CAPACITANCE/CAPACITOR

Subject Name: Electrical Fundamentals

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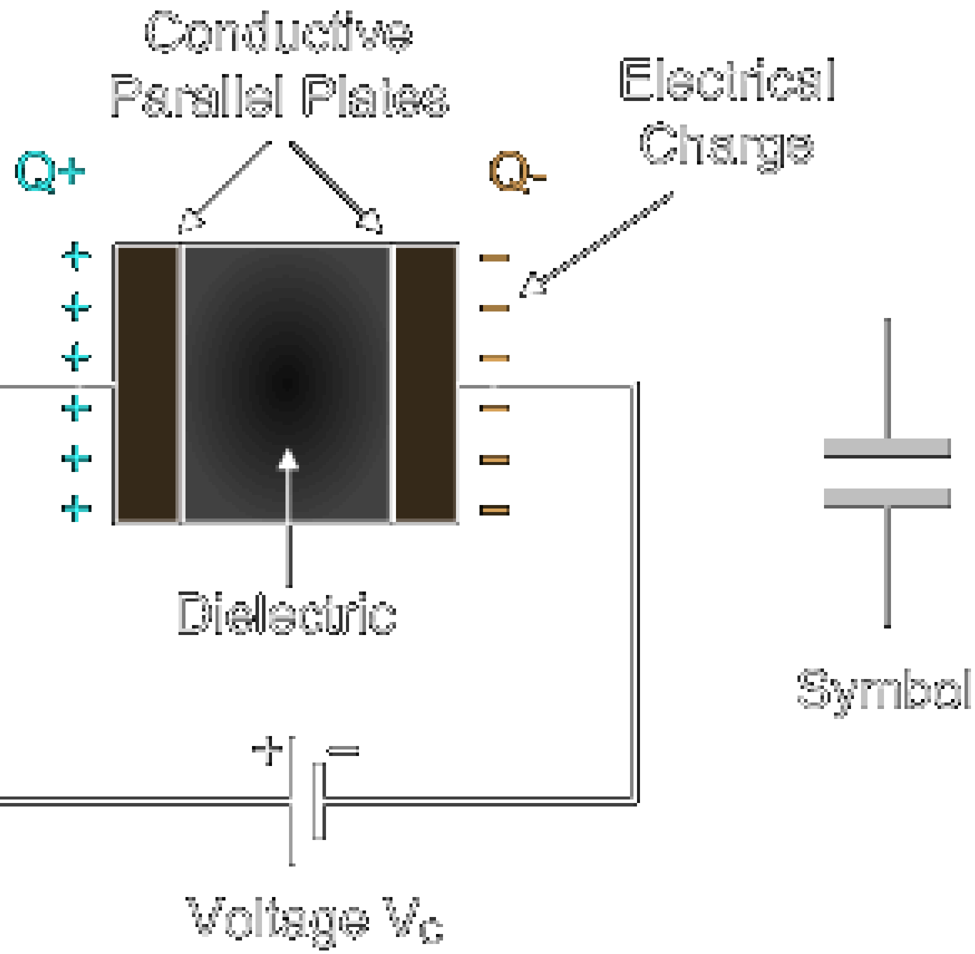
What is a Capacitor?

The capacitor is a component which has the ability or "capacity" to store energy in the form of an electrical charge producing a potential difference (*Static Voltage*) across its plates

Simple Construction

A capacitor consists of two or more parallel conductive (metal) plates electrically separated either by air or by some form of a good insulating material such as waxed paper, mica, ceramic, plastic or some form of a liquid gel as used in electrolytic capacitors.

The insulating layer between a capacitors plates is commonly called the **Dielectric**.


Conductive
Parallel Plates
Electrical
Charge
Q+
Q-
Dielectric
Symbol
Voltage V_C

Due to this insulating layer, DC current can not flow through the capacitor as it blocks it allowing instead a voltage to be present across the plates in the form of an electrical charge.

When used in a direct current or DC circuit

A capacitor charges up to its supply voltage but blocks the flow of current through it because the dielectric of a capacitor is non-conductive and basically an insulator.

When a capacitor is connected to an alternating current or AC circuit, the flow of the current appears to pass straight through the capacitor with little or no resistance.

When a DC voltage is placed across a capacitor, the positive (+ve) charge quickly accumulates on one plate while a corresponding and opposite negative (-ve) charge accumulates on the other plate. For every particle of +ve charge that arrives at one plate a charge of the same sign will depart from the -ve plate.

Then the plates remain charge neutral and a potential difference due to this charge is established between the two plates. Once the capacitor reaches its steady state condition an electrical current is unable to flow through the capacitor itself and around the circuit due to the insulating properties of the dielectric used to separate the plates.

The flow of electrons onto the plates is known as the capacitors **Charging Current** which continues to flow until the voltage across both plates (and hence the capacitor) is equal to the applied voltage Vc. At this point the capacitor is said to be "fully charged" with electrons.

The strength or rate of this charging current is at its maximum value when the plates are fully discharged (initial condition) and slowly reduces in value to zero as the plates charge up to a potential difference across the capacitors plates equal to the source voltage.

The amount of potential difference present across the capacitor depends upon how much charge was deposited onto the plates by the work being done by the source voltage and also by how much capacitance the capacitor has.

In an electrical circuit, a capacitor serves as a reservoir or storehouse for electricity. Capacitors store the energy of the electrons in the form of an electrical charge on the plates.

