CHAPTER 5

Passive Circuit Elements

5.1. General

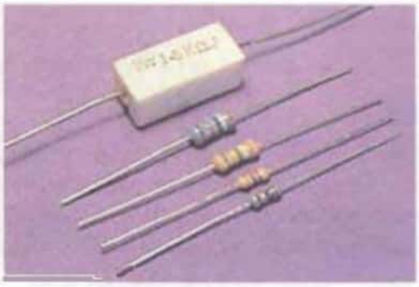
Individual components which make up an electronic circuit are called *elements* or *parameters*. Most commonly-used elements in such circuits are :

1. resistors 2. inductors 3. capacitors

In resistors, current is *directly* proportional to the *applied voltage*. In inductors, voltage required is *directly* proportional to the rate of change of *current* whereas capacitors require current which is *directly* proportional to the rate of change of *voltage*.

5.2. Resistors

A resistor is an electrical component with a known specified value of resistance. It is probably the most common component in all kinds of electronic equipment ranging from a small radio to a colour television receiver. As its name suggests, a resistor *resists* or *opposes* the flow of current through it. Resistance is necessary for any circuit to do useful work. In fact, without resistance, *every circuit would be a short circuit !*



Resistors.

useful work. In Resistors. Capacitor

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Some of the common uses of resistors are :

1. to establish proper values of circuit voltages due to *IR* drops
2. to limit current and
3. to provide load

The two main characteristics of a resistor are its resistance and power rating. Resistors can be connected in the circuit in either direction because they have no 'polarity'.

5.3. Resistor Types

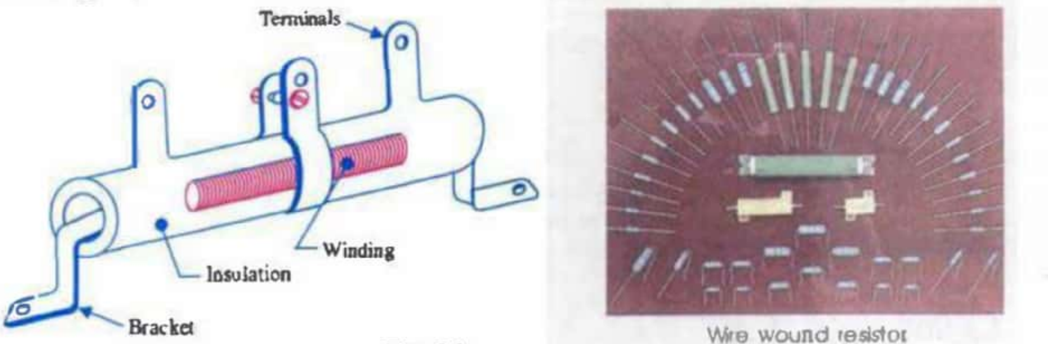
Resistors are mainly of two types and can be either of fixed or variable value.

1. wire-wound resistors
2. carbon resistors
    (*a*) carbon-composition type
    (*b*) carbon-film type
    (*c*) cermet-film type

Another type is called metal thin-film resistor.

5.4. Wire-Wound Resistors

They are constructed from a long fine wire (usually nickel-chromium wire) wound on a ceramic core. The length of the wire used and its resistivity determine the resistance of the unit. The wire is bare but the entire assembly is covered or coated with a ceramic material or special vitreous enamel (Fig. 5.1).



Wire wound resistor

Fig. 5.1

Such resistors are generally available in power ratings from 5 W to several hundred watts and resistance values from 1 Ω to 100 K. These can be of either fixed value or variable type.

Wire-wound resistors are used where

(*a*) large power dissipation is necessary

(*b*) precise and stable resistance values are required as for meter shunts and multipliers.

5.5. Carbon Composition Resistors

They are made of finely-divided carbon mixed with a powdered insulating material in suitable proportion. Often, the resistance element is a simple rod of pressed carbon granules which is usually enclosed in a plastic case for insulation and mechanical strength [Fig. 5.2 (*a*)]. The two ends of the carbon resistance element are joined to metal caps with leads of tinned wire for soldering its connections into a circuit.

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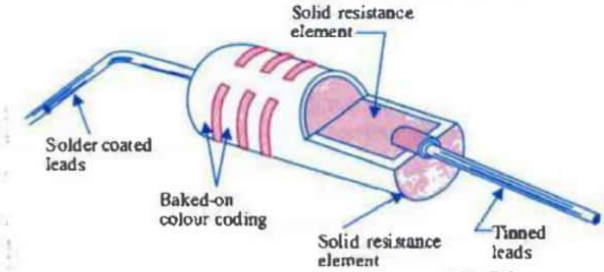
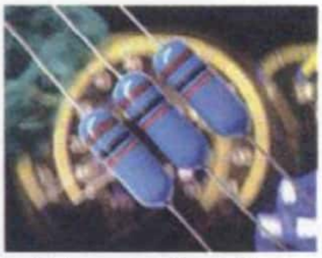


Fig. 5.2



Carbon composition resistors.

Such resistors are available in power ratings of 1/10, 1/8, 1/4, 1/2, 1, 2 watt and in resistance values ranging from 1 Ω to 20 MΩ. Where power dissipation is 2 W or less, such resistors are preferred because they are smaller and cost less. Carbon resistors with power rating of 1 W or less are most common in electronic equipment.

5.6. Carbon Film Resistors

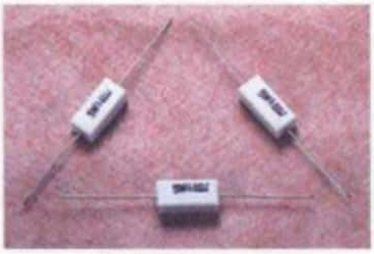
They consist of a high-grade ceramic rod or core (called the substrate) on which is deposited a thin resistive film of carbon. They are cheaper than composition resistors.

5.7. Cermet Film Resistors

They consist of thin carbon coating fired on to a solid ceramic substrate. The main purpose is to have more precise resistance values and greater stability with heat. Very often, they are made in a small square with leads to fit into a printed circuit board (PCB).

5.8. Metal Film Resistors

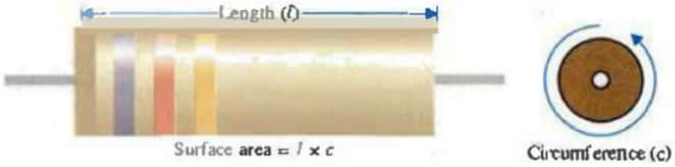
They are also referred to as thin-film resistors. They consist of a thin metal coating deposited on a cylindrical insulating support. The high resistance values are due to thinness of the film. Because it is difficult to produce films of uniform thickness, it is not possible to control their resistance values as accurately as in the case of wire-wound resistors. However, such resistors are free of trouble-some inductance effects so common in wire-wound resistors particularly at high frequencies.



Metal oxide film resistors.

5.9. Power Rating

The power rating of a resistor is given by the maximum wattage it can dissipate without excessive heat. Since it is current which produces heat, power rating also gives some indication of the maximum current a resistor can safely carry. If the current exceeds this value, more heat will be produced than can be carried safely and the resistor will burn out. A 1/2 watt resistor, for example, can dissipate 1/2 watt of heat without damage whereas a 1W resistor can throw off twice as much heat. In a circuit, you may substitute 1 watt resistor of same resistance value for a 1/2 watt resistor but not *vice-versa*.



