Following is a couple of worthwhile modifications that can be applied to the Metal Oxide Fuzz.

8.1 Capacitors

Changing the values of C1 changes what frequencies that get passed into the pedal. Making C1 smaller amplifies less of the lower frequencies, while increasing C1's capacitance will allow more bass into the pedal. At 100nF, frequencies above around 33.8Hz get through.

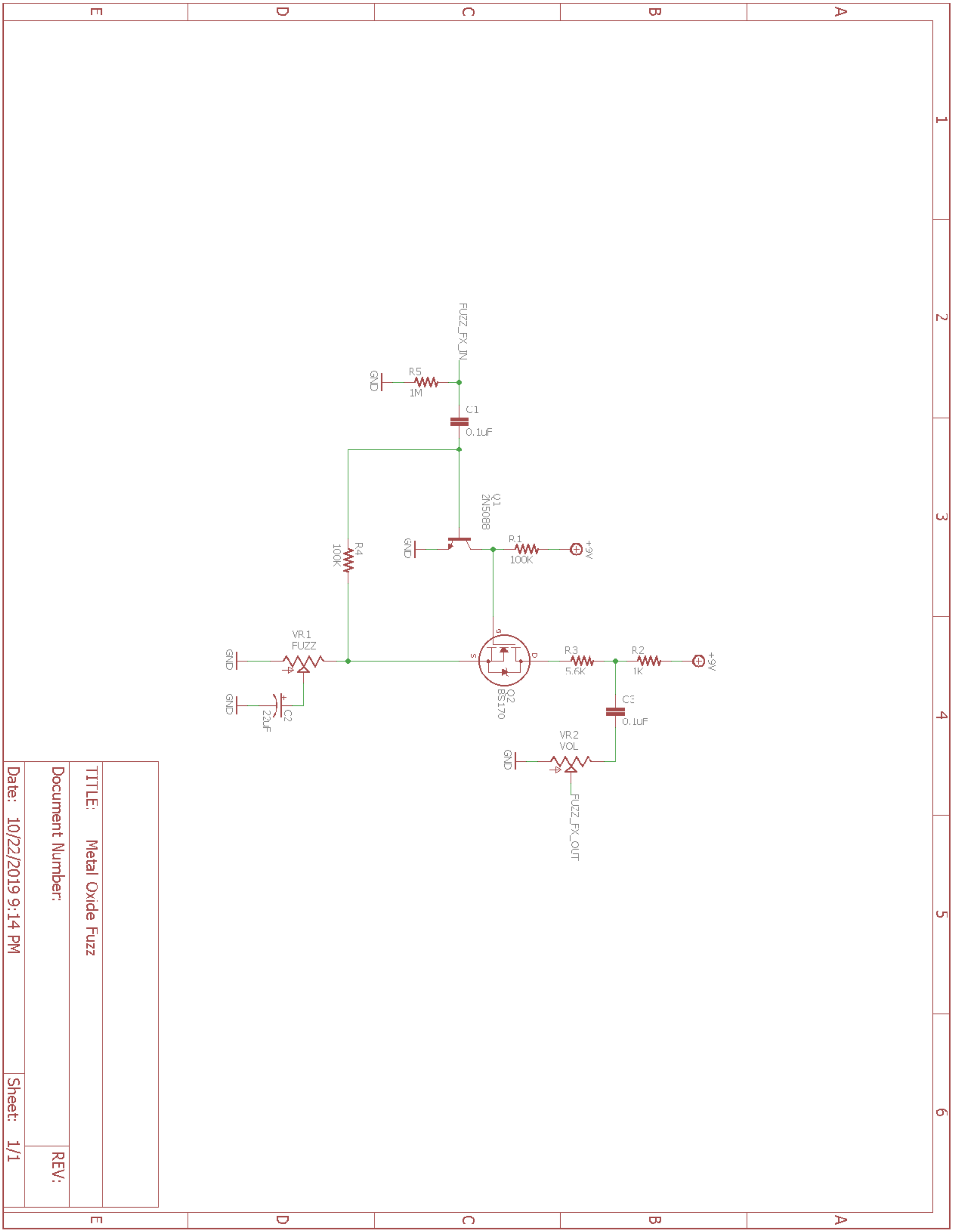
Changing the values of C2 changes what frequencies get amplified in the fuzz creation. Making C2 smaller amplifies less of the lower frequencies. At 22uF, frequencies above around 7.2Hz get amplified.

