Capacitors - types - functions , grouping and uses

Objectives: At the end of this lesson you shall be able to
- **describe capacitor its construction and charging**
- **explain capacitance and the factors determining**
- **state the different types and application of capacitors**
- **state the testing and defects of capacitors**

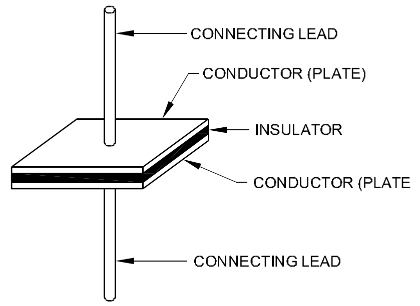
Capacitor:

Capacitor is a passive two terminal electrical/electronic component that stores potential energy in the form of electrostatic field

The effect of capacitor is called as capacitance. It consists of two conducting plates separated by an insulating material called as dielectric. In simple, capacitor is a device designed to store electric charge.

Construction: A capacitor is an electrical device consisting of two parallel conductive plates, separated by an insulating material called the dielectric. Connecting leads are attached to the parallel plates. (Fig 1)

Fig 1



SIMPLE CAPACITOR. THE PLATES OF A CAPACITOR ARE ALWAYS INSULATED FROM EACH OTHER

Function: In a capacitor the electric charge is stored in the form of an electrostatic field between the two conductors or plates, due to the ability of dielectric material to distort and store energy while it is charged and keep that charge for a long period or till it is discharged through a resistor or wire. The unit of charge is coulomb and it is denoted by the letter `C'.

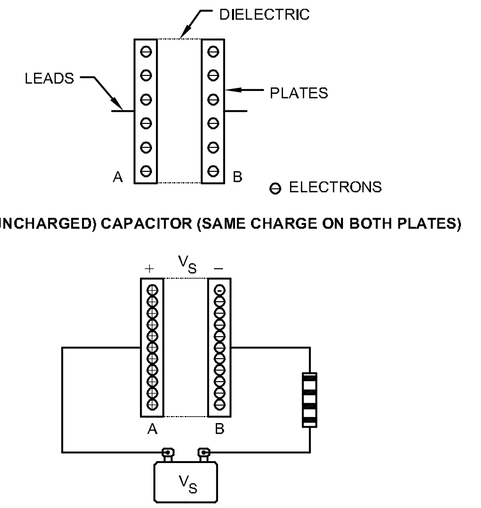
How a capacitor stores charge?: In the neutral state, both plates of a capacitor have an equal number of free electrons, as indicated in Fig 2a. When the capacitor is connected to a voltage source through a resistor, the electrons (negative charge) are removed from plate A, and an equal number are deposited on plate `B'. Plate A becomes positive with respect to plate B as shown in Fig 2b.

The current enters and leaves the capacitor, but the insulation between the capacitor plates prevents the current from flowing through the capacitor.

As electrons flowing into the negative plate of a capacitor have a polarity opposite to that of the battery supplying the current, the voltage across the capacitor opposes the battery voltage. The total circuit voltage, therefore, consists of two series-opposing voltages.

As the voltage across the capacitor increases, the effective circuit voltage, which is the difference between the battery voltage and the capacitor voltage, decreases. This, in turn, causes a decrease in the circuit current.

Fig 2



(b) CAPACITOR CHARGED TO V NO MORE ELECTRONS FLOW

When the voltage across the capacitor equals the battery voltage, the effective voltage in the circuit is zero, and so the current flow stops. At this point, the capacitor is fully charged, and no further current can flow in the circuit.

Capacitance : The ability or capacity to store energy in the form of electric charge is called capacitance. The symbol used to represent capacitance is C.

Unit of capacitance: The base unit of capacitance is the **Farad.** The abbreviation for **Farad** is **F**. One farad is that amount of capacitance which stores 1 coulomb of charge when the capacitor is charged to 1 V. In other words, a Farad is a coulomb per volt (C/V).

Farad

A farad is the unit of capacitance (C), and a coulomb is the unit of charge(Q), and a volt is the unit of voltage(V). Therefore, capacitance can be mathematically expressed

as $C = \frac{Q}{V}$

This relationship is very useful in understanding voltage distribution in series-capacitor circuits. The other forms of equation are $V = \frac{Q}{C}$

Example 1: What is the capacitance of a capacitor that requires 0.5 C to charge it to 25V?

Given: Charge(Q) = 0.5C

Voltage(V) = 25V

Find :

Capacitance(C)

$$C = \frac{Q}{V}$$

Solution $C = \frac{0.5\,C}{25\,V} = 0.02F$

Answer: The capacitance is 0.02F.

Capacitive reactance

Similar to resistors and inductors, a capacitor also offers opposition to the flow of AC current. This opposition offered to the flow of current by a capacitor is called **capacitive reactance** abbreviated as X_C.

Recall expressions,

$$I = \frac{Q}{t} = \text{and } Q = CV$$

Substituting Q = CV in I = Q/t

$$I = \frac{CV}{t}$$

This means,
$I \alpha C$, $I \alpha V$ and $I \alpha f$ (Because, 1/t = f)

From the above equation, the amount of AC current that a capacitor conducts depends on;

- the frequency (f) of the applied voltage
- the capacitance (C) of the capacitor
- the amplitude of the applied voltage(V).

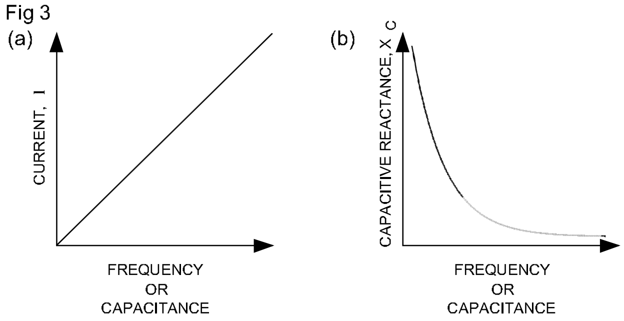
Fig 3a shows the graph of variation of current(I) through a capacitor with frequency or capacitance when the applied voltage is kept constant.

Since current flow through a capacitor is directly proportional to frequency and capacitance, the opposition to current flow by the capacitor is inversely proportional to these quantities.

Capacitive reactance, X_C can be mathematically represented as;

$$X_c = \frac{1}{2\pi fc}$$

Fig 3



CURRENT THROUGH A CAPACITOR INCREASES LINEARLY WITH INCREASING FREAQUENCY OR CAPACITANCE

CAPACITIVE REACTANCE DECREASES NON LINEARLY WITH INCREASE IN FREAQUENCY OR CAPACITANCE

where

X_C is the capacitive reactance in ohms

f is the frequency of the applied voltage in Hz

and C is the capacitance in farads.

Fig 3b shows the graph of variation of X_C with frequency or capacitance.

Capacitive reactance, X_C, expressed in ohms, acts just like a resistance in limiting the AC current flow.

Sub-units of a farad: Most capacitors that you will use in electronics work, have capacitance values in microfarads (μF) and picofarads (pF). A microfarad is one-millionth of a farad (1μF = 1 x 10^{-6} F), and a picofarad is one-trillionth of a farad (1 PF = 1 x $10^{-12}{}_{P}$F) one nano farad (1nF = 1 x 10^{-9} F).

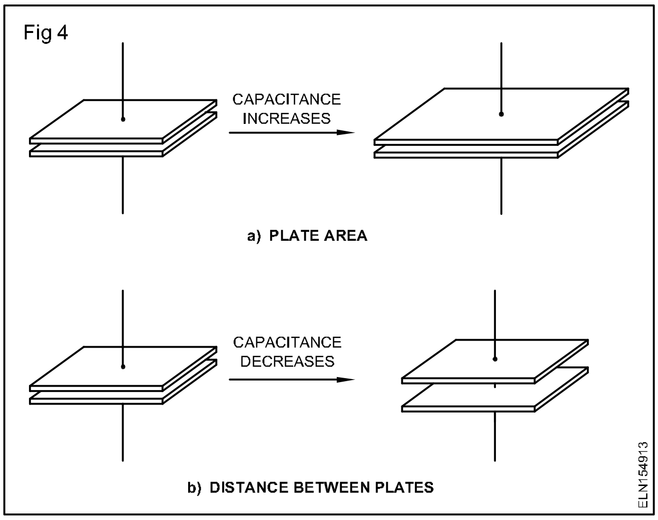
Factors determining capacitance: The capacitance of a capacitor is determined by four factors.

