Capacitors for Beginning DIYers

By Keith Vonderhulls

One of the most common tech support questions we get at BYOC is how to identify the capacitors in our kits. This can be very confusing to beginning DIYers for 3 reasons. The first reason is simply that there are quite a lot of different types of caps – aluminum electrolytic, ceramic disc, tantalum, etc… - and it can be hard to tell which is which if you aren't already familiar with them. The second reason is that capacitor codes often contain a lot of extra gibberish that has nothing to do with the capacitance value such as tolerance and voltage ratings. The third reason is that while capacitance is always measured in farads, the value that is printed on the actual capacitor can be in micro, nano, or pico farads. The purpose of this article is to help familiarize you with the various types of capacitors that you are likely to come across while building guitar effects, how to read the codes printed on capacitors, and how to convert back and forth between micro, nano, and pico farads.

Types of Capacitors

There are a lot of different types of capacitors. Actually, a cap is a cap. They all do the same thing. What I should say is there are a lot of different materials that capacitors are made out of (dielectric materials), each with their own virtues. I like to think of capacitors as being in one of 3 different catagories: Large values, medium values, and small values.

The most common "large value" caps are aluminum electrolytic. They are usually shaped like a beer can. Aluminum electrolytic capacitors usually have a radial lead, but axial leads are more common in things like point-to-point wired amplifiers because they are easier to work with (axial lead means a component that has two leads on opposite sides as if it were a wheel axle running through it. Radial means it has two leads side-by-side running parallel to each other). They are almost always polarized, meaning they have a positive and negative end, but there are non-polarized versions as well. Their capacitance value will be labeled in micro farads and can range anywhere from .1 microfarad to thousands of microfarads. Aluminum electrolytic caps come in a wide range of voltage ratings. They typically have a smaller voltage rating than film or ceramic capacitors, but they are available in higher voltage ratings. Aluminum electrolytic caps with high voltage ratings are extremely large in size. This is why an 8 microfarad aluminum electrolytic cap with a voltage rating of 500VDC that you would find in a guitar amplifier will be 4 or 5 times bigger in size than a 470 microfarad aluminum electrolytic cap with a voltage rating of 16VDC that you would find in a guitar pedal. For the purposes of guitar effects and analog audio circuitry, aluminum electrolytic caps are most often used in power filtering, voltage divides, and cross overs. Aluminum electrolytic caps are often used in the signal path, but are generally considered inferior to film capacitors for handling audio signal. However, sometimes you need a capacitance value in your signal path that is too large and you must use an aluminum electrolytic cap simply because they do not make film caps in a value large enough.

The most common “medium value” caps are film caps. Film caps definitely cause the most confusion for beginners because they have the most variance in both their physical appearance and value codes. It gets even more confusing when you consider that film caps can be broken down even further by different materials such as foil, paper, polyester, polyethylene, polypropylene, and polystyrene. The most common type of film cap you will see in guitar effects is polyester. Polyester film caps come in many different shapes and colors. Everything from the green Chicklet-shaped caps you’d find in old BOSS pedals to the blue box-shaped caps you’d find in Dunlop pedals are polyester film caps. Film caps are not polarized. Film caps are usually radial leaded, however, just like aluminum electrolytic caps, they are usually axial leaded in point-to-point wired amplifiers because they are easier to work with. You will commonly see them range in value from .001mf to 1 whole microfarad. You will rarely see a film cap with a voltage rating less than 50VDC. For the purposes of guitar effects and analog audio circuitry, film caps are most often used in the signal path or applications that require neither an extremely large capacitance nor extremely small capacitance. This is why I like to think of film caps as “medium value” caps.

The most common “small value” caps are ceramic disc capacitors. Silver mica is another type of capacitor that tends to be in the small value range, but it has become somewhat obsolete now due to the fact that it is much more expensive than ceramic. Neither ceramic disc nor silver mica caps are polarized. Ceramic disc caps come is a variety of colors, but orange is the most common color. Ceramic disc caps are easy to spot because they are all pretty much the same shape – a round disc – and you will very rarely ever see a ceramic disc cap that is not radial leaded. Ceramic disc caps commonly range in value from just a few pico farads to .01 micro farads. Ceramic disc caps used to come in medium values. The older MXR and Electro-Harmonix pedals frequently used ceramic disc caps for values where you would expect to see film caps, but for whatever reason, capacitor manufacturers have chosen to no longer make ceramic disc caps in the medium value range. Ceramic disc caps have a voltage rating range similar to film caps. The ceramic disc caps you’ll find in guitar effects will usually be physically smaller than the other caps, but ceramic disc caps with an extremely high voltage rating can get pretty big (as is the case with any type of capacitor). For the purposes for guitar effects and analog audio circuitry, ceramic disc caps are most often used as radio frequency blockers, especially in the negative feedback loops of transistor or op amp gain structures, and in band-pass filters where the cutoff frequency is in the upper range of the spectrum.

