2

CHAPTER

PASSIVE CIRCUIT COMPONENTS

LEARNING OBJECTIVES

After studying this chapter, the student should be able to:

- Describe the constructional features of resistors, capacitors, and inductors.
- Analyze the characteristics of resistors, capacitors, and inductors.
- Illustrate the applications of resistors, capacitors, and inductors.

2.1 INTRODUCTION

A passive component is one that contributes no power gain (amplification) to a circuit or system. It has no control action and does not require any input other than a signal to perform its function. The most commonly used passive circuit components in electronic and electrical applications are resistors, capacitors and inductors. The constructional features, characteristics, and applications of these components are discussed in this chapter.

2.2 RESISTORS

FLASH CARD

What You Learn Here
List resistor types, operational principles, constructional features, characteristics, and applications.

Physical materials resist the flow of electrical current to some extent. Certain materials such as copper offer very low resistance to current flow, and hence they are called *conductors*. Other materials such as ceramic which offer extremely high resistance to current flow are called *insulators*. In electric and electronic circuits like oscillators, amplifiers etc., there is a need for materials with specific values of resistance in the range between that of a conductor and an insulator. These materials are called resistors and their values of resistance are expressed in ohms (Ω).

The resistance R of a given material is proportional to its length L and inversely proportional to its area of cross section, A. Thus, R varies as L/A and $R = \rho(L/A)$, where ρ is the constant of the material known as its *specific resistance* or *resistivity.*

The various types of resistors are given in Table 2.1.

Table 2.1 *Various types of resistors*

Fixed resistors	Variable resistors
Carbon composition	Potentiometer
Carbon film	Rheostat
Metal film	Trimmer
Wire wound	

2.2.1 Fixed Resistors

- ***Carbon-composition Resistor*** Since this resistor yields any fixed value of resistance, it is the most widely used fixed resistor in discrete circuits. The construction of the carbon-composition resistor is shown in Fig. 2.1. The carbon resistors are made of finely divided carbon mixed with a powdered insulating material such as resin or clay in the proportions needed for the desired resistance value. These are then placed in a casing (moulded plastic) with lead wires of tinned copper. Resistances of this type are available in the range from few ohms to hundred megaohms and typical power ratings of 1/8 to 2 W.

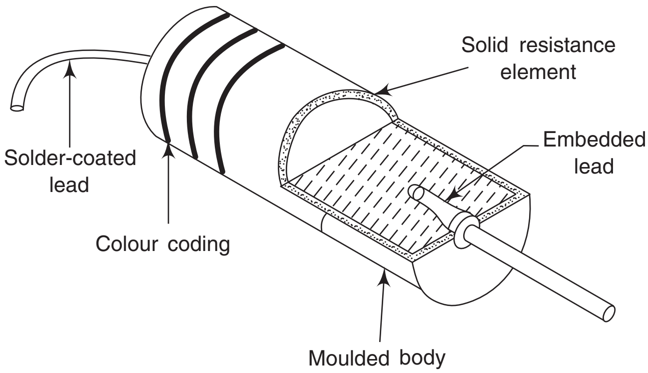


Fig. 2.1 *Cutaway view of a carbon composition resistor*

- ***Carbon-film Resistor*** This is yet another type of carbon resistor. Its basic structure is shown in Fig. 2.2. It is manufactured by depositing a carbon film on a ceramic substrate. In this process, only approximate values of resistance are obtained by either trimming the layer thickness or by cutting helical grooves of suitable pitch along its length. During this process, the value of the resistance is monitored constantly. Cutting of grooves is stopped as soon as the desired value of resistance is obtained. Contact caps are fitted at both ends, and then the lead wires made of tinned copper are welded to these end caps. This type of resistors are available commercially in the range of 10 Ω to 10 MΩ with a power rating of up to 2 W. Carbon-film resistors are less noisy than carbon-composition resistors and they are of low cost.

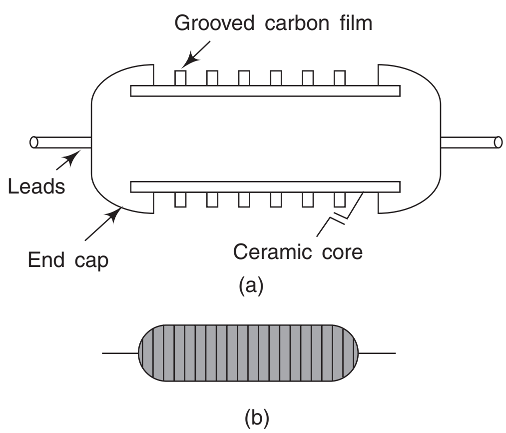


Fig. 2.2 *Carbon film resistor: (a) Construction (b) Carbon-film resistor*

FLASH CARD

What You Learn Here
Classify the metal-film resistor types.

- ***Metal-film Resistor***

Construction of this type of resistor is similar to the carbon-film resistors, the only difference being the material used for constructing the film. In metal-film resistors, the film usually consists of an alloy of tin and antimony metals. Metal film resistors are available as thin and thick-film-type components.

- **Thin-film Resistor** The resistance element in this type is a film having a thickness of the order of one-millionth of an inch. Typically, the thin film is deposited on a ceramic substrate under a high vacuum and this technique is called vacuum deposition. Metals used for deposition include nickel and chromium. This type of resistors are available in the range of 10 Ω to 1 MΩ with a power rating of up to 5 W.

- **Thick-film Resistor** The resistance element in this type is a film having a thickness greater than one-millionth of an inch. Four different types of thick-film resistors are available, viz., tin oxide, metal-glaze, cermet- and bulk-film resistors.

Tin-oxide type In this type of resistors, tin oxide in vapour form is usually deposited on a ceramic substrate under high temperature. The vapour reacting with the substrate, which is heated, results in a tightly formed resistance film. This type of resistor is available in the range of a few ohms to 2.5 MΩ with a power rating of up to 2 W.

Metal-glaze type In this type, a powdered glass and fine metal particle (palladium and silver) mixture is deposited on a ceramic substrate. This combination is then heated to a high temperature, typically 800°C. This results in a fusion of metal particles to the substrate. This type of resistors are manufactured in the range of a few ohms to 1.5 MΩ with a power rating of up to 5 W.

Cermet type A cermet-film resistor is made by screening a mixture of precious metals and binder materials on a ceramic substrate. The word 'cermet' is derived from ceramic and metal. As in the case of metal-glaze resistor, the combination is then heated to a high temperature. It is available in the range of 10 Ω to 10 MΩ with a maximum power rating of 3 W.

Bulk-film type In this type, the metal film is etched on a glass substrate. As metal film and glass have unequal coefficients of expansion, the metal film is compressed slightly by the glass substrate. The compressed film has a negative temperature coefficient which cancels out the inherent positive temperature coefficient of the film. As a result, the bulk film resistor has a temperature coefficient close to zero. This type of resistor is available in the range of 30 Ω to 600 kΩ with a maximum power rating of 1 W.

▪ *Wire-wound Resistor*

It has a wide range of applications. It is used as an ultra-precision resistor in instrumentation and a power resistor in industrial applications. Wire wound resistors are manufactured in two types: (i) power style wire wound resistor, and (ii) precision style wire wound resistor.

PROBE

In the field of instrumentation, name the commonly used ultra precision resistor. Classify this resistor by its manufacturing types.