- Area of the plates ($C \alpha A$)
- Distance between the plates ($C \alpha d$)
- Type of dielectric material
- Temperature
- Resistance of the plates

Area of the plates: The capacitance of a capacitor is directly proportional to the area of its plates (or the area of its dielectric). All other factors remaining the same, doubling the plate area doubles the capacitance.

Thus, when the dielectric area is increased, the amount of energy stored in the dielectric is increased and the capacitance is also increased. (Remember, capacitance is defined as the ability to store energy.) (Fig 4a)

Distance between the plates: Other factors being equal, the amount of capacitance is inversely proportional to the distance between the plates. The strength of the electric field between the plates decreases, when the distance between the plates increases. The force on the electrons in the dielectric decreases accordingly. Again the amount of energy stored in the capacitor, for a given voltage applied to the capacitor, would decrease. Thus, the capacitance decreases. (Fig 4b)



Type of dielectric material: In general, those materials which undergo the greatest distortion store the most capacitance. The ability of a dielectric material to distort and store energy is indicated by its **dielectric constant (K)**.

The dielectric constant of a material is a mere number (that is, it has no units). It compares the material's ability to distort and store energy, when in an electric field, with the ability of air to do the same.

Since air is used as the reference, it has been given K equal to 1. Mica, often used as a dielectric, has a dielectric constant approximately 5 times that of air. Therefore, for mica, K = 5 (approximately). Suppose all the other factors (plate area, distance between plates, and temperature) are the same, then a capacitor with a mica dielectric will have 5 times as much capacitance as the one using air as its dielectric.

Dielectric constants for materials commonly used for dielectrics range from 1 for air to more than 4000 for some types of ceramics.

Temperature: The temperature and resistance of the capacitor is the least significant of the four factors. It need not be considered for many general applications of capacitors.

Types of capacitors: Capacitors are manufactured in a wide variety of types, sizes and values. Some are fixed in value, in others the value is variable.

Fixed capacitors

Ceramic capacitors: Ceramic dielectrics provide very high dielectric constants (1200 is typical). As a result, comparatively high capacitance values can be achieved in a small physical size.

Ceramic capacitors are illustrated in Figs 5a) and (b). These discs are made by using ceramic as an insulator with a silver deposit on each side of the plates. These are used for small values of capacitance and an ordinary TV set might contain several dozens in its circuitry.

Ceramic capacitors are typically available in capacitance values ranging from 1µF to 2.2µ F with voltage ratings up to 6 KV. A typical temperature coefficient for ceramic capacitors is 200,000 PPM/°C.

Mica capacitors: There are two types of mica capacitors, stacked foil as shown in Fig 5(c). It consists of alternate layers of metal foil and thin sheets of mica. The metal foil forms the plate, with alternate foil sheets connected together to increase the plate area, thus increasing the capacitance.

The mica foil-stack is encapsulated in an insulating material such as bakelite, as shown in Fig 5d of the figure. The silver-mica capacitor is formed in a similar way by stacking mica sheet with silver electrode material screened on them.

Mica capacitors are available with capacitance values ranging from 1 pF to 0.1 pF and voltgage ratings from 100 to 2500 V DC. Temperature coefficients from −20 to +100 PPM/°C are common. Mica has a typical dielectric constant of 5.

Electrolytic capacitors: Electrolytic capacitors are polarised so that one plate is positive and the other negative.

These capacitors are used for high capacitance values up to over 200,000µ F, but they have relatively low breakdown voltages (350 V is a typical maximum) and high amounts of leakage.

Electrolytic capacitors are available in two types: aluminium and tantalum. The basic construction of an electrolytic capacitor is shown in Figs 5(e) and (f).

The capacitor consists of two strips of either aluminum or tantalum foil separated by a paper or gauze strip, saturated with an electrolyte. During manufacturing, an electrochemical reaction is induced which causes an oxide layer (either aluminum oxide or tantalum oxide) to form on the inner surface of the positive plate. This oxide layer acts as the dielectric.

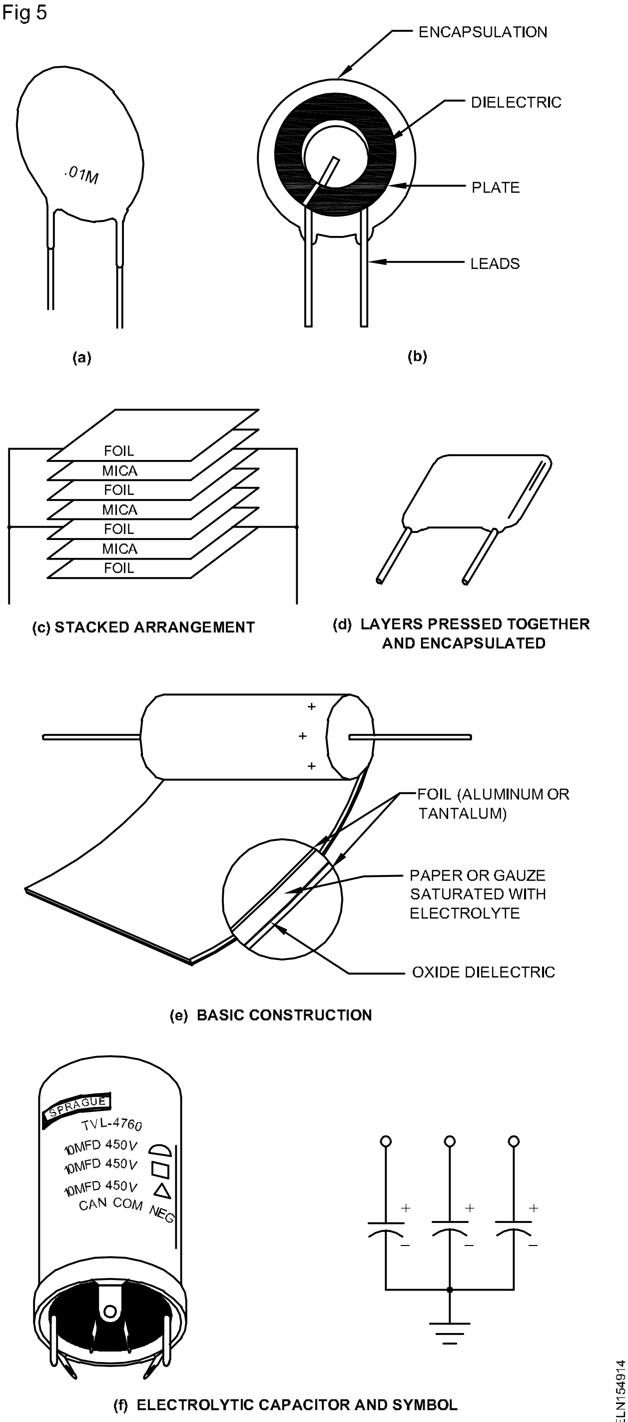
One particular point you must always remember about the electrolytic capacitor is that one end is positive (+) and the other negative (−). You must always observe this polarity when connecting in your circuit. The symbol on a drawing will have positive and negative marks. These polarity marks will tell you it is an electrolytic capacitor.

Since an electrolytic capacitor is polarized, the positive plate must always be connected to the positive side of a circuit. Be very careful to make the correct connection and to install the capacitor only in a DC, not AC, circuit.

Reverse polarity on an electrolytic capacitor causes excessively high current in the capacitor. It causes the capacitor to heat up, and possibly to explode. Thus, the common electrolytic capacitor is limited to use in DC circuits.