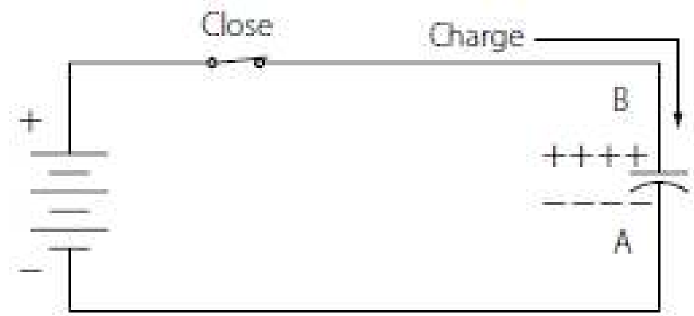
The measure of a capacitor’s ability to store charge is its capacitance. The symbol used for capacitance is the letter C.

By applying a voltage to a capacitor and measuring the charge on the plates, the ratio of the charge Q to the voltage V will give the capacitance value of the capacitor and is therefore given as: $C = Q/V$.
The formula for the quantity of charge on the plates as: $Q = C \times V$.

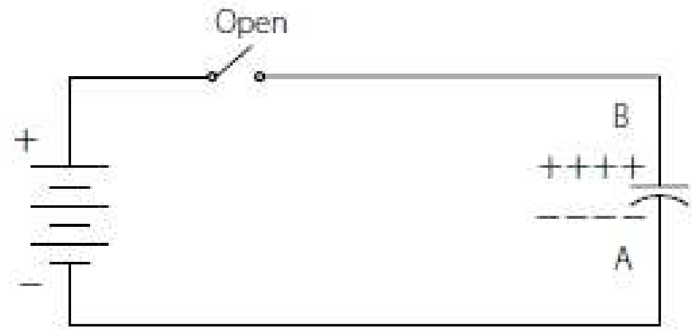
The charge is stored on the plates of a capacitor. The energy within the charge is stored in an “electrostatic field” between the two plates.

When an electric current flows into the capacitor, it charges up, so the electrostatic field becomes much stronger as it stores more energy between the plates.

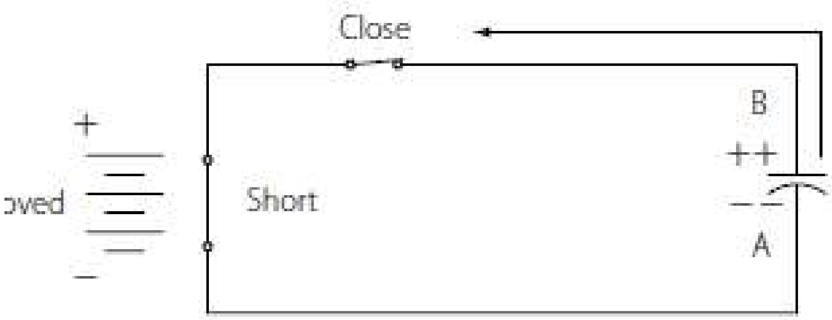
Likewise, as the current flowing out of the capacitor, discharging it, the potential difference between the two plates decreases and the electrostatic field decreases as the energy moves out of the plates.



(A) Capacitor being charged



(B) Capacitor retains charge



(C) Capacitor discharges

Only during the time the capacitor is being charged or discharged, there is current in the circuit, even though the circuit is broken by the gap between the capacitor plates. This period of time is usually short.

When a capacitior charges or discharges through a resistance, a certain amount of time is required for a full charge or discharge. The voltage across the capacitor will not change instantaneously. The rate of charging or discharging is determined by the time constant of
the circuit.

The RC Time Constant

The time required for a capacitor to attain a full charge is proportional to the capacitance and the resistance of the circuit.

The time constant of a series RC (resistor/ capacitor) circuit is a time interval that equals the product of the resistance in ohms and the capacitance in farad and is symbolized by the greek letter tau (τ).

$\tau = RC$

The time in the formula is that required to charge to 63% of the voltage of the source. The time required to bring the charge to about 99% of the source voltage is approximately 5 τ.

The property of a capacitor to store charge on its plates in the form of an electrostatic field is called the **Capacitance** of the capacitor.
Capacitance is also the property of a capacitor which resists the change of voltage across it.

The Capacitance of a Capacitor
Capacitance is the electrical property of a capacitor and is the measure of a capacitors ability to store an electrical charge onto its two plates with the unit of capacitance being the **Farad** (abbreviated to F).

Capacitance is defined as being that a capacitor has the capacitance of **One Farad** when a charge of **One Coulomb** is stored on the plates by a voltage of **One volt**.

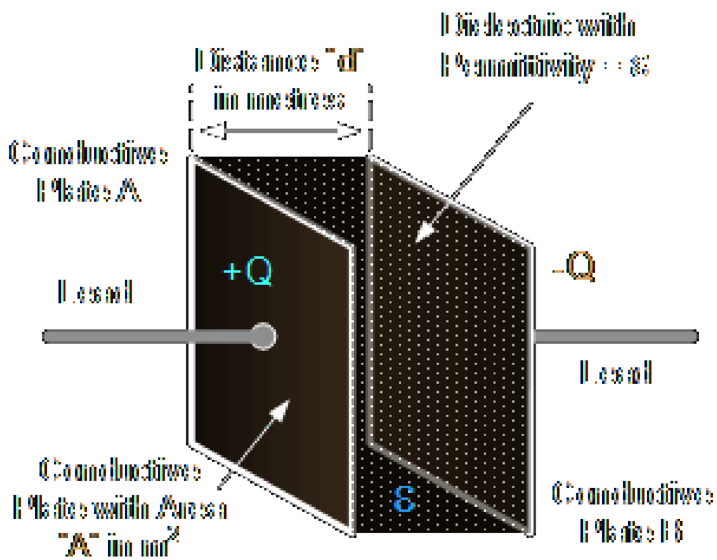
Capacitance, C is always positive in value and has no negative units.