- **Power-style Type** It is made by winding a single layer length of special alloy wire, in the form of a coil around an insulating core. The ends of the winding are attached to metal pieces inserted in the core. Tinned copper wire leads are attached to metal pieces. The unit is then covered with a coating, such as vitreous enamel (an inorganic glass like moisture) or silicone. This coating protects the winding against moisture and breakage. The resistance wire lead must have carefully controlled resistance per unit length of wire and low temperature coefficient, and be able to operate at high temperatures. Alloys used include nickel-chromium-aluminium and nickel-chromium-iron (Nichrome). The cylindrical core is ceramic, steatite or a vitreous material. This type of resistor is available in the range from less than an ohm to greater than a megaohm with a power rating as high as 1500 W. To increase its power rating, the resistor is sometimes placed in a metal housing such as aluminium.

- **Precision-style Wire-wound Resistor** They are wound on ceramic (steatite) tubes or sometimes epoxy moulded tubes as shown in Fig. 2.3. The wire is wound in alternate directions in the adjacent π-sections to minimize inductive effect at high frequencies. This type of winding is referred to as 'bifilar'. Wires of low temperature coefficient alloys (e.g., Manganin) are employed. The leads are usually anchored to the tubes firmly and joined to the wire ends by brazing. The unsealed type of resistors are impregnated with varnish while the sealed types are given a dip of epoxy resin or encased in ceramic or glass tubes.

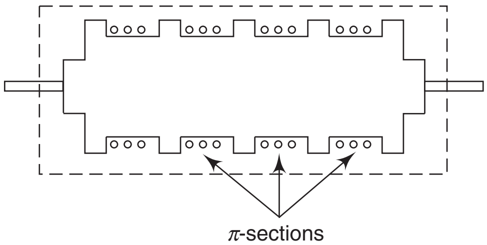


Fig. 2.3 *Precision wire-wound resistor*

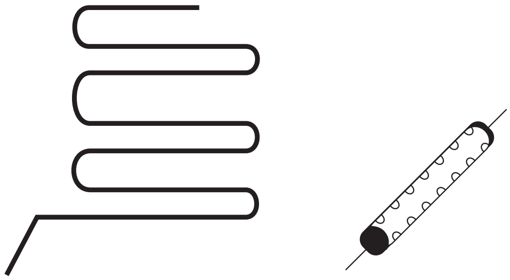


Fig. 2.4 *A serpentine resistor pattern used to reduce inductance in precision wire wound resistor*

Yet another type of construction in which the inductance is virtually reduced to zero is shown in Fig. 2.4. Here, a thick-film serpentine pattern is deposited on a ceramic core. Similar in behaviour to bifilar winding opposite to magnetic fields produced by current flowing in adjacent resistance paths cancel each other, thus reducing the inductance to zero. Precision-style wire-wound resistors are available in the range of a fraction of an ohm to 10 MΩ with a power rating of the order of 2 W.

2.2.2 Variable Resistors

FLASH CARD

What You Learn Here
Recall the resistor type used in brightness control in radios. Classify the different subtypes of this resistor type.

These are the resistors whose resistance can be changed between zero and a certain maximum value. They are used in electronic circuits to adjust the value of voltages and currents. For example, they are used as volume control in radio and brightness control in television. Variable resistors can be broadly classified into three types, viz., potentiometer, rheostat, trimmer.

- ***Potentiometer***

It is a variable resistor either of carbon or wire-wound type. It is smaller in size compared to a rheostat and is usually referred to as “pot.”

- **Carbon Potentiometer** The construction of carbon potentiometer is shown in Fig. 2.5. These are manufactured either in film or moulded track types. Both consist of an annular ring of carbon resistance, formed on a plastic base, over which a movable contact can slide. There is a slip ring (a continuous metal ring) which is also contacted by the movable contact. Three terminals are provided, two of them connected to the ends of the carbon track and one to the slip ring. A shaft runs through a bush in the center of the base to which the movable contact is attached. The assembly is enclosed by a case of sheet metal over which the resistance value and taper are also engraved. The taper refers to variation in resistance along the track which may be a logarithmic or linear variation.

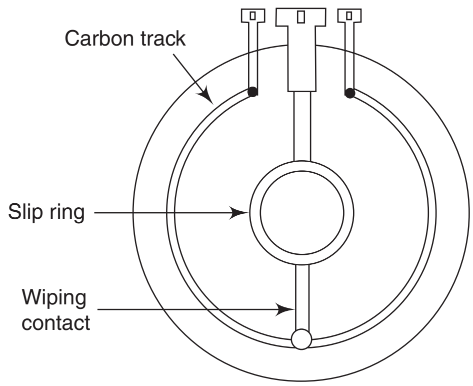


Fig. 2.5 *Carbon potentiometer*

The track may be either the film type or a moulded type. In the film type, a mixture of carbon, graphite and resin in the form of a paste is sprayed on to a plastic (phenolic) sheet, with suitable marks in the form of rings. If a non-linear taper is required, the ring width may be varied circumferentially or the spray may be made from different composition mixtures along the track length.

In the moulded track type, the resistance material and the base plate are moulded together with the slip ring, the terminals and the bushing all being inserted in the moulding operation. The integral moulding of base, track and terminals gets rid of solders, rivets, welds and provides good humidity resistance and fewer mechanical joints.

- **Wire-wound Potentiometers** They are of two types: (i) Single turn, and (ii) Multiturn.

Single-turn wire-wound potentiometer As shown in Fig. 2.6(a), on a flat strip of insulating card made of flexible plastics or anodized aluminium (aluminium oxide formed on aluminium), the resistance wire, usually copper alloy wire for low resistance pots and the nickel chromium for high resistance pots, is wound and then the strip is bent round a cylindrical surface. Contact by means of a slider metal or beryllium copper, which is spring loaded, is made on the inside periphery or the outer edge. Contact from the slider is made through a slip ring or by a coiled spring. The winding is usually of two or three linear resistance sections to approximate ideal taper (such as log). Single-turn pots are available in the range from 50 Ω to 5 MΩ and in power ratings of 2 to 3 W. It is commonly used as a gain control element in an amplifier and as brightness and contrast controls in TV receivers.

PROBE

Identify the potentiometer used for brightness controls in TV receivers and define its principle of operation.

Multi-turn wire-wound potentiometer Multiturn or helical pots are used in applications that require precise setting of a resistance value. An example is the setting of coefficients in an analog computer. Commonly, they have up to 10 turns. As shown in Fig. 2.6(b), the resistance element is wound on a long strip and then formed into a helix and held in a plane using silicone varnish. The contact is of precision metal and has multiple

PROBE

If you had to set up coefficients in an analog computer, which potentiometer type would you use. Define its principle of operation.

