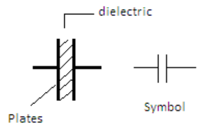
# CAPACITORS

Capacitor is a device which has the ability to store charge, opposes any change in voltage in the circuit in which it is connected & blocks the passage of direct current through it.




Capacitor consists of two conducting plates separated by an insulating medium called dielectric as shown in fig. The dielectric can be air, mica, ceramic, paper, polyester, polycarbonate plastic etc.

**Capacitance:** It measures the ability of a capacitor to store charge. It may be defined as the amount of charge required to create a unit potential difference between its plates. Suppose Q coulomb be the charge on one of the two plates of a capacitor & a potential difference of V volts is established between them, then its capacitance is $C = Q / V$ farad.

**Farad:** one farad is defined as the capacitance of a capacitor which requires a charge of one coulomb to establish a p.d. of one volt between its plates.

Capacitance of a capacitor may also be defined in terms of its property to oppose the change of voltage in the circuit. In that case $C = I / (dV/dt)$ where I is charging current, dV/dt is rate of change voltage. Therefore one farad is defined as the capacitance which will cause one ampere of charging current to flow when the applied voltage across the capacitor changes at the rate of one volt per second.

1 Microfarad = $1\mu F = 10^{-6}$ F
1 Nanofarad = $1nF = 10^{-9}$ F
1Picofarad = $1pF = 10^{-12}$ F

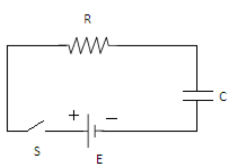
The capacitance of a capacitor depends on the following factors 1)plate area: capacitance increases directly with increase in plate area(A) 2)plate separation : capacitance decrease as plate separation(d) increases 3) type of dielectric: It depends on the relative permittivity €r of the dielectric medium used. Higher the value of €r, greater will be the value of capacitance.

$$C = \frac{€_0 \; €_r A}{d}$$

$€_0$ : absolute permittivity in vacuum $8.854 * 10^{-12}$ Farads/meter

**Capacitive reactance (Xc):** Reactance is the opposition produced by a capacitor to the flow of alternating voltage (current) through it measured in ohm. Capacitive reactance is given by $X_c = 1/\omega C = 1/2\pi FC$

**Charging and discharging of capacitor**




**a)Charging of a capacitor :-**Let a capacitor C, resistor R, battery of EMF E and a switch S are connected in series as shown in fig. above. A capacitor does not allow a direct current to flow through it. But when switch S is closed because of EMF E capacitor plate takes up a small charge and leakage current (I) is set up in the dielectric between the plates. Battery tries to introduce more and more charge on the plate. This charge therefore opposes the introduction of further charge. In other wards a back EMF is set up by the condenser during charging.

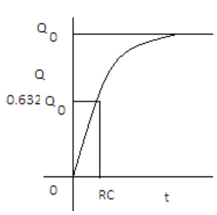
Let Q be the charge on the condenser at instant ' t ' and let Qo be the final charge on it.

Then $Q = Q_o ( 1 - e^{-t/RC} )$ ____________________ [1]

The current in the circuit is given by

$I = I_o \, e^{-t/RC}$ ____________________ [2]

Where I is the current at instant 't' and Io is the final current.




Now let Ec be the potential at instant 't' and Eo be the final potential on the capacitor,

Then $E_c = E_o (1- e^{-t/RC})$ __________________ [3]

If we put t = RC in equation [1] we get

$Q = Q_o (1- e^{-RC/RC})$

$Q = Q_o (1- e^{-1}) = Q_o (1- 1 / 2.72)$

$Q = 0.632\, Q_o$ OR $Q/Q_o = 0.632$

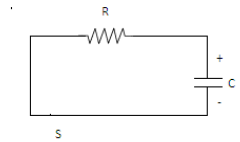
i.e. $Q/Q_o = 63.2\%$

Hence in RC seconds the charge on the capacitor reaches 63.2% of its final value. This RC is called as **time constant** of the circuit.

**Time Constant: -** It is defined as the time taken for the charge on condenser to reach 0.632 of its final value. The graph of charge on capacitor verses time is shown in fig. above.

**b) Discharging of Capacitor: -**

When switch S is closed the capacitor discharges through R , then its charge , current and voltage will start decreasing.




If Q is the charge on the condenser at instant 't' and Qo is the initial charge on condenser then,

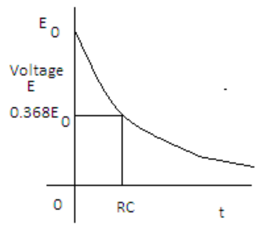
$$Q = Qo\, e^{-t/RC} \qquad \text{--------- [1]}$$

The current I at the instant ' t ' is

$$I = Io\, e^{-t/RC} \qquad \text{--------- [2]}$$

The potential at the instant 't' is

$$Ec = Eo\, e^{-t/RC} \qquad \text{--------- [3]}$$




If t = RC seconds then eqn [3] gives

$$Ec = Eo\, e^{-RC/RC} = Eo\, e^{-1} = Eo / 2.72$$

$$Ec / Eo = 0.368 = 36.8\ \%$$

From the graph shown in fig. we can define the time constant as the time taken for the charge (or potential) on the condenser to decay to 0.368 of its initial value.