The larger the surface area of a resistor, the more power it can dissipate. The power rating of a resistor is directly related to its surface area.

The physical size of a resistor is no indication of its resistance though it does give some indication of its wattage rating. For a given value of resistance, greater the physical size, higher the power rating.

Also, higher-wattage resistors can operate at higher temperatures. Moreover, a higher power rating allows a higher voltage rating. This rating gives the highest voltage that may be applied across the resistor without internal arcing.

5.10. Value Tolerance

Surface area = l × c Circumference (c)

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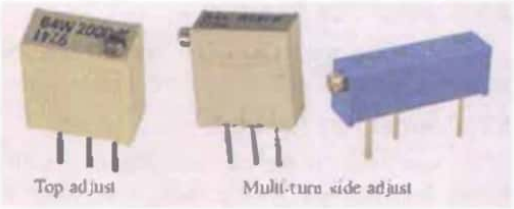
5.10. Value Tolerance

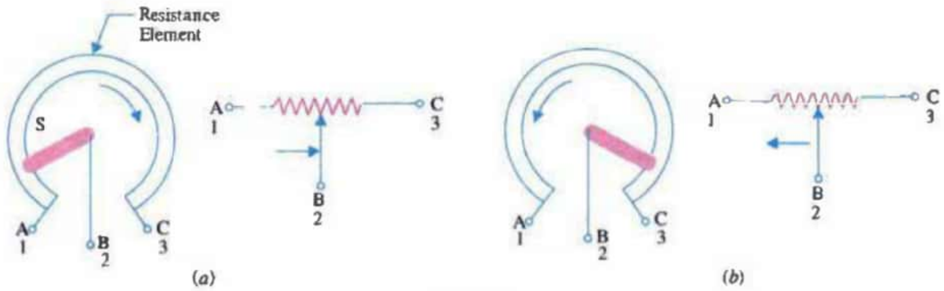
By tolerance is meant the possible variation from the nominal or marked resistance value of a resistor. It means that actual resistance of a resistor may be greater or lesser than its indicated value. All resistors are manufactured and sold with a specified tolerance. For example, a 1000 Ω resistor with a tolerance of 10% will have an actual resistance anywhere between 900 Ω and 1100 Ω *i.e.*, 100 Ω more or less than the rated value.

Carbon-composition resistors have tolerances of ± 5%; ± 10% and ± 20% whereas general-purpose wire-wound resistors usually have a tolerance of ± 5%.

5.11. Variable Resistors



Variable resistors.



(*a*) (*b*)

Fig. 5.3

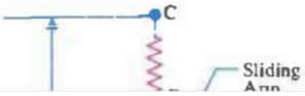
These are the resistors whose resistance can be changed between zero and a certain maximum value. They can be wire wound or carbon type. As shown in Fig. 5.3, the sliding arm has been attached to a shaft which can be rotated in almost a complete circle. As the shaft rotates, the point of contact of the sliding arm on the circular carbon-composition resistance element changes thus changing the resistance between arm terminal *B* and terminals of the stationary resistance *A C*. In Fig. 5.3 (*a*) as we move the sliding arm, the resistance between *B* and *A* increases whereas that between *B* and *C* decreases. In Fig. 5.3 (*b*), with the rotating of the arm, resistance between *B* and *C* increases whereas that between *B* and *A* decreases.

Carbon variable resistors of power ratings 1/2 W to 2 W and resistances of 1 kΩ to 5 MΩ are commonly available. Such controls are often combined with an OFF-ON switch—a common example being the power OFF-ON switch and volume control of a radio receiver.

5.12. Potentiometers and Rheostats

These are variable resistors either of carbon or wire-wound type often used for controlling voltage and current in a circuit.

(*a*) Potentiometers



They generally have carbon composition resistance element and are connected across a voltage source. They have three terminals, the centre one being connected to the variable

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(a) Potentiometers

They generally have carbon composition resistance element and are connected across a voltage source. They have *three* terminals, the centre one being connected to the variable arm which is used for varying voltage division in the circuit as shown in Fig. 5.4. By moving the variable arm B over the fixed resistance R between points A and C, any part of the input voltage can be tapped off. Since in Fig. 5.4, B happens to be at the middle value of R, output voltage is half the input voltage.

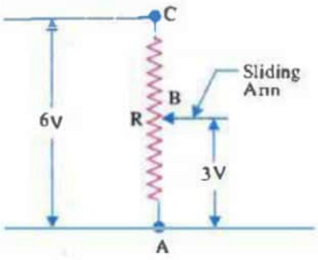


Fig. 5.4

Most variable resistors used in radios are potentiometers meant for controlling volume or tone. When used as a volume control, it picks off a voltage between zero and the full available voltage as shown in Fig. 5.5. By moving B up and down, any desired amount of voltage (signal) can be picked up between maximum signal value at point A and zero signal value at C.

The tone control circuit shown in Fig. 5.6 uses only two terminals on the potentiometer. The resistor allows the capacitor to by-pass to ground either more or less of high frequencies in an audio circuit. When B is at point A, the capacitor becomes a direct by-pass to ground for higher frequencies in the audio signal. Consequently, radio sound becomes 'bassy'. When B is at terminal C, it increases the amount of resistance in series with the capacitor. Hence, less amount of high frequencies is by-passed to ground and consequently, there is more trebble in the sound.

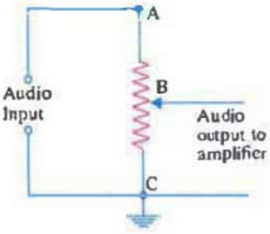


Fig. 5.5

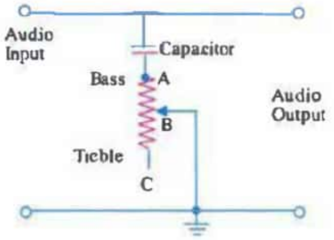


Fig. 5.6

As illustrated above, potentiometers are commonly used as control devices in amplifiers, TV sets and various types of meters. Typical applications include volume and tone controls, balance controls, linearity and brightness control in TV receivers etc.

(b) Rheostats

The resistance element of rheostats is made of high-resistance wire. It has two terminals and is connected in *series* with a circuit for adjusting the amount of current flowing through it. Rheostats are commonly used to control relatively high currents such as those found in motor and lamp loads. Fig. 5.7 shows how a rheostat can be connected into a lamp circuit for controlling its current. As seen, only resistance BC is connected into the circuit.

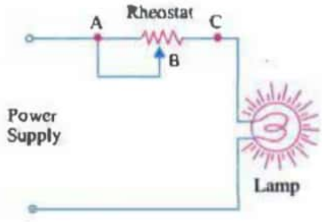
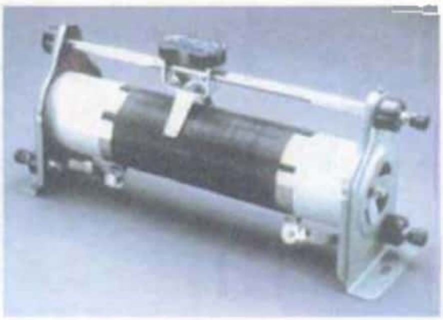


Fig. 5.7



A rheostat.

