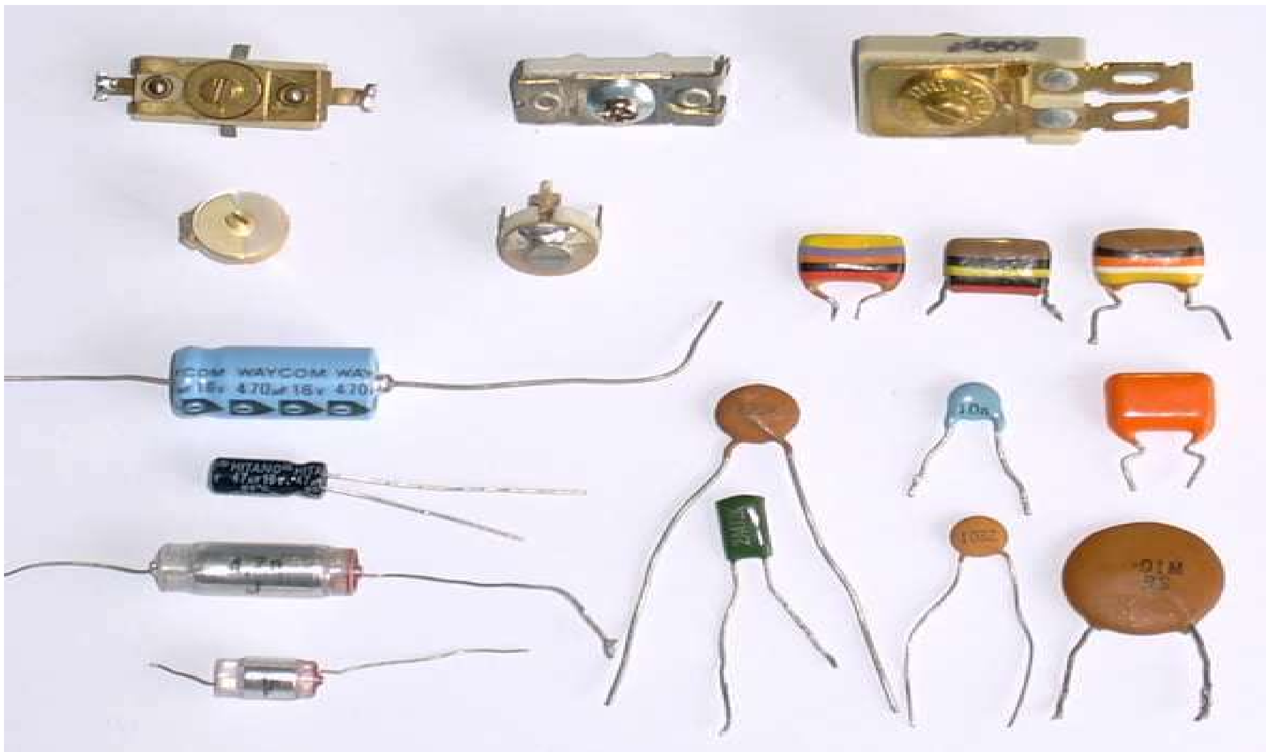
An overview of capacitors

By Tony Riffe AA7FR



A wee bit o' history for your enjoyment

- The Leyden Jar, the first capacitor, was created by Pieter Van Musschenbroek, named after the University of Lieden, in 1746. It was based upon a design discovered in Germany the previous year.
- It was found that a charge could be stored by connecting a high voltage electrostatic generator by a wire to a volume of water in a hand held glass jar.
- The hand and water acted as conductors, whilst the glass acted as the dialectric.
- Pieter was surprised and impressed by the size of the shock of the stored energy, stating "I would not take a second shock for the Kingdom of France".
- The estimated capacitance of these jars was around .001 uF.
- They were the industry standard up until around 1900, when the invention and needs of then new radio medium made them impractical.
- Karol Pollak invented the first electrolytic capacitor in 1896. This was the actual beginning of the modern capacitor as we know them.
- Initially, capacitors were called condensers. This term was widely used in the radio era up to around 1926 when there was a slow transition to the current term, although for some applications, condenser is still used.