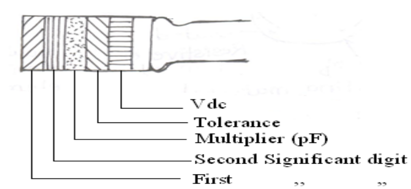
**STRAY CAPACITANCE:** Any pair of conductors, separated by air or any dielectric forms a capacitor. Hence a small amount of capacitance is present between conductors within wire cable. Its value is about 1 to 10 pF. In electronic circuit such capacitance is present between circuit wiring and metal chassis or CB. The capacitance resulting from these sources is called as stray capacitance. The effect of capacitance is very prominent at high frequencies. It is usually unwanted capacitance. The stray capacitance can be minimized by keeping connecting wires or links as short as possible.

The energy stored by the capacitor is

$$W = \int_0^t p\, dt = \int_0^t v\, i\ dt = \int_0^t V\, C \frac{dV}{dt} dt = \int_0^t C\, V\, dV = C \frac{V^2}{2} = \frac{1}{2} C\, V^2$$

**Leakage current**: Ideal capacitor would keep its charge indefinitely. For practical capacitor it is found that, the charge will be neutralized by a small leakage current through the dielectric and across the insulated case between terminals. This current is called leakage current and the resistance offered to this leakage current is called leakage resistance**.**

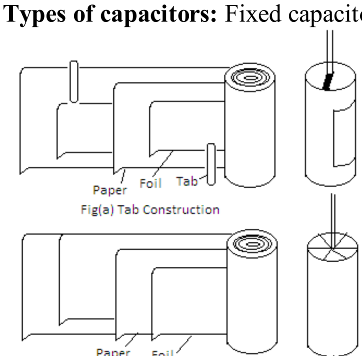
**Colour code for capacitor:** Most capacitors are plainly marked with purchase value, working voltage on the body itself.




colour code for capacitors

| Colour | Significant Digit | Multiplier | Tolerance |
|---|---|---|---|
| **B**lack | 0 | 1 | ±20% |
| **B**rown | 1 | 10 | |
| **R**ed | 2 | 100 | |
| **O**range | 3 | 1000 | |
| **Y**ellow | 4 | 10000 | |
| **G**reen | 5 | 100000 | |
| **B**iue | 6 | 1000000 | |
| **V**iolet | 7 | | |
| **G**rey | 8 | | |
| **W**hite | 9 | | ±10% |
| Gold | | | ± 5% |
| Silver | | | ± 10% |
| No Colour | | | ±20% |

**Types of capacitors:** Fixed capacitors 1) paper 2) ceramic 3) Mica




Fig(a) Tab Construction

Fig(b) Extended foil construction

1) **Paper capacitors:** Paper capacitor is fabricated from strips of metal foil such as tin or copper foil. Theses strips are separated by tissue or waxed paper. For paper capacitor alternate strips of foil& paper are wound into a tight roll. The paper capacitor construction is as shown in fig. There are two types of construction a) Tab construction: In tab construction the leads to be attached to the foils by one or more tabs inserted in the roll. The paper is wider than foil.

b) Extended foil construction: In this construction foil & paper are wound in such a manner that one foil extends out at one end & other foil extends out at other end. After winding, extended foils are crushed over the paper & the leads are then either soldered or welded to the crushed foil ends.

After the leads are attached by either method the roll is vacuum impregnated with wax, plastic resin or a synthetic or mineral oil & then encapsulated to prevent moisture infiltration. Using vapor deposition technique the thin layer of Al or Zn on the surface of paper is given & it is rolled. Leads are brought out for external connection.

Specifications: Generally printed on the case itself. Range of values: 1000PF to 1 µF, tolerance: ±15%, Voltage rating : 400, 600, 1200, 1800 V. Power factor at 1 KHz: 0.005 to 0.01, temp coefficient +100 to 200 ppM/$^0$C

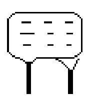
Application: These capacitors have large capacitance to volume ratio. Used in circuits as RF bypass capacitors, coupling & decoupling capacitors & can be used in AC & DC circuits.

**Plastic film capacitors**: These capacitors are made by using plastic materials as a dielectric. The plastics used for this purpose are polyester, polypropylene, polystyrene, Teflon etc. But in actual practice polyester & polystyrene materials are more commonly used. Range of polyester capacitor is 0.001µF to 10 µF, while polystyrene capacitor from 5 pF to 0.05µF, Teflon capacitors may be operated up to 250 0C. The polystyrene capacitors have very low leakage & good high frequency properties.

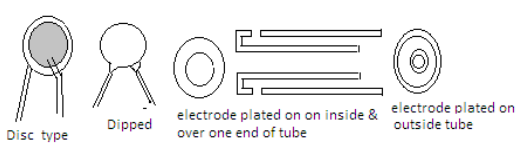
Specifications: range of values up to 1 µF, power factor: 0.0002, operating Voltage: 100V, temp coeff. :-100 to +200 ppM/$^0$C.