There is one other type of capacitor that needs to be mentioned if we are talking about caps that are commonly used in guitar effects, and that is tantalum. Tantalum capacitor values commonly range from .1 micro farad to 47 micro farads, so this would be a range that I consider to be the larger end of the “medium” values and the smaller end of “large” values. Tantalum is pretty much obsolete now because it is quite a bit more expensive than electrolytic capacitors for larger values, and usually more expensive than film capacitors for the medium values. Capacitor manufacturers still continue to offer a fairly decent variety of options, but tantalum is not nearly as popular as it was 30 years ago. Script logo era MXR pedals used tantalum exclusively for values where you’d expect to see aluminum electrolytic. Tantalum caps used to come in a few different colors, but nowadays, you’ll usually only find them in mustard yellow. Some of the smaller values have axial leads, but radial is far more common. They almost always have a “match head” shape. Tantalum caps are polarized. Tantalum capacitors have a relatively low voltage rating range. They are relatively small compared to other capacitors, especially when compared to electrolytic caps. For the purposes of guitar effects and analog audio circuitry, tantalum caps are typically used in voltage divides and in band-pass filters where signal is being bled to ground. You will almost never see a tantalum cap in the actual signal path.

Microfarads, nanofarads, or picofarands?

Capacitance is measured in farads. But one whole farad would make for a ridiculously large capacitor, so the typical capacitor values that you’ll actually see in the real world come in 3 smaller units: microfarads, nanofarads, and picofarads. The first thing you need to understand is that micro is the largest unit of the 3, pico is the smallest, and nano is in the middle. The second thing you need to understand is that even though microfarads is the largest of the capacitance units you’ll be dealing with, it’s still very very small. It’s only one millionth of one whole farad. It’s just like meters. You know that there are 100 centimeters in a meter and there are 1000 millimeters in a meter. You probably know that there are 1 million micrometers in a meter. Nano and pico get even smaller. Nano means one billionth and pico means one trillionth.

I know that for myself, dealing with infinitely small numbers is far more confusing than dealing with absurdly large numbers. So…since you will never ever see a capacitor with a value in units larger than microfarads in guitar effects, it makes things a whole lot simpler if we assume microfarads to be our whole base unit instead of farads. This way, we think of a nanofarad as one thousandth of a microfarad instead of one billionth of a farad, and a picofarad as one millionth of a microfarad or one thousandth of a nanofarad, instead of one trillionth of a farad. It’s still pretty confusing, but it’s less confusing.

Before we get into converting, I need to mention one thing: the symbols for microfarad, nanofarad, and picofarad. Nano and pico are pretty straight forward. Nanofarad is “nF” and picofarad is “pF”. Microfarad is a little more confusing. Sometimes you will see it as “mF”, which is WRONG! “mF” would be millifarads. The symbol for microfarad is very commonly shown as “uF”. However, the lower case U in “uF” isn’t really a lower case U. It’s supposed to be a Greek “M”. The proper symbol for microfarad is μF. But most people don’t know that ALT+230 is how you get the μ symbol or they are using a schematic/CAD program that doesn’t support special characters, so they just use a lower case U instead. So now that we know µF = microfarad, nF = nanofarad, and pF = picofarad, I don't have to type so much and we can start learning to convert units.

RULE #1: When converting to a smaller unit, move the decimal 3 places to the right to get to the next closest unit.

RULE #2: When converting to a larger unit, move the decimal 3 places to the left to get to the next closest unit.

Let's say we have .001µf and we want to convert that to pF. We could just move the decimal 6 places to the right and be done with it, but since we're doing this to learn how to convert between µF, nF, and pF, let's convert it to nF first by only moving the decimal 3 places to the right.

.001µF = 1nF

To convert to pF, we move the decimal another 3 places to the right.