Fun facts

- A capacitor is a device that stores energy in an electrostatic field
- Generally contain 2 conductors separated by a non conductive element (dielectric).
- The type of dielectric can increase a capacitors charge capacity
- An ideal capacitor does not dissipate energy, though in the real world they all do
- They are rated in units of Farad. 1 Farad means 1 coulomb of charge on each conductor causes a voltage of 1 volt across the device.
- Common values in radio equipment are far lower. Most commonly seen are uF, pF and sometimes nF.
- Example: 1 uf= 1 millionth of a Farad. May be noted as mF on older schematics. 1 nF= 1 billionth of a Farad and 1 pF= 1 trillionth of a Farad. Also known as uuF or mmF on older schematics. To break it down, a capacitor noted as .01 uF= 10nF or 10,000 pF.
- When DC voltage is applied to a capacitor in series, an electric field develops across the dielectric, causing a positive charge to collect on one plate and a negative charge on the other plate. No current or voltage actually flows through the dielectric once the charge builds.
- When AC voltage is applied, the capacitor charges and discharges according to frequency of the source, causing current and voltage to flow.

More fun facts

- Putting capacitors in parallel have the same applied voltage, but the capacitance is cumulative.
- Putting capacitors in series increases the voltage capability, but capacitance is reduced.
- Do not parallel a bad capacitor with a good one. I have seen this and it is very wrong.
- Are generally, depending upon type, the only electrochemical device in any circuit other than a battery.
- And, because of this, they are the component that is most likely to fail in the circuit. Again, this depends upon type. Most electrical failures in equipment that I have worked on were due to bad capacitors.
- In circuits, they have a multitude of uses. Coupling and de-coupling of IF stages, audio stages, noise suppression, frequency response, memory backup, tuning and power supply filtering are just a few of the tasks they perform.
- ESR, equivalent series resistance, occurs due to imperfections within the capacitor's material that creates resistance. In effect, as it sounds, there is a resistive element. As frequency of the source increases ESR becomes significant.
- ESL, equivalent series inductance, occurs in the capacitors leads and is only significant at higher frequencies.
- Many capacitors are rated with a life span. 2000 hours is a common one for electrolytics, but several factors must be met for that to be true. It must be operated 24 hours a day, 7 days a week at its rated voltage and maximum allowable temperature. So in reality, the life span is usually longer if not all of the above are true.

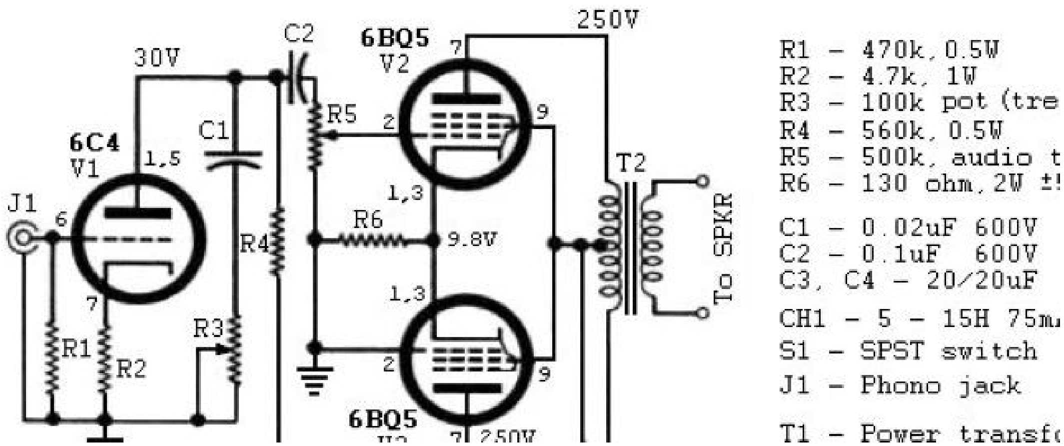
A few pointers

- Lately, there has been an influx of knock-off Chinese capacitors that are of very poor quality.
- With that in mind, you don't want to spend your time repairing an item only to have them fail due to that. Use brands with a good reputation, such as Nichicon, Panasonic, Cornell-Dublier or the like.
- And, there has been standardization of values, so instead of 40 uF for a older filter capacitor, now you would use the standard 47 uF. It is ok.
- And select the type you need. There are general purpose, audio, computer/medical grades. The cost goes up, but so does reliability and tighter tolerances. In some applications, you can change types, but be sure of the circuit and how it may or may not work.
- Observe polarity! Electrolytics and tantalums especially. Though, those two types also come in bi-polar versions for applications that will have reverse voltage imposed, such as in AC circuits. Audio crossover networks are one example of that.
- Speaking of AC, be certain to de-rate any capacitor working voltage if it is to be used in a AC type setup. For example, a film cap rated for 630 VDC is only safe up to 305 VAC. Do your research, this information is on most manufacturer's data sheets.
- I usually order capacitors from Mouser Electronics in Texas. They have a wealth of information about the products they sell and data sheets I can have fun perusing whilst making a decision. And if you have a question, you can get someone on the phone that can actually answer it. Digi-Key is another good source.
- Some capacitors degrade with age, even if unused. If they are replaced in a device and then it sits unused for some time, they can go bad and short when you turn on the device. It could be as little as a year.

