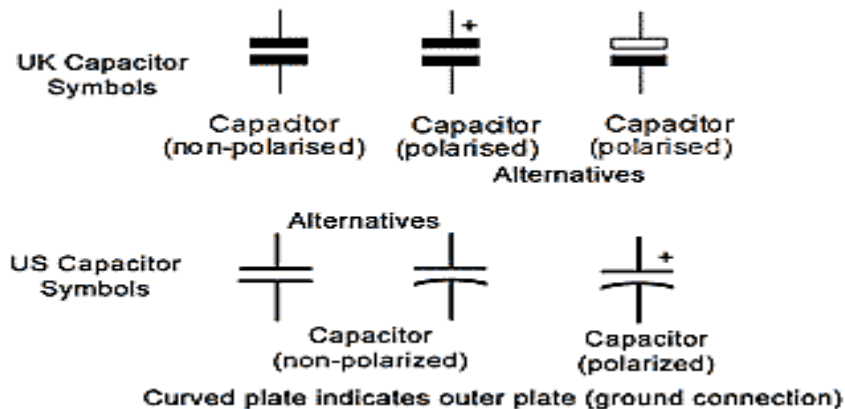


Techo notes – Capacitors – fixed value

Capacitors consist of two conductive plates separated by a dielectric material that can simply be air right through to the most modern plastic and ceramic materials.

Capacitors are said to “store charge” and they also pass AC or pulse signals from one part of a circuit to another while blocking any potential difference between the parts of the circuit (referred to as **coupling capacitors**). They are also used to bypass AC signals to ground to stop interference (referred to as **bypass capacitors**) and to smooth out or filter AC from DC supplies (referred to as **filter capacitors**).



Capacitance units:

The basic unit of capacitance is the **Farad** but a one Farad capacitor is rarely used. The only place I have seen one used is as a battery back-up device in digital equipment where the charge stored in the capacitor maintains power to a volatile memory device or as bypass device in a very exotic car audio system.

More practical values are in the 10 to the minus 6 range. This is a **micro Farad** and this is written **uF**. Other smaller values are 10 to the minus 9, one **nano Farad (nF)** and 10 to the minus 12, one **pico Farad (pF)**. The Greek symbols for these multipliers should be used but as our character sets used in word processing, the English alphabet is used instead.

Capacitors are usually referred to by what they do in a circuit:

Filter capacitors are used in power supplies to ensure the DC voltage produced is steady and has no AC signal superimposed on it. These capacitors are usually high values like 1,000 to 4,700 micro Farad (uF). They are required when we rectify the output of a power transformer in order to supply a DC voltage from the AC mains supply. Electrolytic capacitors are used for this purpose and the values can range from a few 100uF to 10,000uF and higher if the power supply is to supply a very high current.

There is a limit to how large the capacitance on the output of a rectifier can be but we will have to leave that topic for another Techo Note. The filter capacitors have to be very large if we are rectifying the 50Hz mains supply and wish to use the resultant DC to supply circuits directly. Switch Mode power supplies allow smaller value filter capacitors by operating the voltage conversion at a high frequency, usually 20 to 50KHz.

By-pass Capacitors are used in to pass AC signals to ground that may be generated by the operation of circuits. Typical values are 0.01 to 0.1uF if only high frequencies are involved up to hundreds of uF if low frequencies are present. Some types of capacitors have better characteristics for this purpose. See more detail in the chapter on types of capacitor.

Techo notes – Capacitors – fixed value

Coupling Capacitors are used to pass AC signals (and pulses) from one part of a circuit to another so they may be further processed. The output of one part of a circuit may be at a different DC potential to the next circuit the signal is passed to and a coupling capacitor is required to couple the AC signal and block the DC level difference.

Tuning Capacitors: These are not to be confused with variable and trimmer capacitors, their purpose in a circuit is to be attached to an inductor and to provide a resonant circuit at some radio frequency or to modify the value of other tuning components. These must be close tolerance components and have a zero or plus or minus temperature coefficient depending on the circuit design More will be said about this in another Techo Note.