Capacitance of a Parallel Plate Capacitor

The capacitance of a parallel plate capacitor is proportional to the area, A in metres^2 of the smallest of the two plates and inversely proportional to the distance or separation, d (i.e. the dielectric thickness) given in metres between these two conductive plates.

$C = \varepsilon(A/d)$

where ε represents the absolute permittivity of the dielectric material being used. The permittivity of a vacuum, ε_o also known as the "permittivity of free space" has the value of the constant 8.84×10^{-12} Farads per metre.



Dielectric Constant, **k** and a dielectric material with a high dielectric constant is a better insulator than a dielectric material with a lower dielectric constant.

$$\varepsilon = \varepsilon_o \times \varepsilon_r$$

Typical units of dielectric permittivity, ε or dielectric constant for common materials are: Pure Vacuum = 1.0000, Air = 1.0006, Paper = 2.5 to 3.5, Glass = 3 to 10, Mica = 5 to 7

$$\text{Capacitance, } C = \frac{\varepsilon_o \varepsilon_r A}{d} \text{ Farads}$$

to increase the overall capacitance of a capacitor while keeping its size small is to "interleave" more plates together within a single capacitor body. Instead of just one set of parallel plates, a capacitor can have many individual plates connected together thereby increasing the surface area, A of the plates.

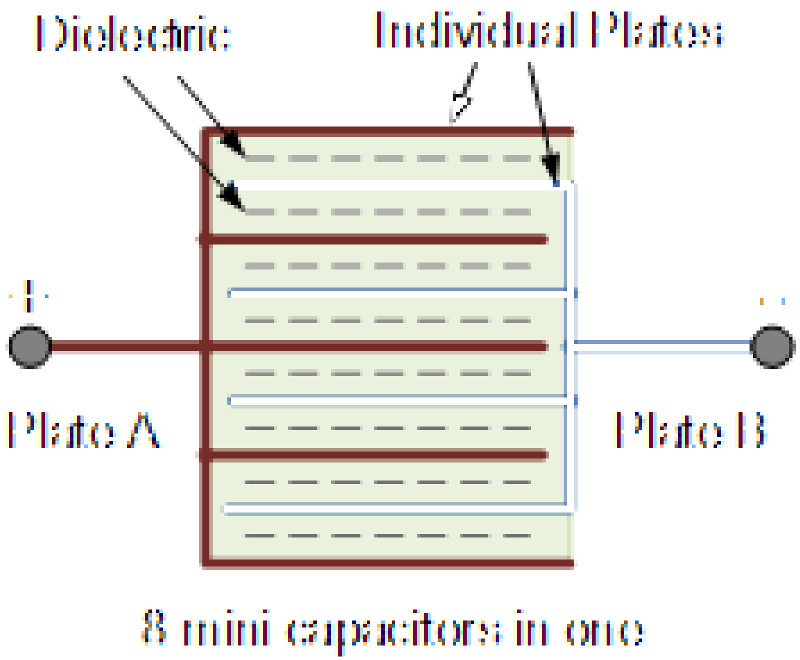
For a standard parallel plate capacitor, the capacitor has two plates, labelled A and B. Therefore as the number of capacitor plates is two, n = 2, where "n" represents the number of plates.

Then equation above for a single parallel plate capacitor:

$$\text{Capacitance, } C = \frac{\varepsilon_o \varepsilon_r (n-1) A}{d} \text{ Farads}$$

Now suppose we have a capacitor made up of 9 interleaved plates, then n = 9 as shown.

Multi-plate Capacitor



$$C = \frac{\varepsilon_0 \varepsilon_r (n-1) A}{d} = \frac{\varepsilon_0 \varepsilon_r (9-1) A}{d} = \frac{\varepsilon_0 \varepsilon_r 8A}{d}$$

Now we have five plates connected to one lead (A) and four plates to the other lead (B). Then BOTH sides of the four plates connected to lead B are in contact with the dielectric, whereas only one side of each of the outer plates connected to A is in contact with the dielectric. Then as above, the useful surface area of each set of plates is only eight and its capacitance is therefore given as:

Voltage Rating of a Capacitor

- The maximum amount of voltage that can be applied to the capacitor without damage to its dielectric material is generally given in the data sheets as: WV, (working voltage) or as WV DC, (DC working voltage).
- The DC working voltage of a capacitor is the maximum DC voltage and NOT the maximum AC voltage.
- The working voltage of the capacitor depends on the type of dielectric material being used and its thickness.
- If the voltage applied across the capacitor becomes too great, the dielectric will break down (known as electrical breakdown) and arcing will occur between the capacitor plates resulting in a short-circuit.
- In practice, a capacitor should be selected so that its working voltage either DC or AC should be at least 50 percent greater than the highest effective voltage to be applied to it.

Another factor which affects the operation of a capacitor is **Dielectric Leakage**.