1nF = 1000pF

So, .001µF = 1000pF

Now let's go the other way. Let's convert 47,000pF to µF. First, let's move the decimal 3 places to the left to convert to nF.

47,000pF = 47nF

Now move the decimal another 3 places to the left to convert to µF.

47nF = .047µF

So, 47,000pF = .047µF

How to Read Capacitor Codes

Deciphering the various gibberish on capacitors is probably the most challenging thing for beginners because every brand of capacitor has its own way of coding, especially film caps. As the manufacturer of BYOC kits, it would be easier for me if I just used one brand/model of capacitor, because it wouldn't be nearly as confusing for my customers. But brands and models are constantly being discontinued or back ordered. It's rare that we ever put together two batches of kits that contain parts that are all exactly the same brand/model. We have a B.O.M. (bill of materials) for each kit that we like to use, but we inevitably always have to source alternate parts.

Some caps will have a code that will tell you the model, the tolerance, the voltage rating, and the capacitance value. Some will have code that will only tell you the capacitance value and nothing else. Knowing how every manufacturer likes to code their caps isn't important. The important thing is learning how to separate the wheat from the chaff. And what I mean by that is that you only need to concern yourself with picking out the parts of the capacitor code that are important to you.

"What is tolerance?" you ask. Tolerance is the component manufacturer's way of letting you know how close to the intended value the component is actually going to be. So for example, if you have a cap that is supposed to be 100nF with a tolerance of ±10%, it's actual value could be anywhere from 90nF – 110nF. The smaller (or tighter) the tolerance, the more precise the component is likely to be to its intended value.

If you are building a pedal from a kit, the only thing you really need to worry about is the capacitance value. Voltage rating is very important too, because you definitely do not want to use a capacitor that cannot handle the voltage for your application. But with guitar effects pedals, it's not as important. Most guitar effects are 9VDC and most caps can easily handle that. If you're running a pedal at 18VDC or using a charge pump, then you need to make sure your aluminum electrolytic caps can handle the voltage, but you really don't even need to give any thought to the voltage ratings of your film and ceramic disc caps. Voltage rating becomes extremely important when you are dealing with higher voltages because capacitors can explode if their voltage rating is exceeded. If you're building something like a vacuum tube amplifier, you'd need to be very concerned with voltage ratings.

Tolerance isn't something that you really need to worry about in this day and age. I'm sure there are a lot of people who would disagree with this. I stipulated in "this day and age" because if you're reading this, you're probably only concerned with capacitors for the purpose of building guitar effects, amplifiers, and maybe some other audio circuitry where tolerance is not as critical as if you were building something like medical equipment, or a space shuttle, or something that was a matter of life or death. Most of these audio circuits were designed 30 or more years ago and used components with incredibly poor tolerances. If you were attempting to replicate the exact Fuzz Face that Jimi Hendrix used at the Monterey Pop Festival, and you had measured the exact values of each component in that specific Fuzz Face, then tolerance would be very important, because perhaps it was the accumulation of tolerance that gave that particular pedal its mojo. But if you were just trying to build a Fuzz Face according to the Dallas Arbiter factory schematic, tolerance would not be that important, because the cheapest components you can buy this day and age would have tolerances that are as good or better than what the original Fuzz Face had. There are also the people who think lower tolerances mean better tone. Lower tolerance components do not improve sound quality in any way. They just cost more. So it's nothing more than a selling point or something for manufacturers to brag about.

I'm digressing a bit. The most important thing to know about voltage rating and tolerance is that if you are building something from a kit, you don't need to worry about them because the manufacturer of the kit has already selected them for you. The only thing you need to worry about is the capacitance value so that you are putting the right cap in the right place. However, we will cover tolerance and voltage rating so that you know how to identify it in capacitor code and so that it will make it easier for you to locate the important code that tells you the cap's actual value.

Let's take a look at a fairly typical film capacitor code and jump right in.

"392J100"

RULE #1: The tolerance will always be represented by a single capitalized letter.

RULE #2: The capacitance value will always come before the tolerance.

RULE #3: If the capacitance value code contains 2, 3 or 4 numeric characters, the capacitance unit will always be in picofarads *unless the capacitance value code has an "n" or "µ" symbol in it.

RULE #4: If the capacitance unit is given in picofarads, and the capacitance value code contains 3 numeric characters, the first and second numbers are to be taken at face value. The third number tells you how many zeroes to add onto the end.

