COMPONENT VALUES, UNITS, & PREFIXES

Some types of components, like **diodes, op amps, and transistors, are referred to by a name** or code indicating which model or type it is. Other types of components, most commonly **resistors and capacitors, have numeric values** that distinguish how they operate. Those numeric values are often expressed with units and utilize prefixes.

Units

Just like we measure distance with units of meters (m) or mass with units of kilograms (kg), we measure electrical properties with units as well. Let's consider resistors and capacitors:

Unit symbol	Unit name	Used for measuring...	Numeric value signifies...
Ω	Ohms	Resistors	how much it reduces current flow
F	Farads	Capacitors	how much charge can be stored in it

When using pedal power supplies you've probably also seen two more important units:

Unit symbol	Unit name	Used for measuring...	Numeric value signifies...
V	Volts	Voltage	how much electric pressure is between two points of the circuit *(e.g. 9V between +VCC and GND)*
A	Amps	Current	rate of flow

Prefixes

In pedal circuits we often deal with values far higher or lower than 1 unit, though. A capacitor may have a value of 0.0000001 Farads. Or a resistor may be 2,200,000 Ohms.

Rather than write those long numbers we instead use metric prefixes. These prefixes tell us by how much to multiply the number to get back to the base unit.

Prefix	Multiplies by...	Units we often use in this range
p *(pico)*	0.000 000 000 001	pF
n *(nano)*	0.000 000 001	nF
µ or **u** *(micro)*	0.000 001	µF
m *(milli)*	0.001	mV, mA
	...	
k *(kilo)*	1,000	kΩ
M *(mega)*	1,000,000	MΩ

Examples

0.0000001F can be written as 100nF (nano Farads). It can also be written as 0.1µF (micro Farads).

2,200,000Ω can be written as 2.2MΩ (mega Ohms)

Conventions You May See

Omitting the Unit Symbol

In a schematic or Bill of Materials (BOM) for a guitar pedal, or in other settings **where the context is clear, people will usually omit the unit symbol**.

Examples:

- Resistor: 100kΩ becomes 100k
- Capacitors: 0.1µF and 47pF become 0.1µ and 47p

> *TIP*
>
> *PREFIX HINTS AT COMPONENT TYPE*
>
> Look at the 3rd column in the prefix table above. We often deal with small capacitances and large resistances, but never the inverse in the context of guitar pedals.
>
> So just by seeing the small values "33p" or "100µ" we can guess they imply Farads and therefore capacitors. Similarly "100" or "4.7k" or "2M" are surely values for resistors.

Prefix as a Decimal

When a numeric value has a decimal, the **metric prefix may be used as the decimal**. Examples:

- 4.7k becomes 4k7
- 2.2µ becomes 2µ2

This is a holdover from days when low fidelity photocopies or blueprints might easily lose a decimal, or add unintentional ones with stray markings. Even with high resolution computer screens it's not a bad idea to do this for clarity. In this document I have chosen to avoid this notation since it may confuse people who skim past this section. Good on you for building a strong foundation of knowledge, though!

By the way, we don't commonly use the prefix as a decimal for values less than one. e.g. 0.1µF would NOT be written as 0µ1. Instead we typically use a different prefix to represent the same value, like the equivalent 100nF.

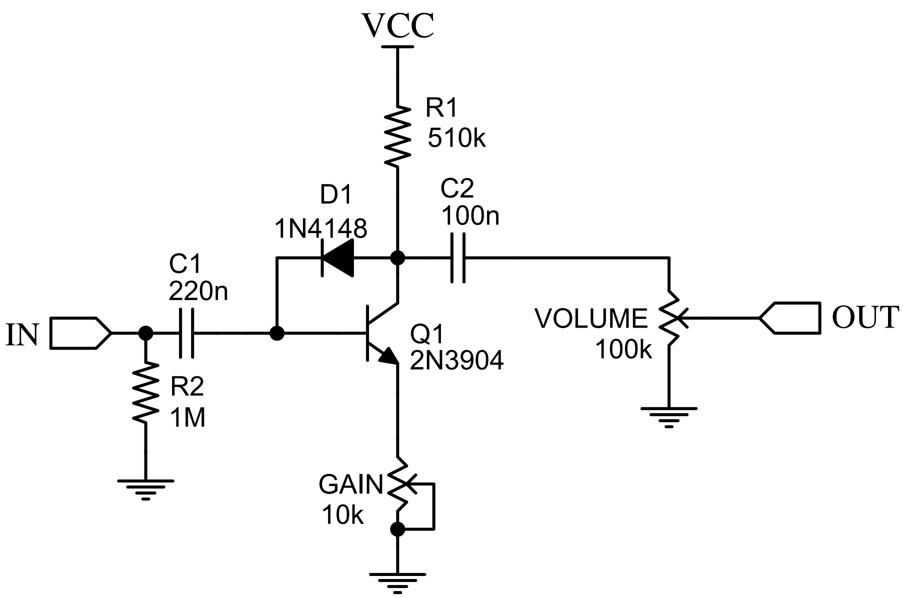
"R" as a Decimal

When a resistor value is less than 1kΩ (i.e. 0Ω to 999Ω), no metric prefix is needed. This created a problem when trying to use the prefix as a decimal, so "R" was used instead.

e.g. 100Ω becomes 100R, and 4.7Ω becomes 4R7

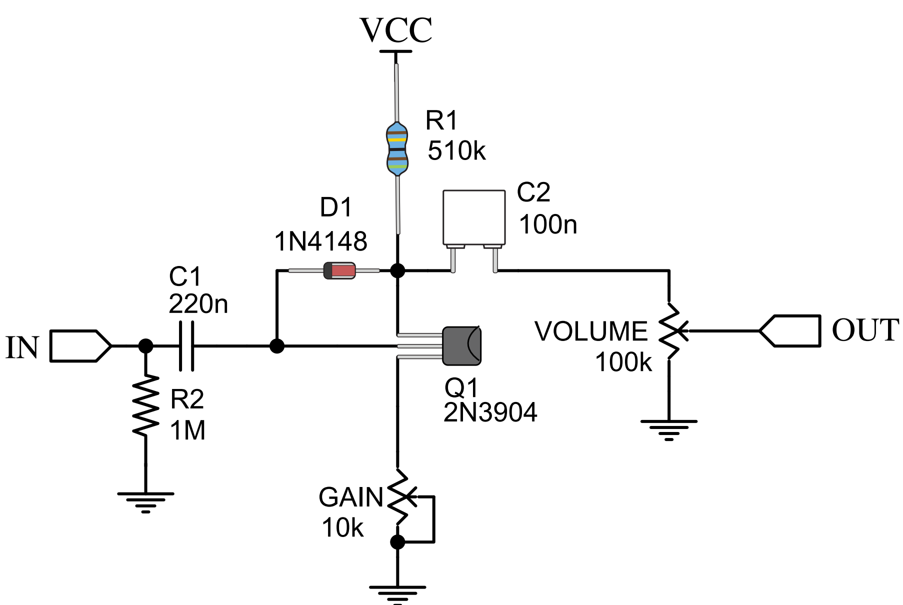
READING THE SCHEMATIC

A schematic is the primary way we **communicate electrical circuits**. It's a drawing of the electrical paths and connections between the components that make up the circuit.