- Generally, the resistance of the dielectric is extremely high and a good insulator blocking the flow of DC current through the capacitor (as in a perfect capacitor) from one plate to the other.
- If the dielectric material becomes damaged due excessive voltage or over temperature, the leakage current through the dielectric will become extremely high resulting in a rapid loss of charge on the plates and an overheating of the capacitor eventually resulting in premature failure of the capacitor.
- **Never use a capacitor in a circuit with higher voltages than the capacitor is rated for otherwise it may become hot and explode.**

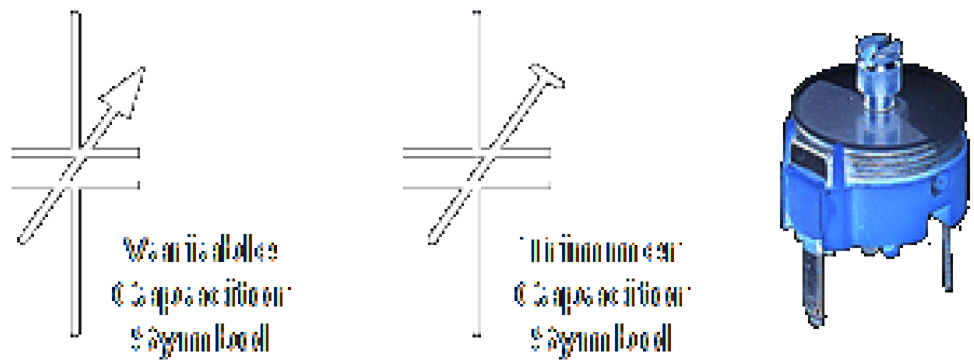
Types of capacitor

Generally made with regards to the dielectric used between the plates.

1. **Dielectric Capacitor**

Dielectric Capacitors are usually of the variable type were a continuous variation of capacitance is required for tuning transmitters, receivers and transistor radios. Variable dielectric capacitors are multi-plate air-spaced types that have a set of fixed plates (the stator vanes) and a set of movable plates (the rotor vanes) which move in between the fixed plates.

Variable Capacitor Symbol



Continuously variable types, preset type variable capacitors are also called **Trimmers**. These are small devices that can be adjusted or “pre-set” to a particular capacitance value with the aid of a small screwdriver and are available in very small capacitance’s of 500pF or less and are non-polarized.

Film Capacitor Type

1. **Film Capacitors** include polyester (Mylar), polystyrene, polypropylene, polycarbonate, metalised paper, Teflon etc. Available in capacitance ranges from as small as 5pF to as large as 100uF depending upon the actual type of capacitor and its voltage rating.
2. Film capacitors also come in an assortment of shapes and case styles which include:

a) Wrap & Fill (Oval & Round) – capacitor is wrapped in a tight plastic tape and have the ends filled with epoxy to seal them.

b) Epoxy Case (Rectangular & Round) – capacitor is encased in a moulded plastic shell which is then filled with epoxy.

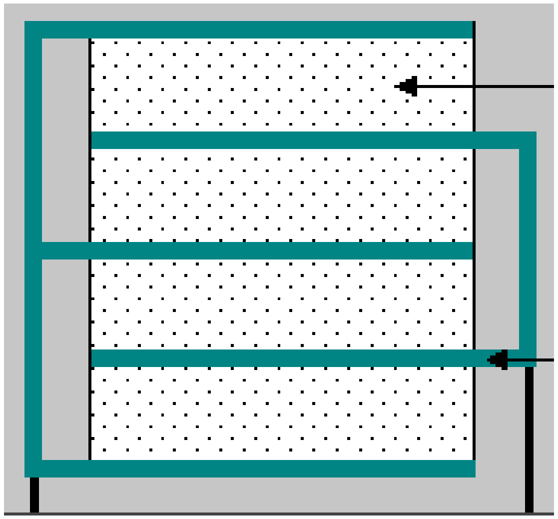
c) Metal Hermetically Sealed (Rectangular & Round) – capacitor is encased in a metal tube or can and again sealed with epoxy.

d) Above case styles available in both Axial and Radial Leads.

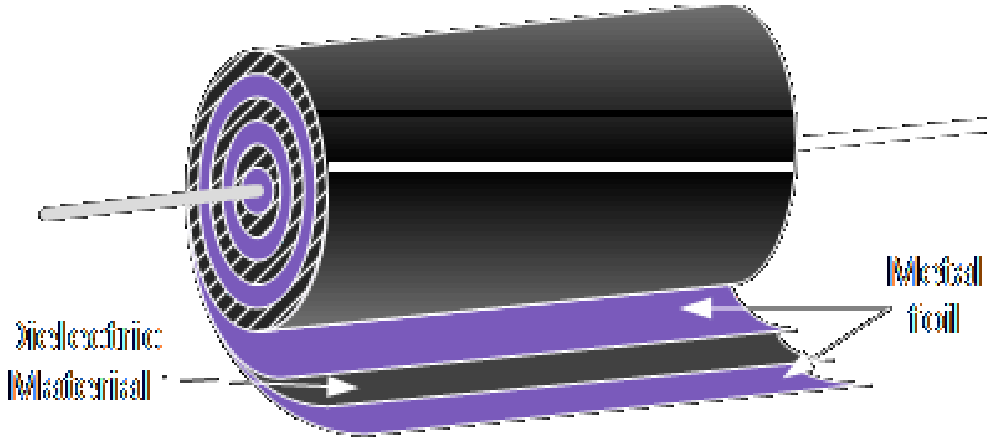
“Plastic capacitors”

1. use polystyrene, polycarbonate or Teflon as their dielectrics.
2. The main advantage of plastic film capacitors compared to impregnated-paper types is that they operate well under conditions of high temperature, have smaller tolerances, a very long service life and high reliability.

Examples of film capacitors are the rectangular metalised film and cylindrical film & foil types as shown.



Radial Lead Type



Axial Lead Type

The film and foil types of capacitors are made from long thin strips of thin metal foil with the dielectric material sandwiched together which are wound into a tight roll and then sealed in paper or metal tubes.