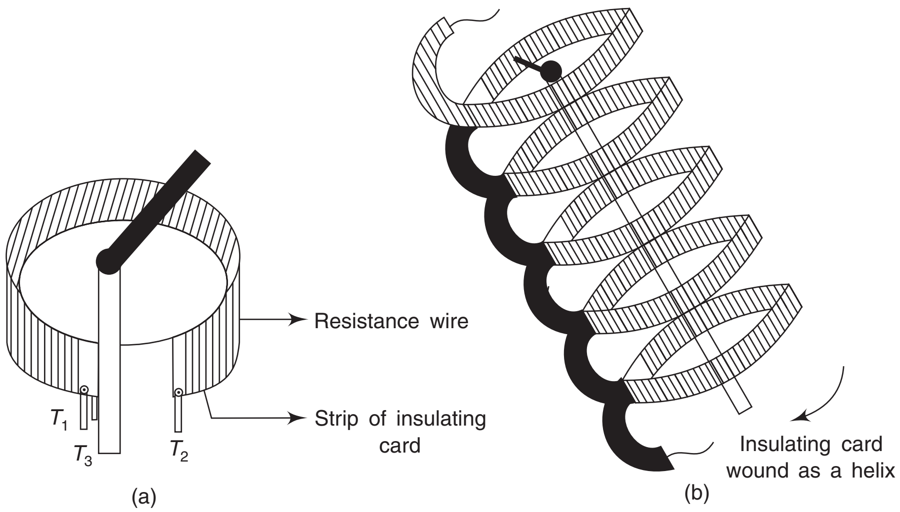


Fig. 2.6 *(a) Single-turn wire-wound potentiometer (b) Multiturn (helical) potentiometer*

"fingers". Usually, the groove between the helical turns of the element may be used to guide the contact. Because of its construction, the wire wound pot has appreciable stray inductance and capacitance which may be a problem at high frequency operation. They are available in the range from 50 Ω to 250 kΩ with a power rating of up to 5 W.

- ***Rheostat*** A wire-wound pot that can dissipate more than 5 W is referred to as a rheostat. As shown in Fig. 2.7, the resistance wire is wound on an open tube of ceramic which is covered with vitreous enamel, except for the track of the movable contact. The rheostat is capable of withstanding temperatures up to 300°C. It is used to control motor speed, X-ray tube voltages, welding current, ovens, and in many other high-power applications.

PROBE

Identify the variable-resistor type seen in ovens and illustrate its uses.

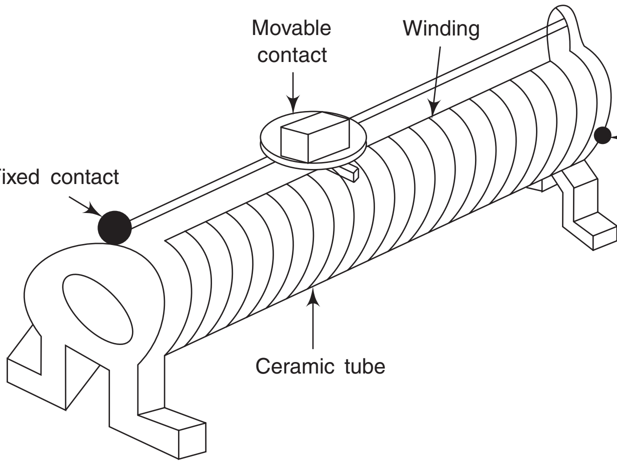


Fig. 2.7 *Rheostat*

- ***Trimmer*** A trimmer, or trimming potentiometer, is used where the resistance must be adjustable but not continuously variable. It finds a very important place in calibration and balancing of electronic equipments. These are screw activated and the resistance can be adjusted by a screw driver. Figure 2.8 shows the commonly used rotary trimmer. Here, the resistance track is made of carbon and cermet. The carbon track along with the movable slide is housed in a steel casing. Typically, their resistance range is from a few ohms to 5 MΩ and the power rating is 1 W.

PROBE

For calibration in electronic equipment, name the variable-resistor type used and recount why.

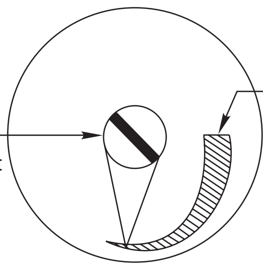


Fig. 2.8 *Rotary trimmer*

2.2.3 Tolerance

In the manufacture of resistors where thousands of resistors are made in a day, it is not possible to adjust every ordinary resistor to an exact value. The term *tolerance* denotes the acceptable deviation in the resistance value of a resistor. The usual specified tolerances are 5%, 10%, and 20% for ordinary resistors, while precision resistors have a tolerance close to 0.1%. For example, the resistance marked as 1 kΩ with a 10% tolerance can have any value between 900 Ω and 1100 Ω.

FLASH CARD

What You Learn Here
Define tolerance of resistors.

Table 2.2 gives the tolerance values for the various types of resistors.

Table 2.2 *Tolerances for various resistors*

Type of resistor	Tolerance
Fixed	
1. Carbon composition	5% or above
2. Carbon film	5% or above
3. Metal film	
(a) Thin film	< 0.5%
(b) Thick film	
(i) Tin oxide	< 1%
(ii) Metal-glaze	< 1%
(iii) Cermet type	≥ 1%
(iv) Bulk film	≥ 0.005%
4. Wire wound	
(a) Power style	5% to 20%
(b) Precision style	< 0.5%
Variable	
1. Potentiometer	
(a) Carbon type	10% to 20%
(b) Wire wound	
(i) Single-turn	10% to 20%
(ii) Multi-turn	3%
2. Trimmer	10%

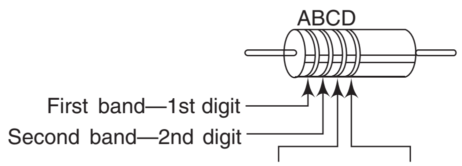
2.2.4 Colour Coding of Resistors

Resistors are coded to indicate the resistance value and tolerance. As shown in Fig. 2.9, there are four colour bands (A, B, C, and D), one by the side of the another starting from the left end. The first two bands (A and B) denote the first and second digits of the resistance value and the third band (C) indicates how many zeros follow the first two digits. Tolerance is given by the fourth band (D).

Figure 2.9 shows the colour code and tolerance values for the various colours. For example, a resistor with the following colour bands sequence

Yellow–Violet–Orange–Gold

denotes a 47000 Ω with 5% tolerance resistor.



Color	Digit	Multiplier	Tolerance
Black	0	1	—
Brown	1	10	±1%
Red	2	100	±2%
Orange	3	1000	—
Yellow	4	10000	—
Green	5	100000	—
Blue	6	1000000	—
Violet	7	10000000	—
Gray	8	—	—
White	9	—	—
Gold	—	0.1	±5%
Silver	—	—	±10%
No color	—	—	±20%

Fig. 2.9 *Standard colour code for composition and some axial-type resistors*

2.2.5 Connecting Resistors

- ***Resistors in Series*** Figure 2.10 shows *n*-fixed resistors connected in series. The current *I* flowing through each resistor is the same in a series circuit. The total equivalent resistance of the series circuit R_{TS} is equal to the sum of the individual resistances, i.e.,

Probe

Illustrate total equivalent resistance for fixed resistors connected (a) in series, and (b) in parallel.

$$R_{TS} = R_1 + R_2 + \cdots + R_n$$

When all resistors have equal value, then $R_{TS} = nR$

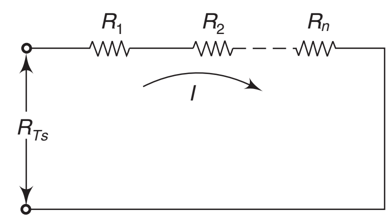


Fig. 2.10 *n-fixed resistors connected in series*

- ***Resistors in Parallel*** Figure 2.11 shows *n* fixed resistors connected in parallel. Here, the voltage *V* across each resistor is the same. The total equivalent resistance of the parallel circuit R_{TP} can be calculated by

$$\frac{1}{R_{TP}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$

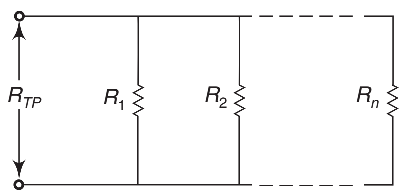


Fig. 2.11 *n-fixed resistors connected in parallel*

Considering two resistors R_1 and R_2 connected in parallel, the total equivalent resistance of the parallel circuit R_{TP} is equal to their product divided by their sum, i.e.,

$$R_{TP} = \frac{R_1 R_2}{R_1 + R_2}$$

When all resistances are equal, then $R_{TP} = \dfrac{R}{n}$.