RULE #5: If the capacitance units is given in picofarads, and the capacitance value code contains 2 or 4 numeric characters, it is to be taken at face value.

RULE #6: If the capacitance value code contains only 1 numeric character, or a decimal point and any number of numeric characters, AND no symbols that define the units of capacitance, then it can be assumed that the units are in microfarads and is to be taken at face value.

Based on Rule #1, we can assume that "J" is the tolerance of our example capacitor. But what does "J" mean? Tolerance is difficult to figure out only because there are 5 letters that you need to memorize. Once you have them memorized and know what tolerance they correspond to, it's very simple.

F = ±2%
G = ±3%
J = ±5%
K = ±10%
M = ±20%

So our sample capacitor has a tolerance of ±5% because J = ±5%. You really only need to memorize 2 letters, J and K. These are the most common. You will rarely ever see caps with a tolerance of less than ±5% in audio circuitry. The only time lower tolerances are necessary is when you're building something like a graphic EQ and you want more precise control over which frequencies you are affecting. Aluminum electrolytic caps commonly have a tolerance of ±20%, but film caps with a tolerance of ±20% are very rare. You're likely to only see them in vintage electronics.

Now that we've picked the "J" out of "392J100", that leaves us with "392" and "100". Based on Rule #2, we can assume that "100" is the voltage rating. Other common numbers you will see a lot for voltage ratings on film caps are 50, 63, 250, 500, and 630. As I mentioned earlier, you will rarely ever see a film cap with a voltage rating less than 50VDC (which is why you don't need to be very concerned with the voltage rating of your film and ceramic disc caps for the purposes of guitar effects). Aluminum Electrolytic caps in effects pedals will more often than not have voltage ratings less than 50VDC, but fortunately, aluminum electrolytic caps usually have the value and voltage rating printed on the cap in a very obvious way, so this section on how to read capacitor codes doesn't apply to aluminum electrolytic caps.

In the case of our "392J100" example cap code, the voltage rating came after the tolerance, but you could just as likely see the voltage rating come first. If this was the case, the code would most likely read "100V392J". The important thing is that the bit of code that tells us what the capacitance value is, comes before the tolerance letter, as stated in RULE #2. So we can assume that "392" is the bit of code that is trying to tell use what the actual capacitance value is.

Now comes the important part – figuring out the capacitance value. Based on rules #1 and #2, we have deduced that "392" is the portion of the capacitor code that pertains to the capacitance value. Based on rule #3, we can assume that the capacitance is being given to us in picofarads. So does that mean the value of the cap is 392pF? NO!!!!! It's not that easy. The capacitance of our example cap is not 392pF. We need to take Rule #4 into consideration. According to Rule #4, the capacitance value is 39 x 100pF or 39-with-two-zeroes-on-the-end pF. Or if we use our conversions:

$$3900pF = 3.9nF = .0039\mu F$$

So…a capacitor with the code, "392J100", lets us know that the capacitor is .0039µF, with a tolerance of ±5%, and a voltage rating of 100VDC.

Ceramic disc caps are often times physically too small to fit a lot of print on them, so ceramic disc capacitor codes usually do not have the tolerance or voltage rating printed on them. They usually only have a 2 or 3 digit code and will almost always be in picofarads. Pretty easy, right? Wrong! For the most part, the code on ceramic disc caps is pretty easy and straight forward to read, especially if it has 2 or 4 digits, because we don't need to add any zeroes onto the end. According to RULE #5, if it reads, "22", then it's just a 22pF cap. If it reads, "51", then it's just a 51pF cap. If it reads "4700", then it's a 4700pF or .0047µF. If it reads "1000" it's a 1000pF or .001µF. But if it has 3 digits, sometimes manufacturers try to fool you with the "zero zeroes" trap.

Let's say we have a ceramic disc cap that reads, "471". According to RULE #4, we know to take the 4 and the 7 at face value, and then add 1 zero on the end. This tells us that the cap is 470pF. But what if we have a cap that reads, "470"? Our first instinct is to assume that the capacitance is 470pF, but that would be wrong. "470" means we take the 4 and the 7 at face value and add ZERO zeroes to the end, giving us a capacitance value of 47pF.