Though similar in construction to potentiometers, they are usually larger in size because they possess much higher power rating.

A given potentiometer can be

A rheostat.

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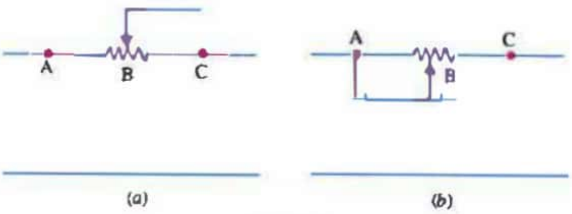
A given potentiometer can be used as a rheostat. One method is just to use two ends only leaving the third end unconnected as shown in Fig. 5.8 (*a*). The other method is to wire the third unused terminal to the central terminal as shown in Fig. 5.8 (*b*).

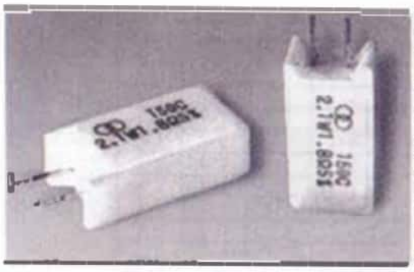


(*a*) (*b*)

Fig. 5.8

5.13. Fusible Resistors

These are wire-wound devices similar in appearance to ordinary wire-wound resistors. They are sometimes used in amplifiers and TV sets to protect certain circuits. They have resistance of less than 15 Ω. Their resistance element is quite similar to the fuse link in a cartridge fuse and is designed to burn out whenever current in the circuit exceeds a certain predetermined value.



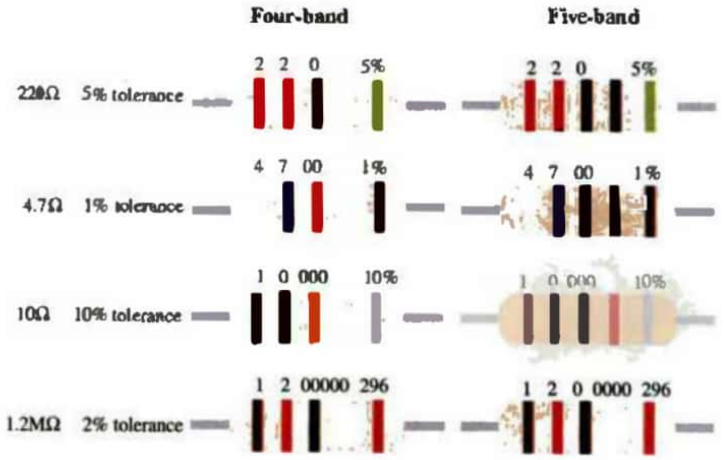
Fusible resistors.

5.14. Resistor Colour Code

Since fixed carbon-composition resistors having axial leads are physically small, they are colour-coded to indicate their resistance in ohms. The system is based on the use of colours (painted on the body of the resistor) as numerical values. In general, it should be remembered that dark colours like black and brown correspond to lowest numbers of zero and one respectively, the light colours to next higher numbers and lastly, white colour to nine. The colours used with the code and the numbers they represent are given in Table 5.1.

Table 5.1

Colour	*Value*
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9



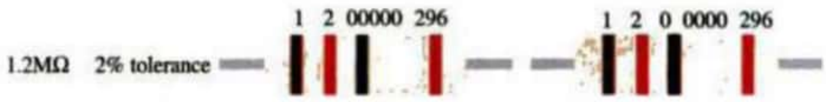
Some examples of the resistor colour code.

5.15. Resistance Colour Bands

These bands are printed around the body of the resistor near its one end (Fig. 5.9). Each colour stands for a digit. Often, there are four bands though sometime there may be five. In eachcase, *the first three bands give the resistance value.*

(*a*) Three Bands Only

They represent the resistance value as per the colour code. Absence of fourth band means a



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(*a*) Three Bands Only

They represent the resistance value as per the colour code. Absence of fourth band means a resistance tolerance of ± 20%.

(*b*) Four Bands Only

As before, the first three bands give resistance value and the fourth one gives tolerance.

Fourth gold ring means a tolerance of ± 5% whereas a fourth silver ring means a resistance tolerance of ± 10%.

(*c*) Five Bands

The first three bands, as usual, give resistance, fourth one gives tolerance and the fifth one indicates reliability level or failure rate for which colour code is,

Brown = 1% ; Red = 0.1%; Orange = 0.01% ; Yellow = 0.001%

Starting from left to right, the colour bands (Fig. 5.9) are interpreted as follows :

1. The first band close to the edge indicates the first digit in the numerical value of the resistance.
2. The second band gives the second digit.
3. The third band is *decimal multiplier i.e.*, it gives the number of zeros after the two digits. It is important to note that if the third band is black, it means "*do not add zeros to the first two digits*". The resulting number is the resistance in ohms.
4. The fourth band gives resistance tolerance. If there is no fourth band, tolerance is understood to be ± 20%.

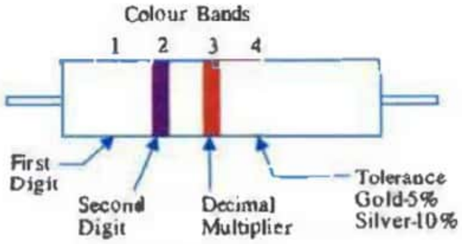


Fig. 5.9

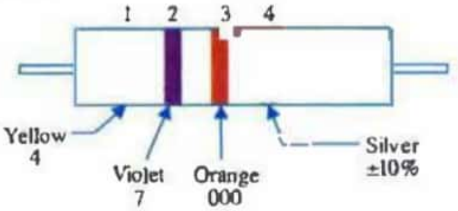
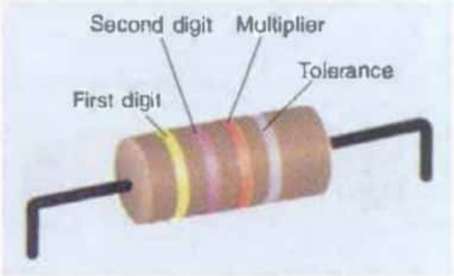


Fig. 5.10



This Resistor has a value of 47,000Ω, ± 10%

The resistance value of the carbon-composition resistor shown in Fig. 5.10 is 47,000Ω ± 10%. It means that its value is 47,000 ± 4,700 Ω *i.e.*, it can lie anywhere between 42,300 Ω and 51,700 Ω.

5.16. Resistors under Ten Ohm

In their case, the third band is either gold or silver which serves as *fractional* multiplier. If third band is gold, multiply the first two digits by 0.1. If it is silver, then multiply by 0.01. However, fourth band, as before, gives tolerance.

As seen from Fig. 5.11, the value of resistor is 6.9 ± 10% ohm.

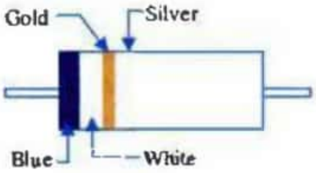


Fig. 5.11

5.17. Resistor Troubles

The most common trouble with resistors is 'open' which happens due to excessive current and heat. A charred or discoloured resistor should be discarded straight away *though it will usually check good with an ohmmeter.*

5.18. Checking Resistors with an Ohmmeter

Since an ohmmeter has it own voltage source, it is always used without any external power being supplied to the resistance under measurement.