Here's a schematic of the pedal we just built.

This is just for the effect portion of the circuit, and you can find the full schematic at the end of the document, which includes the jacks, foot switch, and LED.



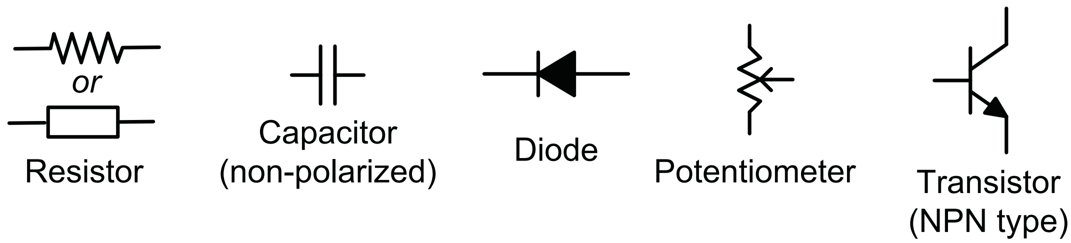
Here we've replaced the R1, D1, C2, and Q1 symbols with illustrations of those components.

You can see a schematic is very nearly a drawing of the actual physical circuit.

Symbols and Designators

We discussed designators before (e.g. R1), but just a reminder that they help uniquely identify the components. Along with the reference designator a schematic will also list **the numeric value of a component** (e.g. 100nF), if it has one, or its model name/number/code (e.g. 1N5817).

You'll also find **a symbol** to represent the type of component. Here are some common examples:



You can find a list with even more common symbols here.

Electrical Connections

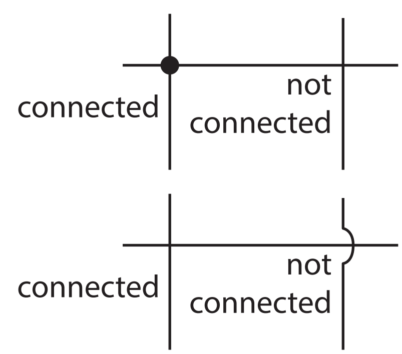
There are two ways to show that parts of the circuit are electrically connected together.

Lines and Dots

The lines represent electrical paths, typically either wires or copper traces on the PCB.

The dots where lines intersect indicate those paths are connected. If some of the intersections don't have dots, those paths are NOT connected electrically.

An alternate convention, which I don't use, is to omit the dots and assume an electrical connection when lines intersect UNLESS the line curves when crossing paths with another.

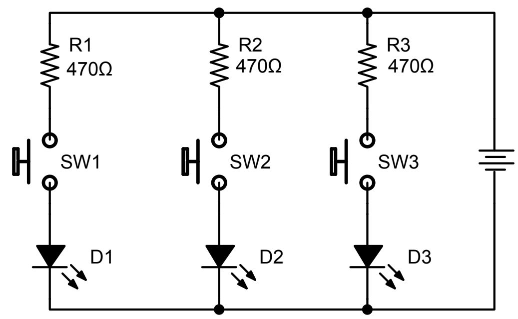


One of these two conventions will be used in most schematics. Look for EITHER dots OR curved intersection lines to determine which is being used.

Electrical Connections (continued)

Nets and Net Symbols

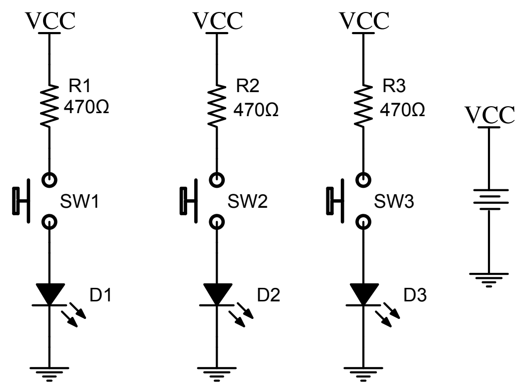
Nets are what we call the connections between components. These can be represented by lines and dots as described above, but we can also use **special net symbols**. We use these to keep the schematic drawing tidy and to avoid having too many criss-crossing or distracting lines.



Any lines connected to a net symbol are assumed to be connected to any others connected to the same symbol.

Ground (or GND) and the positive voltage (often VCC), or reference voltage (often VBIAS or VREF) are the most common. You may see others too, like IN and OUT in our schematic for this pedal.

The two schematics, shown here which you probably recognize from the Soldering Practice Kit **are equivalent**. The second one labels the battery's positive terminal with a "VCC" net symbol, and the negative terminal with a GND symbol.



PRO-TIP: "GROUND" AND "GROUNDING"

What is GND?

One of the most common points of confusion I see in DIY pedal forums is when people are talking about what to "ground *to*." They want to ground their pedal "to" something.

While you can often form a correct answer around such questions, it'll serve you better to simply throw out the notion and instead **think of the GND as any other net**.

Ground points in your circuit are simply points that are connected *TO EACH OTHER*. That's it.

Does GND Always Connect to the Ground, i.e. the Earth?

No, not necessarily. Often it does, though, through the output jack sleeve, through sleeves of your instrument cables, into your amp, through its GND net and power cord, and eventually through an earth wire in your building.

Conventions

The reason we give GND and VCC special names and symbols is that they represent a reference point we use for measuring voltage differences. GND is the point we call "0V."

On a 9V battery, for example, we choose its (-) terminal as "GND" and then measure the (+) terminal with respect to GND and find it's 9V higher, making it +9V.

Unconventional But Valid

We could just as easily choose the (+) terminal to be GND and 0V, then we'd find the (-) terminal to be -9V.

The nets and their labels are arbitrary (though chosen based on conventions usually), and the important thing is that the terminals have a 9V difference between them. That's what voltage is, by the way, a *difference* in electric potential.

HOW DOES IT WORK?

This pedal uses a popular DIY circuit called the Bazz Fuss. It uses an incredibly low number of parts, but don't let that fool you into thinking it's simple. In fact this particular circuit is a bit more complicated than many, much larger ones.

> *GOING DEEPER*
>
> This is going to be a hand-wavy, high level walkthrough. If instead you want a deeper understanding with more details, you'll want to thoroughly study these multi-part tutorials: DC circuits, AC circuits, Capacitors and reactance, and Transistors.
>
> Even then you may struggle since this transistor is not set up in any of the typical amplification configurations. Reading this post (after the previous prerequisites) is probably the clearest step-by-step description of what's going on.