This is the "zero zeroes" trap. It's not that common on capacitors. If a ceramic disc cap only has 2 digits in its capacitance value, then the code will usually only be 2 digits long. Manufacturers usually only use a 3 digit code if the value is 3 or more digits long. But just be aware of it, because it does happen from time to time. It's much more important that you be aware of the "zero zeroes" trap when reading resistor codes because resistors will always have 3 or more bands, and it is not possible to have 2 digits without the last band equaling zero. Now on to discussing exceptions to Rule #3.

Rule #3 says, unless the capacitor code has an "n" or "µ" symbol in it, the capacitance value will always be in picofarads. So what happens if the capacitor code has an "n" or "µ" symbol in it? It's pretty simple actually. Rules #1 and #2 still remain the same. The bit of code that precedes the tolerance letter will still be the part that tells you want the capacitance value is. But now, RULE #4 no longer applies. If the capacitor code has an "n" or "µ" anywhere in it, ALL of the numbers that precede the tolerance letter are taken at face value in the unit of capacitance denoted by the symbol. So for example, "1µK63" means the cap has a value of 1µ, with a tolerance of ±10%, and a voltage rating of 63VDC. If we have a capacitor code that reads, "100V47nJ", then we have a cap with a value of 47n (or .047µ), a tolerance of ±5%, and a voltage rating of 100VDC.

This is pretty easy. A lot easier than having to figure out the value in picofarads, and how many zeroes to add onto the end, and then most likely having to convert to microfarads. But when dealing with the exception to Rule #3, there is one small thing to consider. What if we had a cap with a code that read, "µ1K63" or "100V4n7J"? The thing to consider or always keep in mind when dealing with the exception to Rule #3 is that the "µ" and "n" symbols not only tell us what unit of capacitance we are dealing with, but it is also a DECIMAL POINT. So this means that the capacitance value of "µ1K63" is 0.1 microfarads, and "100V4n7J" is 4.7 nanofarads.

That just leaves us with RULE #6 to discuss. Let's look at the example code, "1K100". By now you should be able to quickly determine that the tolerance is ±10% and the voltage rating is 100VDC. But what about that lone "1"? According to RULE #6, it's in microfarads and should be taken at face value, because the bit that makes up the value code only contains one numeric character and no "n" or "µ" symbol, so that would make the capacitance value 1µF. If the code read, ".0047J63", RULE #6 would still apply because there is a decimal point and no "n" or "µ" symbol. You should see that the tolerance is ±5% and the voltage rating is 63VDC. We can also assume the .0047 is in microfarads and should be taken at face value giving us a capacitance value of .0047µF, or 4.7nF, or 4700pF.

Test yourself

Now that you know a little more about capacitors, here's a few examples of real capacitors to test your new skills. Look at the pictures and figure out what type of capacitor (the dielectric material) is in each picture, the type of lead (radial or axial), and the capacitance value. And if the capacitor tells you the tolerance and voltage rating, figure that out too. The answers are at the end of this article.

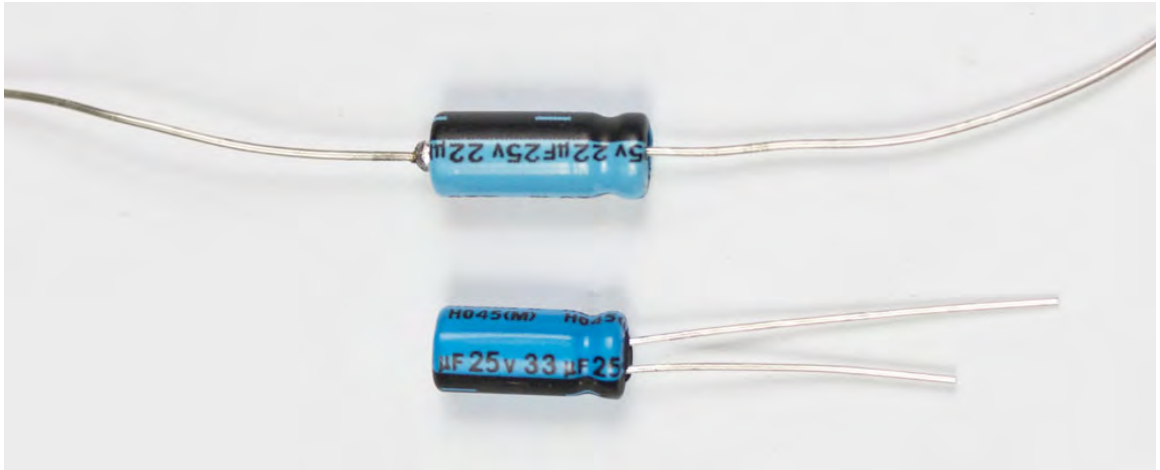

Figure 1.