2.3 CAPACITORS

Next to resistors, capacitors are the most widely used passive elements in circuits. Capacitors are the devices which can store electric charge. Capacitors may be used to build up sufficient electric charge to fire, for example, flash tube or a laser. They are used in tuned circuits, timing circuits, filters, amplifier circuits, oscillator circuits and relay circuits. They are also used for power-factor correction and for starting single-phase motors.

FLASH CARD

What You Learn Here
Discuss the types of capacitors and understand their connections in series and parallel, their colour coding, etc. Illustrate principles and applications.

PROBE

Mention an important area within electrical machines where capacitors are used.

The reactance of a capacitor of capacitance C at frequency f is given by

$$X_C = \frac{1}{2\pi f C}\ \Omega$$

The capacitive reactance (X_C) varies inversely with the frequency of the applied ac voltage. Therefore, the capacitor allows higher frequency currents more easily than lower frequency currents. For dc voltages, i.e., $f = 0$, $X_C = \infty$. Hence, a capacitor blocks (cannot conduct) the dc voltage or current.

A capacitor essentially consists of two conducting plates separated by a dielectric material as shown in Fig. 2.12. The capacitance of a parallel-plate capacitor is given by

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

where A = area of each plate in m^2

d = distance between parallel plates in m

ε_0 = dielectric constant (permittivity) of free space

$$= \frac{10^{-9}}{36\pi}\ \text{F/m} = 8.854 \times 10^{-12}\ \text{F/m}$$

ε_r = relative dielectric constant (permittivity)

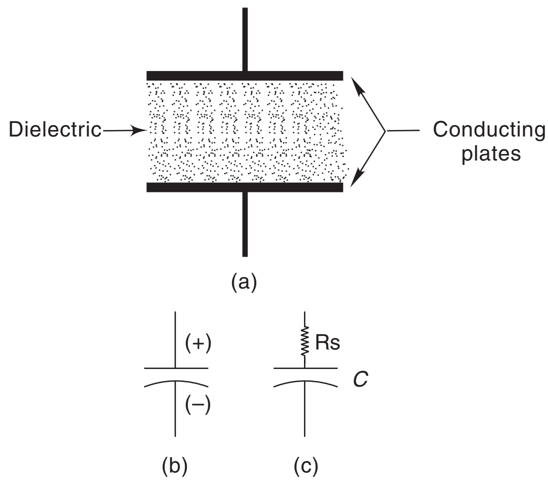


Fig. 2.12 *Capacitor: (a) Basic structure (b) Symbol (c) Series equivalent circuit*

For large capacitance, the area A and the value of the relative permittivity of the dielectric ε_r, must be large, while d must be very small. Larger capacitances can be obtained by using high permittivity dielectrics of smaller thickness.

When a voltage V is applied across the capacitor plates, the electrons accumulate on the side of the capacitor connected to the negative terminal of the voltage source. The plate connected to the positive terminal of the voltage source loses electrons. This accumulation of electrons produces a negative charge on one side of the capacitor, while the opposite side has a positive charge.

PROBE

Explain the charging of a capacitor and depict its mathematical representations.

Thus, with the application of voltage, the electrons are simply redistributed from one side of the capacitor to the other. This redistribution process of the electrons is called the charging of the capacitor.

The charging continues until the potential difference across the capacitor is equal to the applied voltage. The more the applied voltage, the stronger is the electric field and more charge is stored in the dielectric. The amount of charge q stored in the capacitor is, therefore, proportional to the applied voltage. Also, a large capacitance can store more charge. These relations can be mathematically expressed as

$$Q = CV \text{ coulombs}$$

where Q = charge stored in the dielectric, V = voltage across the capacitor, and C = capacitance of the capacitor.

From the above equation, when one coulomb is stored in the dielectric with a potential difference of one volt, the capacitance is one farad. In order to store a given charge, more voltage is needed for a small capacitor and less voltage for a large capacitor. The maximum voltage that can be impressed across a capacitor, without causing irreparable damage depends on the dielectric used and the separation d of the plates.

In a capacitor, the dielectric strength is the ability of a dielectric to withstand a potential difference without breakdown. This voltage rating is very important because breakdown of the insulator provides a conducting path through the dielectric. Since the breakdown voltage increases with greater thickness, capacitors of higher voltage ratings have more distance between the plates. The increased distance between the plates reduces the capacitance.

A charged capacitor has energy stored in the electric field existing between its plates. The expression for stored energy is

$$W = \frac{1}{2} CV^2$$

The typical values of dielectric constant and dielectric strength of various dielectric materials are shown in Table 2.3.

Table 2.3 *Dielectric properties*

Material	Dielectric constant	Dielectric strength volts/mil (breakdown)
Air or vacuum	1	20
Plastic film	2–3.5	1000–5000
Oil	2–5	500–1000
Paper	2.5–6	500–1000
Mica	3–8	600–1500
Glass	4–7	<500
Electrolytic	7–11	2000
Ceramics	80–12000	100–300

Capacitors are generally classified according to the dielectric used. Most commonly used dielectrics are air, electrolyte, ceramic, plastic, mica, and paper. Only electrolytic capacitors have polarity. The capacitance of a fixed capacitor is never constant except under certain fixed conditions. It changes with temperature, frequency, and age, and the capacitance value marked on the capacitor strictly applies only at room temperature and at low frequencies. Some of the fixed capacitors are discussed in the following sections.

2.3.1 Fixed Capacitors

- ***Electrolytic Capacitors*** Electrolytic capacitors normally have the smallest volume and cost for a given capacitance. These types of capacitors are mainly used in applications where a large value of capacitance in a small volume is required, such as filter in a power supply.

Electrolytic capacitors are very widely used in filters, time constant circuits, bypass, coupling/decoupling, smoothing, and power electronic applications.

Probe

Recall where one would commonly find electrolytic capacitors.

They are manufactured in many shapes and configurations from as low as 0.1 μF up to 1.0 F, for voltages up to 500 V dc. They are generally polarized and are used on dc only. They are also available in non-polarized form and are used in motor-start applications. Based on the type of metal, used for etching anode and (or) cathode, they are classified as (i) aluminium type, and (ii) tantalum type.

In the case of polarized electrolytic capacitor, a plus sign or minus sign is printed on the package near one of the two leads. The lead near the plus sign must be connected to a higher dc potential point when the capacitor is put in a circuit. If it is connected reversely then the capacitor may be short-circuited and permanently damaged. For non-polarized electrolytic capacitor, there is no such restriction when it is connected in a circuit.

- **Polarized Electrolytic Capacitor** The basic structure of polarized electrolytic foil capacitor is shown in Fig. 2.13(a). Certain metals like aluminium, tantalum, vanadium, and bismuth are used to form anode and cathode foils. Then a very thin layer of aluminium or tantalum oxide is electrochemically formed on the anode foil. The oxide layer becomes the dielectric for the capacitor. Such a very thin film of dielectric results in a large capacitance value. The cathode and oxide-coated anode is separated by a paper spacer which is soaked in an electrolytic solution. This spacer is required to prevent short circuiting between the anode and cathode foils. For high-voltage rating capacitors, the spacer is thicker than for low-voltage rating capacitors. The most common shape of electrolytic capacitor is the roller type, inside which the paper spacer is sandwiched between the anode and cathode foils.