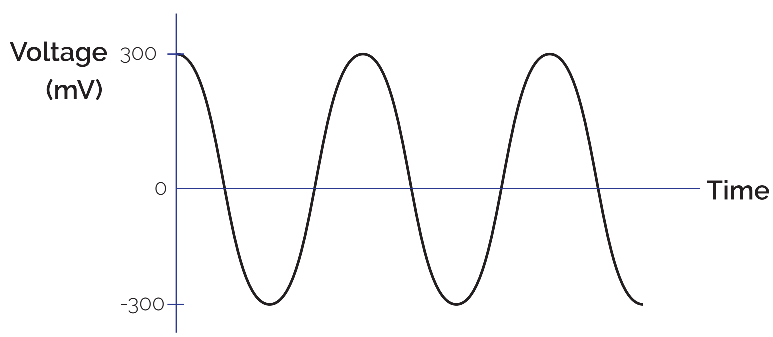
Prerequisites For a Conceptual Walkthrough

We're going to go through a conceptual explanation of this circuit and how it works. To follow along you need to first have an understanding of Voltage and Current (see this SparkFun article), as well as Alternating Currents (AC) and Direct Current (see this SparkFun article).

Input Signal

The audio signal on the "IN" net of our schematic is carried by an Alternating Current (AC).

It has a voltage - or the difference between the top of the wave and the bottom of the wave - typically in the 500mV range (peak to peak). This range can vary wildly, though, depending on the guitar's pickup types, how hard you're playing, and can go much higher (e.g. over 1V) when boosted.



Voltage over Time

It's actually a representation of the movements the speaker will make to push the air and form sound waves. **The amplitude or height of the wave, i.e. the voltage, represents the volume**. Larger peaks are louder; Smaller peaks are quieter.

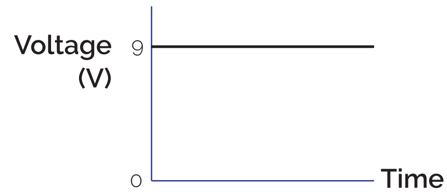
The frequency, or distance between the peaks, represents the pitch. Closer peaks have higher pitch; Farther peaks have lower pitch.

Now it's important to understand that its 0V center is theoretical. In practice a DC voltage may be inadvertently added, and it shifts the center of this wave to a different voltage. We'll see more about that when we examine the capacitors.

9V DC Voltage (VCC)

The pedal's indicator LED and transistor both require a steady DC voltage to operate. This comes from the DC power supply.

Its graph is much simpler. It remains at 9V regardless of time.



Jacks, Power, Shielding

Examining the full schematic in the appendix will reveal a lot of nets used to show connections between the jacks, ribbon cables, and the main circuits. It can be a bit confusing, so we'll cover the important concepts here.

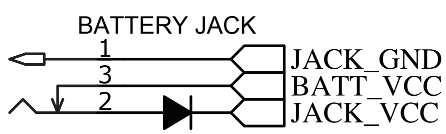
DC Power: Battery vs. DC Jack

You probably don't have a battery, and that's okay. This is an optional add-on project for people who really need it. However let's still examine how it's all hooked up.

The symbol for our DC jack shows a middle pin (labeled 3) with an arrow, connected to the battery's positive terminal. It represents a switch inside the DC jack. When no barrel connector is plugged in, this is connected to the bottom pin as shown in the symbol.

When a power supply's barrel connector is inserted, it disconnects this pin leaving the battery's positive terminal cut off from the circuit. And recall, without a loop allowing the current to flow from one terminal to the other, the battery is no longer powering our circuit (even if its negative terminal is still connected).

So in short: **When the plug is inserted, the battery is disconnected and vice versa**.



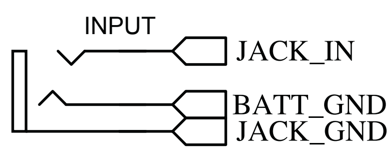
Phone Jack as a Power Switch (for battery power)

When a pedal is bypassed and the LED is off, it's still consuming power. We don't turn pedals on and off with the foot switch; We instead let the audio signal bypass or go through them. Powering up the pedal can take time that, if you did it with a foot switch in the middle of a song, would result in a noisy delay that could really ruin your performance.

If your pedal has no battery then you simply unplug it to turn it off (or turn off your power supply). With a battery, however, it is inconvenient to open the back of the enclosure to disconnect it.

So instead we use a mono cable on the input jack to bridge the ring and tip lugs of the jack to connect and disconnect the battery's negative terminal to the pedal's GND net (labeled here as BATT_GND and JACK_GND respectively).

To disconnect battery power, simply remove the input cable.

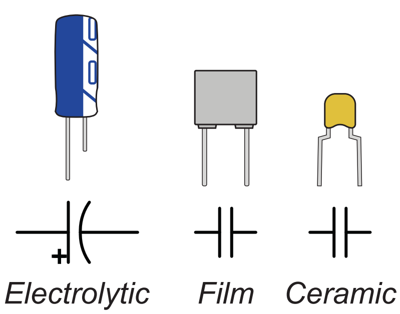


Capacitors in General

Quick Overview of Capacitors

Capacitors store charge, and the amount they can store is measured in units called Farads (F).

There are several types of capacitors that vary in construction methods: ceramic, film, and electrolytic are the most common. **Film** is the most popular type for pedals since it is generally the least likely to introduce noise. But for very small values, it isn't a practical construction method so **ceramic** is used instead. Similarly for very large values we use **electrolytic** since large film capacitors are impractical.



Unfortunately electrolytics, due to the way they're made, have **polarity** and can only be used in the correct orientation. If a large enough reverse voltage is applied it may damage it and even cause it to explode. When a schematic calls for an electrolytic capacitor, you can always swap in a non-polarized capacitor. But you cannot use a polarized capacitor in place of a non-polarized one without careful consideration.

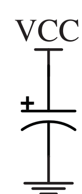
In addition to considering their capacity, when choosing a capacitor you need to check its **maximum voltage**. Ensure it's greater than the power supply your pedal uses. For a 9V pedal we typically use 16V or more. If the pedal may be powered by 18V, then we'll use 25V or 35V capacitors. Going with even greater voltages is okay, but it may be physically larger so make sure fits into your PCB and pedal.

Capacitors are typically used for 2 things in guitar pedals: Storing power, and filtering low frequencies (including DC).

Capacitors for Storing Power (Extra Info FYI)

Although this pedal doesn't have one, we'll often see one or more capacitors used to store power for pedals.

They simply sit between the positive and GND sides of the power supply. If the power supply has a momentary interruption, the pedal can draw charge from the capacitors.



Capacitors in General (continued)

Capacitors for Filtering

Capacitors store charge. When a voltage difference (e.g. 9V and 0V, or 9V DC) is applied over its leads, charge flows from one side of the capacitor to the other and builds up. If that voltage difference remains, the capacitor becomes "full" and current stops flowing. We utilize this to **block DC voltage**.

When the direction of current changes, the charge will flow again, but in the opposite direction. You could simplify and say "capacitors block DC and allow AC." But it's not quite as simple.