The ohmmeter must have an ohm scale appropriate to the value of resistance being measured, otherwise it will not give correct value. In checking a 10 MΩ resistor, if the highest reading of the meter scale used is 1 MΩ resistor, the instrument will read infinity even if the resistor has its normal value of 10 MΩ. It is essential to use a scale of 100 MΩ for checking such high resistances.

Similarly, for checking resistances of value 10 Ω or less, a low ohm scale of 100 Ω or less should be used. Otherwise, the ohmmeter will read a low resistance such as zero thus indicating a short.

Another very important precaution one should take while checking a resistance is to make sure that there are no parallel paths across the resistance being measured. Otherwise, the measured resistance can be much lower than the actual resistance. As shown in Fig. 5.12 (*a*), the ohmmeter reads $R_1 \parallel R_2$ *i.e.*, 10/2 = 5 K. To check R_2 alone, its one end should be disconnected as shown in Fig. 5.12 (*b*).

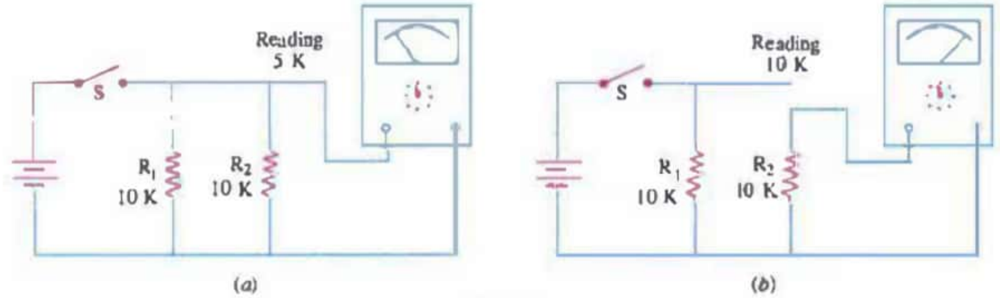
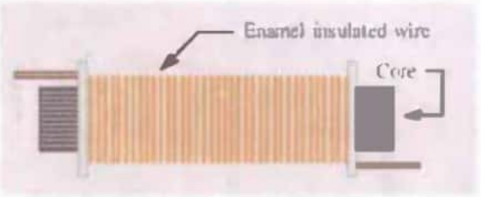


Fig. 5.12

Another point worth remembering is : not to touch the ohmmeter leads. There is no danger of electric shock but body resistance of about 50 K acting in parallel with the resistance being measured will lower the ohmmeter reading.

5.19. Inductor

It is another basic component commonly used in electronic circuits. It is nothing else but a coil wound on a core or former of some suitable material.



This one example of what an inductor might look like.

(*a*) Air-core Inductor

It consists of number of turns of wire wound on a former made of ordinary cardboard [Fig. 5.13 (*a*)]. Since there is nothing but air inside of the coil, an air-core inductor has the least inductance for a given number of turns and core length.

(*b*) Iron-core Inductor

It is that inductor in which a coil of wire is wound over a solid or laminated iron core [Fig. 5.13 (*b*)]. Putting iron inside an inductor has the effect of increasing its inductance as many times as the relative permeability (μ_r) of iron. In order to avoid eddy current loss, iron core is laminated *i.e.*, it is made up of thin iron laminations pressed together but

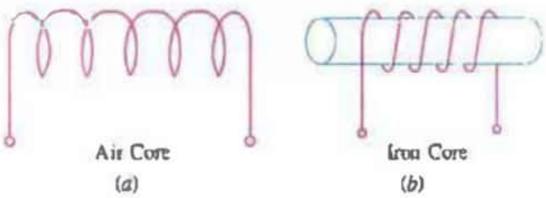


Fig. 5.13

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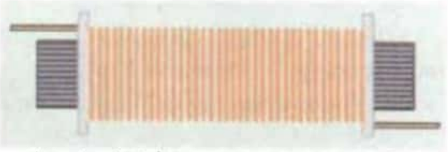
of iron. In order to avoid eddy current loss, iron core is laminated *i.e.*, it is made up of thin iron laminations pressed together but

(*a*) (*b*)

Fig. 5.13

insulated from each other. Sometimes, such an inductor is also called a choke.

The iron core has been found to work more efficiently particularly at low frequencies if it is in the form of a closed core *i.e.*, if the core not only goes through the centre of the coil but also surrounds it on its two sides as shown in Fig. 5.14.



Laminated iron cores are generally used in low cost, low power inductors.

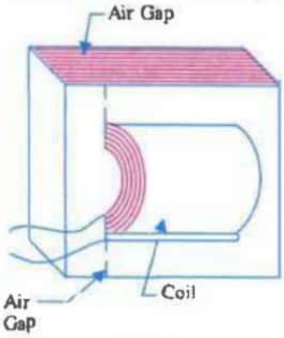


Fig. 5.14

(*c*) Ferrite-core Inductor

In this case, coil of wire is wound on a solid core made of highly ferromagnetic substance called ferrite. Ferrite is a solid material consisting of fine particles of iron powder embedded in an insulating binder. A ferrite core has minimum eddy current loss.

Ferrite core inductors are used in moderately high power systems.

The symbols for different types of inductors discussed below are shown in Fig. 5.15.

5.20. Comparison of Different Cores

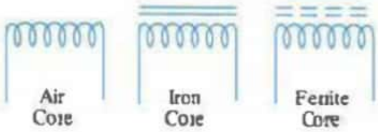


Fig. 5.15

In air-core coils, there are no core losses even at high frequencies but their inductances are limited to low values in the μH or mH range.

In iron-core coils, losses are minimal at low *i.e.*, audio frequencies but become considerable at high frequencies even when iron core is laminated. They possess comparatively much larger inductance as compared to air-core coils.

Ferrite-core coils have high inductance value with minimum eddy current and hysteresis losses even at very high frequencies. The built-in antennas used in transistor radios have ferrite core.

5.21. Inductance of an Inductor

It is found that whenever current through an inductor changes (*i.e.*, increases or decreases), a counter emf is induced in it which tends to oppose this change. This property of the coil due to which it opposes any change of current through it is called inductance (L). Its unit is henry (H). The inductance of a coil is given by

$$L = \frac{\mu_0 \mu_r A N^2}{l} \text{ henrys}$$

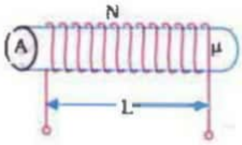


Fig. 5.16

It is seen that L varies

1. directly as relative permeability of the core material,
2. directly as core cross-sectional area,
3. directly as square of the number of turns of the coil,
4. inversely as core length.

5.22. Another Definition of Inductance

Suppose, current through an inductor is changed at the rate of di/dt because of which a counter emf of 'c' is induced in it. Then, it is found that

$$e = L\frac{di}{dt} \quad \text{or} \quad L = \frac{e}{di/dt}$$

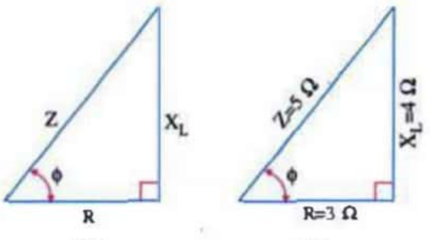
However, it should be noted that X_L and R are not added arithmetically but *vectorially* as shown in Fig. 5.22 (*a*).