Types of capacitor:

Paper Capacitors: These were to be found in radio equipment from the early days of radio to 1960's. They consisted of layers of aluminum foil and paper impregnated with wax or oil. They were housed in a cardboard tube and sealed with wax or pitch. The pitch or wax dried out and they were effected by atmospheric moisture and became leaky (relatively low resistance). Some paper capacitors were encased in plastic of some sort and these often did not last into the 1970's either, as the case often split open. They have very poor high frequency performance as they also exhibit high series inductance.



Techo notes – Capacitors – fixed value

Polyester Capacitors: This was the next development in low cost capacitor. Instead of foil, some had an extremely thin layer of metal deposited on the paper and were known as metallised capacitors. This construction saved space and rendered the capacitor self-healing in the event of a breakdown, with the metal deposit vapourising around the trouble spot. One synthetic impregnating material used in paper capacitors, PCB, has excellent dielectric characteristics but has been outlawed because it is practically indestructible and can enter the food chain. Be suspicious of metal cased capacitors that leak a clear viscous fluid.

Early in the 1960's many radio manufacturers abandoned paper capacitors and changed over to the buff coloured plastic coated capacitors made by Philips and other manufacturers. These polyester capacitors were available in both Radial and Axial construction. These have proved to be excellent in service and most are still in good condition today after perhaps fifty years of service. They introduced a wave of modern capacitors made in similar ways using a wide variety of plastic materials.

More information on modern plastic dielectric capacitors

Polyester film capacitors used where a low-cost medium capacitance (up to 4 μ F) is required at a moderately high voltage with moderately good temperature stability and tolerance. Left hand example is resin-dipped (cheaper). MKT capacitors pictured below are good examples of a type that use polyester called polyethylene terephthalate (PTPE).



MKT or plastic capacitors: These are available in values from 0.0001 μ F to perhaps 10.0 μ F with the most commonly used values in the range of 0.001 μ F to 1.0 μ F. They are available with tolerance ratings from 5% to 20% and voltage ratings from 63 to 630 Volt. Quite often referred to as film capacitors

Polystyrene film capacitors used where a small capacitance is needed with low tolerance spread (2% or better) and good temperature stability. Drawbacks include relatively high inductance and cost and susceptibility to cleaning solvents. Yellow example is of the "extended" type which is better sealed against ingress of liquids. Polystyrene capacitors are most often used in tuned circuits (oscillators and filters) where frequency stability is important.

Polypropylene dielectric capacitors offer very low dielectric losses and good temperature coefficient. Used in power electronics applications such as for mains interference suppression, switch mode power supplies and TV deflection circuits.