Depending on the capacitor's size, and depending on the frequency of the an AC voltage, it can also **block low frequency AC signals**. This is because it takes time to charge and discharge, and for lower frequency signals it has more time to become saturated and block the flow of charge.

This is why a smaller capacitor can cut the low end from your signal.

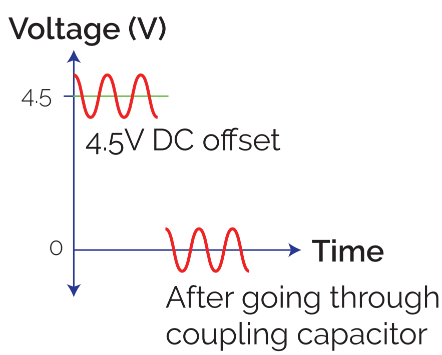
Since capacitors can allow or resist current based on the frequency, we utilize them to make low pass filters and high pass filters. For a more detailed look at how capacitors behave in audio circuits, see this article and the ones that precede it.

Capacitors: C1 & C2

C1 & C2: Coupling Capacitors

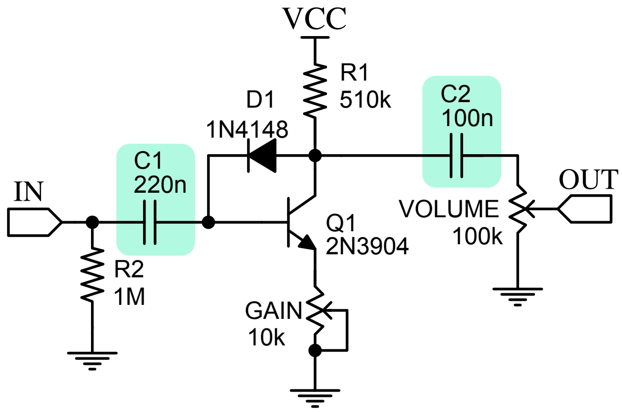
Audio signals going through your instrument cables should be **centered around 0V**.

Sometimes for manipulating the signal, circuits will introduce a **DC offset** which shifts the signal up or down. Sometimes problems in other equipment may also introduce a DC offset. To remove this offset, as described in "Capacitors for Filtering," we'll use a capacitor, called a **coupling capacitor** to remove any DC from the signal.



Capacitors: C1 & C2 (continued)

C1 & C2: Coupling Capacitors (continued)



C1 and C2 are both coupling capacitors.

C1 blocks any DC current that our circuit might add from being introduced to your guitar or the pedal before this one in the chain. Similarly, C2 ensures no DC offset leaves the pedal and goes into your amplifier or other pedals, as well as blocks any DC those devices may leak from affecting our circuit.

After passing through the capacitors, the signal is centered back at 0V. Depending on the size of the capacitors and the frequencies in our audio, though, we may also find **they change our signal**! As we noted in "Capacitors for Filtering," the lower the frequency of a signal, the more time a capacitor has to become fully charged and halt the flow of electrons. Smaller capacitors will charge up faster, and therefore will block lower frequency sounds.

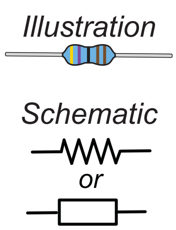
FYI: On choosing coupling capacitors:

Choosing values for input and output capacitors depends on whether filtering makes your circuit sound better or not, and what frequency ranges you expect (e.g. guitar vs. bass). In practice, it's often simplest to audition a few values to find what sounds best to your ears.

The values chosen here work well for both bass and guitar. Switching to lower values will cut some of the low end growl, but higher values shouldn't make much noticeable difference.

Resistors in General

Resistors limit the flow of current through them. The amount of resistance they provide is measured in **units called Ohms (Ω)**.



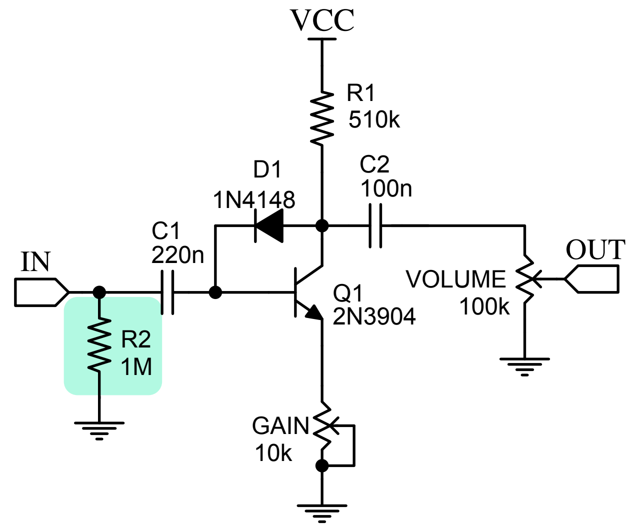
The bands of color on them can be used to determine the resistor's value and tolerance (i.e. accuracy to its value).

When choosing one, the main consideration besides its value, is its **power rating** (measured in watts (W)). This specifies the maximum power the resistor can handle without damage. 1/4W (0.25W) resistors are the most commonly used in guitar pedals, and are usually a safe and sensible choice.

There are a variety of materials used to make resistors, but in DIY guitar pedals we typically find **carbon composition, metal film**. Metal film (usually blue, as opposed to the brown or beige carbon composition) typically have less thermal noise and tighter tolerances so they're the best choice if both types are readily available. That said, in guitar pedals the differences are typically insignificant so use what you have or can find. Most older pedals used carbon composition simply because that's what was available at the time.

Most modern commercial pedals also use *surface mount* resistors, which are much smaller and do not have leads that go through the PCB ("through hole"). They are cheaper to buy, and can be more easily placed and soldered with automated equipment, further reducing cost. You can use these for DIY pedals, too, but they're less common since it takes a bit more learning and practice to solder them easily by hand.

Resistor: R2



R2 provides a path to GND for any DC that leaks from C1. It **prevents a common source of popping**.

Ideally capacitors would hold their charge indefinitely, but in practice they may leak. If the pedal is bypassed and we allow this charge to build up at the input, when the switch is pressed to engage the pedal, a surge of DC would be introduced to the audio signal causing a loud *POP* sound. So we instead slowly drain this charge through a large resistor to GND. The resistor will also send some of our audio signal to GND, reducing its volume, so it's important to use a large value that only allows a trickle of current to pass.

Transistors in General

Transistors are used as **switches, or to amplify signals**.

They come in a few broad categories, the two most common for pedals being: Bipolar Junction Transistor (**BJT**), and Field Effect Transistor (**FET**).

FETs come in two types: MOSFET and JFET. These are outside the scope of this guide, but you can learn more about them at electronics-tutorials.ws (JFET, MOSTFET).

Bipolar Junction Transistor (BJT)

> *NOTICE*
>
> For the rest of this document when talking about transistors we are referring to BJTs.