Here, $Z = \sqrt{R^2 + X_L^2}$ (and $\neq R + X_L$)

The right-angled triangle of Fig. 5.22 (*a*) is known as impedance triangle.

For example, an inductor coil having a resistance of 3 Ω and an inductive reactance of 4 Ω offers an impedance of 5 Ω and not (4 + 3) = 7 Ω. The vector addition is shown in Fig. 5.22 (*b*).

Incidentally, the angle φ in Fig. 5.22 represents the phase difference between the applied alternating voltage and circuit current.



(*a*) (*b*)

Fig. 5.22

Example 5.3. *A coil has a resistance of 30 Ω and an inductance of 127.3 mH. It is connected across a 200 V, 5 Hz ac supply. Find*

1. impedance *2. circuit current* *3. phase angle φ*

Solution.

$$X_L = 2\pi f L$$

$$= 2\pi \times 50 \times (127.3 \times 10^{-3}) = 40\,\Omega$$

1. $Z = \sqrt{R^2 + X_L^2} = \sqrt{30^2 + 40^2} = 50\Omega$

2. $I = V/Z = 200/50 = 4\text{ A}$

3. $\tan\phi = \dfrac{X_L}{R} = \dfrac{40}{30} = 1.333 \qquad \therefore \phi = 53°$

5.34. Q-Factor of a Coil

The quality or merit of a coil is measured in terms of its Q-value given by

$$Q = \frac{X_L}{R} = \frac{2\pi f L}{R}$$

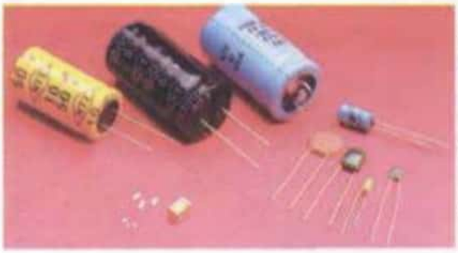
As seen, smaller the d.c. resistance of a coil as compared to its inductance, higher its Q-factor. In tuned radio receiver circuits, a high Q-coil is preferred because

1. it increases sharpness of tuning *i.e.*, makes the tuned circuit more selective,
2. it additionally increases its sensitivity.

5.35. Capacitors

Apart from resistors and inductors, a capacitor is the other basic component commonly used in electronic circuits. It is a device which

1. has the ability to store charge which neither a resistor nor an inductor can do;
2. opposes any change of *voltage* in the circuit in which it is connected*;
3. blocks the passage of direct current through it.



Capacitors.

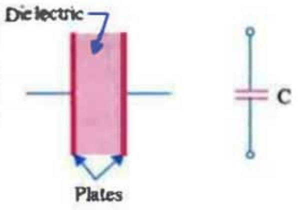


Fig. 5.23

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* An inductor opposes change of current.

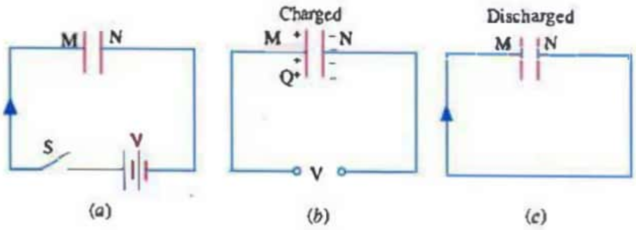
Capacitors are manufactured in various sizes, shapes, types and values and are used for hundreds of purposes.

Essentially, a capacitor consists of two conducting plates separated by an insulating medium called *dielectric* as shown in Fig. 5.23. The dielectric could be air, mica, ceramic, paper, polyester, Capacitors are manufactured in various sizes, shapes, types and values and are used for hundreds of purposes.

Essentially, a capacitor consists of two conducting plates separated by an insulating medium called *dielectric* as shown in Fig. 5.23. The dielectric could be air, mica, ceramic, paper, polyester, polystyrene or polycarbonate plastics etc.

5.36. Capacitor Connected to a Battery

When switch S in Fig. 5.24 (a) is closed, the capacitor gets connected across the battery. There is momentary flow of electrons from plate M to plate N. The positive terminal of the battery attracts and pulls away negatively-charged electrons from plate M which consequently becomes positive. Similarly, as these electrons collect on plate N, it becomes negative. Hence, a potential difference is established between the two plates M and N. This *transient* flow of electrons from one plate to another through the connecting wires gives rise to charging current which establishes positive charge of $+Q$ coulomb on the plate M. The strength of this charging current is maximum in the beginning when the two plates are uncharged but it then decreases and finally ceases when p.d. across the two plates becomes slowly and slowly *equal and opposite* to the battery emf *i.e.*, V volts. The capacitor then becomes fully charged as shown in Fig. 5.24 (b).



(a) (b) (c)

Fig. 5.24

Following two points should be noted :

1. no current can flow '*through*' the capacitor because of the presence of dielectric in the circuit which offers infinite resistance. The electric charge is momentarily displaced from one plate to another through the *external circuit only*;
2. as p.d. between the plates is increased, the dielectric medium comes under increasing stress. If this p.d. is increased, the stress in the dielectric increases till it can no longer bear it. At that stage, electrical breakdown occurs accompanied by a spark between the two capacitor plates. The maximum voltage per metre thickness which a medium can withstand without a rupture or breakdown is called its *dielectric strength*. Usually, it is given in kV/mm instead of the basic unit V/m. If the two leads of a charged capacitor are connected together as shown in Fig. 5.24 (c), the p.d. between the two plates is equalized and the capacitor becomes discharged;
3. since there exists a p.d. between the two plates, an electric field is set up between them whose strength is given by

$$E = V/d \text{ volt/metre}$$

5.37. 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, we give $+Q$ coulomb of charge to one of the two plates of a capacitor and if a p.d. of V volts is established between them, then its capacitance is

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

If $Q = 1$ C and $V = 1$ volt, then $C = 1$ farad (F).

Hence, 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.

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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,

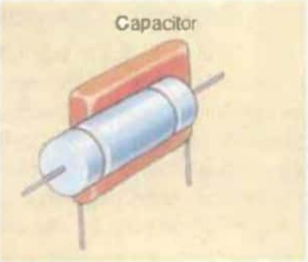
$$C = \frac{i}{dv/dt}$$

where i = charging current

dv/dt = rate of change of voltage

$i = 1$ ampere, $dv/dt = 1$ volt/second

then $C = 1$ farad



The amount of charge the device can store for a given voltage difference is called the capacitance.

Hence, one farad may be 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.

Farad is too large for practical purposes. Hence, much smaller units like microfarad (µF), nanofarad (nF) and micro-micro-farad (µµF) or picofarad (pF) are generally employed.

$$1\ \mu F = 10^{-6} F$$

$$1\ nF = 10^{-9} F$$

$$1\ pF \text{ or } 1\ \mu\mu F = 10^{-12} F$$

5.38. Factors Controlling Capacitance

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

As plate separation (d) decreases, capacitance increases and *vice-versa*. Since plate separation often equals the thickness of the dielectric used, we may say that thinner the dielectric slab, greater the capacitance and *vice-versa*.