Special electrolytic capacitors are manufactured for use in AC circuits. These capacitors are usually listed in catalogues as `non-polarised' or `AC' electrolytic capacitors. An AC electrolytic capacitor is really two electric capacitors packaged in a single container.(Fig 6)

Fig 5

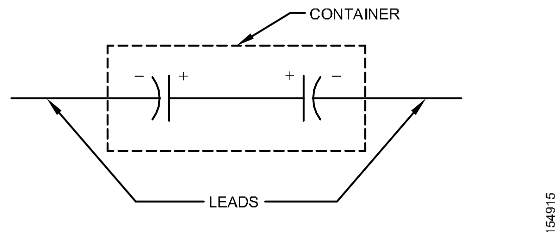


The two internal capacitors are in series, with their positive ends connected together. Regardless of the polarity on the leads of the AC electrolytic capacitor, one of the two internal capacitors will be correctly polarized.

Paper/plastic capacitors: There are several types of plastic-film capacitors and the older paper dielectric capacitors. Polycarbonate, parylene, polyester, polystyrene, polypropylene, mylar, and paper are some of the more common dielectric materials used. Some of these types have capacitance values up to 100µF.

Fig 7 show a common basic construction used in many plastic-film and paper capacitors. A thin strip of plastic-film dielectric is sandwiched between two thin metal strips which act as plates. One lead is connected to the inner plate and the other to the outer plate as indicated. The strips are then rolled in a spiral configuration and encapsulated in a moulded case. Thus a large plate area can be packaged in a relatively small physical size, thereby achieving larger capacitance values. Fig 7b shows a construction view for one type of plastic-film capacitor.

Fig 6



NON-POLARIZED CAPACITOR.

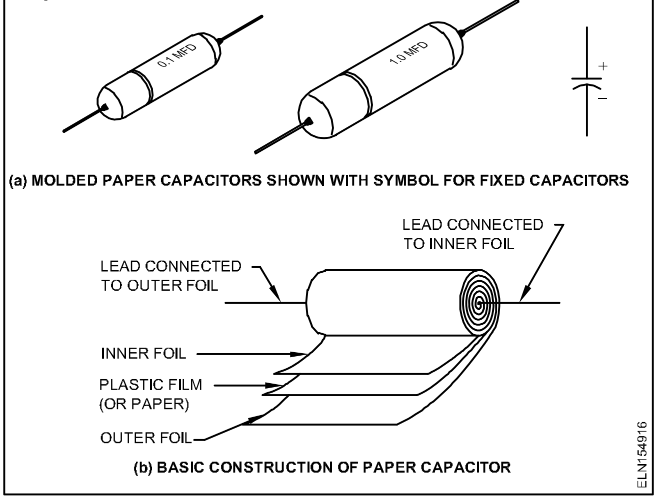
Variable capacitors

Variable capacitors are used in a circuit when there is a need to adjust the capacitance value either manually or automatically. For example, in radio or TV tuners. The major types of variable or adjustable capacitors are now discussed.

Air capacitor: Variable capacitors with air dielectrics, such as the one shown in Fig 8(b), are sometimes used as tuning capacitors in applications requiring frequency selection. This type of capapcitor is constructed with several plates that mesh together. One set of plates can be moved relative to the other, thus changing the effective plate area and the capacitance. The movable plates are linked together mechanically so that they move when a shaft is rotated.

The schematic symbol for a variable capacitor is shown in Fig 8(a).

Fig 7

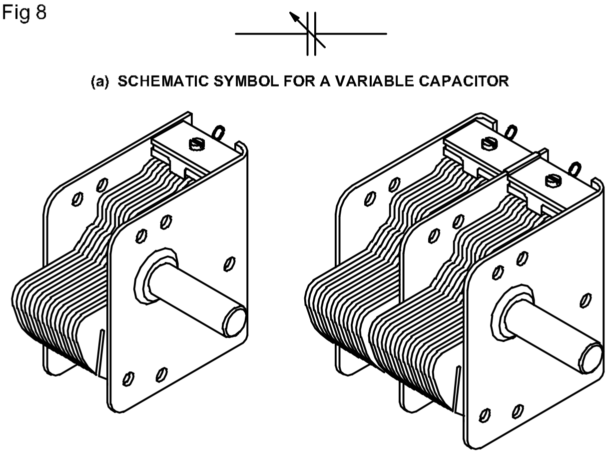


(b) BASIC CONSTRUCTION OF PAPER CAPACITOR

Trimmers and padders: These adjustable capacitors normally have screwdriver adjustments, and are used for very fine adjustments in a circuit. Ceramic or mica is a common dielectric in these types of capacitors, and the capacitance usually is changed by adjusting the plate separation.(Fig 9)

Varactors: A varactor is a semiconductor device that exhibits a capacitance characteristic which is varied by changing the voltage across its terminals. This device is usually covered in greater detail in a course on electronic devices.

Fig 8



(b) SINGLE AND TWO-GANG VARIABLE CAPACITORS WITH AIR DIELECTRIC

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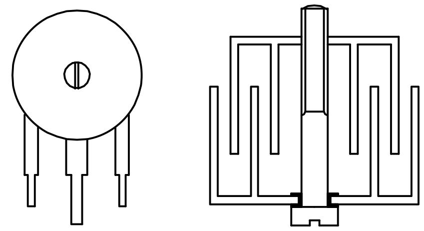
Fig 9



TRIMMER CAPACITORS

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Application of capacitors with type and ratings - Chart I

Type	Capacitance	Voltage WVDC (Working voltage DC)	Applications
Monolithic	1 pF-10µF	50-200	UHF,RF coupling.
Disc and tube ceramics	1pF - 1µF	50-500	General, VHF.
Paper	0.001-1µF	200-1600	Motors, power supplies.
Film - polypropylene	0.001-0.47µF	400-1600	TV vertical circuits, RF.
Polyester	0.001-1µF	100-600	Enetertainment- electronics.
Polystyrene	0.001-1µF	100-200	General, high stability.
Polycarbonate	0.01 -18µF	50-200	General.
Metallized polypropylene	4-60µF	400 VAC 50Hz	AC motors.
Metallized polyester	0.01-10µF	100-600	Coupling, RF filtering.
Electrolytic-aluminum	1-500,000µF	5-500	Power supplies, filters.
Electrolytic-tantalum	0.1-1000µF	3-125	Small space requirement, high reliability, low leakage.
Electrolytic-Non-polarised (either Al or Ta)	0.47-220µF	16-100	Loudspeaker cross-overs.
Mica	330pF-0.05µF	50-100	High frequency.
Silver-mica	5-820pF	50-500	High frequency.
Variable-ceramic	1-5 to 16-100pF	200	Radio, TV, communications.
Film	0.8-5 to 1.2-30pF	50	oscillators, antenna, RF circuits.
Air	10-365pF	50	Broadcast receivers.
Teflon 0.25-1.5pF		2000	VHF, UHF.

Common defects in capacitors

Short circuited capacitors: In the course of normal usage, capacitors can become short-circuited/shorted. This is because of the deterioration of the dielectric used due to ageing.

Usually such a defect occurs when the capacitor is used over a period of years under the stress of changing voltage across it. This period gets reduced if the capacitor is operated at higher temperatures.

Short-circuiting of capacitors is more common in paper and electrolytic capacitors than in the other types.

Short circuiting of capacitor also occurs due to puncturing of the dielectric when voltages much higher than its rated and applied. A shorted capacitor cannot store energy.

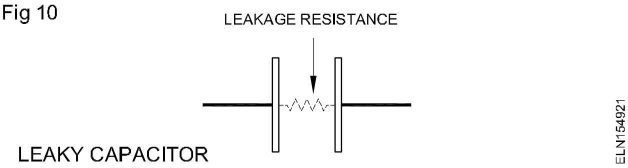
Open capacitors: A capacitor may become open due to loose/broken lead connections or due to the electrolyte. In electrolytic capacitors, the electrolyte develops high resistance with age, particularly when operated at high temperatures. After a few years of usage, the electrolyte may dry up resulting in open-circuit of the capacitor. An open capacitor cannot store energy.