A few more pointers

- Therefore, it is a good idea to use a device you have restored every few months to keep those capacitors formed.
- On that topic, reforming old capacitors is not a good idea. It may work in the short term but you are inviting disaster.
- When replacing capacitors, use ones close to the working voltage that you took out. Using too high a voltage rating will not allow the capacitor to form correctly which will shorten its life.
- Safety is always first. Some capacitors hold a charge, even when you discharge them they can reform (dielectric absorption) and still have voltage present. If uncertain, place a small value resistor across the terminals to keep it in a discharged state. Some circuits have bleeder resistors to mitigate this.
- Capacitor checkers can give false impressions, know how to interpret the readings. They are usually based on a time constant.
- There are in circuit testers, but be certain of how to use them. Damage to other components could occur if used incorrectly.
- And since they hold a charge, when testing with power off you could inadvertently send voltage to a component that will not appreciate it. This is particularly important with solid state units.
- Don’t be misled by size. Older capacitors are physically larger then their modern counterparts for the same value.
- Ok, now let’s get to the real exciting part…We will be covering 8 common types, failure modes and a few other morsels of information. But just before that, let’s look at a schematic to get a basic idea of what all this is about.

An illustration of what a capacitor does, we will be looking at C2 mostly but will not ignore C1.



Electrolytic

Modern axial

Older axial

More electrolytic examples

Can type

Cap failure

The electrolytic capacitor

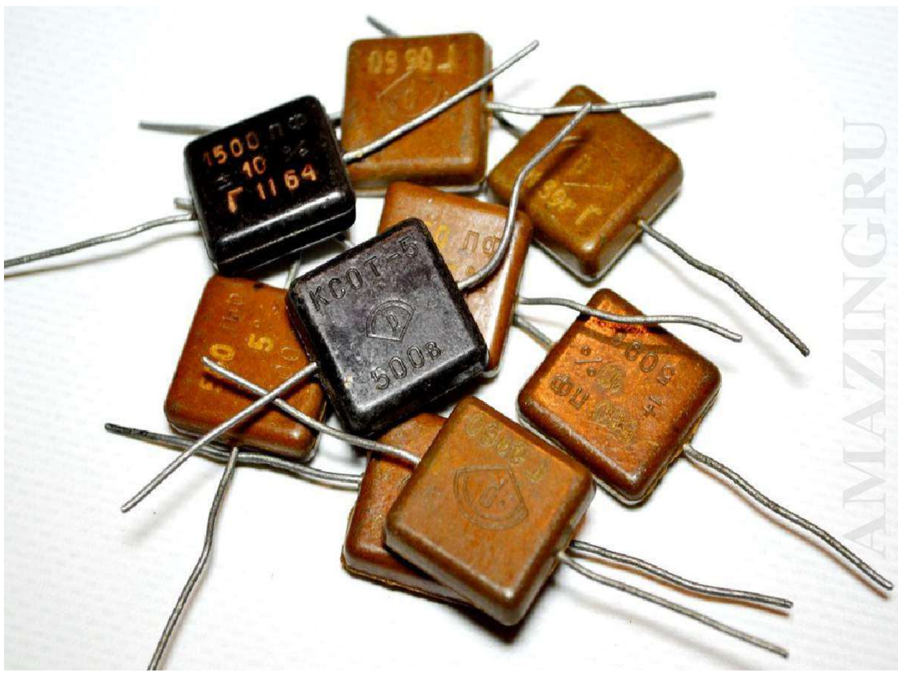
- As noted previously, the earliest type developed.
- Used extensively in power supply circuits and other stages as appropriate.
- Are generally polarity sensitive and marked as such, although there are many uses for bi-polar electrolytics as well.
- Generally range in value from 1 uF on up, they will normally be the largest capacitor in the circuit.
- Generally the weakest link in a circuit. As they age, whether being used or stored, they become leaky due to electrolyte drying out. Nothing has changed in that regard in 120 years. Many failures in modern equipment can be traced back to bad capacitors as some manufacturers try to use the cheapest ones they can get away with.
- Are temperature sensitive, they may not operate well when it gets too cold or fail quickly when run above their rated temperature, usually noted as 85C or 105C.
- Sometimes there are no indications they are faulty, and in others, it is quite evident. They can explode, spewing their guts all over the device.
- Older equipment, over 30 years old, if working on them, just go ahead and replace them. You will thank yourself.
- Their failure can cause collateral damage. Leaky electrolyte will destroy circuit boards (Ford found this out) and can cause failure of other components. In a PS section, they can wipe out the tube or SS diode, other downstream components or even the power transformer itself. IF cans, IC’s and transistors can also be destroyed when these caps fail. The electrolytic capacitor has the least life expectancy of any capacitor we will be talking about.