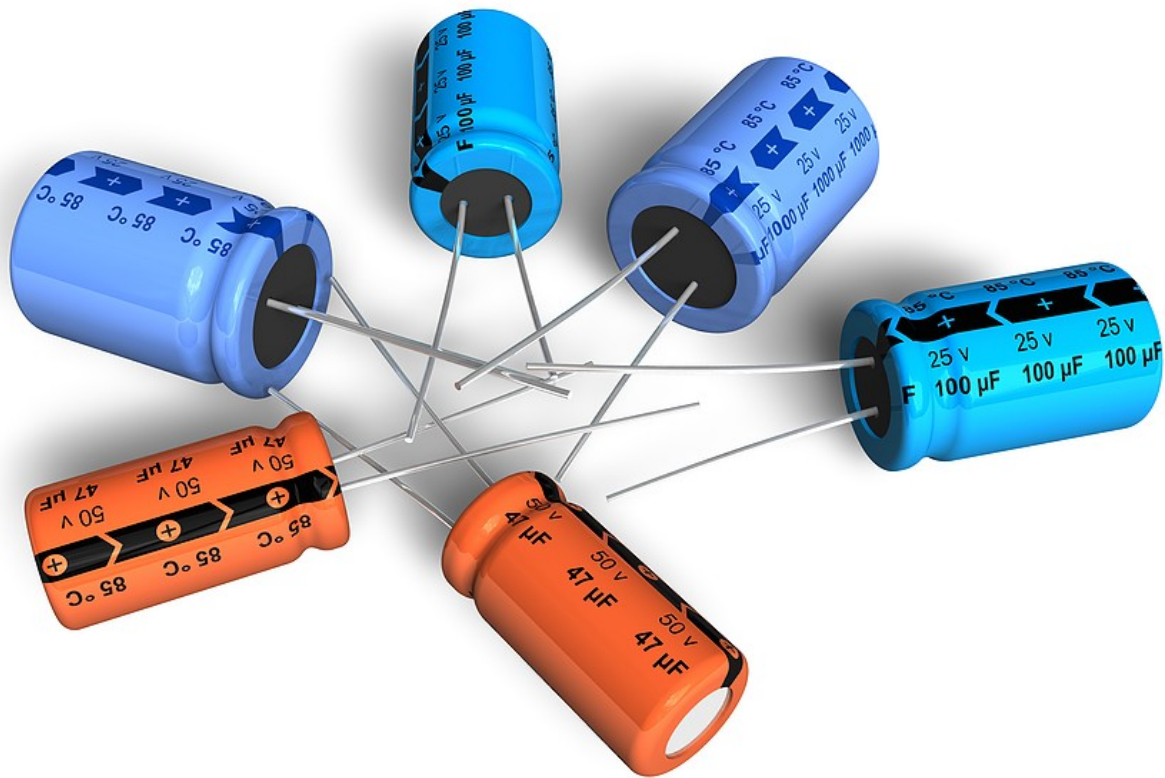
Polycarbonate dielectric capacitors offer a low temperature coefficient and lower dielectric losses at high frequency. Most often chosen for temperature stability.

More exotic types using, for example, **PTFE (polytetrafluoroethylene)** dielectric are used for demanding applications where the utmost temperature stability is required, however these offer no advantage in household or office appliances, being required only in aircraft/spacecraft or medical equipment where extremes of temperature are encountered.

Electrolytic Capacitors: These are very small for their ratings and are typically available in values from 1.0 μ F to 10,000 μ F. These capacitors are polarized, that is, when used in circuits with different DC voltages on each side of the capacitor they must be connected the correct way round. The positive lead to the most positive potential in the circuit. The first electrolytic capacitors used a

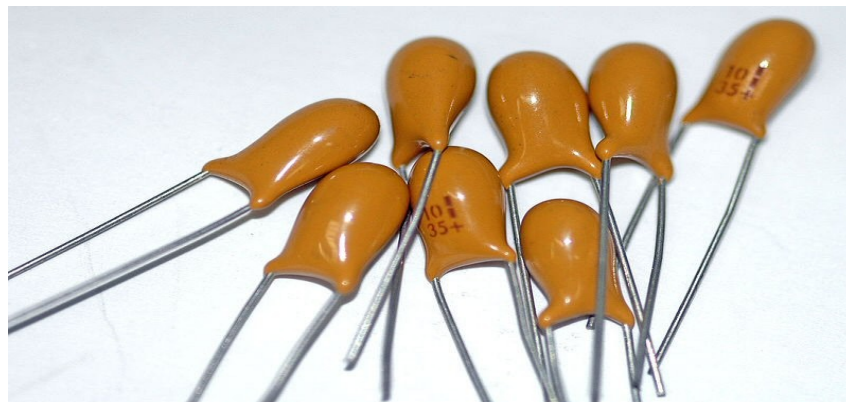
Techo notes – Capacitors – fixed value

wet electrolyte and if they were mounted on their side they usually failed. They also had a vent in the top of the case to let any gas that may be generated out without bursting the device.