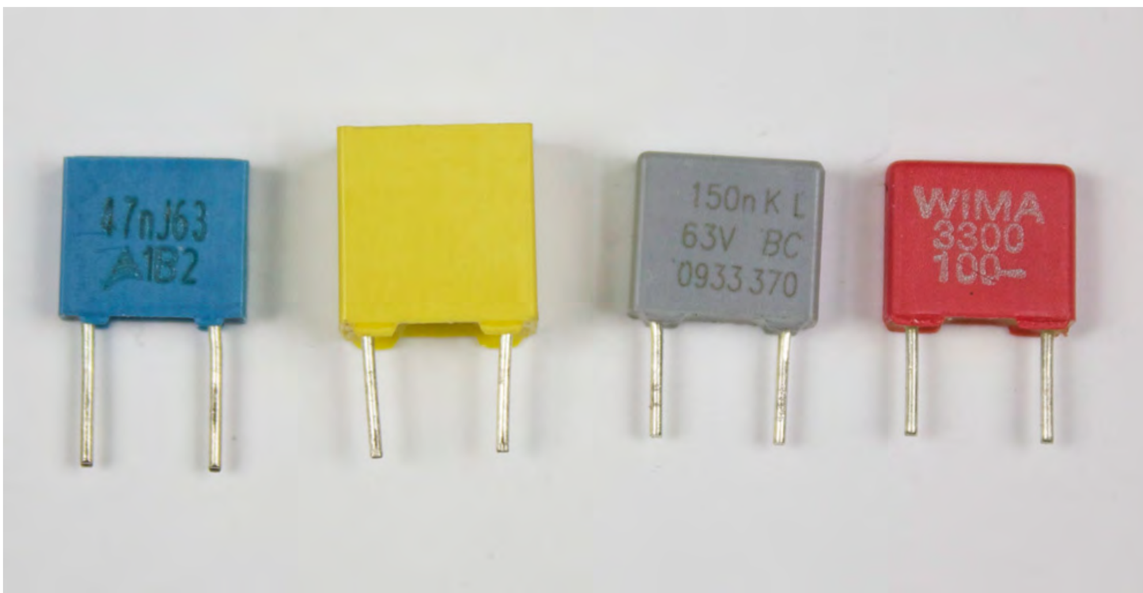

Figure 2.

Figure 3.