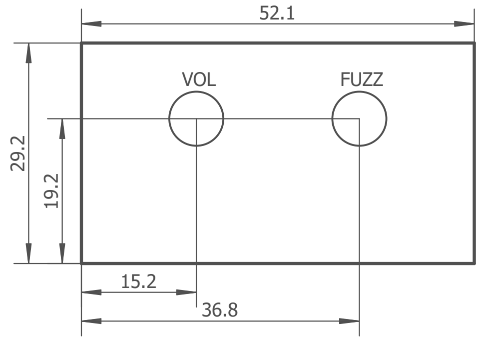
The output capacitor C3 blocks the DC level from saturating any device following the Metal Oxide Fuzz. It creates a high pass filter together with Volume Pot Resistance that will determine the lowest frequency that gets out of the pedal. Making C3 smaller will let less low harmonics out. At 100nF, frequencies and harmonics above 3.1Hz are allowed to pass.

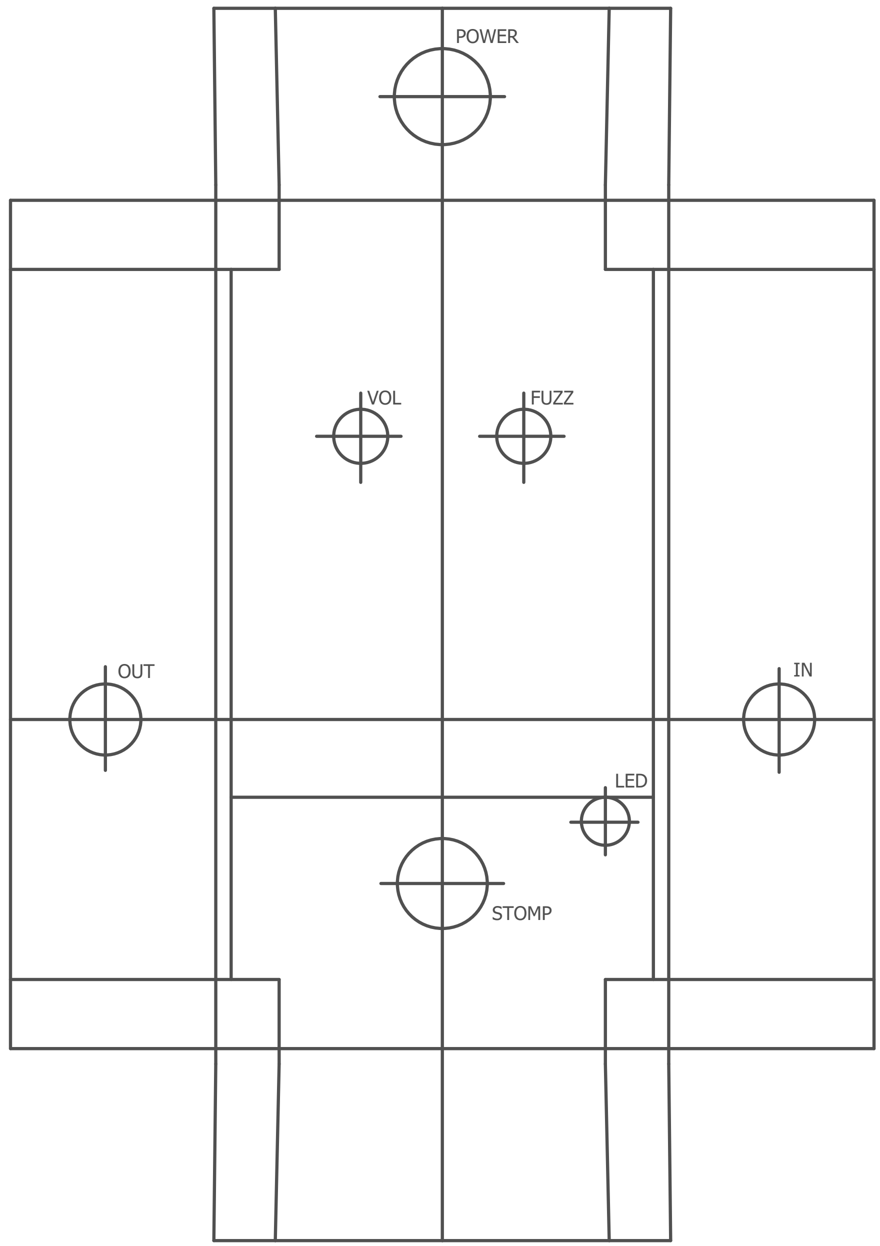
8.2 Potentiometers