Modern electrolytic capacitors usually have the negative lead marked with a minus sign, and with Radial styles the positive lead is often longer than the negative lead. They have very poor high frequency performance and when used in circuits where high frequencies and/or fast pulses are present, they must have another more suitable capacitor in parallel with them. Typically 0.1 µF monolithic type capacitors are used in this role.

Solid TAG Capacitors: These are also very small for their ratings and have very good high frequency performance. They are also polarized and will often explode if wired incorrectly. They are available in values from 0.1 µF to 100 µF. Tantalum bead capacitors are polarised and have low voltage ratings like electrolytic capacitors. They are expensive but very small, so they are used where a large capacitance is needed in a small size.



Techo notes – Capacitors – fixed value

Bi Polarised Capacitors: These look like Electrolytic capacitors but have no polarity markings and are also labeled “BP”. They are available ranging in values from 1.0 uF to 470 uF and are used in circuits where the polarity of any DC voltage present may be likely to change or there are only AC signals present, for example in cross over networks in speaker enclosures.

Oil filled Capacitors: are often used in high-voltage electronic equipment. An oil-filled capacitor is nothing more than a paper capacitor that is immersed in oil. Since oil impregnated paper has a high dielectric constant, it can be used in the production of capacitors having a high capacitance value. Many capacitors will use oil with another dielectric material to prevent arcing between the plates. If arcing should occur between the plates of an oil-filled capacitor, the oil will tend to reseal the hole caused by the arcing. Such a capacitor is referred to as a SELF-HEALING capacitor.

Ceramic Capacitors: These are usually low value capacitors and are available in a wide range of types. Values range from as low as just a few pico Farad to 0.1 uF. The smaller values up to about 1000 pF (0.001 uF) are available in high stability and close tolerance and are used as tuning capacitors in tuned circuits. Larger values usually have a tolerance rating as wide as plus 80% - minus 20% and are only used as bypass capacitors in high frequency circuits. Ceramic Capacitors have excellent high frequency characteristics.



Mica and Silvered Mica capacitors: These were the common high stability capacitors used in Radio Frequency (RF) circuits for many years and were available in a range of values from as low as 1pF to 1000pF. Some devices were very odd values for padding capacitors in Super Hetrodyne radio receivers and other tuned circuits. They often developed short circuits or high leakage and changes in values due to individual plates cracking or going open circuit. Many Mica Capacitors manufactured in the USA during the 40's to the 60's used a colour code marking system. This can be found with a web search.



Techo notes – Capacitors – fixed value

Monolithic Capacitors: These are very compact and have excellent high frequency characteristics. Only available in a few values and are used as by-passes in high frequency and digital logic circuits. Commonly used values are 0.001 μF and 0.1 μF but are available up to 1 μF and beyond.

Door Knob Capacitors: Very high working voltage and are used in high power transmitting equipment.



Capacitor physical construction:

Axial capacitors: The leads come out of each end of these capacitors. This is the oldest construction method and is best for point-to-point wiring.



Radial capacitors: Both leads come out of the same end of these capacitors. They are designed for mounting on printed circuit boards.



Surface mount capacitors: Some types of capacitor are now available as Surface Mount devices. That is, they have no lead wires attached and are soldered directly to pads on a circuit board.



Techo notes – Capacitors – fixed value

Polyester Capacitors with colour codes:

It is quite unusual to find capacitors with colour codes as they are no longer manufactured, but they will still be found in older equipment and parts boxes.

Look at the photo below and reading from the top of the capacitor the colours are: It must be remembered that unlike resistors there is no space between the coloured bands so if, for example, you have 22,000 pF capacitor of this type there will not be two separate thin red stripes but one thick red stripe.

Below is the colour code for some of these capacitors and gives the value in pico Farads (pF).



This example is 47,000 pF (i.e. 0.047 μ F) +/- 20% at 250V

Yellow = 4, Violet = 7, Orange = Multiply by 1000, Black = 20 % Tolerance, Red = 250 Volts



wide red, yellow means 220nF = 0.22 μ F, 250 Volt

There are no gaps between the colour bands, so 2 identical bands actually appear as a wide band.