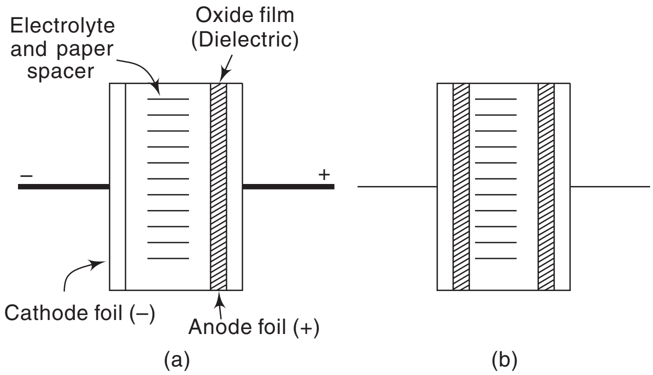


Fig. 2.13 *An elementary electrolytic capacitor: (a) Polarized (b) Non-polarized*

- **Non-polarized Electrolytic Capacitor** The basic structure of a non-polarized electrolytic capacitor is shown in Fig. 2.13(b). This type has two oxide-coated anodes. For an equal size polarized capacitor, the non-polarized type has one-half the capacitance for the same voltage rating. They are generally used in applications such as ac motor starting, crossover networks, and large pulse signals.

Aluminium type This type of electrolytic capacitors are available in polarized or non-polarized form. The construction of this type of capacitors is similar to the construction of polarized or non-polarized capacitors, discussed in the previous section. This type of capacitors have high dc leakage and low insulation resistance. They are low in cost and have a high volumetric efficiency. The disadvantages are that their shelf life is limited and their capacitance deteriorates with time and use.

Tantalum type Tantalum electrolytic capacitors have long shelf life, stable operating characteristics, increased operating temperature range and greater volumetric efficiency. The disadvantages of tantalum type in comparison to the aluminium type are its greater cost and lower voltage rating.

PROBE

Did you know tantalum capacitors have high capacitance per weight and volume compared to other capacitors?

Tantalum electrolytic capacitors can be divided into three types, namely, foil, wet anode and solid anode.

- ***Foil type*** The tantalum foil type is similar in construction to aluminium-foil electrolytic type.
- ***Wet-anode type*** As shown in Fig. 2.14, the wet-anode type capacitor is made by moulding a mixture of tantalum powder and binder into the shape of a pellet. Under high temperature and in a vacuum, the pellet mixture is welded together (sintered) and due to this sintering, the binder and impurities are driven off. The result is a porous pellet on which a layer of tantalum oxide is electrochemically formed. The volumetric efficiency of wet anode type is about three times that of the foil type.
- ***Solid-anode type*** As shown in Fig. 2.15, this type of capacitor is made by sintering an anode pellet on which a layer of tantalum oxide is formed. The pellet is then formed with a manganese dioxide layer which serves as a solid dielectric. The cathode connection is made by coating this pellet by carbon and silver paint. The solid-anode construction is most widely used. It has the longest life and lowest leakage current of the three types of tantalum capacitors.

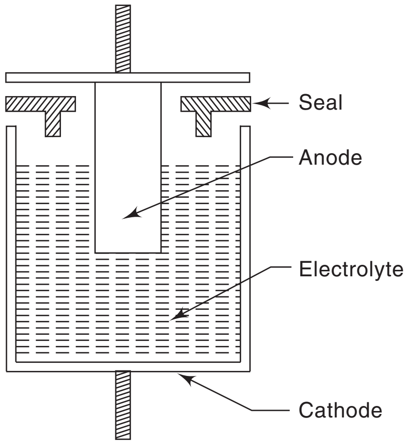


Fig. 2.14 *Wet-anode type tantalum capacitor*

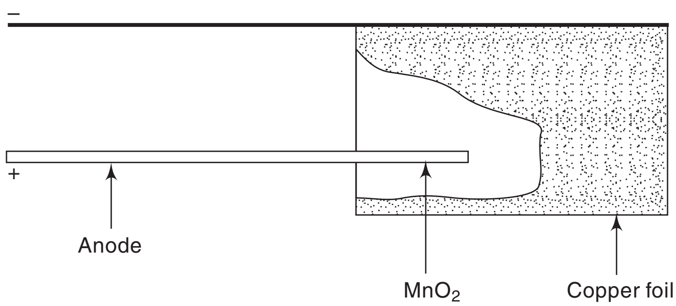


Fig. 2.15 *Solid-anode type tantalum capacitor*

▪ *Ceramic Capacitors*

These capacitors use ceramic dielectric with thin metal films as electrodes bonded to the ceramic. There are three basic types of a ceramic dielectrics: (i) low permittivity, (ii) medium permittivity, and (iii) high permittivity types.

Low-permittivity ceramic capacitors can be made to exhibit zero temperature coefficient and they find wide use in temperature compensation networks. The permittivity usually ranges from 6 to 400. It operates at voltages as high 6 kV and temperatures up to 125°C. Its capacitance value is generally limited to 0.001 μF.

In the medium-permittivity ceramic capacitors, the permittivity is in the range from 500 to about 4000 and is relatively stable over a wide temperature range of –55 to + 125°C with a maximum capacitance change of ±15%.

In the high-permittivity ceramic capacitors, the permittivity ranges from 5000 to 30,000. They have capacitance values up to 2.2 μF and maximum working voltage of 100 V. However, these capacitors change their values appreciably with temperature, dc voltage, and frequency.

The medium- and high-permittivity ceramic capacitors are used for bypass and decoupling applications or frequency discrimination where *Q*-factor and stability are not of major importance.

The ceramic capacitors are available as disc, tubular, monolithic, and barrier-type capacitors.

◆ **Disc Capacitor** In the disc-type capacitor, silver is fixed on to both sides of ceramic to form conductor plates. The sheets are then baked and cut to different sizes of 0.5 mm. The terminal leads are attached by pressure contact or soldering. The disc capacitors have high capacitance per unit volume. Round-disc types with axial leads are used for high voltage operation. The discs are lacquered or encapsulated in plastic or phenolic moulding. They are available up to a value of 0.01 μF. They have voltage rating of up to 750 V dc (350 V ac). Some disc type capacitors are shown in Fig. 2.16.

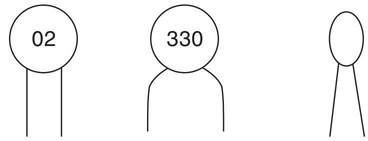


Fig. 2.16 *Disc-type ceramic capacitors*

◆ **Tubular Capacitor** The low-loss type capacitors are normally made of steatite or similar material. Steatite has a permittivity of 8. These are usually made in tubular structures. The construction of tubular capacitor is shown in Fig. 2.17. The required materials are ground and mixed thoroughly. The mixture is compressed and fixed with suitable fluxes and moulded into tubes. Silver metal is deposited outside and inside the tube. Leads are formed and soldered. The outer surface may be protected by lacquer in the uninsulated types. The tubular capacitors are available in the range of 5 pF to 1000 pF in voltage ranges up to 5 kV, and up to 10,000 pF in the lower voltage ranges.