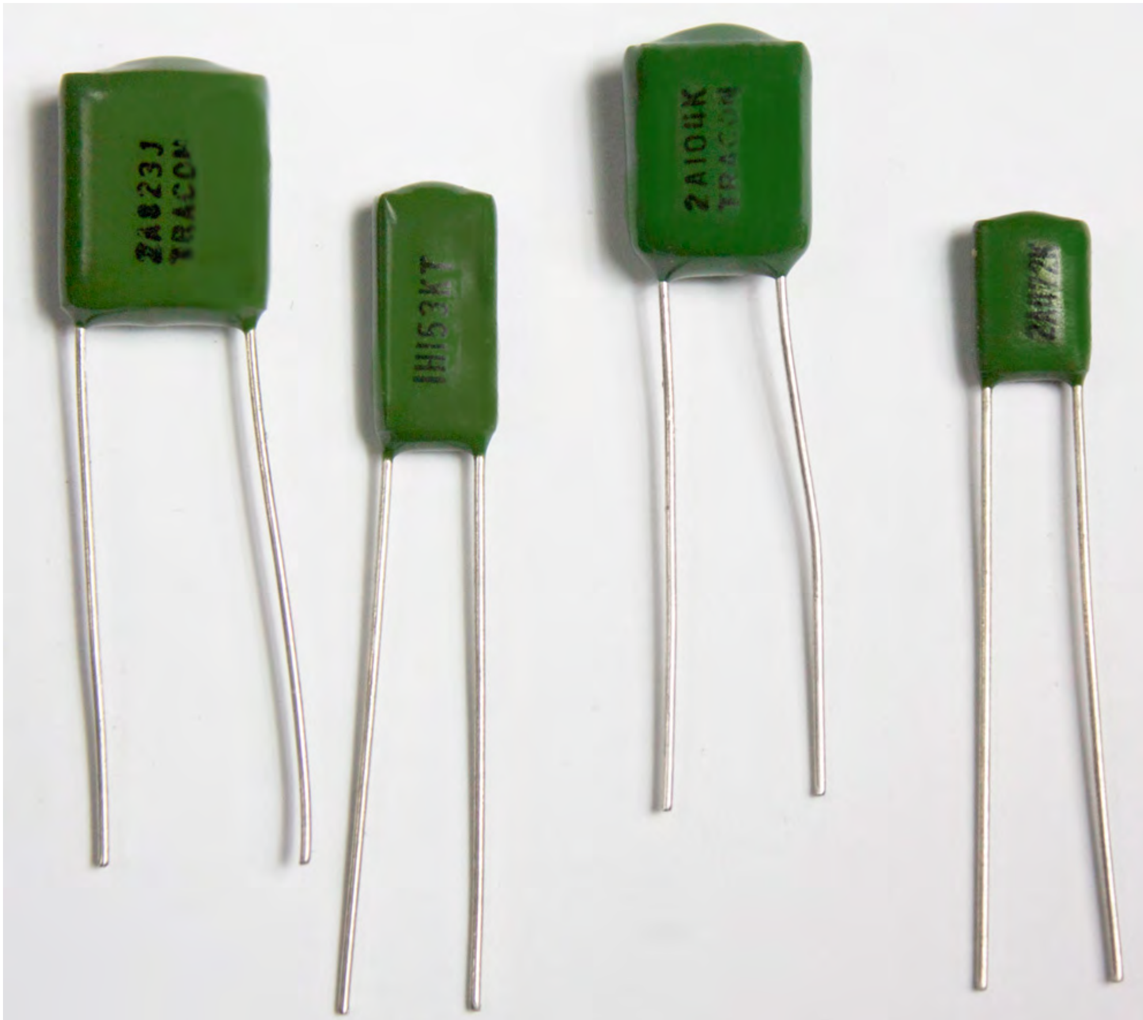

Figure 4.