The table for polyester capacitors works in pretty much the same way as for resistors.

FIRST DIGIT (pF) First Colour		SECOND DIGIT (pF) Second Colour		MULTIPLIER Third Colour		TOLERANCE Fourth Colour	
BLACK	0		0		x 1		20%
BROWN	1		1		x 10		
RED	2		2		x 100		
ORANGE	3		3		x 1000		
YELLOW	4		4		x 10,000		
GREEN	5		5		x 100,000		5%
BLUE	6		6		x 1,000,000		
VIOLET	7		7		x 10,000,000		
GREY	8		8		x 100,000,000		
WHITE	9		9		x 1,000,000,000		10%

The colours should be read like the resistor code, the top three colour bands giving the value in pF. Ignore the 4th band (tolerance) and 5th band (voltage rating).

The Fifth Colour Band Is The Voltage Rating:

Techo notes – Capacitors – fixed value

Brown 100 Volts	Red 250 Volts	Yellow 400 Volts
--------------------	------------------	---------------------

Older Tantalum Bead (TAG) Capacitors used colour codes: Modern tantalum bead capacitors are printed with their capacitance, voltage and polarity in full. However older ones use a colour-code system which has two stripes (for the two digits) and a spot of colour for the number of zeros to give the value in μF . The standard colour code is used, but for the spot, **grey** is used to mean $\times 0.01$ and **white** means $\times 0.1$ so that values of less than $10\mu\text{F}$ can be shown. A third colour stripe near the leads shows the voltage (yellow 6.3V, black 10V, green 16V, blue 20V, grey 25V, white 30V, pink 35V). The positive (+) lead is to the right when the spot is facing you: 'when the spot is in sight, the positive is to the right'.

Capacitor Characteristics

There are a bewildering array of characteristics associated with the humble capacitor so here are just a few of the more important ones.

1. Working Voltage

The **Working Voltage** (WVdc, WVac) is the maximum continuous voltage that can be applied to the capacitor without failure during its working life. DC and AC values are usually not the same as the AC value refers to an RMS value of the applied AC voltage. Common working DC voltages are 10V, 16V, 25V, 35V, 63V, 100V, 160V, 250V, 400V and 1000V and are usually printed onto the body as a voltage or a code. The rated maximum operating voltage must not be exceeded. It is all right to operate most capacitors at lower than their operating voltage but this may not be true for some high voltage electrolytic capacitors. Some capacitors have an AC voltage rating as they are used as filters in AC power circuits and the AC rating is about one third the DC rating of such capacitors.

Letter codes for working voltage:

Although this information is not entirely confirmed, some capacitors may have voltage indicated by a letter, as in the table below: (This table is unconfirmed information!)

D = 16 volts	Q = 500 volts	U = 4000 volts
F = 25 volts	R = 1000 volts	W = 5000 volts
H = 50 volts	S = 2000 volts	X = 6000 volts
K = 100 volts	T = 3000 volts	Y = 7500 volts

2. Tolerance, ($\pm\%$)

As with resistors, Capacitors also have a tolerance rating expressed as a plus-or-minus value either in Picofarads ($\pm\text{pF}$) for low value capacitors generally less than 10pF or as a percentage ($\pm\%$) for higher value capacitors generally higher than 10pF . Capacitors are rated according to how near their actual values are to the rated capacitance with coloured bands or letters used to indicated the actual tolerance. The most common tolerance for capacitors is 5% or 10% but some electrolytic capacitors are rated as high as 20%, and some as minus 20 to plus 60 or 80 %.