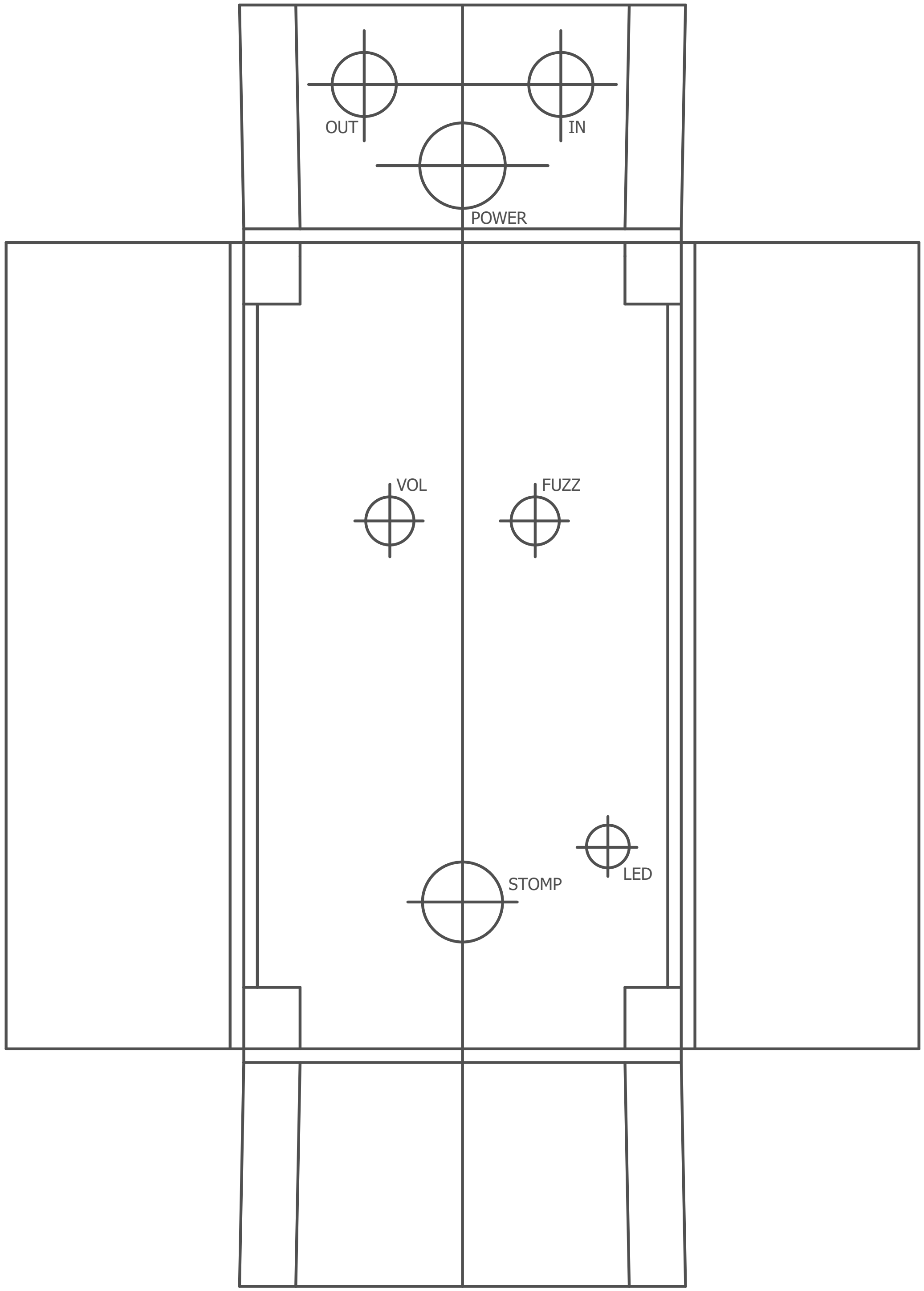
In regards to C3 and its high pass filter, changing the potentiometer down to a 100K pot will change the value of what frequencies will be filtered. By decreasing the pot to 100K, the sound becomes brighter as it will begin to cut more of the lower frequencies and harmonics. For example, changing C3 to 10nF and the pot to 100K, frequencies and harmonics above 160Hz are allowed to pass. Also reducing the value of the pot will improve output impedance.