3. Type of Dielectric

It depends on the relative permittivity ε_r (previously called dielectric constant) of the dielectric medium used. Higher the value of ε_r, greater the value of capacitance.

Combining the above three factors, we get

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d} \text{ farad}$$

where ε_0 is the absolute permittivity of vacuum = 8.854×10^{-12} F/m.

The relative permittivities of some dielectric media are listed in Table 5.2 on next page.

Table 5.2

Material	*Dielectric Constant* *or*

∴ $C = 4 \times 8.854 = 35.4\ \mu\mu F$

Since charge remains constant, p.d. will *decrease* to one-fourth of its previous value because $V \propto 1/C$

∴ $$V = 56.5/4 = 14.1\ \text{V}$$

5.39. Types of Capacitors

All capacitors commonly used in electronic circuits may be divided into two general classes (*a*) fixed capacitors and (*b*) variable capacitors.

Fixed capacitors may be further sub-divided into (*i*) electrolytic and (*ii*) non-electrolytic capacitors.

5.40. Fixed Capacitors

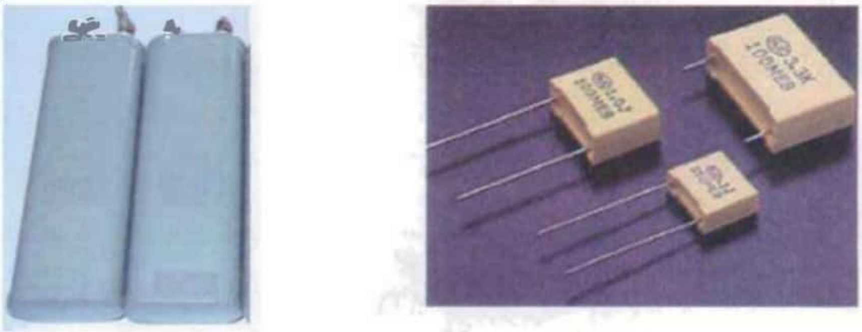
These can be grouped into two classes as detailed below :

(a) Non-electrolytic type

It includes paper, mica and ceramic capacitors. Such capacitors have no polarity requirement *i.e.*, they can be connected in either direction in a circuit.

(*i*) Paper Capacitor

It consists of two tinfoil sheets which are separated by thin tissue paper or waxed paper. The sandwich of foil and paper is then rolled into a cylindrical shape and enclosed in a paper tube or encased in a plastic capsule. The lead at each end of the capacitor is internally attached to the metal foil. Fig. 5.25 (*a*) shows a 2.0 μF tubular paper capacitor of maximum ac voltage rating of 2000 V whereas Fig. 5.25 (*b*), shows polyester capacitor having moulded plastic box encapsulation suitable for use in printed circuit boards.



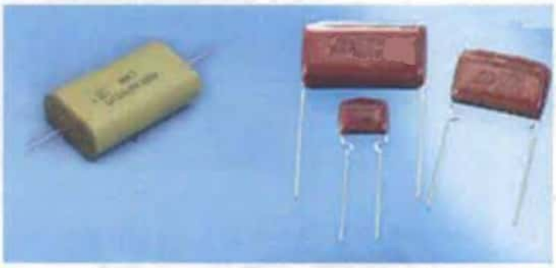
(*a*) (*b*)

Fig. 5.25

Paper capacitors have a capacitance range of 0.001 to 2.0 μF and working-voltage rating as high as 2000 V. These specifications are usually printed on the capacitor case. Paper capacitors have large physical size as compared to their capacitance and also become inefficient as the frequency of applied ac voltage exceeds a few megahertz. These facts prevent their use in most FM TV circuits except in low-frequency portions of the circuits *i.e.*, in audio stages.

These days such foil construction capacitors use thin plastic film instead of paper as the dielectric medium. Two most commonly-used plastic films have trademark names of Teflon and Mylar. Such capacitors have

1. high insulation resistance of 1000 M and above,
2. low losses, and
3. longer shelf life without breakdown as compared to paper capacitors.



(c) (*d*)

Fig. 5.25

Fig. 5.25 (*c*) and (*d*) show tubular and flat metallised polyester film capacitors which are ideal for coupling and by-pass applications in radio, TV, hi-fi equipment and instrumentation etc.

Fig. 5.25 (*c*) and (*d*) show tubular and flat metallised polyester film capacitors which are ideal for coupling and by-pass applications in radio, TV, hi-fi equipment and instrumentation etc.

(*ii*) Mica Capacitor

It is a sandwhich of several thin metal plates separated by thin sheets of mica. Alternate plates are connected together and leads attached for outside connections. The total assembly is encased in a plastic capsule or bakelite case as shown in Fig. 5.26. Such capacitors have small capacitance values (50 to 500 pF) yet high working voltage ratings (500 V and above).

Fig. 5.26

Once such capacitors were used extensively in radio circuits but, of late, they have been superseded by ceramic capacitors because of excellent properties of ceramics and their economy.

Fig. 5.27. The small value ceramic capacitors.

(*iii*) Ceramic Capacitors

Such capacitors have disc- or hollow tubular-shaped dielectric made of ceramic material such as titanium dioxide and barium titanate. Thin coatings of silver compound are deposited on both sides of the dielectric disc which act as capacitor plates. Leads are attached to each side of the disc and the whole unit is encapsulated in a moisture-proof coating (Fig. 5.27).

Because of the very high value of the dielectric constant of ceramics ($\varepsilon_r = 1200$), disc type capacitors have very large capacitances (upto 0.01 μF) compared to their size.

In the case of tubular ceramics, the hollow ceramic tube has a silver coating on the inside and outside surfaces. The capacitance range varies from 1 to 500 pF with working voltage rating exceeding 10 kV. Ceramic capacitors have many advantages as compared to mica and paper capacitors. These capacitors

1. are economical,
2. have very small size but large capacitance. Hence, they occupy less space.
3. have very high working-voltage rating,
4. have very low power factor (*i.e.*, loss) which further *decreases with increase in the frequency*. Hence, they are very useful for short-wave work in radio.

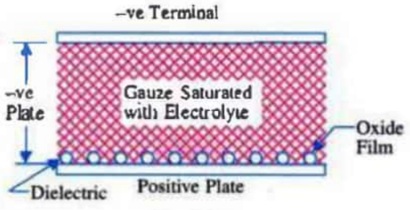


Fig. 5.28

(*b*) Electrolytic Capacitors

These capacitors are called *electrolytic* because they use an electrolyte (borax or a carbon salt) as *negative* plate. The capacitor consists of

1. a positive plate of aluminium;
2. an extremely thin (*i.e.*, molecular thin) insulating film of aluminium oxide (Al_2O_3) as dielectric medium. It is electrochemically deposited on the surface of anode itself (Fig. 5.28);
3. an electrolyte of borax (phosphorus or carbonate). As shown in Fig. 5.28, an absorbent gauze saturated with the electrolyte is kept in contact with the dielectric. The second aluminium plate serves merely as contact to the electrolyte. It forms the negative terminal.