These film types require a much thicker dielectric film to reduce the risk of tears or punctures in the film, and is therefore more suited to lower capacitance values and larger case sizes.

Film Capacitor

Metalised foil capacitors have the conductive film metalised sprayed directly onto each side of the dielectric which gives the capacitor self-healing properties and can therefore use much thinner dielectric films. This allows for higher capacitance values and smaller case sizes for a given capacitance. Film and foil capacitors are generally used for higher power and more precise applications.

Ceramic Capacitors

1. **Ceramic Capacitors** or **Disc Capacitors** are made by coating two sides of a small porcelain or ceramic disc with silver and are then stacked together to make a capacitor.
2. For very low capacitance values a single ceramic disc of about 3-6mm is used.
3. Ceramic capacitors have a high dielectric constant (High-K) so that relatively high capacitance’s are obtained in a small physical size.
4. Exhibit large non-linear changes in capacitance against temperature.
5. They are non-polarized devices.
6. Values ranging from a few picofarads to one or two microfarads, (µF) but low voltage ratings.

7. Have a 3-digit code printed onto their body to identify their capacitance value in pico-farads. The first two digits indicate the capacitors value and the third digit indicates the number of zero's to be added. For example, a ceramic disc capacitor with the markings 103 would indicate 10 and 3 zero's in pico-farads which is equivalent to 10,000 pF or 10nF.
8. Letter codes are sometimes used to indicate their tolerance value such as: J = 5%, K = 10% or M = 20% etc.

Electrolytic Capacitors

1. Have large capacitance values for a small physical size.
2. Are **Polarised.**
3. Polarity clearly marked with a negative sign to indicate the negative terminal and this polarity must be followed.
4. An incorrect polarisation will break down the insulating oxide layer and permanent damage may result.
5. Not be used on AC supplies.
6. The electrolyte has the ability to conduct electricity, if the aluminium oxide layer was removed or destroyed, the capacitor would allow current to pass from one plate to the other destroying the capacitor.
7. Two basic forms; **Aluminium Electrolytic Capacitors** and **Tantalum Electrolytic Capacitors**.

Three easy ways to destroy an electrolytic capacitor:

1. Over-voltage – excessive voltage will cause current to leak through the dielectric resulting in a short circuit condition.
2. Reversed Polarity – reverse voltage will cause self-destruction of the oxide layer and failure.
3. Over Temperature – excessive heat dries out the electrolytic and shortens the life of an electrolytic capacitor.

Capacitor Colour Code

Band Colour	Digit A	Digit B	Multiplier D	Tolerance (T) > 10pf	Tolerance (T) < 10pf	Temperature Coefficient (TC)
Black	0	0	x1	± 20%	± 2.0pF	
Brown	1	1	x10	± 1%	± 0.1pF	-33×10^{-6}
Red	2	2	x100	± 2%	± 0.25pF	-75×10^{-6}
Orange	3	3	x1,000	± 3%		-150×10^{-6}
Yellow	4	4	x10,000	± 4%		-220×10^{-6}
Green	5	5	x100,000	± 5%	± 0.5pF	-330×10^{-6}
Blue	6	6	x1,000,000			-470×10^{-6}
Violet	7	7				-750×10^{-6}
Grey	8	8	x0.01	+80%,-20%		
White	9	9	x0.1	± 10%	± 1.0pF	
Gold			x0.1	± 5%		
Silver			x0.01	± 10%		

Capacitor Voltage Colour Code Table

Band Colour	Voltage Rating (V) Type J	Type K	Type L	Type M	Type N
Black	4	100		10	10
Brown	6	200	100	1.6	
Red	10	300	250	4	35
Orange	15	400		40	
Yellow	20	500	400	6.3	6
Green	25	600		16	15
Blue	35	700	630		20
Violet	50	800			
Grey		900		25	25
White	3	1000		2.5	3
Gold		2000			
Silver					

Capacitor Voltage Reference

Type J – Dipped Tantalum Capacitors.

Type K – Mica Capacitors.

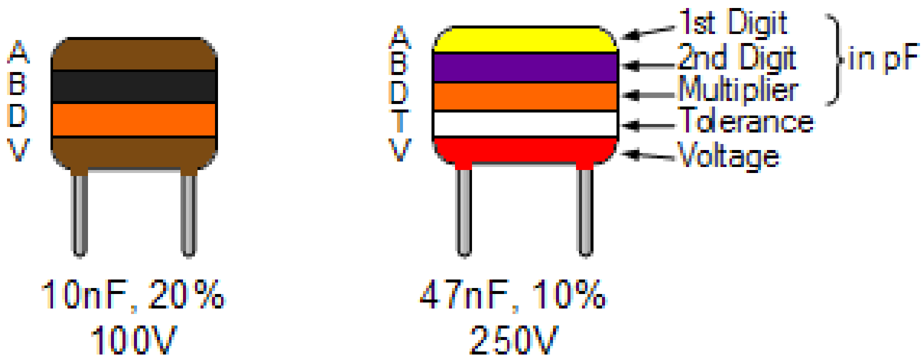
Type L – Polyester/Polystyrene Capacitors.

Type M – Electrolytic 4 Band Capacitors.