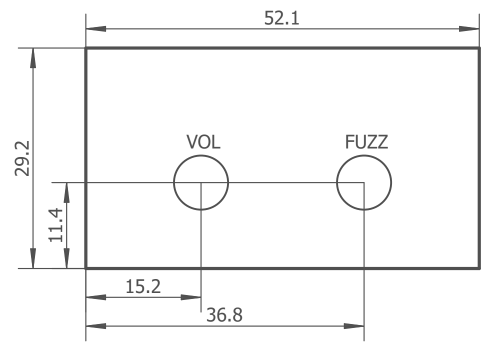
9. Schematic

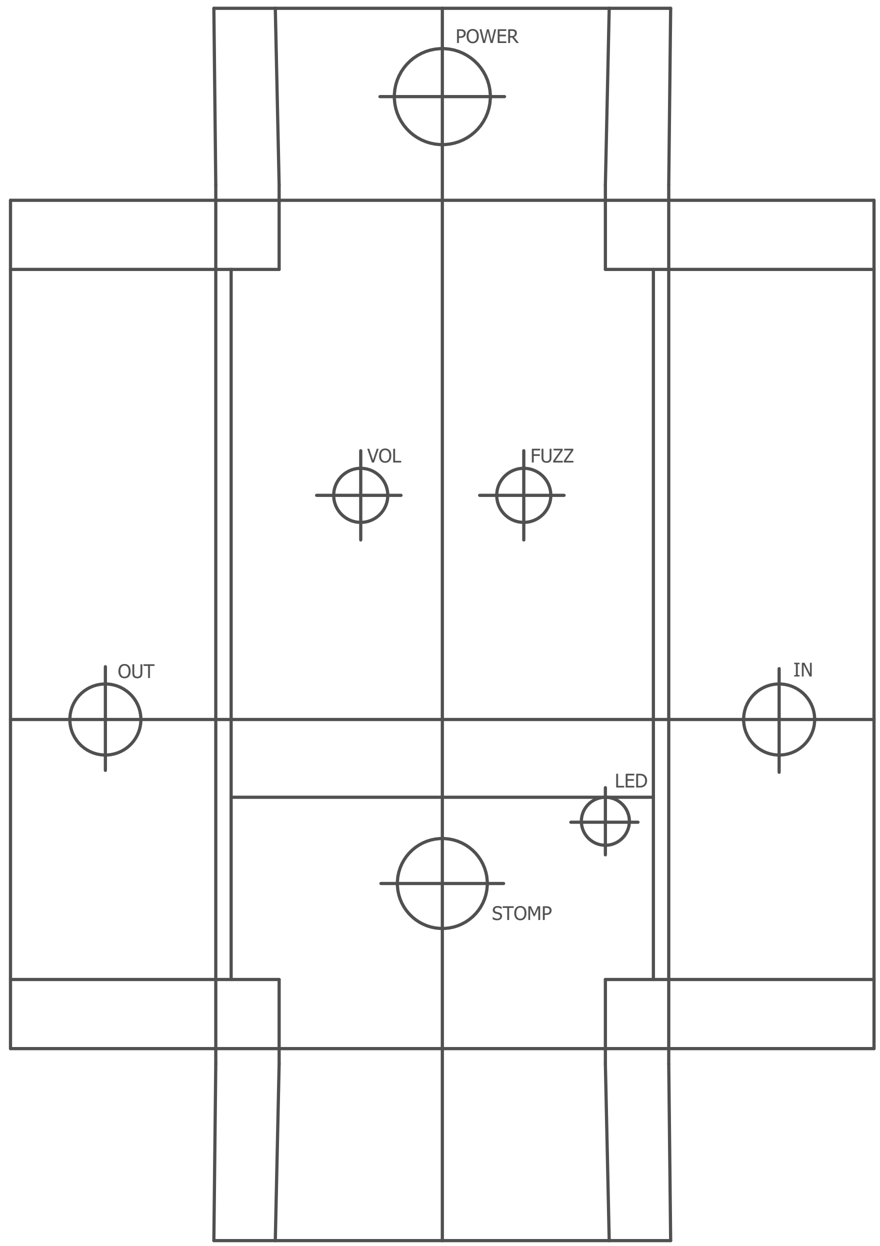

FUZZ_FX_IN
GND
R5
1M
C1
0.1uF
Q1
2N5088
GND
R1
100K
+9V
R4
100K
VR1
FUZZ
GND
GND
C2
22uF
Q2
BS170
R3
5.6K
R2
1K
+9V
C3
0.1uF
VR2
VOL
GND
FUZZ_FX_OUT
TITLE: Metal Oxide Fuzz
Document Number:
REV:
Date: 10/22/2019 9:14 PM
Sheet: 1/1