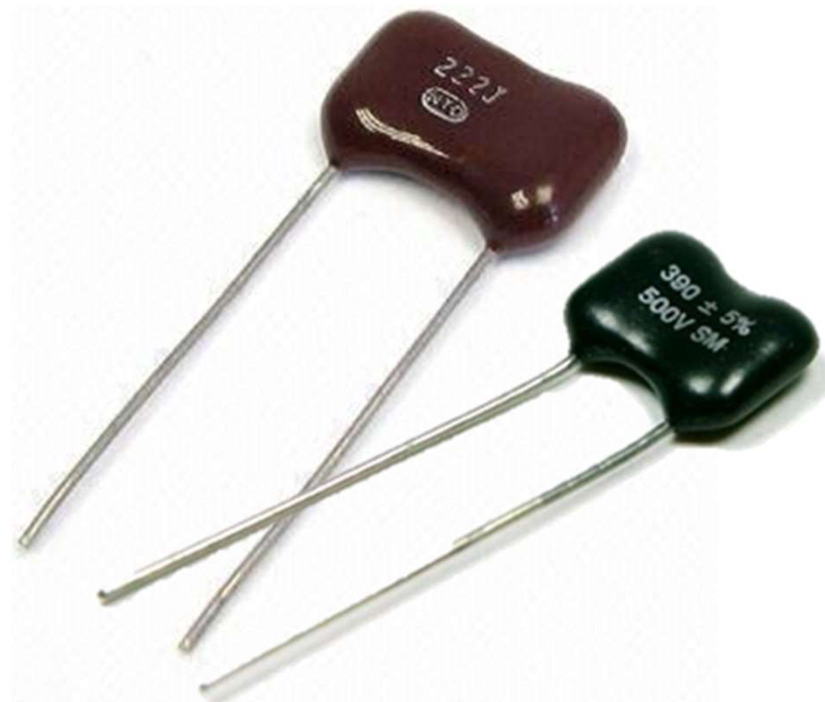
Paper capacitor

The paper capacitor

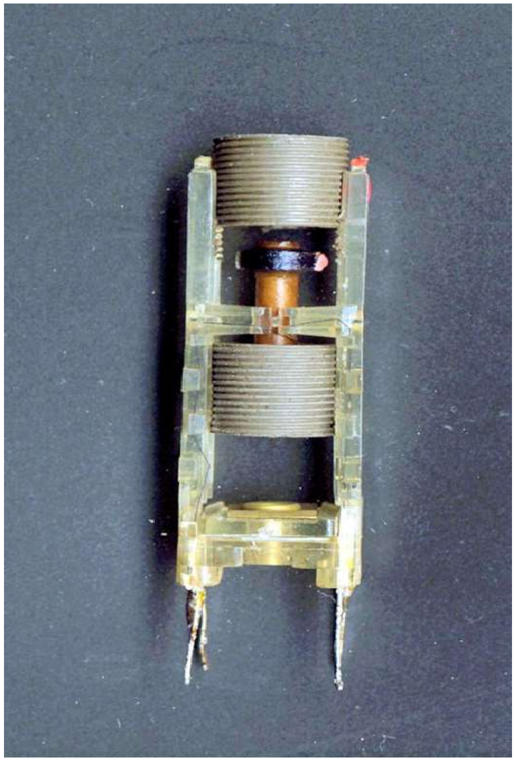
- Another very early type that was used up through the 60's in various forms.
- Earlier ones were also known as wax capacitors, later ones as bumblebees or "tiny grief's" in the case of the pink ones. Bumblebees had coloured bands similar to resistors and that is how they are read.
- Not polarity sensitive, though on earlier ones, there is a band which indicates the outside foil connection.
- Despite their low values, usually .001 uF up to 1 uF, they are large in size due the surface area needed by the dielectric and plates.
- Notoriously unreliable. If you see them, testing is not needed, they will need replacing. They do not age well, either used or unused. I have never, not once, seen one that has tested acceptable.
- Usual failure mode is becoming leaky, they will start to act like a resistor and heat up. Often if you see one that looks bubbly, it has become hot due to this and the wax has melted. It is also common for them to short.
- They are used most often for coupling/decoupling of IF and AF stages as well as power line filtering.
- Their failure can also be catastrophic for equipment in their vicinity. Tubes, transistors, IF cans, and audio output transformers can be destroyed. Their failure can even pull down the B+ and strain the power supply, even though they are not directly coupled to it.