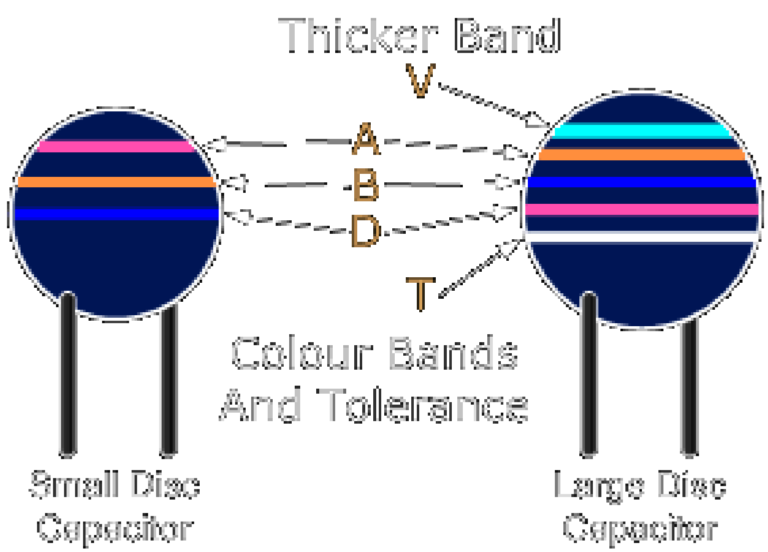
Type N – Electrolytic 3 Band Capacitors.

Example of capacitor colour codes :

Metalised Polyester Capacitor



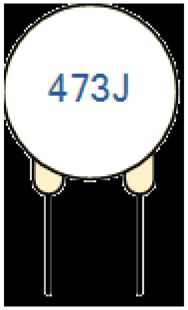
Disc & Ceramic Capacitor



LETTER OR NUMBER CODED SYSTEM

The code consists of 2 or 3 numbers and an optional tolerance letter code to identify the tolerance.

1. Where a two number code is used the value of the capacitor only is given in picofarads. Example, 47 = 47 pF and 100 = 100pF etc.
2. A three letter code consists of the two value digits and a multiplier much like the resistor colour codes in the resistors section. Example, the digits 471 = 47*10 = 470pF.
3. Three digit codes are often accompanied by an additional tolerance letter code as given below.



A ceramic disc type capacitor has the code 473J printed onto its body.

DECODING

4 = 1st digit

7 = 2nd digit

3 is the multiplier in pico-Farads, pF and the letter J is the tolerance.

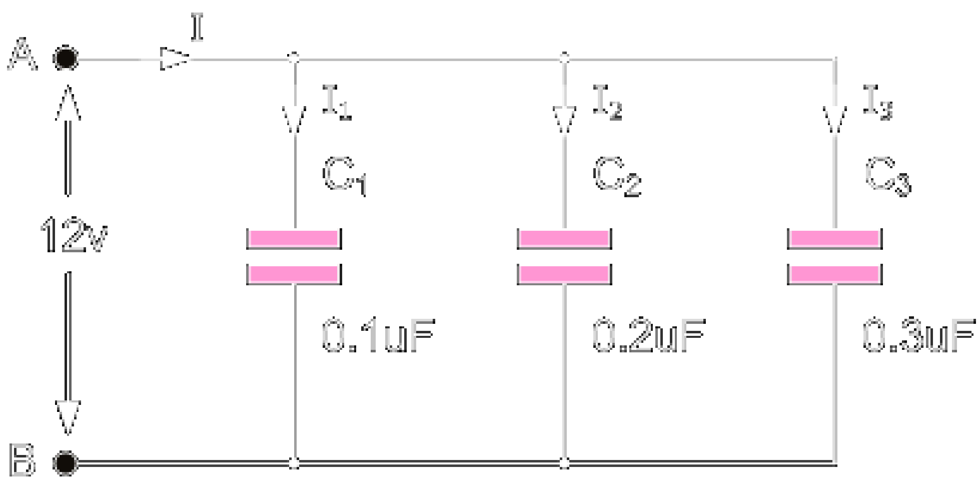
The value is: 47pF * 1,000 (3 zero's) = 47,000 pF, 47nF or 0.047uF the J indicates a tolerance of +/- 5%

Capacitors in Parallel

The voltage (V_c) connected across all the capacitors that are connected in parallel is **THE SAME**. Then, **Capacitors in Parallel** have a "common voltage" supply across them giving:

$V_{C1} = V_{C2} = V_{C3} = V_{AB} = 12V$.

The total charge Q_T stored on all the plates equals the sum of the individual stored charges on each capacitor.

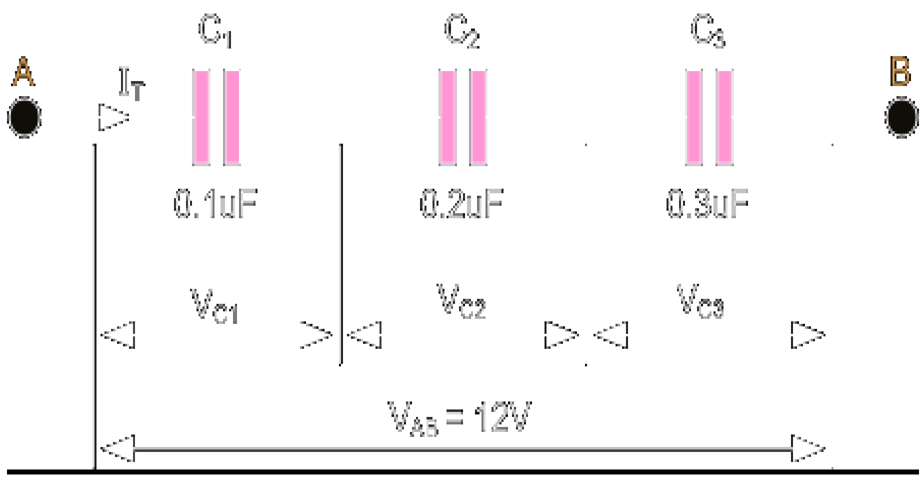


When adding together capacitors in parallel, they must all be converted to the same capacitance units, whether it is μF, nF or pF.

$$C_T = C_1 + C_2 + C_3 + \ldots .etc$$

Capacitors in Series

For series connected capacitors, the charging current (i_C) flowing through the capacitors is **THE SAME** for all capacitors as it only has one path to follow.