CAPACITOR TOLERANCE TABLE	
C	+/- 0.25pF
D	+/- 0.5pF
F	1%
G	2%

Techo notes – Capacitors – fixed value

J	5%
K	10%
M	20%
Z	+80 -20%

3. Leakage Current

The dielectric used inside the capacitor is not a perfect insulator resulting in a very small current flowing or "leaking" through the dielectric when applied to a constant supply voltage. This small current flow in the region of micro amps (μA) is called the **Leakage Current**. This **leakage current** is a result of electrons physically making their way through the dielectric medium, around its edges or across the leads. The "leakage current" of a capacitor is sometimes called the "insulation resistance" and can be found using Ohm's law. The film/foil type capacitor has extremely low leakage currents while the leakage current of aluminum electrolytic's increases with temperature.

4. Working Temperature

Changes in temperature around the capacitor affect the value of the capacitance because of changes in the dielectric. If the air or surrounding temperature becomes too hot or too cold the capacitance value of the capacitor may change so much as to affect the correct operation of the circuit. The normal working range for most capacitors is -30°C to $+125^{\circ}\text{C}$ with nominal voltage ratings given for a working temperature of no more than $+70^{\circ}\text{C}$. Generally electrolytic's can not be used below about -10°C , as the electrolyte jelly freezes.

5. Temperature Coefficient

The **Temperature Coefficient** of a capacitor is the change in its capacitance with temperature expressed linearly as parts per million per degree centigrade (PPM/ $^{\circ}\text{C}$), or as a percent change over a specified temperature range. Some capacitors are non linear and increase their value as the temperature rises giving a temperature coefficient that is expressed as a positive (p.t.c.). Some capacitors decrease their value as the temperature rises giving a temperature coefficient that is expressed as a negative (n.t.c.). For example $\pm 10\%$, or $+80\% / -20\%$ etc. However, some capacitors do not change their value and remain constant over a certain temperature range, such capacitors have a zero temperature coefficient.

It is also possible to connect a capacitor with a positive temperature coefficient in series or parallel with a capacitor having a negative temperature coefficient the net result being that the two opposite effects will cancel each other out over a certain range of temperatures. Another useful application of temperature coefficient capacitors is to use them to cancel out the effect of temperature on other components within a circuit, such as inductors or resistors etc.

6. Polarization

Polarization refers to the Electrolytic type capacitors with regards to their connection. Polarized types of capacitors must be wired such that any DC voltage across the device is connected to the correct capacitor terminals. Incorrect polarization can cause the oxide layer inside the capacitor to break down resulting in very large currents flowing through the device. The majority of electrolytic capacitors have their negative terminal clearly marked with a black stripe or black arrows down the side to prevent any incorrect connection. Some electrolytic capacitors may have their metal can connected to the negative terminal but most high voltage types have their can insulated with the electrodes being brought out to separate terminal for safety.

Techo notes – Capacitors – fixed value

7. Equivalent Series Resistance, (ESR)

Equivalent Series Resistance is the AC impedance of the capacitor when used at high frequencies and includes the resistance of the dielectric, plate and terminal leads. ESR acts like a resistor (less than 0.1Ω) in series with the capacitor (hence the name Equivalent Series Resistance), and is frequency dependent. The ESR of electrolytic capacitors increase over time as their electrolyte dries out. Capacitors with very low ESR ratings are available. Meters are available to measure the ESR of capacitors.

Marking on modern capacitors

Capacitors have got so very small these days there is not much room to write on them and the markings are often hard to interpret. To help make sense of capacitor marking, in particular surface mount capacitors types and to be able to easily convert from nF to pF to uF, here are a couple of very handy tables:

Remember that the code marking, when decoded, will provide the value in Picofarads (pF), but the table below shows you the values in microfarads (uF) and nanofarads (nF) too.

CODE / Marking	μF microfarads	nF nanofarads	pF picofarads
1R0	0.000001	0.001	1
100	0.00001	0.01	10
101	0.0001	0.1	100
102	0.001	1	1,000
103	0.01	10	10,000
104	0.1	100	100,000
105	1	1,000	1,000,000
106	10	10,000	10,000,000
107	100	100000	100,000,000

A selection of Surface Mount Capacitors, the first two rows are Monolithic types, the rest are Electrolytic types.