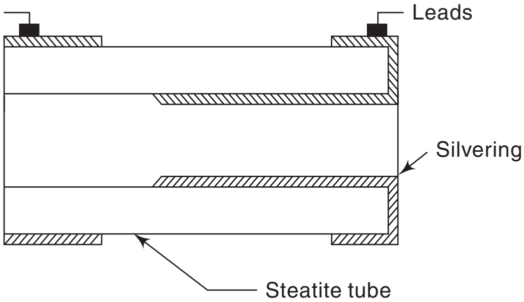


Fig. 2.17 *Tubular ceramic capacitors*

◆ **Monolithic Capacitor** As shown in Fig. 2.18(a), the monolithic capacitors are formed by interleaving layers of ceramic and platinum electrodes. The first stage in the manufacturing process is the preparation of a slurry or slip in either aqueous or organic solution. Organic binders and plasticizers are added to the slurry to give strength and flexibility to the film. This is then cast on a carrier substrate in thicknesses of 0.025 mm to 0.75 mm and cut into strips. The next step is to apply screen, electrodes of platinum or palladium to the film. The electrode configuration is designed in such a way that each layer of film when blanked will carry an electrode. The deposition of metallic layer extends to alternate faces and accurate location of electrode pattern is required. After the required number of layers have been formed for a specific value of capacitance, the strips are subjected to consolidation under pressure. Then external electrodes are applied in order to pick up the edges of the internal electrodes and form a parallel connection. This entire structure is fired to form a monolithic block. Sintering is done at high temperature (1300°C) to reduce the volume of the block by 40 per cent. Some monolithic type ceramic capacitors are shown in Fig. 2.18(b).

- **Barrier-layer Capacitors** Barium titanate is used as the dielectric medium in these capacitors. If such a ceramic disc is reduced at 1300°C, it becomes highly non-conducting medium. If reoxidized, a conducting layer of ceramic forms at the surface. This barrier of conducting to non-conducting layer possesses high values of dielectric constants. Suitable additives will improve the dielectric constant and the loss angle. Silver electrodes are fired on to this barrier layer and the entire assembly is reoxidized in hot air once again. This is encapsulated to prevent the entrance of moisture. The construction of a barrier type capacitor is shown in Fig. 2.19.

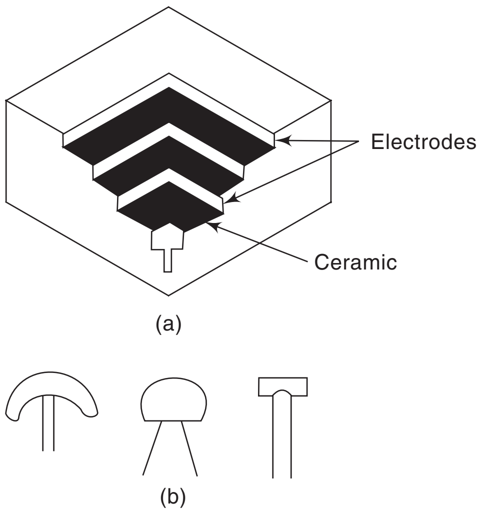


Fig. 2.18 *Monolithic-type ceramic capacitors*

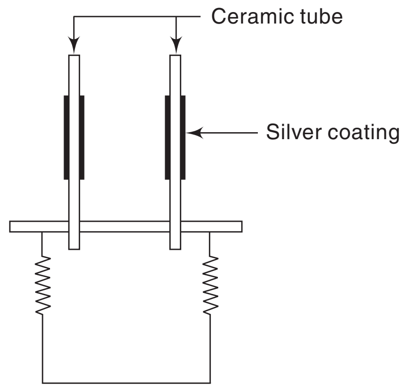


Fig. 2.19 *Barrier-type capacitor*

The capacitors have much lower insulation resistance and are used only for low voltage applications. They have temperature limitation and can operate from –40°C to 80°C. These are used in very high frequency circuit applications.

- **Uses of Ceramic Capacitors** The ceramic capacitors are widely used as bypass capacitors and in decoupling and biasing applications. The major drawback is that the capacitance value varies with the temperature. Ceramic capacitors of the insulated type are used in TV receivers. Tubular capacitors are used to isolate the antennas in receivers. Capacitors with little temperature–capacitance variations are used to compensate for impedance–temperature changes in circuits.

PROBE

Explain some uses of ceramic capacitors in our daily lives.

Plastic Capacitors

These capacitors use a plastic film as a dielectric. The plastics used include polystyrene, polycarbonate, PTFE (Poly Tetra Fluora Ethylene), and polyester (mylar). Plastic capacitors are available in typical ranges of 500 pF to 10 μF. When sealed properly, these plastics exhibit good mechanical strength, resistance to heat and chemical inertness. The chief characteristics of these capacitors are their very high insulation resistance, high reliability, small physical size and low dielectric absorption.

- **Polystyrene Capacitors** Polystyrene is a hydrocarbon material and has a lower permittivity than polyester and polycarbonate. These capacitors are made by rolling the polystyrene film with aluminium foils. These are compactly wound and the leads are soldered at the ends. The entire assembly is carefully heat treated so that the plastic softens (softening temperature, 90°C) and makes good contact with the metal foil. The winding requires particular attention because it may accumulate electrostatic charges and attract dust. Polystyrene is not suitable for metallizing because of lack of available oxygen for the self-healing action and low tensile strength.

They exhibit a low dissipation factor, small capacitance change with temperature and very good stability. They tend to be large in size, and their maximum operating temperature is 85°C. Polystyrene capacitors are normally used in coupling, resonant, and measuring circuits. As these capacitors have low dissipation factor, they can be used for ac applications.

- **Polyester Capacitors** They are made of polyesters like Mylar, Melinex, Terelyne, etc. Usually, this is metallized to give better results. Sometimes impregnation is done with silicone or mineral oil to improve the dielectric characteristics. A thin film of silver is deposited on to this plastic by vacuum evaporation. These capacitors are capable of withstanding temperatures up to 150°C and voltages up to 400 V. These capacitors are available in the range from 100 pF to 2 μF. As the dielectric is prone to moisture, good encasement is needed. The capacitors are usually encased in glass or resin moulded or ceramic containers.

Polyester is a tough polymer with high tensile strength, free from pinholes and with good insulating properties over a reasonably wide temperature range. Its combination of good insulation properties over a wide temperature range and high mechanical strength are the outstanding characteristics. It also has a low moisture absorption. The high mechanical strength (up to approximately 210°C) make polyester ideally suited for metallizing by vacuum evaporation. It consists of sufficient oxygen to produce good self-healing.

Due to the good all-round mechanical and electrical properties and the high dielectric constant of polyester film, these capacitors are the most widely used of any film or paper capacitors. Polyester capacitors are normally used for coupling/decoupling applications at low and medium frequencies but find many other applications in general, and in power electronics as well as in certain ac applications. Polyester is ideal for dc applications because of its high dielectric strength and resistivity.

- **Polycarbonate Capacitors** Polycarbonate is a polyester of carbonic acid bisphenols. It combines good physical properties with a lower dissipation factor than polyester. The metallized polycarbonate film is rolled and sealed in a metal case with epoxy resin. It is insulated with a polyester sleeve. As it does not have as much available oxygen, its self-healing properties are not quite as good as for polyester. It has a higher insulation resistance. It can operate at temperatures as high as 125°C. Polycarbonate allows the manufacture of close-tolerance (typically ±1%), stable, small physical size, long life capacitors and is mainly used for dc applications, though it can also be used for ac applications. They are available in the range of 0.1 to 10 μF. They are not capable of withstanding higher voltages.

A comparison chart of some of the main characteristics of the three types of plastic dielectric capacitors is given in Table 2.4.