Among BJTs, you'll find two types: **NPN** and **PNP**. They operate, roughly speaking, opposite to one another. To learn the details of how they operate you can visit the first 3 chapters of the Transistors section of electronics-tutorials.ws.

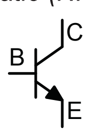
BJTs have 3 leads:

- **Collector (C)**
- **Base (B)**
- **Emitter (E)**

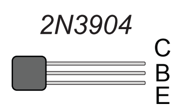
Here you can see an illustration of a transistor and its 3 leads, and the schematic symbol which has 3 corresponding lines coming from it.

Illustration

Schematic (NPN BJT)



Our particular transistor in this circuit is the very common 2N3904 with EBC "pinout" (i.e. the order of its leads).



This pinout is **NOT universal** though! You must refer to a transistor's datasheet to learn the order of its leads. A datasheet is a document published by the manufacturer which details all the specifications for a part, and it can be easily found with a search such as "*2N3904 datasheet.*"

Transistors in General (continued)

Transistor Material (Extra Info FYI)

Transistors are typically made from Silicon (Si) or Germanium (Ge). Most modern transistors are made from Silicon because it's more stable, doesn't behave differently at different temperatures, has virtually no leakage, is very inexpensive, and offers other advantages over Germanium.

They operate differently, and have electrical characteristics which allow for different sounds. This leads to a lot of tone chasing and internet arguments, not to mention oversimplified blanket statements (e.g. common claims that Germanium is better). While people focus on the material of the transistor, they often neglect the arguably more important circuitry surrounding it. **How the transistor is used within the circuit can have more impact than its material**.

Which is better? Well, if you can get a circuit with Silicon transistors to sound a way that's equally pleasing to your ears, it's objectively better than an alternate circuit using Germanium due to the all the advantages noted above.

That said you can create some types of distortion sounds with Germanium circuits that are difficult to replicate with Silicon. When you need that particular sound, then obviously Germanium is necessary.

Transistors as Switches (Extra Info FYI)

This pedal uses a transistor as an amplifier, but it's worth briefly noting that transistors can also act as a switch.

When setup for switching, transistors can be used to digitally control LEDs, relays, and more. You'll also find JFETs are often used in pedals to switch the audio and bypass or engage it (though they have a Drain (D), Source (S), and Gate (g) rather than Collector, Base, and Emitter).

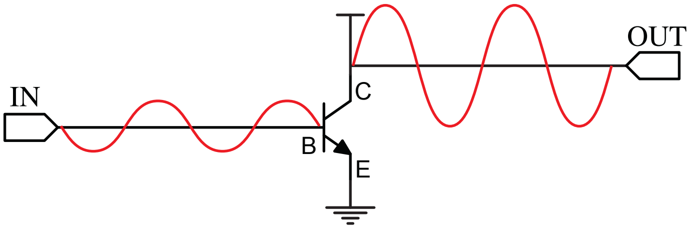
You can learn more about this topic at SparkFun, or in much greater depth from electronics-tutorials.ws.

Transistors in General (continued)

Transistors as Amplifiers

Transistors can also amplify a signal, which is useful in audio circuits both for boost and distortion (or overdrive, fuzz, and any other name for a clipped signal). They do so in a variety of configurations.

Please note **these drawings are conceptual**. In reality you need resistors to setup and bias the circuits.

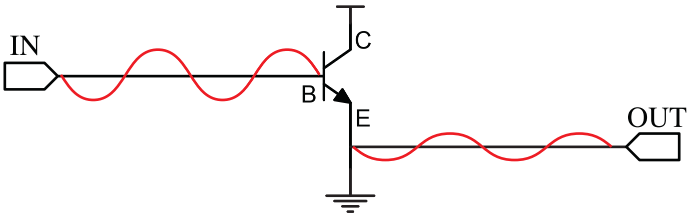


Common Emitter

By far the most common configuration.

This inverts, or flips the signal. You might also see this called a 180 degree phase shift. Notice the output starts by rising, whereas the input started by falling.

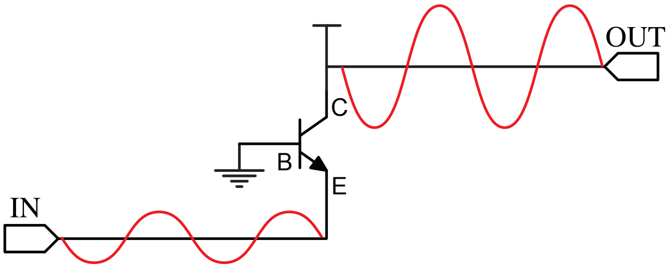
It has high voltage gain and can amplify audio signals significantly.



Common Collector

aka Emitter Follower

The voltage output of this amplifier is actually slightly less than the input. It's typically used as a voltage buffer to keep later stages of a circuit from interfering with the earlier stages.



Common Base

Just as the Common Collector can be used to buffer voltage, this configuration can be used to buffer current.

It can also act as a voltage amplifier.

Transistors in General (continued)

Transistors as Amplifiers (continued)

We've primarily focused on voltages so far, but there are other factors that are important to consider when using transistors as amplifiers. For example they present different input and output impedance, or resistance to AC signals, as well as provide different levels of current gain.

We won't discuss the other factors here, but this is a conceptual summary of the different types of transistor amplifiers:

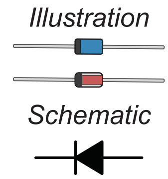
	Inverted?	Voltage Gain	Input Impedance (Z)	Output Z	Current gain
Common Emitter	Yes	High	Low	High	High
Common Collector	No	No	Very high	Low	High
Common Base	No	Moderate	Low	Very High	No

This guide is intended to give you a **high-level conceptual** understanding of how pedal circuits work. We've glossed over important details in all the sections, but given the complexity of transistors and amplifier circuits, this has been a particularly cursory description.

If you want to learn how to analyze and configure transistor amplifiers here are some sufficiently detailed tutorials: Transistors, Amplifiers.

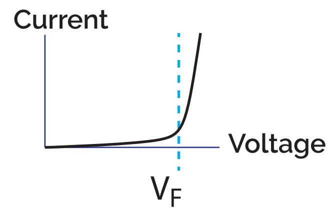
Diodes in General

Diodes allow current to flow in one direction, and block current from flowing in the opposite direction.



Forward Voltage V_F

Diodes have a property called the forward voltage (V_F) that tells you the approximate minimum voltage needed to get current flowing through the diode.



If you apply a very small positive voltage - meaning the voltage at the anode (positive side) is greater than the voltage on the voltage at the cathode (negative side) - no current will flow. If you increase that voltage, current will flow as you approach V_F.

V_F varies for different types of diodes, but broadly speaking you'll find values in the range listed here:

Type	Approximate Voltage Range (V)
Silicon	0.6 to 0.7
Schottky	0.3 to 0.5
LED	2 to 3
Germanium	0.3

Types of Diodes

Some types of diodes, like small signal diodes such as the 1N4148 we used in this pedal, are only rated for a small amount of current. We call these **signal diodes** since they're great for limiting signals like our audio, but less useful for directing the flow of power.