The storage (shelf) life of wet type electrolytic capacitors is small because the electrolyte dries up over period of time.

Leaky capacitors/leakage resistance: Theoretically, the current that flows in a pure capacitive circuit results from the charge and discharge currents of the capacitors. The dielectric, which is an insulator, should prevent any current flow between the plates. However, even the best dielectric conduct very small current.

The dielectric, then has some high value of resistance, known as leakage resistance. This leakage resistance, as shown in Fig 10, allows some leakage current to flow. This leakage current tends to reduce the capacitance value.

Fig 10



In a good capacitor, the leakage resistance is generally of the order of several tens of megohms and hence can be considered negligible for most applications. As the capacitor ages, the leakage resistance could reduce. Generally, the leakage resistance is lower with high value capacitors than with low value capacitors.

The reason for this is that, larger capacitors have larger plate areas that are closer together. Therefore their dielectrics must have large areas and be thin. Recall, resistance reduces as the -sectional area is increased or when the length or thickness is decreased.

So, larger the capacitor, lower the leakage resistance, and higher is the leakage current.

Normal leakage resistance across a good capacitor has to be very high. Depending upon the type of dielectric used, the normal resistance varies.

For paper, plastic, mica and ceramic capacitors the normal resistance will be of the order of 500 to 1000 M or more. For electrolytic capacitors the normal resistance will be of the order of 200 KΩ to 500 KΩ.

A capacitor is said to have become leaky when the resistance across it is less than normal when read with any average quality ohmmeter.

Checking capacitors: The two simple methods to check a capacitor is by carrying out,

i capacitor action-normal resistance test, using a ohm-meter/multimeter (This test is also referred as quick test)

ii charging-holding test, using a battery and voltmeter/ multimeter.

Capacitor action-normal charging test: When an ohmmeter is connected across a fully discharged capacitor, initially, the battery insider the meter charges the capacitor. During this charging, at the first instance, a reasonably high charging current flows.

Since more current through the ohm meter means less resistance, the meter pointer moves quickly towards zero ohms of the meter scale as shown in Fig 11a.

Fig 11

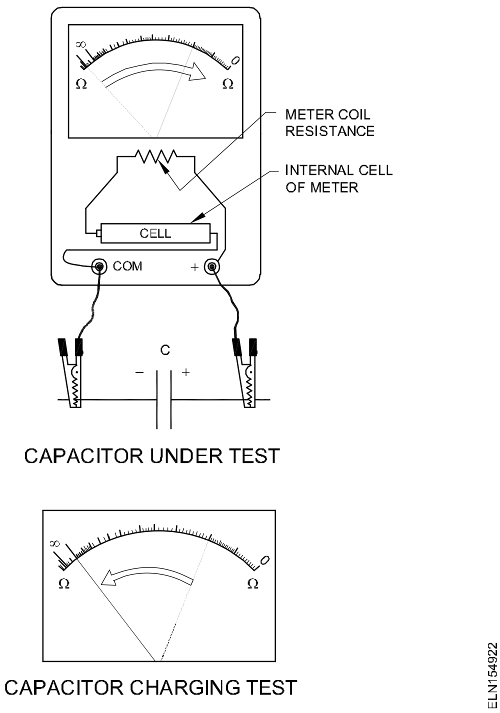


Fig 11b

As the initial charging, the charging current to the capacitor slowly decreases (as the voltage across the capacitor increases towards the applied voltage). Since less and less current through the ohmmeter means high and higher resistance the meter pointer slowly moves towards infinite resistance of the meter scale as shown is Fig 11b. Finally, when the capacitor is completely charged to the ohmmeter internal battery voltage, the charging current is almost zero and the ohmmeter reads the normal resistance of the capacitor which is a result of just the small leakage current through the dielectric.

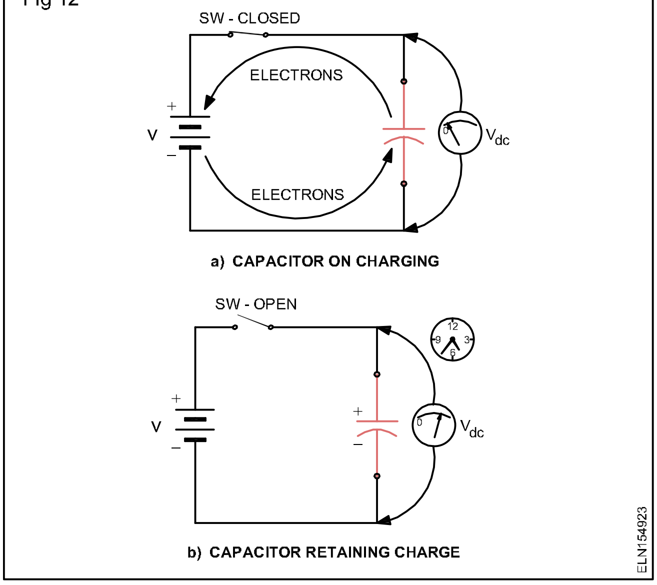
This changing effect commonly known as Capacitor action indicates, whether the capacitor can store charge, whether the capacitor is excessively leaky, whether the capacitor is fully short-circuited or whether the capacitor is fully open-circuited.

The capacitor-action test is most suitable for high value capacitors and specially electrolyte capacitors. When small value capacitors such as ceramic disc or paper capacitors are tested for capacitor-action, due to the extremely low charging current the capacitor-action can not be observed on the meter dial. For such small capacitors the capacitor-charging-holding test is preferred. However, if small capacitors are subjected for the capacitor-action test, if the meter shows high resistance the capacitor can be taken as not shorted and hence may be taken as good.

Charging-holding test on capacitors: In this test, a given capacitor is charged to some voltage level using an external battery as shown in Fig 12a.

Once the capacitor is charged to the applied voltage level, the battery is disconnected and the voltage across the capacitor is monitored as shown in Fig 12b. The voltage is monitored for a period of time to confirm whether he capacitor is able to hold the charge atleast for a small period of time (of the order of few seconds).

Fig 12



In this test, when the capacitor is tried for charging, if the capacitor does not charge at all even after connecting the battery for a considerable period of time, it can be concluded that the capacitor is either short-circuited or fully open circuited.

If the capacitor is unable to hold the charge even for a considerably small period of time, then it can be concluded that the capacitor is excessively leaky.

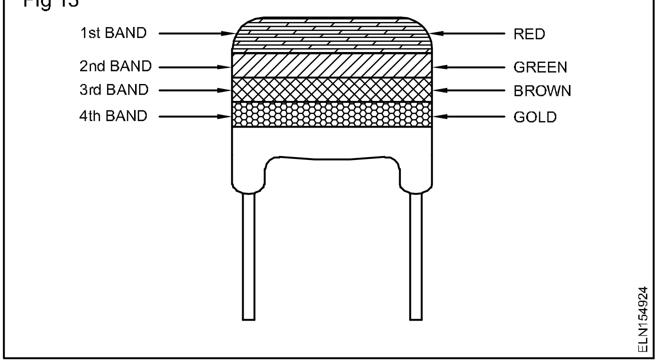
The following points are important and are to be noted to get correct results from the test.

- If the capacitor to be tested is marked + and – at its terminals (polarized-capacitor) then connect the battery with the same polarity. If a polarized capacitor is tried for changing with wrong polarity, the capacitor may get permanently damaged.
- Use a FET input voltmeter or high ohm/volt voltmeter to monitor the holding of voltage across the charged capacitor. This is because a low ohm/volt voltmeter will draw current from the charged capacitor resulting in a early discharge of stored charges on capacitor.

Note: FET voltmeters have input resistance in the order of 6 to 10 Megohms and draws only micro ampere current for full scale deflection.

For determining values of capacitors by colour code of capacitor is given in chart-2 for reference (Fig 13).