The effective plate area has decreased to the smallest individual capacitance connected in the series chain. Therefore the voltage drop across each capacitor will be different depending upon the values of the individual capacitance's.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots.\text{etc}$$

Notes:

1. The total circuit capacitance (C_T) of any number of capacitors connected together in series will always be **LESS** than the value of the smallest capacitor in the series.
2. The series connected capacitors act as a capacitive voltage divider network.Hence, the voltage divider formula applied to resistors can also be used to find the individual voltages for two capacitors in series. Then:

$$V_{CX} = V_S \frac{C_T}{C_X}$$

Example

Find the overall capacitance and the individual rms voltage drops across the following sets of two capacitors in series when connected to a 12V AC supply.

a) two capacitors each with a capacitance of 47nF

b) one capacitor of 470nF connected in series to a capacitor of 1µF

a) Total Equal Capacitance.

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2} = \frac{47nF \times 47nF}{47nF + 47nF} = 23.5nF$$

Voltage drop across the two identical 47nF capacitors,

$$V_{C1} = \frac{C_T}{C_1} \times V_T = \frac{23.5nF}{47nF} \times 12V = 6\,volts$$

$$V_{C2} = \frac{C_T}{C_2} \times V_T = \frac{23.5nF}{47nF} \times 12V = 6\,volts$$

b) Total Unequal Capacitance,

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2} = \frac{470nF \times 1uF}{470nF + 1uF} = 320nF$$

Voltage drop across the two non-identical Capacitors: C_1 = 470nF and C_2 = 1μF.

$$V_{C1} = \frac{C_T}{C_1} \times V_T = \frac{320nF}{470nF} \times 12 = 8.16volts$$

$$V_{C2} = \frac{C_T}{C_2} \times V_T = \frac{320nF}{1uF} \times 12 = 3.84volts$$

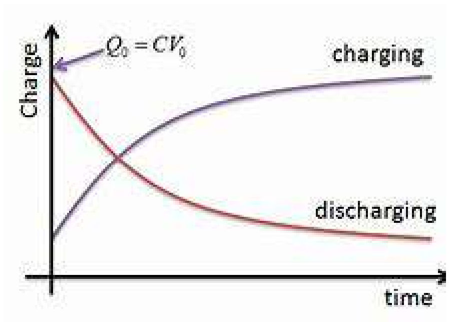
Notes:

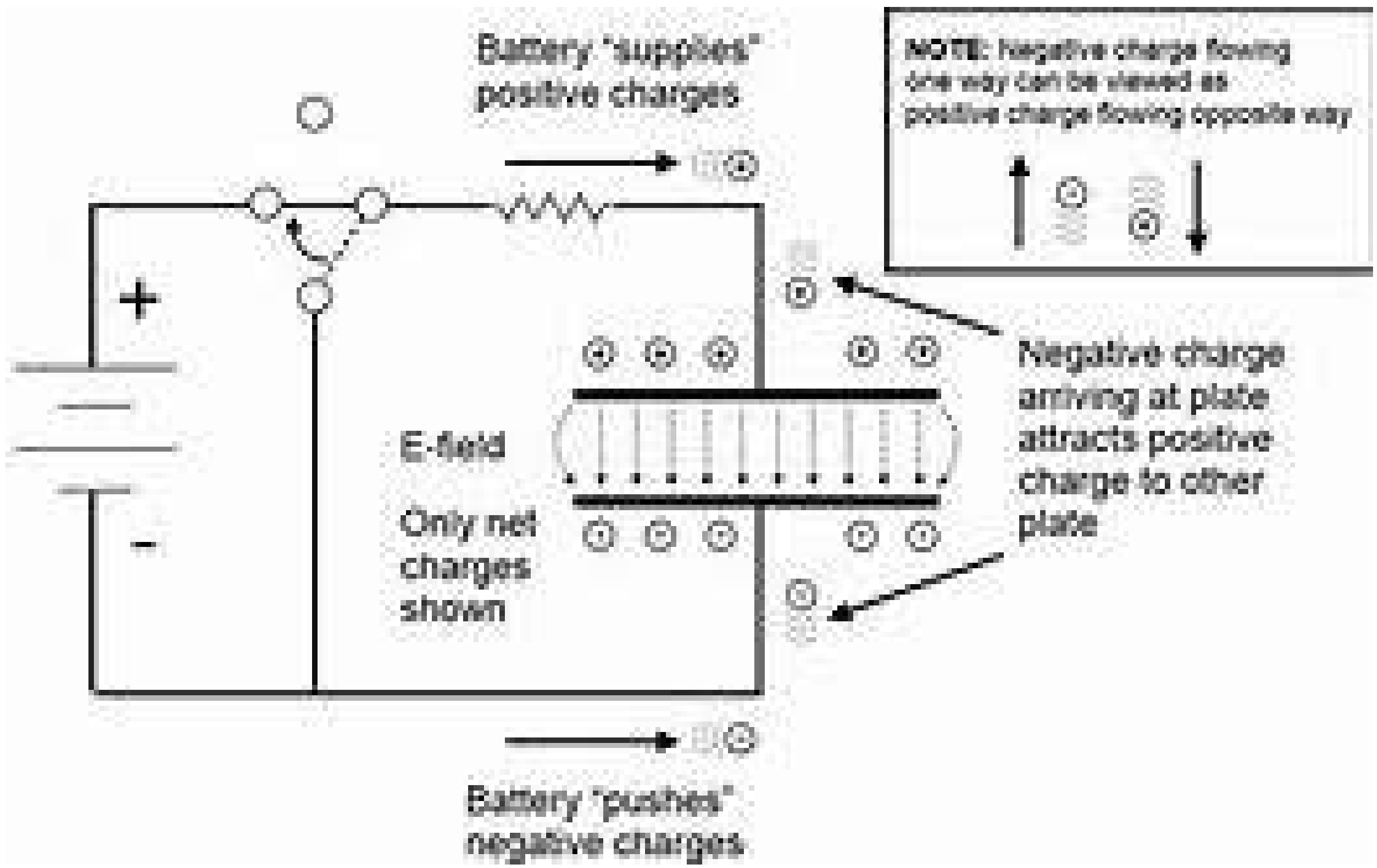
1. **Case-1: Equal value capacitor:** Each capacitor in the series chain shares an equal and exact amount of charge ($Q = C \times V = 0.564\mu C$) and therefore has half of the applied voltage, V_S.
2. **Case-2 : when the series capacitor values are different.** The larger value capacitor will charge itself to a lower voltage and the smaller value capacitor to a higher voltage, and in our second example above this was shown to be 3.84 and 8.16 volts respectively. This difference in voltage allows the capacitors to maintain the same amount of charge, Q on the plates of each capacitors as shown.