Rectifier diodes (like 1N4001) or **Schottky diodes** (like 1N5817) will allow for much higher current, so we'll often use them for power. We'll discuss these further when we take a look at D2.

Light Emitting Diodes (LEDs) are diodes that, as you can infer, emit light. We house them in translucent plastic and use them for power and status indicators in all sorts of electronics, but they're still just diodes that can be used for other jobs like clipping (more on that in a moment).

Diodes in General (continued)

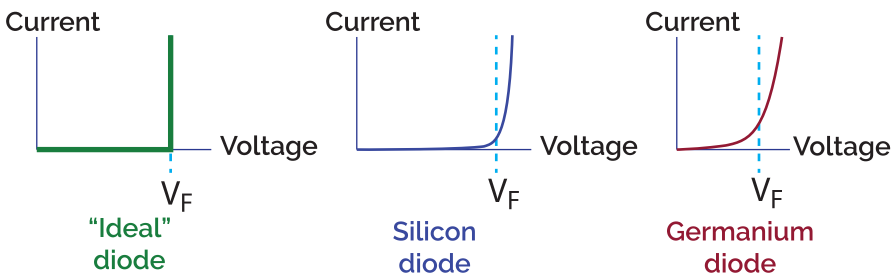
Diode Material (Si vs. Ge)

The earliest guitar pedals used Germanium (Ge) diodes because that's simply what was most readily available. Now nearly all modern diodes are made with Silicon (Si) because it is cheaper, more abundant, and diodes made with Si are superior to Ge in nearly every way (e.g. less leakage, less temperature sensitive, more suitable for high voltage and high current applications).

Two key differences that often matter in guitar pedals are

1. the value of VF, approximately 0.3V for Ge and 0.7V for Si
2. how quickly or slowly current flows as voltage is applied, i.e. the Voltage-Current graph

Let's revisit the Voltage-Current graph and look at an "ideal" diode, i.e. a simple model of how we imagine current flows as soon a large enough forward voltage is applied. Compare that to the Silicon and Germanium diodes and you'll see Silicon behaves much closer to the ideal. It has a tighter curve, also described as a "knee."



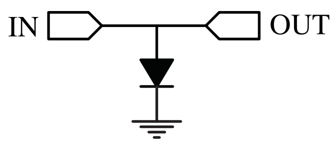
This sharp "knee" is preferable in most applications, but in guitar pedals there are times when Germanium's softer knee might be desired. Let's look at the most common case: Clipping.

Diodes in General (continued)

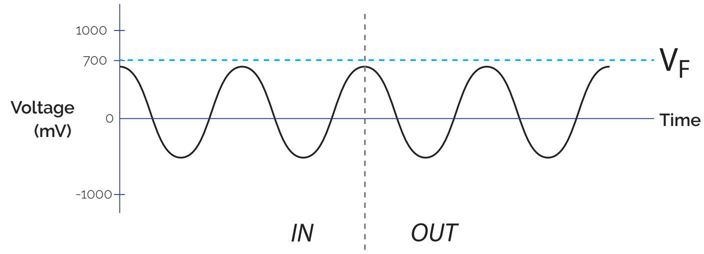
Diode Clipping (Extra Info FYI)

Clipping means taking the tops and/or bottoms off the signal, which results in a distorted (or overdrive, or fuzz) sound. Whether we call it "Fuzz," "Overdrive," or "Distortion" is a matter of opinion based on the amount of clipping, and the shape of the corners of the clipped signal. Ultimately, though, they're all just clipping.

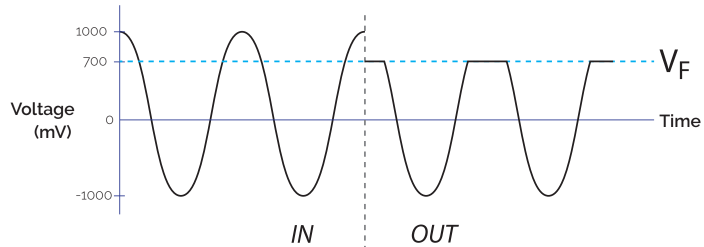
Consider this simple example circuit:



When your signal is lower than V_F it flows uninterrupted from IN to OUT.



When the signal swings positive (i.e. voltage is greater than 0, the top half of the graph), and then exceeds V_F, the diode starts to allow current to flow to GND. The voltage across the diode is equal to its V_F, leaving the output at exactly V_F regardless of how high the input signal was.



We just clipped the input signal, causing distortion!

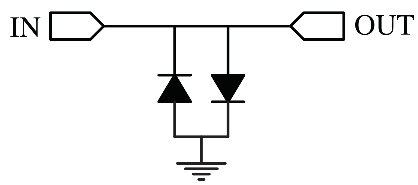
Recall from <u>the Input Signal section</u> that the voltage (height) represents our volume. So we see that low volumes can avoid clipping while higher volumes clipped. This is why you can dial in the volume and gain in your pedal chain or on your amplifier to the "**edge of breakup,**" then use your guitar's volume knob or your picking dynamics to alternate between clean and distorted sounds.

Also recall that Germanium diodes have a lower V_F than Silicon diodes. This means that, all other things being equal, **Germanium diodes result in a quieter output signal than Silicon** in a diode clipping circuit.

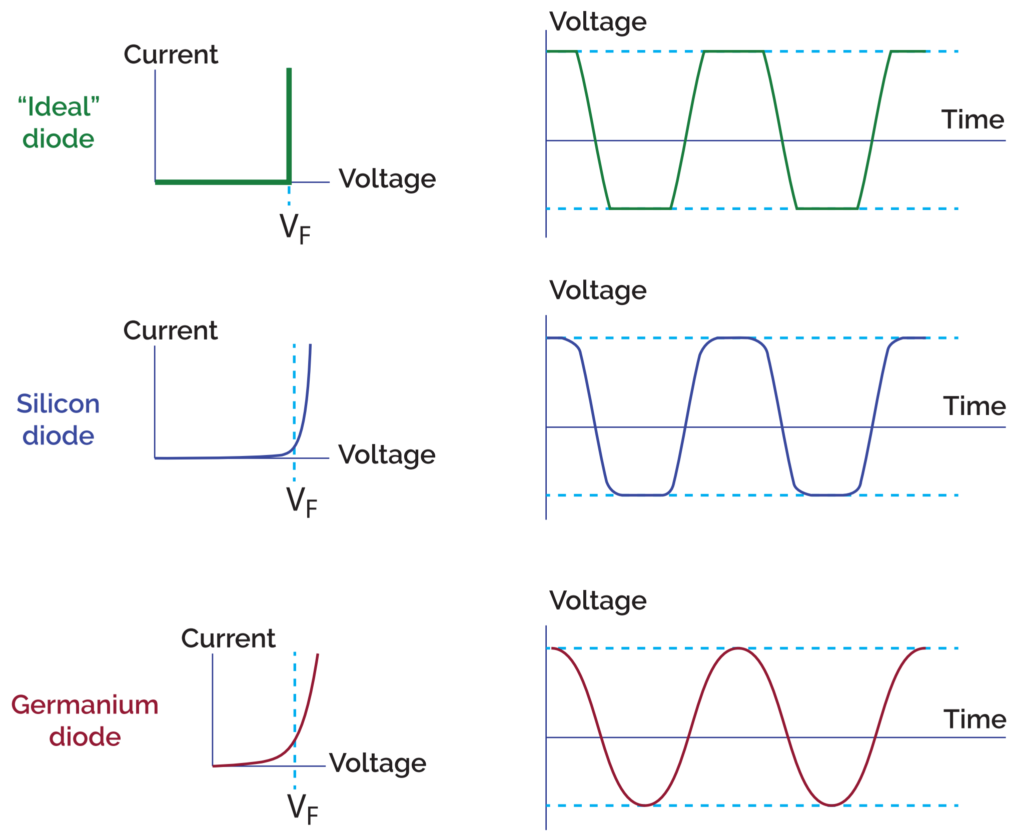
Diodes in General (continued)