Fig 13



Capacitors colour code chart-2

Colour	Significant figures	Multiplier	Tolerance		Dipped tantalum voltage rating
			Over 10pF	Under 10pF	
Black	0	1	±20%	± 2 pF	4 VDC
Brown	1	10	±1%	± 0.1 pF	6 VDC
Red	2	10^2 or 100	±2%	-	10 VDC
Orange	3	10^3 or 1000	±3%	-	15 VDC
Yellow	4	10^4 or 10,000	+100%	-	20 VDC
			- 0%		
Green	5	10^5 or 100,000	±5%	± 0.5 pF	25 VDC
Blue	6	10^6 or 1,000,000	-	-	35 VDC
Violet	7	10^7 or 10,000,000	-	-	50 VDC
Grey	8	10^{-2} or 0.01	+80%	± 0.25 PF	-
		-20%			
White	9	10^{-1} or 0.1	±10%	± 1 pF	3 VDC
Gold	-	-	-	-	-
Silver	-	-	-	-	-
None	-	-	±10%	± 1 pF	-

Note: Main types of fixed value capacitors are given in Chart 3. Constructional details of fixed value capacitors are shown in Chart 4.

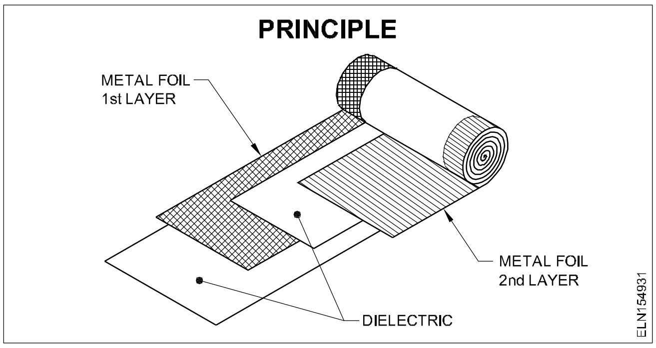
CHART - 3

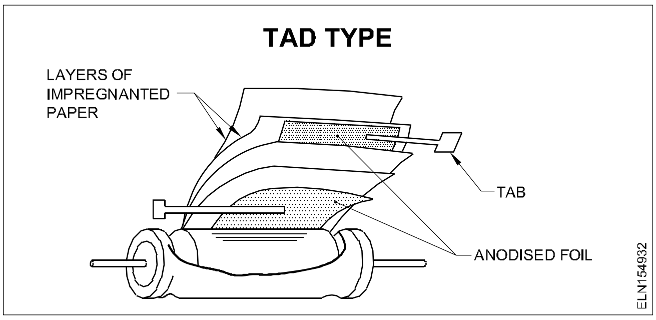
Main types of fixed value capacitors

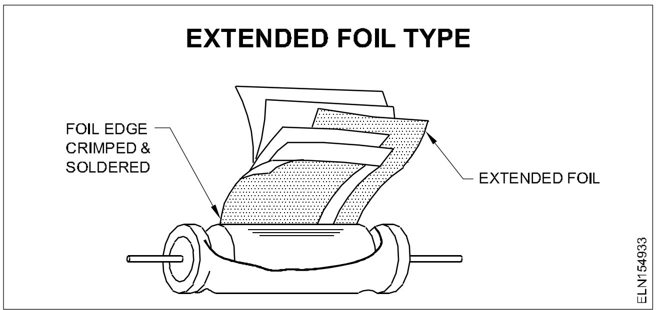
Type	Main sub-types	Dielectric used	Construction	Available capacitances	Rated voltage	Applications
Paper	Foil type & Metallized type	Impregnated special craft paper Special tissue paper	Rolled foils	0.001-1μF	200-1600VDC	Motor - starting, PF correction power supply- filters.
Plastic film	Foil type & Metalised type	i) Polystyrene ii) Polyster (Mylar capacitor)- iii) Poly propylene- iv) Poly carbonate v) Metallized polypropyene- vi) Metallized polyester- vii) Polystyrol (Styroflex)	- Rolled foils	0.001-1μF 0.001-1μF 0.001-0.47μF 0.01-18μF 4-60μF 0.01-10μF	100-200VDC 100-600VDC 400-1600 VDC 50-200 VDC 400 VAC, 50 Hz 100-600 VDC	General purpose, high stability. General purpose. RF circuits. General purpose. AC motors. Coupling, RF filtering.
Ceramic	Disc type Tube type Monolithic (chip type) Feed-through-stand-off-button type	Class-1 (Non ferro-electric) -Steatite (Talc) -Mix of MgO, TiO_2 -TiO_2, CaO Class-2 (Ferro-electric) -Barium titanate -Ba, Sr, TiO_2+Mg, Zr	Drawn ceramic films Moulded tubes Substrate-Screening-sintering	1PF -1μF 1PF-1000PF 1pF-10μF	50-500 VDC 500-5K VDC 50-200 VDC	General purpose, RF. General, VHF. VHF, RF coupling. Coupling in VHF range. Decoupling in VHF range. HF circuit feeders.
Electro-lytic	Aluminium (polor, non-polar)(Wet, dry type) Tantalum (polar, non-polar)(Wet, dry type)	Aluminium oxide Tantalum pentoxide	Rolled foil - metallic can Rolled foil - Can/cup/tank	1-500,000μF 0.1-1000μF	5-500 VDC 3-125 VDC	Power supplies, filters. Space electronics. Nonpolar Al and Ta capacitors are used in loudspeaker cross-overs.
Mica	Stacked mica- Silvered mica Button type	White mica, Rose mica, Amber mica	Stacked	5 pF-10,000pF 5pF-3300pF	50-100 50-500	High frequency High frequency H.F line feeders
Glass		Thin layer of glass	Stacked	5 pF-5000pF		VHF applications
Vitreous Enamel		Mixture of silica, Potassium, lead oxide and fluorides	Deposited in layers		50-500	

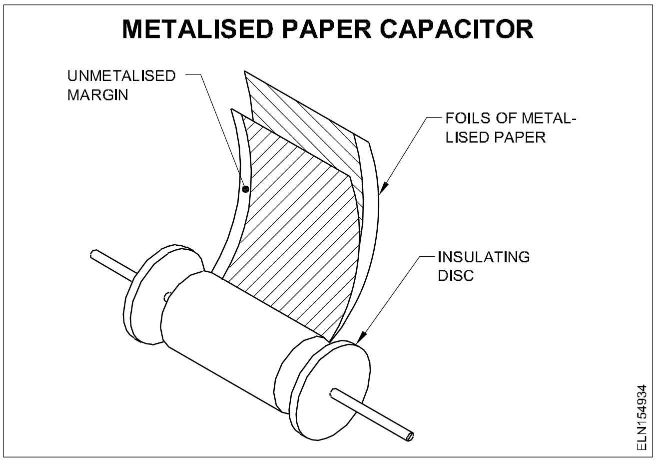
CHART - 4
Constructional details of fixed value capacitors