Table 2.4 *Characteristics of different types of plastic capacitors*

	Polystyrene	Polyester	Polycarbonate
Permittivity (at 1 kHz, 20°C)	2.5	3.3	2.9
Dissipation factor (at 1 kHz, 20°C)	0.0002	0.005	0.001
Dielectric strength (V/μm) (at 20°C)	200	304	184
Insulation resistance (Ω – F) (at 20°C)	1×10^6	3×10^4	6×10^4
Dielectric absorption (%) (at 20°C)	0.01	0.2	0.05
Maximum operating temperature (°C)	85	125	125
Film molecular structure	Non-polar	Polar	Polar
Metallization	Not available	Available	Available

▪ *Mica Capacitors*

The dielectric used in mica capacitors is muscovite or white mica, ruby or rose-coloured mica, and amber mica. It has a dielectric constant between 3 and 8, and a dielectric strength of 600–1500 V/mil. Its breakdown voltage widely varies from 500 V to 20 kV. It has low losses and the power factor varies depending on the dryness from 0.01 to 2% and can respond to very high frequencies. It can withstand temperatures up to 400°C. It has better temperature coefficient and frequency characteristics. It is highly stable and its capacitance variation is within 1%. It has no dielectric absorption. The drawbacks are that it absorbs moisture and it is big in size. It is good for cheap and rugged capacitors. Mica capacitors are used for small capacitance values of 50 to 500 pF. They are used as coupling capacitors at high frequency, in radio-frequency transmitters and also in measuring circuits, bypassing circuits and RF resonant circuits. However, ceramic and glass capacitors have replaced them in most applications.

There are two types of mica capacitors. They are (i) stacked mica capacitors, and (ii) silvered mica capacitors.

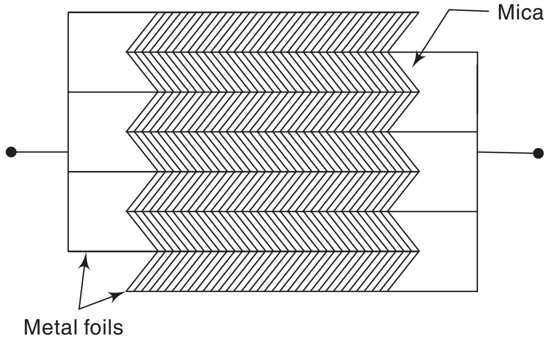


Fig. 2.20 *Stacked mica capacitor*

◆ **Stacked Mica Capacitor** Perfect mica sheets are selected and stacked between tin foil sections as shown in Fig. 2.20 to provide the required capacitance. Stacking should be done under controlled pressure, as excess pressure may increase the capacitance value. Alternate metal foils are connected together and brought out to opposite sides to provide capacitor leads. These capacitors are used over a wide temperature range (–55 to +150°C) and have a high insulation resistance. Their capacitance values range from 1.0 pF to 0.1 μF.

◆ **Silvered Mica Capacitor** As shown in Fig. 2.21, the silvered mica capacitor is made of stacked silver coated mica sheets alternatively and sealed in a wax modulated case. The coating of mica is done at 500°C with silver oxide solution. Compared to the stacked mica capacitor, it is smaller in size and has greater mechanical stability and uniform characteristics. It can withstand higher voltages.

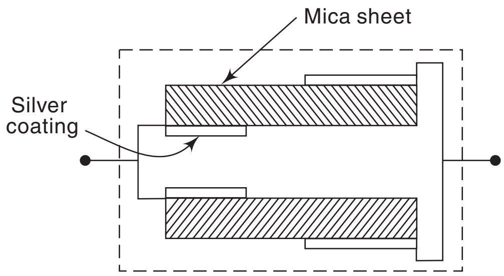


Fig. 2.21 *Silver mica capacitor*

▪ *Paper Capacitors*

The dielectric in paper capacitors is Kraft paper impregnated with wax or resin. It is generally packaged as a rolled sandwich. Paper capacitors are available in the range of 500 pF to 50 μF, can withstand high voltages, can operate in ambient temperatures as high as 125°C, and are inexpensive. The two types of paper capacitors are (i) impregnated paper capacitor, and (ii) metallized paper capacitor.

◆ **Impregnated Paper Capacitor** It consists of two thin sheets of paper between metal foils compactly rolled and impregnated with an impregnant like mineral oil, mineral wax, petroleum jelly, castor oil, polyisobutylene, or chlorinated diphenyl. Two types of construction, called the 'tab' and 'extended foil' are common. In the tab type, a metal tab is inserted after rolling and the lead wires are soldered to the tabs. In the extended-foil type, sheets of foil are allowed to extend over the margin of the paper, one foil on one side and another foil at the other side. The extended foil type is inexpensive and suitable for higher voltage operation but has a disadvantage of occupying more space. The impregnated paper forms the dielectric medium. Special Kraft paper free from salts and alkalies of 7 to 25 microns thickness is used. For higher voltage ratings, two or three sheets are used. The capacitance values are smaller ranging from 0.001 to 1.0 F.

◆ **Metallized Paper Capacitor** Instead of a separate foil, a layer of metal can be sprayed on to the paper. The layer is very thin, about 50 microns. A single sheet of metallized paper can be used up to 200 volts. In some capacitors, a layer of metallized paper along with a plastic film of Teflon (PTFE) and Mylar are used. This rolled capacitor is impregnated with an impregnant and enclosed in a metal case. This type has low insulation resistance and power factor, and it occupies small space. They are used for power-factor correction and motor starting. They are also used as bypass and filter capacitors in audio-frequency applications. The dielectric absorption is comparatively higher than other capacitors. They have very high insulation resistance of over 1000 MΩ and have longer service life.

2.3.2 Variable Capacitors

Variable capacitors are used in tuning circuits of communication receivers, transmitters, and in oscillators. The most commonly used type is the air-variable capacitor shown in Fig. 2.22. It is composed of two set of plates, usually made of aluminium. One set, known as rotor, is mounted on a shaft and meshes with a set of fixed metal plates, known as stators. The two set of plates are insulated and are never permitted to touch each other.

When the shaft is rotated, the effective area that exists between the rotor and stator plates varies, thereby varying the capacitance. The shape of the plates determines the manner in which capacitance varies with shaft rotation. The variation will be linear if the moving plates are semicircular. For tuning purposes, a uniform scale for frequency is required. A simple relation between the capacitance and the angular rotation is given by

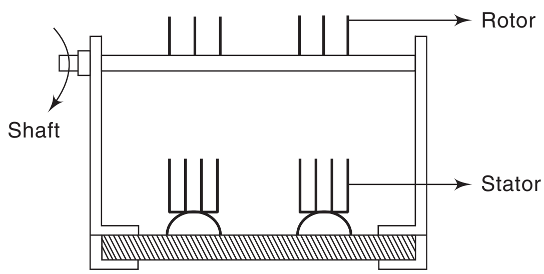


Fig. 2.22 *Variable tuning capacitor*

$$\frac{1}{C} = (a\theta + b)^2$$

where C is the capacitance, a and b are constants, and θ is the angular rotation.

Capacitance values for air-variable capacitors range from a few picofarads up to 500 pF with a maximum voltage rating of 9 kV. For higher operating voltages up to 60 kV; a vacuum variable capacitor is used.

Miniature type of variable capacitors use thin plastic film dielectrics between the plates. The entire assembly is enclosed in a moulded transparent plastic case to prevent entry of dust. These capacitors are typically low-voltage units and they have a limited type.