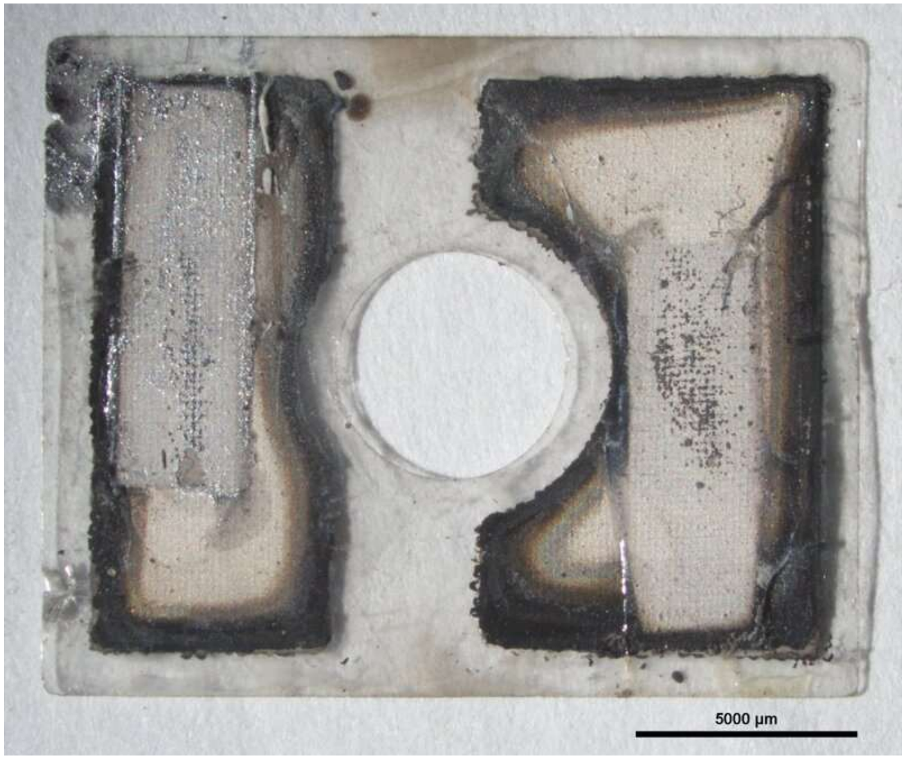
Silver mica





More silver mica examples





The silver mica capacitor

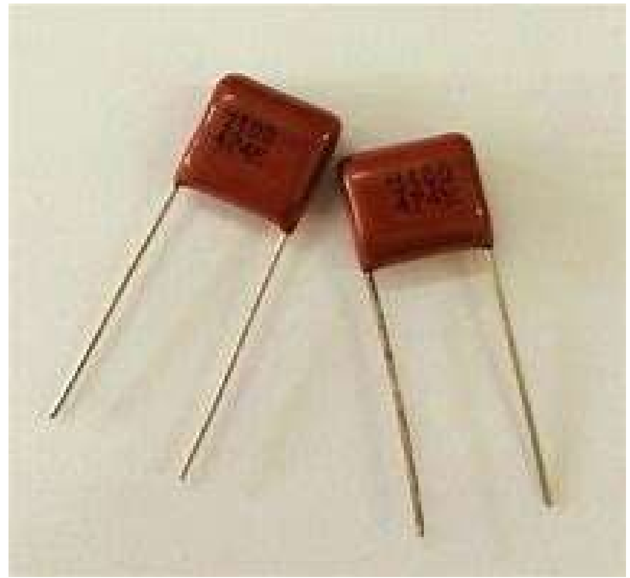
- Yet again, another early design that is still being used today in differing forms.
- They are generally used in IF stages and in other areas where coupling is required, but their usage is not limited to that.
- Generally low in value, less than .001 uF. They are usually measured in pF.
- They are also quite stable, even the ones found in antique equipment.
- With one exception, they rarely fail. In fact, you do not want to replace them if you do not have to. You will have to retune the circuit if you do.
- Temperature does not alter their characteristics nearly as much as it does for some other types.
- However, there is something called “silver mica disease” which I showed on the previous slide. In the 50’s they went cheap on the IF cans and put exposed silver and mica in sheets at the bottom of IF cans. Exposure to humidity and so on caused oxidation and migration of the silver, ruining the can which is almost impossible to repair.
- The square silver mica caps shown before that rarely had that issue as they were sealed.
- I have personally never seen a silver mica cap fail, other than in the IF cans of cheaply made devices.
- The early styles of these caps were often called “dominoes” as they had coloured dots indicating their value. How to read them is found online and in the ARRL handbook.