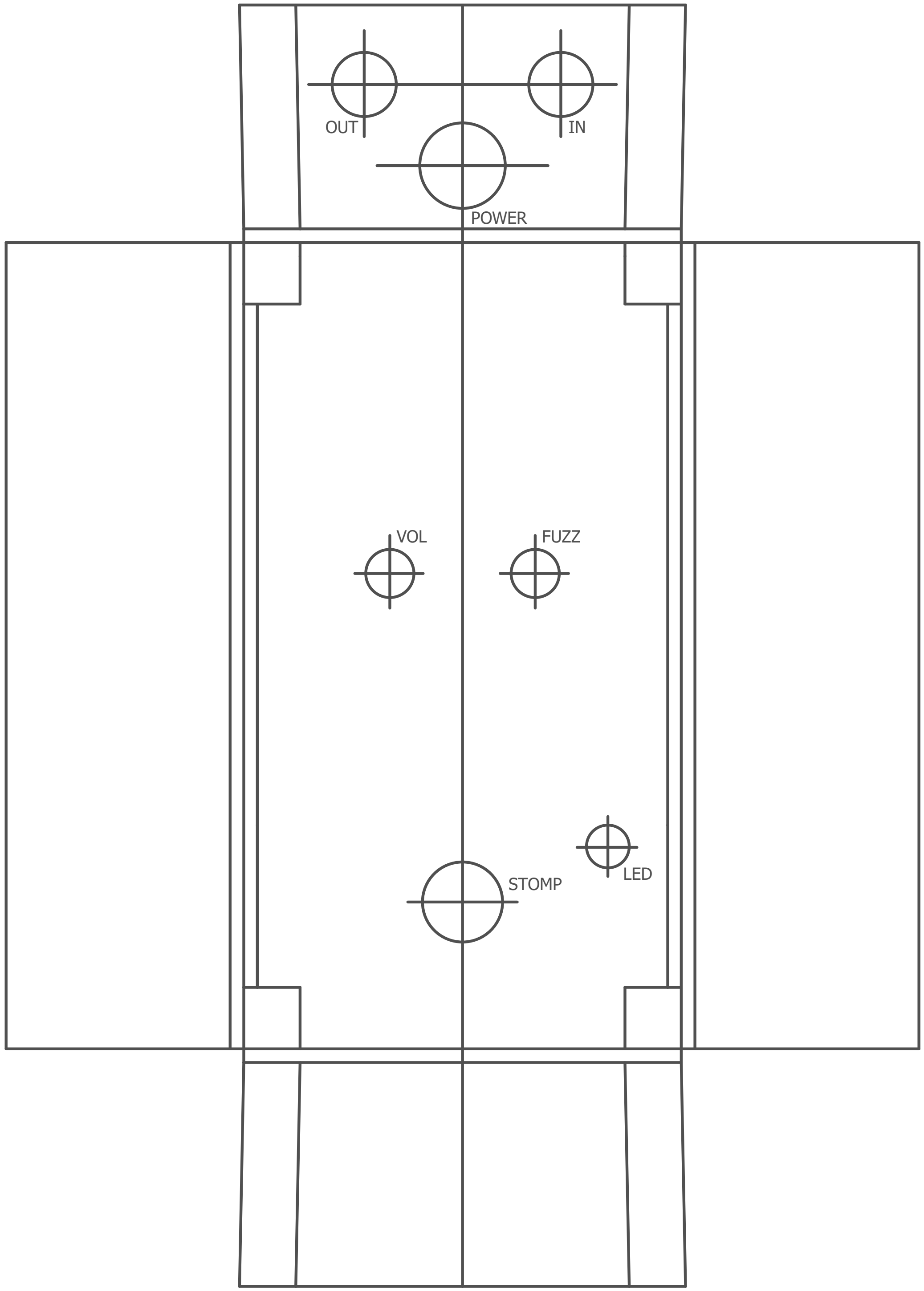

52.1
VOL
FUZZ
29.2
19.2
15.2
36.8


POWER
VOL
FUZZ
OUT
IN
LED
STOMP


OUT
IN
POWER
VOL
FUZZ
STOMP
LED


52.1
29.2
VOL
FUZZ
11.4
15.2
36.8


POWER
VOL
FUZZ
OUT
IN
LED
STOMP


OUT
IN
POWER
VOL
FUZZ
STOMP
LED