Applications: used in RF tuned circuits, used as storage capacitors in digital instruments, in measuring instruments & in X-ray Therapy.

**Mica capacitors:** Thin mica sheets are stacked between tin foil sections to provide the required capacitance. Alternate strips of tin foil are connected together & brought out as one terminal for one set of plates, while the opposite terminal is connected to the other set of plates. The total assembly is generally molded in a Bakelite case. Range: 10 to 1000pF, working voltage 500V. These capacitors are used in radio & TV circuits. These are suitable for blocking & for coupling widely used in radio & telecommunication application. Typical mica capacitors are as shown in fig.



**Ceramic capacitors:** In these capacitors titanium dioxide& barium titanate is used. thin coating of silver compound is deposited on both sides of dielectric disc, which acts as capacitor plates. Leads are attached to each side of disc & whole unit is encapsulated in a moisture proof coating. In case of tubular ceramics, the hollow ceramic tube is silver coated from both inner & outer side surfaces. Disc & tubular ceramic capacitors are as shown in fig.



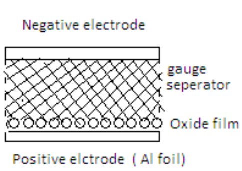

Specifications: voltage rating: 3 to 3000V, capacitance value: 1 to 500pF &0.01µF, power factor at 1 KHz is 0.07

Application: these capacitors are used as blocking, bypassing & filter capacitors. These capacitors are cheap in cost & excellent in performance up to 200 MHz.

**Fixed electrolytic capacitors (Aluminum capacitors)**

These capacitor consists of two metal electrodes usually aluminum in an electrolyte of borax (phosphorus or carbonate). When the DC voltage is applied to form the capacitor during the manufacture, the electrolytic action accumulates a molecular thin layer of aluminum oxide at the junction between the positive Al electrode & electrolyte. Since the oxide film is an insulator, there is capacitance between the positive Al electrode & electrolyte. The negative Al electrode simply provides a connection to the electrolyte.

With the extremely thin dielectric film, very large capacitance values can be obtained. The area is increased by means of long strips of Al foil & gauge, which are rolled into a compact cylinder having very high capacitance e.g. an electrolytic capacitor the same size as a 0.1µF paper capacitor, rated at 10 v break down, may have 1000µF capacitor.




Electrolytic capacitors are used in circuits that have a combination of DC & AC voltage. The DC voltage maintains the polarity. A common application is in the filter capacitor, to eliminate the AC ripple in a DC power supply. Other application include in starting motors, blocking DC current, filtering unwanted signal, tuning currents to a specific frequency, coupling & bypassing signals.

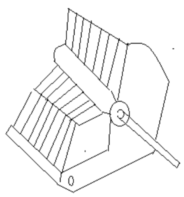
If the capacitors are connected in opposite direction they may become short circuited or get overheated due to excessive leakage current through its dielectric. The reversed polarity forms gas & the capacitor becomes hot & may explode.

The disadvantage of electrolysis in addition to required polarization is their relatively high leakage current, since the oxide film is not perfect insulator. This leakage current through dielectric is 0.1 to 0.5 mA/µF capacitance. They have lower working voltage than other capacitors of similar capacity. They have poor storage life, as their dielectric loses its properties over long period of service.

**Tantalum capacitors:** These capacitors are superior to the aluminum electrolytic. They have longer life, temp range, low leakage current, stability, reliable operating life etc. They have a high resistance to mechanical shock & vibrations. These are available in variety of sizes & shapes.

**Variable capacitors:** The capacitors, in which the capacitance value may be changed by some means, are called variable capacitors. The capacitance value is changed by either by varying the area between plates or by adjusting the spacing between them. The variable capacitors have capacitance in pF range. These capacitors are made by using air, mica, ceramic or plastic as dielectric. The variable capacitors using air as a dielectric, are called ganged capacitor in radio receivers. The variable capacitors using other dielectric are called trimmers or padders.

**Air dielectric capacitors:** This capacitor consists of two sets of metal plates separated from each other by air. One set of plates is fixed while the other set is connected to a shaft & can be rotated. The fixed set of plates is insulated from the body of the capacitor on which it is mounted. The set of moving plates can be moved in or out of a fixed set of plates with the help of a suitable knob connected to a shaft. As the plates are moved in & out of fixed plates, the capacitance value varies. The capacitance is minimum when the moving plates are completely out & maximum when these are completely in.



Sometimes, two or more such capacitors are operated by a single shaft. Such a capacitor is known as ganged capacitor..

**Trimmers or Padders:** A trimmer consists of two small flexible metal plates separated by a dielectric (ceramic, mica or plastic). The spacing between the plates can be changed by means of a screw adjustment. As the screw is rotated inwards, the plates are compressed & its capacitance is increased. The capacitance value of trimmers can be adjusted over a range from 5pF to 30pF. Padders are large in size or may have more plates. Capacitance value of padders can be adjusted over a range from 10pF to 500pF.