Ceramic capacitors

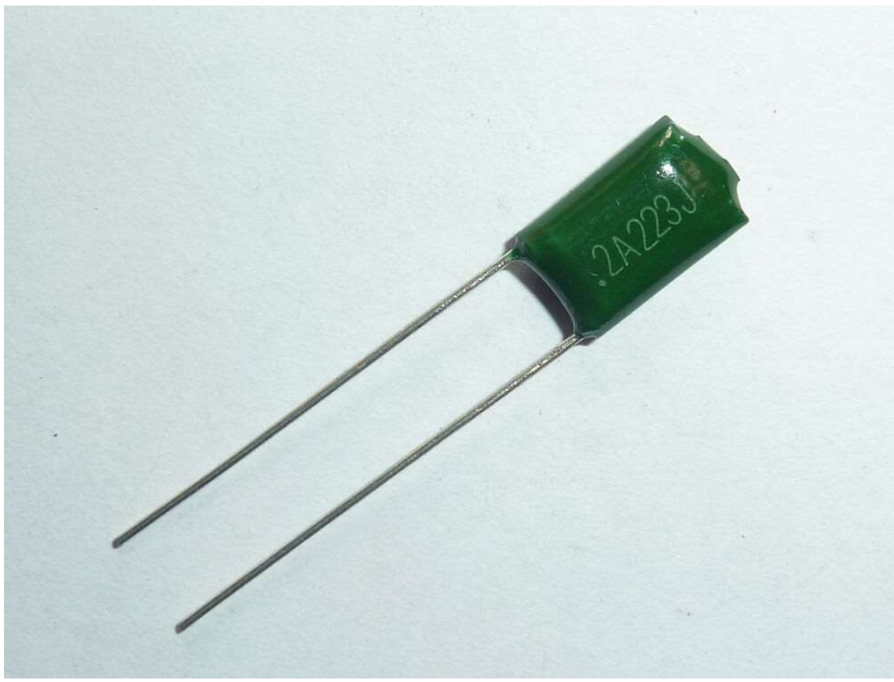
The ceramic capacitor

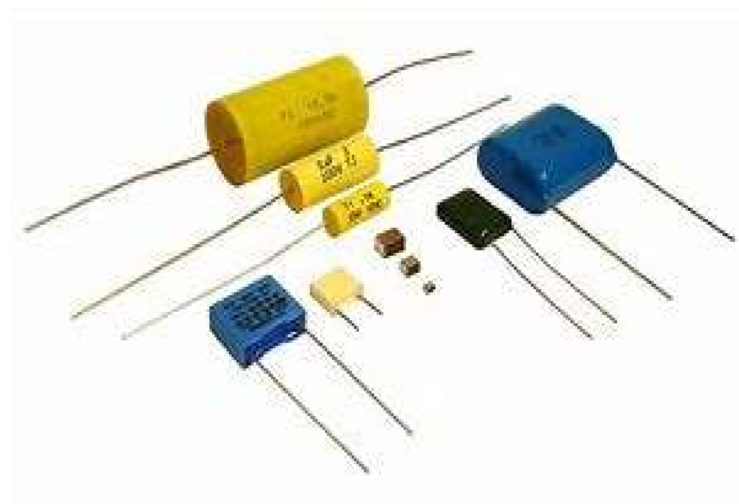
- They appeared in early incarnations in some devices in the 30’s and became more prevalent after WW2.
- They have a wide variety of uses such as in IF, tuning and coupling networks.
- Generally low uF values, .5 uF and under, but can handle high voltages in a small package due to the nature of the ceramic dielectric. They are always bi-polar.
- They generally have a wide tolerance and can easily change value according to temperature and/or voltage applied.
- You can use them to replace paper or film capacitors in some instances, but be certain before doing so.
- They can be unsuitable in some applications due to their tendency to be microphonic (piezoelectric effect).
- Are generally very reliable and have a long life span, I have rarely seen them fail in devices I have worked on. They usually fail shorted if that happens. Failure, from what I have seen, is usually caused by excessive heat or vibration.
- There are modern XY rated types (across the line or line to chassis) called safety caps. They are designed to always fail open and are required in modern equipment where those conditions apply such as in SMPS.
- They take several forms, the familiar disc is the most common, but can be a square block or something similar.
- They are among the least expensive capacitor, making them popular with manufacturers.