$$Q_{C1} = V_{C1} \times C_1 = 8.16V \times 470nF = 3.84\mu C$$

$$Q_{C2} = V_{C2} \times C_2 = 3.84V \times 1uF = 3.84\mu C$$

Characteristic of charging & discharging of capacitor





Battery "supplies" positive charges
NOTE: Negative charge flowing one way can be viewed as positive charge flowing opposite way
+
-
E-field
Only net charges shown
Negative charge arriving at plate attracts positive charge to other plate
Battery "pushes" negative charges

Charging and Discharging Capacitors

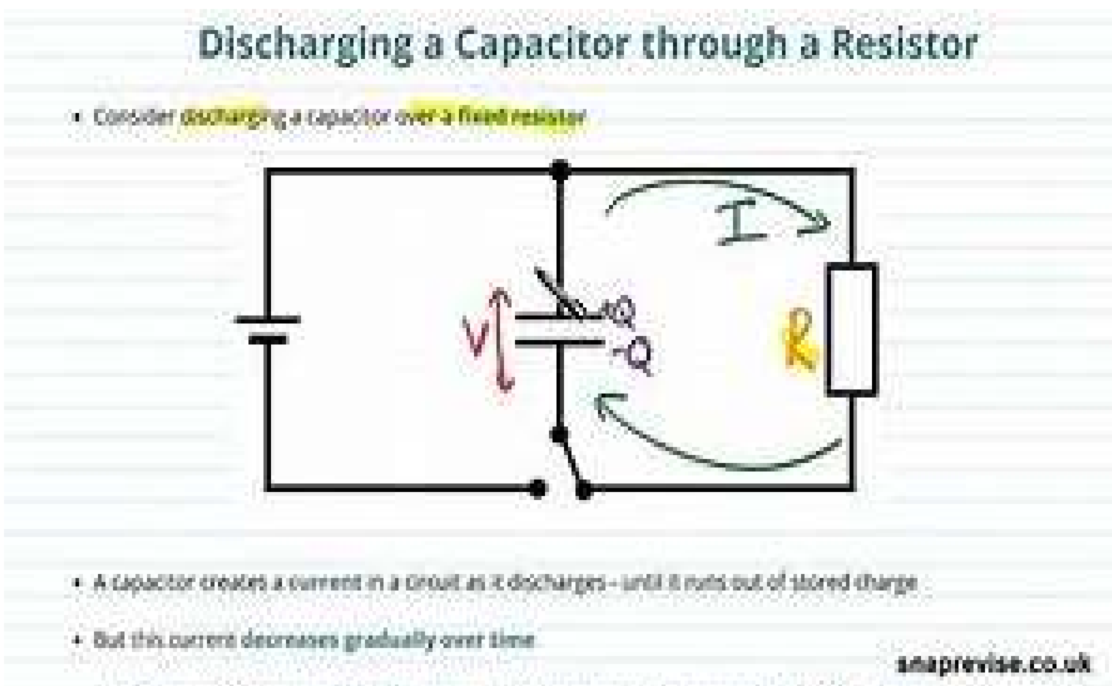
1. Charging a Capacitor

- As a capacitor charges the voltage increases to the supply voltage *(exponential growth curve)*

- and the current decreases as the plates become "full" of charge *(exponential decay curve)*

The shape of these curves can be controlled by a resistor in series, the higher the resistance the slower the charge

Discharging of Capacitor



Testing of capacitor

- **How to Test a Capacitor?**
- Method 1 Checking a Capacitor using Multimeter with Capacitance Setting. This is one of the easiest, quickest and accurate way to test a capacitor. ...
- Method 2 Checking a Capacitor using Multimeter without Capacitance Setting. Most of the low end and cheap Digital Multimeters do not include Capacitance Meter or Capacitance Settings.
- Method 3 Testing a Capacitor by measuring the Time Constant. This method is applicable only if the capacitance value is known and if we want to test whether a capacitor ...

Testing of capacitor by using Multimeter