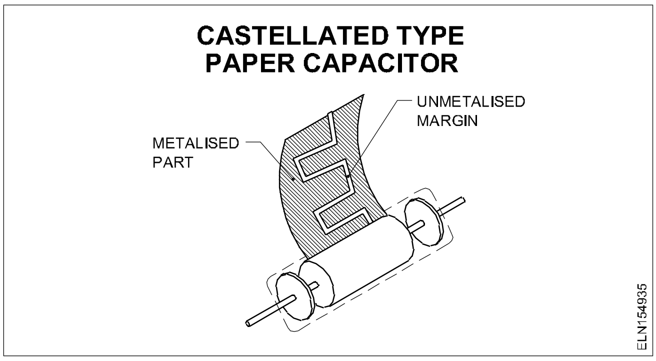
Paper Capacitors



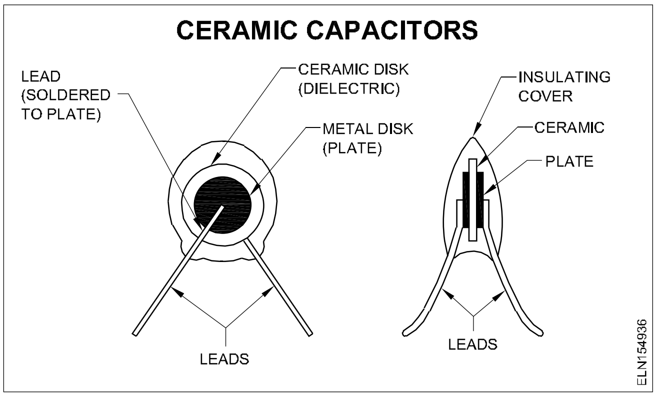


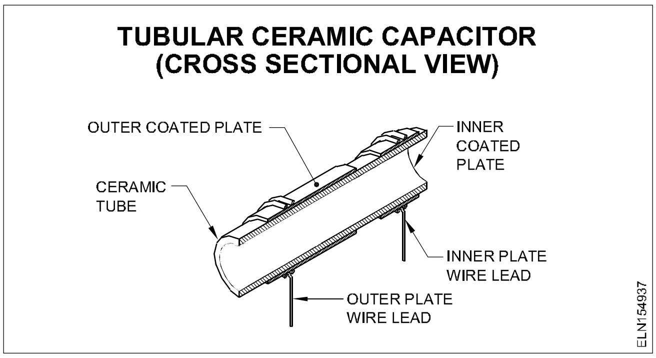


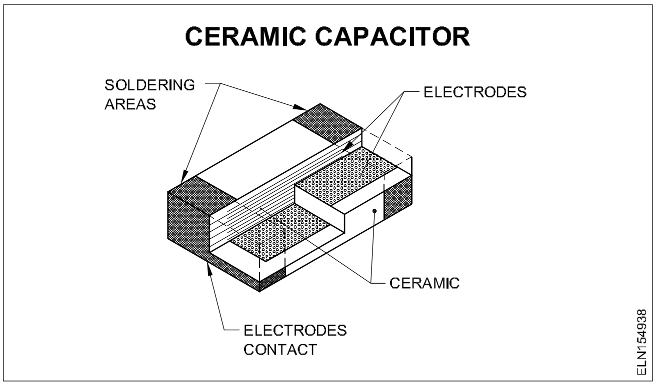




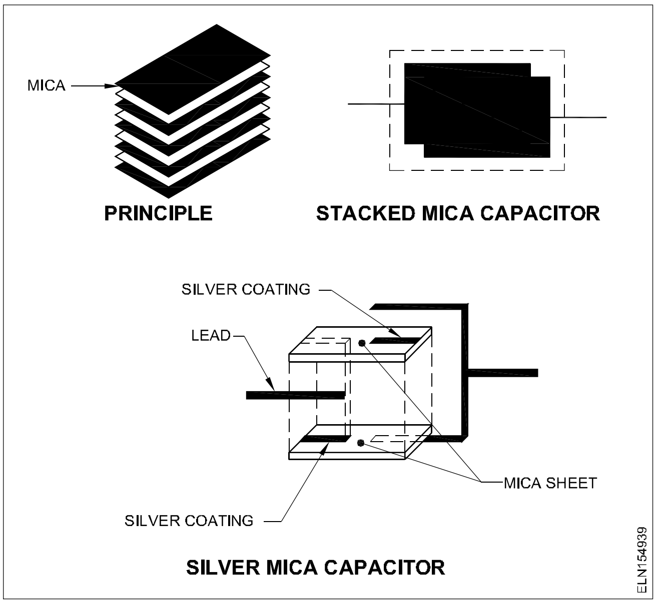
Ceramic Capacitors



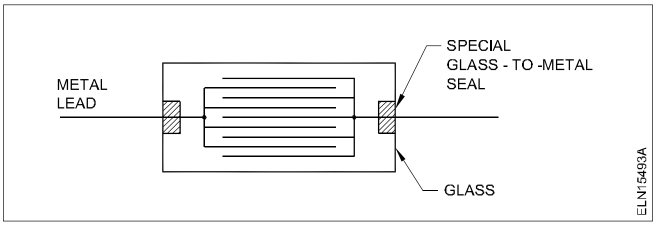


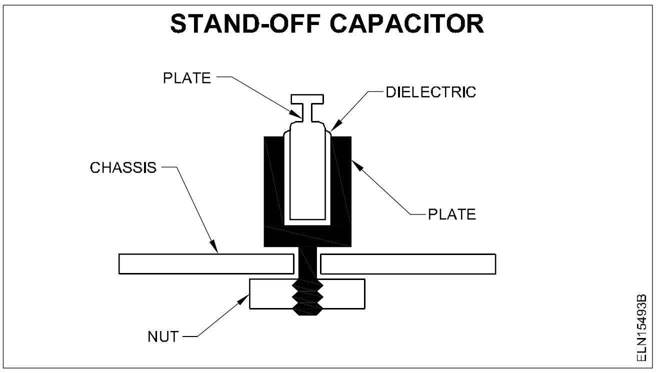


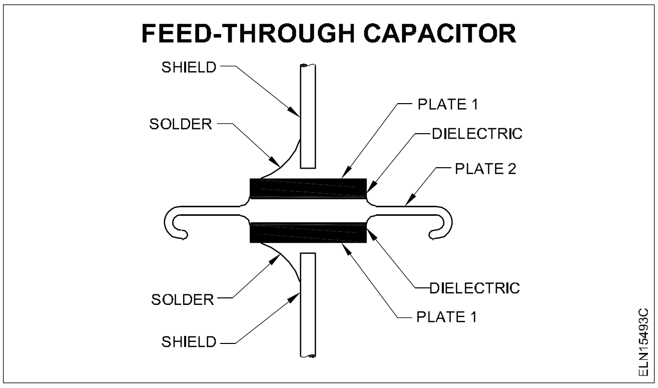
MICA Capacitors



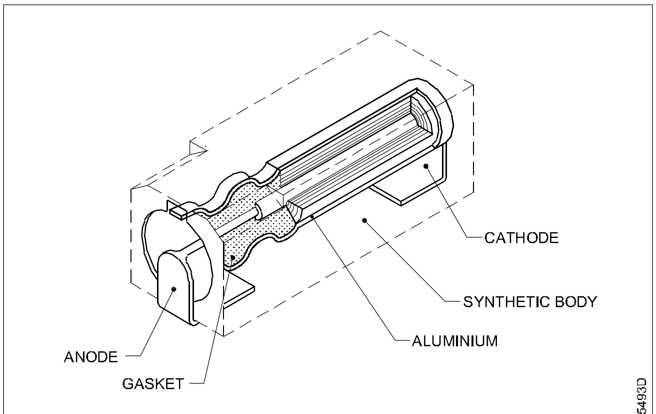
Glass Capacitors



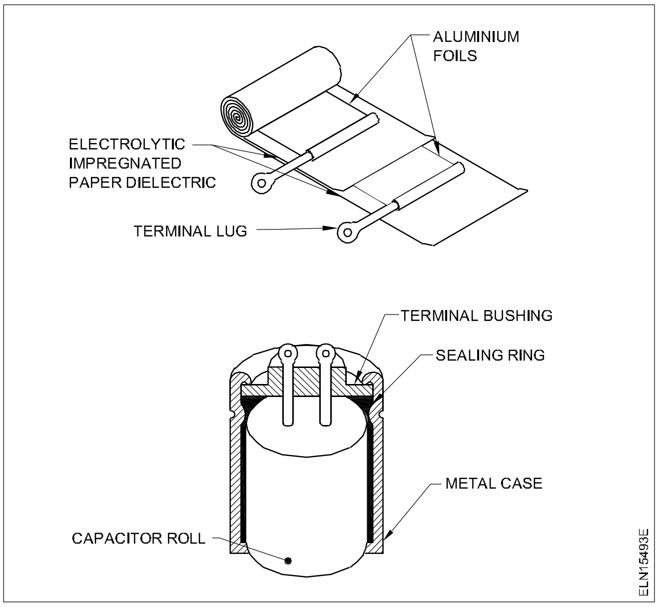




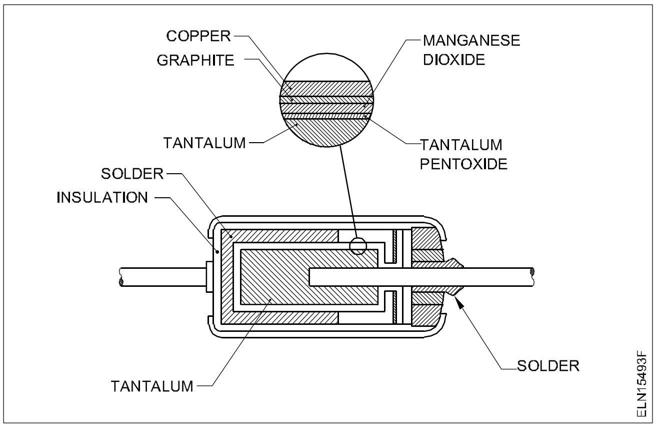
Electrolytic Capacitors Aluminium Type

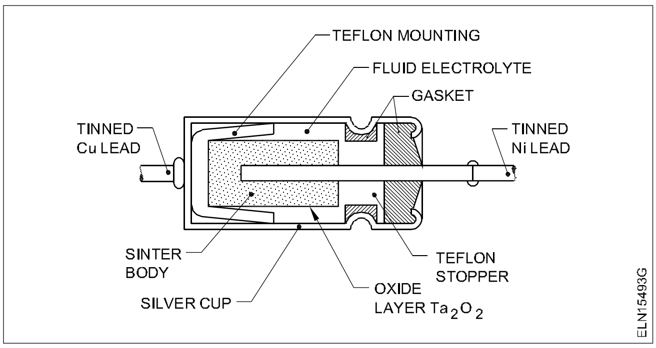


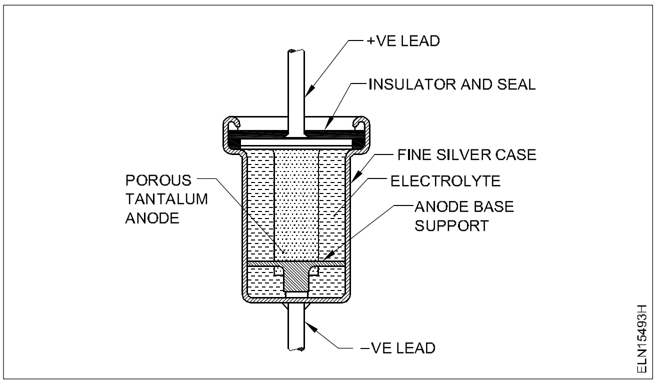
ALUMINIUM CHIP ELECTROLYTIC CAPACITOR

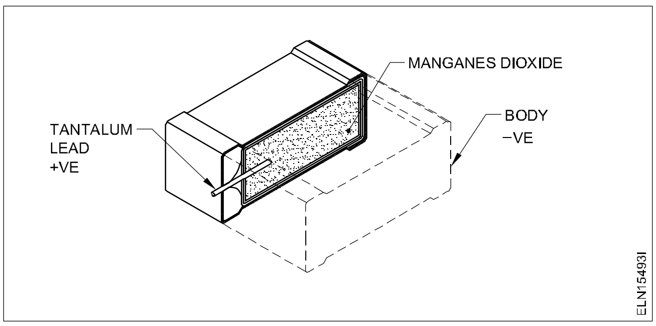


Tantalum Capacitors









Grouping of capacitors

Objectives: At the end of this lesson you shall be able to
- **state the necessity of grouping capacitors and method of connection**
- **state the conditions for connecting capacitors in parallel and in series**
- **explain the values of capacitance and voltage in parallel and series combination**

Necessity of grouping of capacitors: In certain instances, we may not be able to get a required value of capacitance and a required voltage rating. In such instances, to get the required capacitances from the available capacitors and to give only the safe voltage across capacitor, the capacitors have to be grouped in different fashions. Such grouping of capacitors is very essential.

Methods of grouping: There are two methods of grouping.

- Parallel grouping
- Series grouping

Parallel grouping

Conditions for parallel grouping

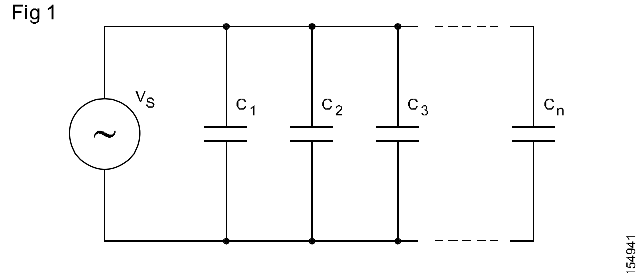
- Voltage rating of capacitors should be higher than the supply voltage Vs.
- Polarity should be maintained in the case of polarised capacitors (electrolytic capacitors).

Necessity of parallel grouping: Capacitors are connected in parallel to achieve a higher capacitance than what is available in one unit.