Such a capacitor is made as described below:

A thin strip of aluminium is coated with a molecular-thin film of aluminium oxide by an electrochemical process. It is covered with a layer of gauze soaked in the electrolyte of borax. On top of this is another metal plate in contact with the electrolyte which, in reality, is the second plate of the capacitor (and not the top plate). The entire sandwhich dielectric medium. It is electrochemically deposited on the surface of anode itself (Fig. 5.28);

3. an electrolyte of borax (phosphorus or carbonate). As shown in Fig. 5.28, an absorbent gauze saturated with the electrolyte is kept in contact with the dielectric. The second aluminium plate serves merely as contact to the electrolyte. It forms the negative terminal.

Fig. 5.29. The aluminium electrolytic capacitors.

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A thin strip of aluminium is coated with a molecular-thin film of aluminium oxide by an electrochemical process. It is covered with a layer of gauze soaked in the electrolyte of borax. On top of this is another metal plate in contact with the electrolyte which, in reality, is the second plate of the capacitor (and not the top plate). The entire sandwhich is rolled up into a compact cylinder and placed inside a metal cylinder (Fig. 5.29) or can.

This enclosing cylinder contacts the outside metal foil of the capacitor and serves as the negative terminal. Such capacitors are made as single capacitors or with two or three capacitors in a single container having a common negative terminal. The outside metal cylinder is usually enclosed in a paper tube in order to insulate it from components and to protect radio technicians from shock.

Because of extremely thin dielectric film, such capacitors possess very large capacitance ranging from 1 μF to 10,000 μF in very compact sizes. Hence, they are used where lot of capacitance is required in a small space. Since they use an electrolyte as the negative plate, electrolytic capacitors are classed as "*polarised*" capacitors *i.e.,* they must be connected in the circuit according to the plus (+) and minus (−) markings on the case. If this is not done, the capacitor may become short-circuited or get overheated due to excessive leakage current through its dielectric. Moreover, reversed polarity results in gas formation which may cause the capacitor to explode.

Electrolytic capacitors are frequently used in the filter circuits in order to remove the a.c. ripple from the power supply. They are also used as blocking or coupling capacitors for blocking d.c. in a circuit but allowing a.c. to pass through.

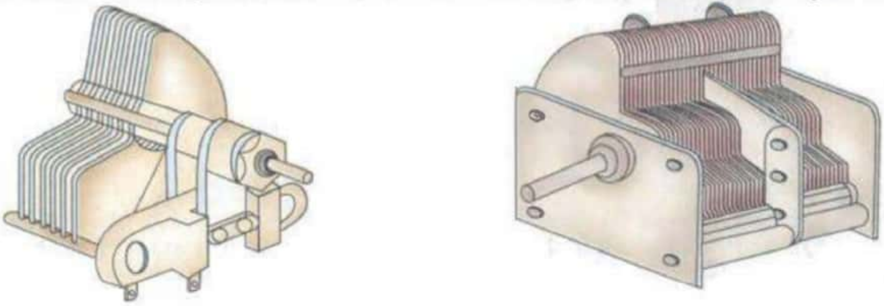
The miniature and high-voltage aluminium foil electrolytic capacitors manufactured by Bharat Capacitors Limited (BCL), Hyderabad are characterised by low leakage current, low dissipation, close tolerance in capacitance value, excellent reliability and long life. They meet all performance characteristics as laid down in JIS–C–5141 or MIL–C–62 specifications.

The two disadvantages of electrolytic capacitors are that they

1. are polarity sensitive,
2. have low leakage resistance because the oxide film is not a perfect insulator. In other words, they have high leakage current which can become troublesome.

5.41. Variable Capacitors

A variable capacitor is one whose capacitance can be varied usually by rotating a shaft. It consists of two sets of metal plates separated from each other by air. One set of plates is stationary and is called the stator [Fig. 5.30 (*a*)]. It is insulated from the frame of the capacitor upon which



(*a*) Single section **Fig. 5.30** (*b*) Two-gang

it is mounted. The other set of plates is connected to the shaft and can be rotated. That is why it is called the rotor. By rotating the rotor with the help of a suitable knob, rotor plates can be made to move in or out of the stator plates. Capacitance is maximum when rotor plates are fully 'in' and

(*a*) Single section **Fig. 5.30** (*b*) Two-gang

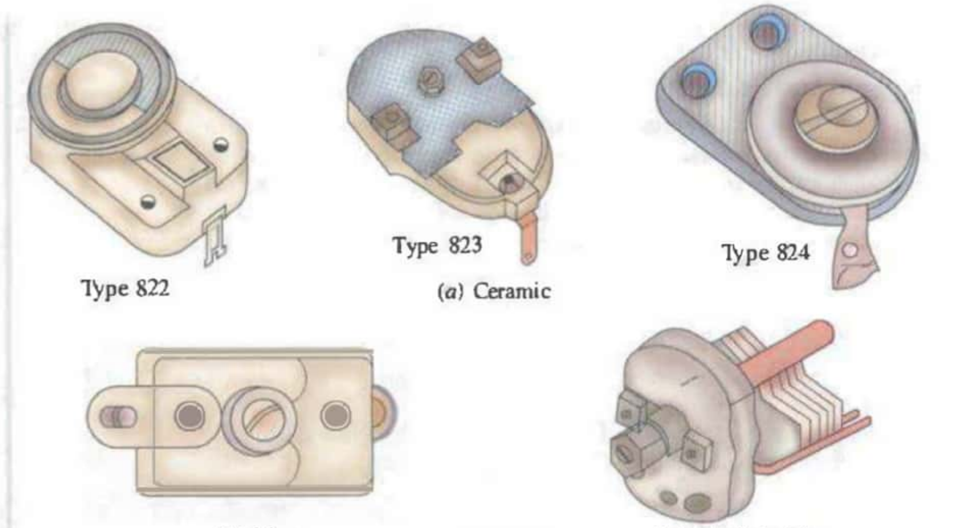
it is mounted. The other set of plates is connected to the shaft and can be rotated. That is why it is called the rotor. By rotating the rotor with the help of a suitable knob, rotor plates can be made to move in or out of the stator plates. Capacitance is maximum when rotor plates are fully 'in' and minimum when 'out.'

If n is the total number of plates and d is the separation between any two adjacent plates, then capacitance for air dielectric is

$$= \frac{(n-1)\,\varepsilon_0\,A}{d}$$

When two or more such capacitors are operated by a single shaft, it is known as a *ganged* capacitor. Fig. 5.30 (*b*) shows a 2-gang capacitor *i.e.*, one having two separate variable capacitors in one unit rotated by a single control. Commercial receivers and those used by short-wave listeners often have a variable capacitor with three gangs.

Another type of small variable capacitor which is often used in parallel with the main variable capacitor is sometimes known as trimmer and sometimes as padder. It is used primarily for making fine adjustments on the total capacitance of the device.



(*a*) Ceramic

(*b*) Mica **Fig. 5.31** (*c*) Air dielectric

A trimmer (Fig. 5.31) consists of two small flexible metal plates separated by air or mica or ceramic slab as the dielectric. The spacing between the plates can be changed by means of a screw adjustment. As the screw is turned inward, plates are compressed and its capacitance is increased.

Trimmers and padders are usually similar in appearance except that a padder may be somewhat larger or may have more plates. Capacitance of trimmers can be changed from 5 pF to a maximum value of 30 pF. Corresponding values for padder are 10 pF to 500 pF.

Variable capacitors are used primarily as tuning capacitors in radio receivers. When we tune two different stations, we actually vary the capacitance by moving the rotor plates in or out of the stator plates. Combined with an inductance, the variable capacitance tunes the receiver to a different resonant frequency for each transmitting station.