Diode Clipping (Extra Info FYI) (continued)

But wait, we only clipped the tops of the wave. If you want to clip the bottom too you can just add another diode in the opposite direction:



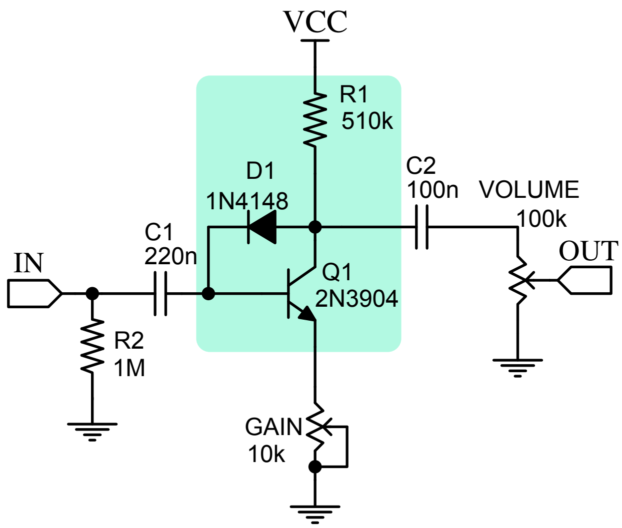
Now let's look at what happens to our signal in this clipping circuit through 3 different types of diodes:



These are exaggerated for effect but you can see, the sharper the knee, the sharper the output wave. This gives a type of distortion we typically describe as fuzz.

The softer the knee, the softer the edges of our clipped signal become. We typically call this (predictably) softer distortion, or overdrive. When you're trying to soften up the sound of diode clipping, Germanium diodes are great. As you can see with our Distortion 250 beginner kit, you can also find modern diodes like BAT41 that display a very similar shape in the current-voltage graph, and as a result sound practically identical to Germanium.

Boost and Clipping: R1, Q1, & D1



Common distortion pedals boost the signal, then clip it. Or they boost while clipping uniformly, either with transistors or op amps. This circuit clips the signal in a different, complicated, and unique way. That fuzzy, distorted sound comes from an interesting dance between the transistor Q1, and the diode D1.

The transistor amplifies the signal, and is set up as a common emitter, but it is biased in an unusual way. Biasing is typically done with resistors that help ensure the collector and base (two of the three transistor legs) have appropriate current and voltage conditions to allow the transistor to operate correctly. In this circuit, however, the diode is being used instead.

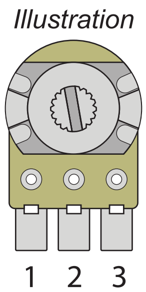
The diode's job is different depending on whether the incoming signal is currently positive or negative. When the input is negative, the diode allows current to flow to the base of the transistor. This upsets the bias at the collector and results in distortion. R1 determines to what extent this happens. The signal is also able to bypass the transistor through the diode, and experiencing clipping through it.

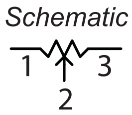
When the signal is positive, however, the diode does not conduct and the transistor's gain increases significantly to the point that the transistor directly clips it.

This results in **asymmetric clipping**; i.e. the positive and negative halves of the signal are clipped differently. This gives the pedal a unique sound.

It's also worth noting that this transistor setup results in an **inverted, or phase shifted** output. That is, peaks of the wave become valleys, and valleys become peaks. On its own this does not matter. If, however, your pedal board is splitting the input and mixing the output with another chain, you may need to invert it in the mixer to avoid a loss of volume when the signals are added together.

Potentiometers in General

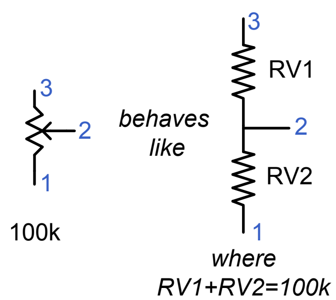




Potentiometers (pots) have 3 lugs. The resistance between lugs 1 and 3 is **its value**, e.g. 100kΩ.

Lug 2 is called a **wiper**. As you turn the knob the wiper moves and changes the resistance between lug 2 and the other lugs. It acts as a **voltage divider.**

Consider for example this 100k pot and its equivalent voltage divider. The resistance between 1 and 3 is always 100k, but the resistance between 1 and 2, and between 2 and 3 varies depending how you turn the knob. But those two resistance values will always add up to 100k.



Voltage dividers give the current two paths to follow, each with a different resistance.

In addition to using it as a voltage divider, we can wire a pot like a **variable resistor** or rheostat by simply using the resistance between the wiper and one of the outer lugs. The other lug can be left floating (disconnected) or can be tied (connected) to the wiper. We commonly do this so if pot fails we have a predictable resistance between the two sides.

Pots also have a property called **taper**, which describes how quickly or slowly the resistance changes as you turn the knob. Common values are "audio" or "logarithmic", and "linear."

The taper is represented by a letter code, e.g. "A" for audio and "B" for linear. The code and the pot value will typically be written together when describing it (e.g. in the Bill of Materials for a pedal, or stamped on the body of the pot).