Connection of parallel grouping: Parallel grouping of capacitors is shown in Fig 1 and is analogous to the connection of resistance in parallel or cells in parallel.

Total capacitance: When capacitors are connected in parallel, the total capacitance is the sum of the individual capacitances, because the effective plate area increases. The calculation of total parallel capacitance is analogous to the calculation of total resistance of a series circuit.

Fig 1



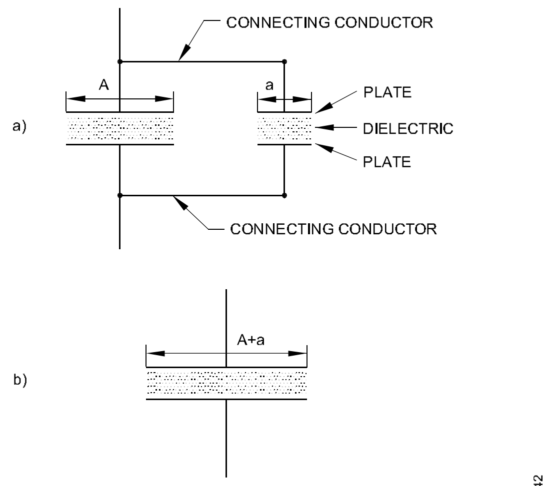
CAPACITORS IN PARALLEL

By comparing Figs 2a and 2b, you can understand that connecting capacitors in parallel effectively increases the plate area.

General formula for parallel capacitance: The total capacitance of parallel capacitors is found by adding the individual capacitances.

$$C_T = C_1 + C_2 + C_3 + \ldots\ldots\ldots\ldots + C_n$$

Fig 2



CAPACITORS IN PARALLEL. THE EQUIVALENT CAPACITANCE IN (b) IS EQUAL TO THE SUM OF THE CAPACITANCES IN (a).

where C_T is the total capacitance,

C_1, C_2, C_3 etc. are the parallel capacitors.

The voltage applied to a parallel group must not exceed the lowest breakdown voltage for all the capacitors in the parallel group.

Example: Suppose three capacitors are connected in parallel, where two have a breakdown voltage of 250 V and one has a breakdown voltage of 200 V, then the maximum voltage that can be applied to the parallel group without damaging any capacitor is 200 volts.

The voltage across each capacitor will be equal to the applied voltage.

Charge stored in parallel grouping: Since the voltage across parallel-grouped capacitors is the same, the larger capacitor stores more charge. If the capacitors are equal in value, they store an equal amount of charge. The charge stored by the capacitors together equals the total charge that was delivered from the source.

$$Q_T = Q_1 + Q_2 + Q_3 + \ldots\ldots + Q_n$$

where Q_T is the total charge

Q_1, Q_2, Q_3.....etc. are the individual charges of the capacitors in parallel.

Using the equation Q = CV,

the total charge $Q_T = C_T V_S$

where V_S is the supply voltage.