Polyester/film/mylar capacitors



More examples

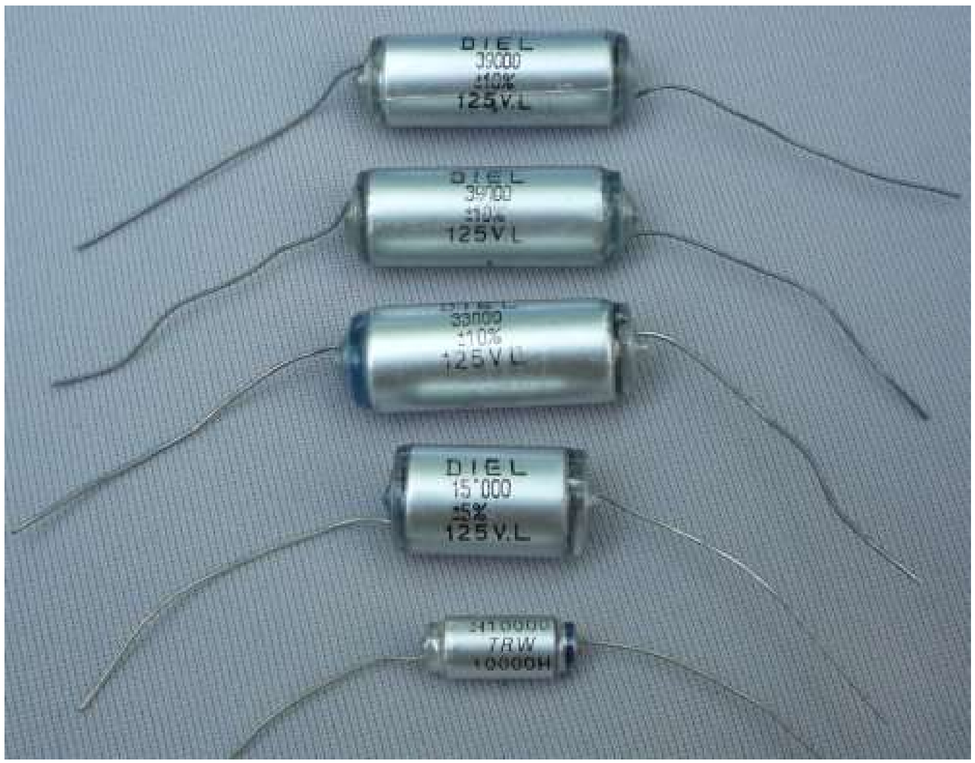




The polyester/film/mylar capacitor

- I included these three types under one heading as they are so similar in characteristics and performance.
- First appeared in the 60's as a replacement for the paper capacitor.
- Generally have values from 5 uF down to .001 uF. This is what you will run across most of the time.
- Can handle high voltages and to a point are self healing. They are always bi-polar.
- They have tight tolerances and are very stable. They have a long life span. Equipment I have worked on that has had them from the 60's, they were operating as if they were new.
- They rarely fail, I have not seen it often. If they do, it normally is due to a fault upstream from them causing excessive voltage or ripple. I have seen them detonate because of that. They can fail shorted, but it is not common.
- They also are not very tolerant of high heat for extended periods, their capacitance may not change much until they reach the point of no return. They are basically a form of plastic.
- However, that all being said, stick with reputable brands for long life. Chinese knock-offs have a poor reliability rate.
- They are excellent replacements for paper caps as well as some ceramic caps in some applications and are usually fairly inexpensive.