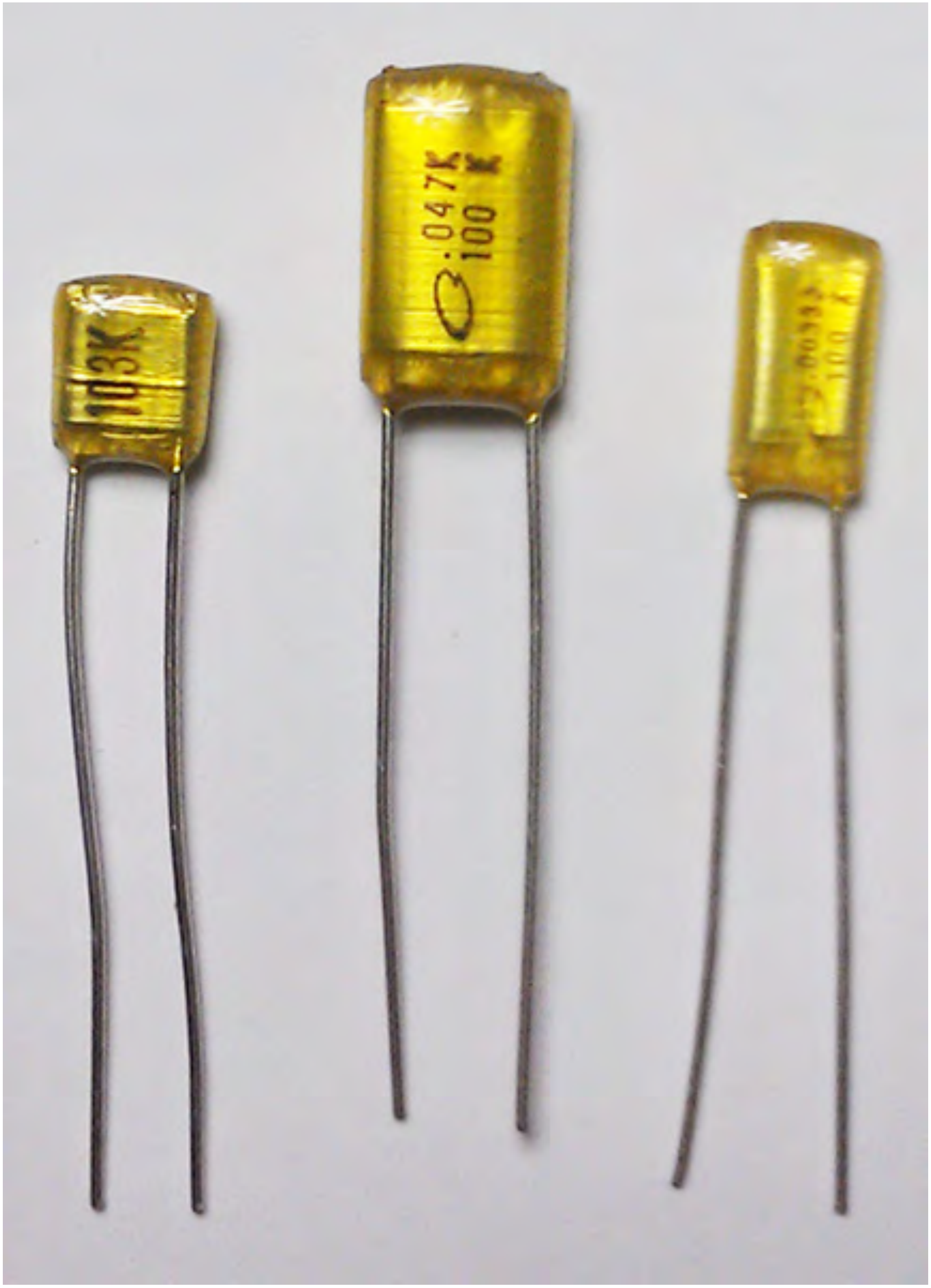

Figure 5.

Figure 6.

Figure 7.


Figure 8.

Figure 1: These are aluminum electrolytic caps. The cap on top is has an axial lead and is 22 microfarads. The cap on the bottom has a radial lead and is 33 microfarads. Both caps have a voltage rating of 25VDC. We can't see the tolerance on the 33uF cap, but we can see an M on the 22uF cap which means it's a 20%.

Figure 2: These are all radial leaded polyester film caps. These are what people typically refer to as "box" caps. You can see they come in a variety of colors. Going from left to right: .047uF/5%/63VDC; ? the code is on the top of the cap; .15uF/10%/63VDC; .0033uF/tolerance unknown/100VDC

Figure 3: These are all radial leaded ceramic disc caps. From left to right: .01uF; 330pF/5%; .05uF; 680pF/5%

Figure 4: These are all radial leaded polyester film caps. These are what are commonly referred to as "greenies". They are extremely common in vintage Japanese made guitar pedals. The bit of code ("2A" & "1H") at the beginning of each is proprietary and tells what the voltage rating is. From left to right: .082uF/5%; .015uF/10%; 0.1uF/10%; .0047uF/10%.

Figure 5: These are all radial leaded polyester film caps. These are what are commonly referred to as "mylar" caps. From left to right: .01uF/10%; .047uF/10%/100VDC; .0033uF/5%/100VDC.

Figure 6: These are all radial leaded polyester film caps. A lot of people call this sort of dark red capacitor, a "Panasonic" cap because Panasonic makes a popular model that looks like these, but there are many brands that have the exact same appearance. The cap, second to left, in figure 6 is made by Cornell Dublier. From left to right: .012uF; 0.18uF/10%/250VDC; 0.1uF; 1uF.

Figure 7: These are all radial leaded tantalum caps. As with most polarized components, the positive lead is longer than the negative, but in the case of the cap on the far right, the manufacturer was kind enough to put a "+" symbol on the positive side. From left to right: 10uF/6VDC; 10uF/25VDC; 0.15uF/35VDC; 6.8uF/35VDC (the "K" probably means a 10% tolerance, but it's not certain).

Figure 8: This is an example of an axial leaded polyester film cap. In case the picture is too blurry for you to make it out, it very plainly states that it is .047uF/5%. You won't find this type of cap in many guitar effects pedals. Mostly in vintage effects like the Dallas Arbiter Fuzz Face or one of the earlier Tonebenders. If you do see them in more modern effects, it's purely for aesthetics. Axial leaded components are much more common in point-to-point applications like amplifiers.