Again $C_T V_S = C_1 V_S + C_2 V_S + C_3 V_S$

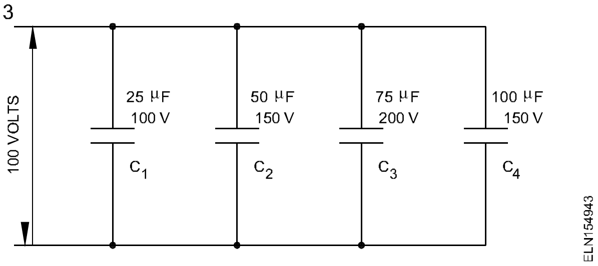
Because all the V_S terms are equal, they can be cancelled.

Therefore, $C_T = C_1 + C_2 + C_3$

Example: Calculate the total capacitance, individual charges and the total charge of the circuit given in Fig 3.

Solution

Fig 3



Total capacitance = C_T

$C_T = C_1 + C_2 + C_3 + C_4$

C_T = 250 micro farads.

Individual charge = Q = CV

$Q_1 = C_1V$

$= 25 \times 100 \times 10^{-6}$

$= 2500 \times 10^{-6}$

$= 2.5 \times 10^{-3}$ coulombs.

$Q_2 = C_2V$

$= 50 \times 100 \times 10^{-6}$

$= 5000 \times 10^{-6}$

$= 5 \times 10^{-3}$ coulombs.

$Q3 = C_3V$

$= 75 \times 100 \times 10^{-6}$

$= 7500 \times 10^{-6}$

$= 7.5 \times 10^{-3}$ coulombs.

$Q_4 = C_4V$

$= 100 \times 100 \times 10^{-6}$

$= 10000 \times 10^{-6}$

$= 10 \times 10^{-3}$ coulombs.

Total charge $= Q_t = Q_1 + Q_2 + Q_3 + Q_4$

$= (2.5\times10^{-3}) + (5\times10^{-3})$

$+ (7.5\times10^{-3}) + (10\times10^{-3})$

$= (2.5+5+7.5+10) \times 10^{-3}$

$= 25 \times 10^{-3}$ coulombs.

or $Q_T = C_TV$

$= 250 \times 10^{-6} \times 100$

$= 25 \times 10^{-3}$ coulombs.

Series grouping

Necessity of grouping of capacitors in series: The necessity of grouping capacitors in series is to reduce the total capacitance in the circuit. Another reason is that two or more capacitors in series can withstand a higher potential difference than an individual capacitor can. But, the voltage drop across each capacitor depends upon the individual capacitance. If the capacitances are unequal, you must be careful not to exceed the breakdown voltage of any capacitor.

Conditions for series grouping

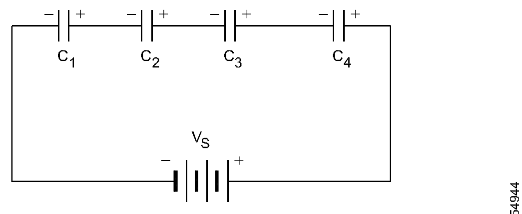
– If different voltage rating capacitors have to be connected in series, take care to see that the voltage drop across each capacitor is less than its voltage rating.

– Polarity should be maintained in the case of polarised capacitors.

Connection in series grouping: Series grouping of capacitors, as shown in Fig 4 is analogous to the connection of resistances in series or cells in series.

Total capacitance: When capacitors are connected in

Fig 4



SERIES CONNECTION OF CAPACITORS

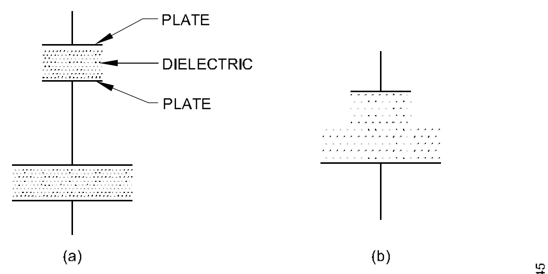
series, the total capacitance is less than the smallest capacitance value, because

- the effective plate separation thickness increases
- and the effective plate area is limited by the smaller plate.

The calcualtion of total series capacitance is analogous to the calculation of total resistance of parallel resistors.

By comparing Figs 5a and 5b you can understand that connecting capacitors in series increases the plate separation thickness, and also limits the effective area so as to equal that of the smaller plate capacitor.

Fig 5



THE EQUIVALENT CAPACITANCE IN (b) IS LESS THAN THE LOWER OF THE TWO CAPACITANCES IN (a).

General formula for series capacitance: The total capacitance of the series capacitors can be calculated by using the formula

$$C_T = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\ldots\ldots+\frac{1}{C_n}}$$

or

$$\frac{1}{C_T} = \frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\ldots\ldots+\frac{1}{C_n}$$

If there are two capacitors in series

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

If there are three capacitors in series

$$C_T = \frac{C_1 C_2 C_3}{(C_1C_2)+(C_2C_3)+(C_3C_1)}$$

If there are `n' equal capacitors in series

$$C_T = \frac{C}{n}$$

Maximum voltage across each capacitor: In series grouping, the division of the applied voltage among the capacitors depends on the individual capacitance value according to the formula

$$V = \frac{Q}{C}$$

The largest value capacitor will have the smallest voltage because of the reciprocal relationship.

Likewise, the smallest capacitance value will have the largest voltage.

The voltage across any individual capacitor in a series connection can be determined using the following formula.

$$V_X = \frac{C_T}{C_X} \times V_S$$

where V_x - individual voltage of each capacitor

C_x - individual capacitance of each capacitor

V_s - supply voltage.

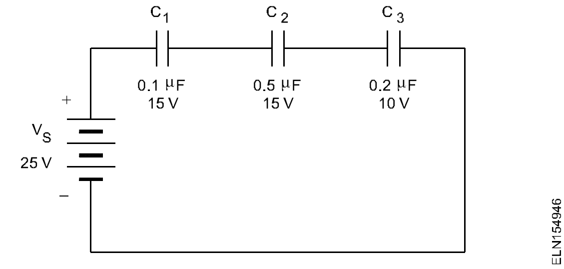
The potential difference does not divide equally if the capacitances are unequal. If the capacitances are unequal you must be careful not to exceed the breakdown voltage of any capacitor.

Example: Find the voltage across each capacitor in Fig 6.

Solution

Total capacitance: C_T

Fig 6



$$\frac{1}{C_T} = \frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}$$

$$\frac{1}{C_T} = \frac{1}{0.1}+\frac{1}{0.5}+\frac{1}{0.2} \text{ macro farad}$$

$$\frac{1}{C_T} = \frac{10}{1}+\frac{2}{1}+\frac{5}{1}$$

$$\frac{1}{C_T} = \frac{17}{1} \text{ and CT} = 0.0588 \text{ micro farad}$$

$$V_1 = \frac{C_T}{C_1} \times V_S$$

V_1 = 14.71 V_s

$$V_2 = \frac{C_T}{C_2} \times V_S$$

$$V_2 = \frac{0.0588}{0.5} \times 25$$

V_2 = 2.94 volts

$$V_3 = \frac{C_T}{C_3} \times V_S$$

$$V_3 = \frac{0.0588}{0.2} \times 25$$

V_3 = 7.35 volts

Charge stored in series grouping: Based on previous knowledge, we know that

– the current is the same at all points in a series circuit the current is defined as the rate of flow of charge.

(I = Q/t) or Q = It

The same current is flowing for the same period through the different capacitors of the series circuit. So the charge of each capacitor will be equal (same), and also equal to the total charge Q_T.

$$Q_T = Q_1 = Q_2 = Q_3 = ... = Q_n$$

But the voltage across each one depends on its capacitance value.

$$\left(V = \frac{Q}{C}\right)$$

By Kirchoff's voltage law, which applies to capacitive as well as to resistive circuits, the sum of the capacitor voltages equals the source voltage.

$$V_9 = V_1 + V_2 + V_3 + ... + V_n$$