5.42. Voltage Ratings of Capacitors

Voltage rating of a capacitor is given by the maximum potential difference that can be applied across its plates without puncturing its dielectric. Such ratings are given for temperatures up to 60°C.

Higher temperatures result in lower voltage ratings. For general purpose paper, mica and ceramic capacitors, voltage ratings are typically 200-500 V dc. Ceramic capacitors with voltage ratings of 1 to 12 kV are also available. Electrolytic capacitors are commonly used in 25, 150 and 450 V ratings.

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Higher temperatures result in lower voltage ratings. For general purpose paper, mica and ceramic capacitors, voltage ratings are typically 200-500 V dc. Ceramic capacitors with voltage ratings of 1 to 12 kV are also available. Electrolytic capacitors are commonly used in 25, 150 and 450 V ratings. Additionally, miniature electrolytics with 6 V and 10 V ratings are often used in transistor circuits. These ratings are for dc voltages. Those for ac voltages are less because of internal heat produced by continuous charge and discharge.

Voltage across a capacitor should not be allowed to exceed its rating. However, a capacitor with a higher voltage rating can be used in a low voltage circuit. For example, a 200 V, 0.05 μF capacitor can be replaced by a 400 V, 0.05 μF capacitor but not *vice-versa*.

5.43. Stray Circuit Capacitance

In an electronic circuit, the wiring and other components have capacitance to the metal chassis which acts as negative or grounded plate. Typical values of such stray capacitance are from 5 to 10 pF. Though at ordinary frequencies this value is quite small as compared to concentrated or lumped values of capacitance, it becomes important at high radio frequencies when one is forced to use small values of capacitance. The stray capacitance can be minimised by keeping connecting wires short and by placing leads and components as high off the chassis as possible. Sometimes, for very high frequencies, stray capacitance is included as part of the circuit design itself.

5.44. Leakage Resistance

A perfect or ideal capacitor is one which given the charge once will keep it forever. However, in practice, all capacitors get discharged in the long run due to small leakage current through their dielectric. Since leakage current is very small, leakage resistance is very high being almost 1000 MΩ for paper and mica capacitors and about 0.5 MΩ for electrolytic ones. An actual capacitor can be represented by an ideal capacitor having leakage resistance connected in parallel with it as shown in Fig. 5.32.

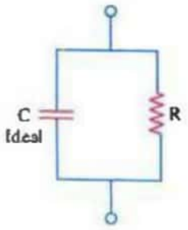

Fig. 5.32

5.45. Capacitors in Series

Connecting capacitors in series is equivalent to *increasing the thickness of the dielectric*.

Hence, combined capacitance is less than the *smallest* individual values.

Following points about series combination of capacitors should be noted :

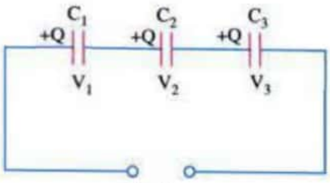

Fig. 5.33

1. charge on each capacitor is the *same* irrespective of its capacitance,
2. p.d. across each capacitor is *different* being inversely proportional to its capacitance,
3. sum of voltages across the capacitors equals the applied voltage.

   As seen from Fig. 5.33,

   $$V = V_1 + V_2 + V_3$$
4. combined capacitance is given by the reciprocal formula.

   In Fig. 5.33,

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \quad \text{or} \quad C = \frac{1}{1/C_1 + 1/C_2 + 1/C_3}$$

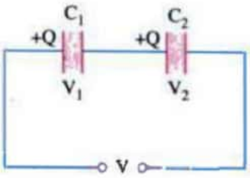

Fig. 5.34

Capacitors are used in series to provide a higher voltage breakdown rating for the combination. For example, combined voltage rating of three equal 200 V capacitors becomes 600 V when connected in series (even though overall capacitance is reduced).

5.46. Two Capacitors in Series

As seen from Fig. 5.34, charge on each capacitor is the same though voltages are different.

1. $$C = \frac{C_1 C_2}{C_1 + C_2}$$
2. $$V_1 = V \frac{C_2}{C + C}$$

$V = V_1 + V_2 + V_3$

4. combined capacitance is given by the reciprocal formula. In Fig. 5.33,

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ or } C = \frac{1}{1/C_1 + 1/C_2 + 1/C_3}$$

Capacitors are used in series to provide a higher voltage breakdown rating for the combination. For example, combined voltage rating of three equal 200 V capacitors becomes 600 V when connected in series (even though overall capacitance is reduced).

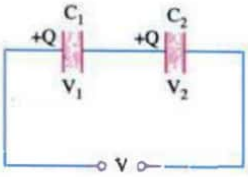

Fig. 5.34

5.46. Two Capacitors in Series

As seen from Fig. 5.34, charge on each capacitor is the same though voltages are different.

1. $C = \frac{C_1 C_2}{C_1 + C_2}$

2. $V_1 = V \frac{C_2}{C_1 + C_2}$

3. $V_2 = V \frac{C_1}{C_1 + C_2}$

5.47. Capacitors in Parallel

Connecting capacitors in parallel is equivalent to *adding their plate areas*. Hence, combined capacitance equals the sum of individual capacitances.

Following facts about parallel combination of capacitors (Fig. 5.35) should be noted :

1. charge across each capacitor is different, being directly proportional to its capacitance ($\because \quad Q = CV$)
2. p.d. across each capacitor is the same *i.e.*, the applied voltage V,
3. the sum of the individual charges is equal to the total charge supplied by the power source
$$Q = Q_1 + Q_2 + Q_3$$
4. combined capacitance is equal to the sum of individual capacitances
$$C = C_1 + C_2 + C_3$$

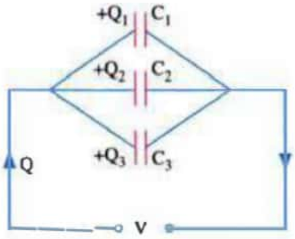

Fig. 5.35

5.48. Two Capacitors in Parallel

Consider the case when only two unequal capacitors are connected in parallel as shown in Fig. 5.36. In this case

1. since V is the same across both capacitors

$$\because \quad V = \frac{Q_1}{C_1} = \frac{Q_2}{C_2}$$

$$\therefore \quad \frac{Q_1}{C_1} = \frac{Q_2}{C_2} \text{ or } \frac{Q_1}{Q_2} = \frac{C_1}{C_2}$$

2. the two capacitor charges can be expressed in terms of the total charge Q taken from the power source.

$$Q_1 = Q\frac{C_1}{C_1 + C_2} ; Q_2 = Q\frac{C_2}{C_1 + C_2}$$

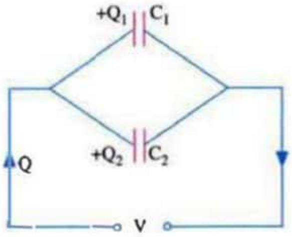

Fig. 5.36

5.49. Energy Stored in a Capacitor

Energy is required to charge a capacitor and is supplied by the charging agency *i.e.*, a battery or any other voltage source. This energy is stored in the electric field set up in the dielectric medium. On discharging the capacitor, the field collapses and the stored energy is released.

Stored energy $= \frac{1}{2}CV^2$ joules