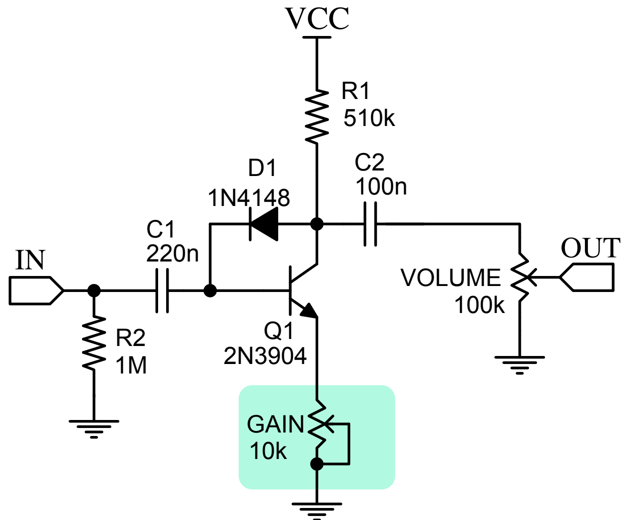
For example an A100k pot is a 100kΩ audio taper pot, and B10k is a linear 10kΩ pot.

Gain Knob

Adding resistance at the emitter of the transistor reduces its gain.

We've added a 10k potentiometer, wired as a variable resistor, to allow you to reduce the gain on this pedal.

When the knob is fully clockwise, the resistance between the transistor's emitter and GND is 0Ω, allowing for maximum gain. When the knob is fully counter-clockwise, there is 10kΩ between the emitter and GND which reduces the transistor's gain.

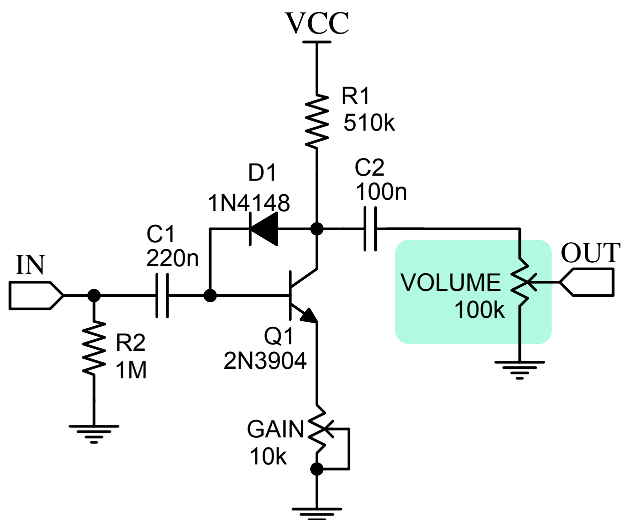


Volume Knob

The volume potentiometer is set up as a voltage divider. It provides a path to GND for some of the audio signal, effectively quieting it.

When you turn the volume knob completely up, there is nearly 0Ω of resistance to the output, and 100kΩ resistance to GND. This ensures all of the voltage (i.e. signal volume) is makes it to the output.

Likewise, when you turn the volume knob all the way down, there is almost no resistance to GND which gives the current an easier path. This effectively pulls your output down to 0V (the GND voltage) and kills the volume completely.



EXTRA CREDIT

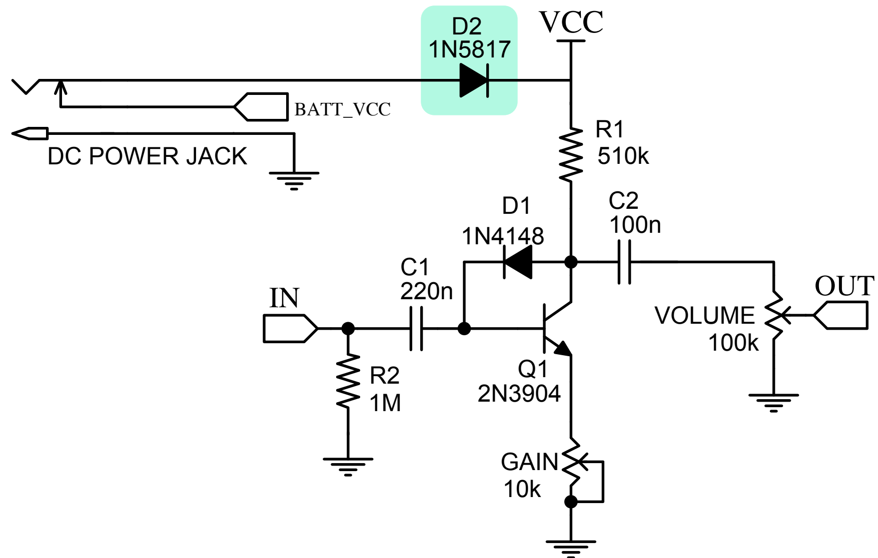
Technically this potentiometer also acts with C2 to form a high pass filter that blocks lower frequencies. The frequency cutoff depends on the volume knob setting and the input impedance (like resistance) of whatever follows this pedal. In practice this is typically outside the range of what we can hear, so we don't worry about this unintended side-effect.

If you're interested, learn more about passive low pass filters and high pass filters at those links.

Reverse Polarity Protection: D2

We haven't seen D2 on the schematics yet because we've been looking at only the audio effect part of the circuit. If you refer to the full schematic in APPENDIX A you'll find D2 on the jack PCB.

A simpler version is shown here.



Recall that diodes act as a one-way filter for DC. Its anode (positive side) is connected to the positive sleeve of the DC jack. When a center negative supply is used, as expected, the diode will allow current to flow and the circuit operates as normal.

If a center-positive power supply is accidentally plugged into this pedal, **D2 will block the flow of current, protecting the rest of the pedal** from a reverse voltage which could damage components.

This is an extremely simple, effective, and inexpensive way to protect the circuit. As with everything in engineering, though, there's a tradeoff. The primary downside to this method is that the voltage drops across the diode (by V_F), leaving a lower voltage difference for the effect circuit. That's a precise way to say it "has less headroom." To mitigate this we choose a **Schottky diode** since it has a low V_F while still being able to handle our voltage and current requirements. In particular we're using a 1N5817.

If you wanted to avoid even a small voltage drop, another protection scheme could be used. For example we sometimes see pedals, especially older ones, use a reverse biased rectifier diode (e.g. 1N4001). In other words the diode goes directly from GND to the positive side of the power supply, but reversed so ordinarily it doesn't conduct. If a reverse power supply is used, it provides a short circuit across the supply preventing this reverse voltage from affecting the rest of the circuit. Unfortunately this can burn up components or damage your power supply. You avoid the voltage drop but the protection is limited.

You can also use transistors to protect the circuit, though it's a lot more complicated than a single component. You can read more about it in this article at geofex.com.

Op Amps (Extra Info FYI)

If you'd like to learn about op amps, which are commonly used in pedals (but not this one) then check out the Comprehensive Build Guide for the Distortion 250 version of this kit.

Going Further

Want to learn more? Later this year we'll have a curated collection of links to guide you through your journey on all things DIY pedals at diypedals.net

In the meantime, here are a few extremely useful resources:

- electrosmash.com has, in its "PEDALS" menu, detailed walkthroughs of a variety of popular pedal circuits
- geofex.com has many great articles if you poke around for a while
- amxfx (muzique.com) likewise has detailed walkthroughs on a wide variety of topics.

Or if you're looking for something in particular, drop a message in r/maseffects and we'll point you in the right direction.