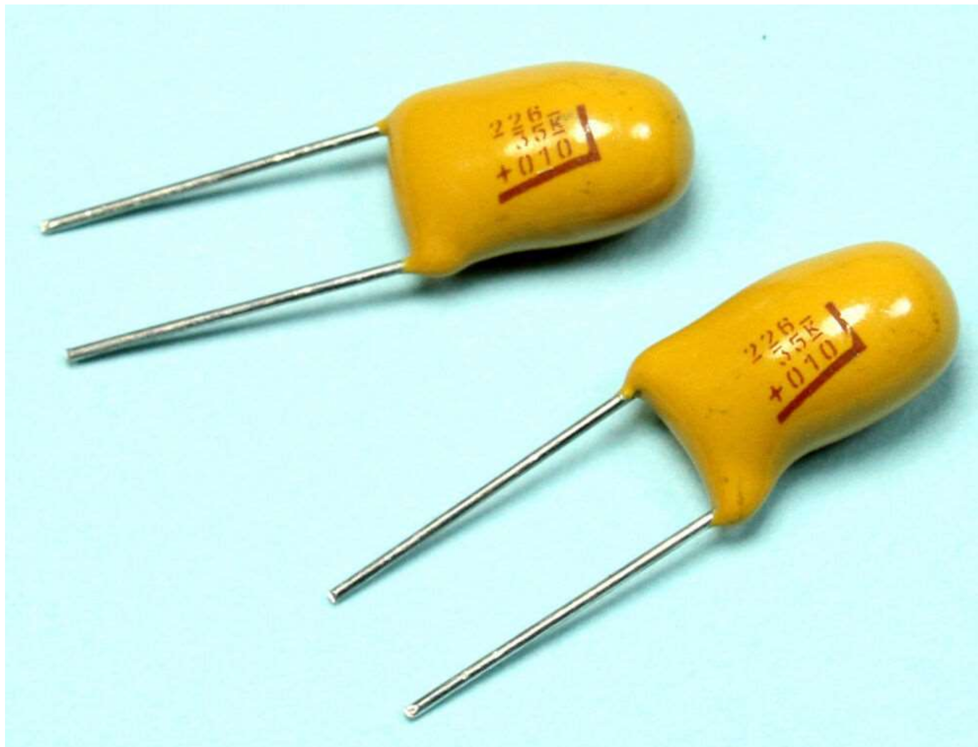
Polystyrene capacitors



The polystyrene capacitor

- Though invented earlier, they first really started appearing in devices in the 50's.
- Not encountered in newer applications that we would work on, they were being phased out in the early 90's, but are worth mentioning as you may run into them in older equipment.
- It was the capacitor of choice for precision tuned circuits due to its stability.
- They can be either polarized or bi-polar.
- They are reliable in a sense, but I have seen them fail because...
- They have one weakness. They are temperature sensitive, but in a different manner than other types. If exposed to moderate heat, whether soldering them in or ambient temperature, their capacitance will permanently change. It will, in most cases, increase. Often by quite a bit.
- This was a major drawback to this design. It's maximum operating temperature was less than any other capacitor mentioned here. This negated its electrical stability qualities.
- They are usually replaced with certain film types that do not exhibit the heat issue, such as polypropylene foil capacitors.

Tantalum capacitors



The tantalum capacitor

- As circuits have gotten smaller, capacitors have been a limiting factor in size reduction as a certain size was needed for a given capacitance. The development of the tantalum capacitor changed all of that.
- The anode is set up as one chunk of material inside the case, far different than the layering found in others. The dielectric is very thin, making for higher capacitance per size and reducing physical size overall. They are generally polarised.
- Used for decoupling AC signals, cleaning up DC into an IC, bypassing to reduce the impact of inductance on conductors and filtering out unwanted frequencies. They are not suitable for power supply filtering, though.
- They have excellent stability across a wide range of temperatures and frequencies, which is very important for frequency filters. They are also highly resistant to vibration issues.
- However, they can fail in a spectacular manner. Even small over voltages will lead to failure known as field crystallisation. They usually fail shorted and can catch on fire or go off in a pop. This does not bode well for the IC next to it, for instance.
- Therefore, it is important to derate their voltage capabilities. Depending upon type of electrolyte (there are two; a polymer type and a magnesium based type), they should be derated from 20% to 50%. Data sheets are essential for these characteristics.
- Used properly, they are very reliable and an excellent choice for modern electronics.

Trimmer and variable capacitors

Another variable capacitor

The trimmer and variable capacitors

- I included both in this section as they have some similarities in as much as they both can tune circuits in a variable manner by varying capacitance via an adjustment.
- They generally operate in the pF range. It does not take much of a change in pF to make a large difference in the circuits they are in.
- The basic variable capacitor is another very old type and is still in use for some applications. Variable capacitors are used for tuning, such as the dial on your radio, or in the case of vacuum capacitors, they are often used to tune antennas for a desired operating frequency. IF cans are also a form of variable capacitor.
- Trimmer capacitors are used in circuits to fine tune operating parameters. This is another way of saying they are often used in circuits so that they can be calibrated. They are found in test equipment or, really, any device that may need calibration. Very useful when replacing components, you can easily recalibrate it with these devices. Be cautious, though, these are likely to have voltage present on them.
- These types are very reliable, failure modes are mostly caused by people.
- In the case of trimmers, being put in a moist environment for an extended period can cause them to oxidize and/or rust, rendering them useless.
- With variable caps, physical damage to the plates is the most common issue. The spacing between the moving plates is carefully calculated. Any physical damage alters that dynamic.
- With vacuum caps, transmitting beyond the power limit they are designed for will cause them to arc over, effectively ruining them.

Final thoughts

- As you have seen, capacitors perform vital functions in all types of circuitry and there are a wide variety to choose from.
- Not all capacitors are created equal. If you are looking for a certain value, say .1uF at 200 WVDC, there are many different types to choose from. Yes, the capacitance will be the same as well as the working voltage, but differing dielectrics will perform in different ways within the same circuit. So, knowing your circuit is important to determine the best choice.
- Never feel shy about asking for advice on what is best to use. Even though I have worked with them for a long while, I still have questions at times and need some wise words to guide me.
- Be wary of advice on You Tube and some internet sources. There is a lot of false or misleading information out there on this and other topics. Talk to someone you trust. As Amateurs, that is something I believe we are good at…helping each other.
- Questions?