2.3.3 Dissipation Factor

An ideal capacitor when discharged gives up all the electrical energy that was supplied to it in charging. But practical capacitors dissipate some of the energy delivered to them, i.e., they suffer from losses due to (i) dielectric losses—particularly at higher frequencies, (ii) insulation or leakage resistance, and (iii) resistance of the leads and plates. The insulation resistance and dielectric strength are lowered if the capacitor is operated at high temperature, and high voltage and humidity. The leakage losses increase with frequency, applied voltage and temperature. The voltage rating of capacitors has to be reduced if operated at higher temperatures and humidity conditions.

The power factor (PF) of a capacitor expresses the ratio of the power dissipated per cycle to the power stored per cycle in a capacitor. The power factor is the ratio of the equivalent series resistance to the total impedance of the capacitor, i.e.,

$$PF = \frac{R_s}{Z} = \frac{R}{\sqrt{R_s^2 + X_c^2}}$$

PROBE

Define power factor of a capacitor and display its mathematical representation.

The dissipation factor (DF) of a capacitor is the ratio of the equivalent series resistance to the capacitive reactance, i.e., DF = R_s/X_c. For low losses (i.e., $R_s < X_c$), the power factor is equal to dissipation factor. The equivalent series resistance is due to capacitor plates with leads and insulation or leakage resistance. For an ideal capacitor $R_s = 0$ and hence PF = 0. Due to the losses, a practical capacitor has a non-zero power factor. For a practical capacitor, the power factor angle Φ is not 90° but slightly differs given by $90° - \theta$. This angle is called the loss angle of a capacitor and tan θ is usually specified as the *dissipation factor* (DF). Dissipation factor is another parameter used to describe the quality of a capacitor. The reciprocal of the dissipation factor can be considered as the Q of the capacitor and is the ratio of the capacitor reactance (X_c) to the equivalent series resistance (R_s).

FLASH CARD

What You Learn Here
Dissipation factor is used to describe quality of a capacitor. Define DF and show how a higher Q means better quality.

$$Q = \frac{1}{\text{DF}} = \frac{X_c}{R_s} = \frac{1}{\omega C R_s} = \tan\Phi = \tan(90° - \theta) = \cot\theta = \frac{1}{\tan\theta}$$

Thus, higher Q means better quality of the capacitor.

2.3.4 Colour Coding of Capacitors

Generally, the values of capacitance, voltage, and tolerance are marked into the body of the capacitors. The value of a capacitor is specified in either picofarads (pF) or microfarads (μF). If a capacitor, other than an electrolytic capacitor, is labeled as a whole number such as 33, 220, or 680, then the capacitance C is specified in pF. If a capacitor is printed with a decimal fraction such as 0.1, 0.001, or 0.047, then the capacitance C is specified in μF. The manufacturer indicates the value of a capacitor using colour coding systems in different ways.

The values of ceramic, mylar, and polyester-type capacitors are stamped on their bodies as a numerical code, 103, 471, 474, etc. These codes can easily be converted into a standard value in pF. The first two digits of the code represent the two significant digits of the value. The third digit is the number of zeros to the right, which will yield the value in pF. For example, if a capacitor has 471 marked on it, then the first two digits are 47. Since the third digit is 1, one zero will be added to the right as 470 pF, which is equal to 0.47 nF.

Table 2.5 shows the standard codes for different tolerances. These letter codes are labeled on the capacitor next to or below the value of the capacitor.

Table 2.5 *Standard code for tolerance of this capacitors*

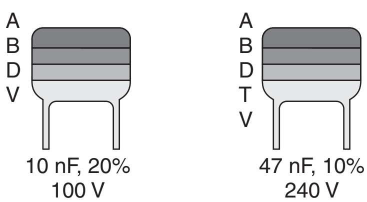
$B = \pm 0.1$ pF	$J = \pm 5\%$
$C = \pm 0.25$ pF	$K = \pm 10\%$
$D = \pm 0.5$ pF	$M = \pm 20\%$
$F = \pm 1\%$	$P = \pm 100\%, -0\%$
$G = \pm 2\%$	$Y = +50\%, -20\%$
$H = \pm 3\%$	$Z = +80\%, -20\%$

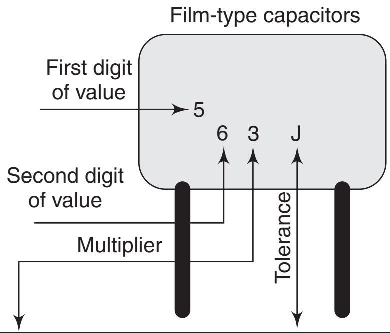
To reduce the confusion regarding letters, numbers, and decimal points, an international colour coding scheme was developed many years ago as a simple way of identifying capacitor values and tolerances. It consists of coloured bands, in spectral order, whose meanings are illustrated in Table 2.6.

Table 2.6 *Capacitor colour code*

Colour	Digit *A*	Digit *B*	Multiplier *D*	Tolerance $T > 10$ pF	Tolerance $T < 10$ pF	Temperature coefficient *TC*	Working voltage *V*
Black	0	0	×1	± 20%	± 2.0 pF		
Brown	1	1	×10	± 1%	± 0.1 pF	-33×10^{-6}	
Red	2	2	×100	± 2%	± 0.25 pF	-75×10^{-6}	250 V
Orange	3	3	×1000	± 3%		-150×10^{-6}	
Yellow	4	4	×10 k	± 100%		-220×10^{-6}	400 V
				– 0%			
Green	5	5	×100 k	± 5%	± 0.5 pF	-330×10^{-6}	100 V
Blue	6	6	×1 m			-470×10^{-6}	630 V
Violet	7	7				-750×10^{-6}	
Grey	8	8	× 0.01	+80%			
				– 20%			
White	9	9	× 0.1	± 10%			

- ***Film-Type Capacitors*** Figure 2.23 shows a coding system used with film-type capacitors. The first two digits of the code indicate the first two digits in the numerical value of the capacitance. The third digit is the multiplier included to the right, which will yield the value in pF. For example, if a capacitor is with 563J marked on it, then the first two digits are 56 and the third digit 3 represents three zeros to be appended to the right as 56000 pF, which is equal to 56 nF or 0.056 μF. The last letter 'J' at the right indicates the capacitor tolerance of ±5%.





Multiplier		Tolerance of capacitor		
For the number	Multiplier	Letter	10 pF or less	Over 10 pF
0	1	B	± 0.1 pF	
1	10	C	± 0.25 pF	
2	100	D	± 0.5 pF	
3	1,000	F	± 1.0 pF	± 1%
4	10,000	G	± 2.0 pF	± 2%
5	100,000	H		± 3%
		J		± 5%
8	0.00	K		± 10%
9	0.1	M		± 20%

Fig. 2.23 *Film-type capacitor colour codes*

- ***Ceramic Disk Capacitors*** The capacitance of the disc ceramic capacitors is labeled either as a whole number or as a decimal fraction as shown in Fig. 2.24.

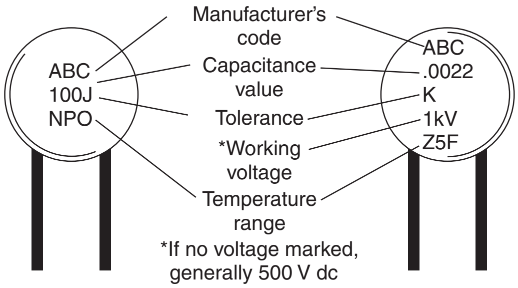
- ***Tantalum Capacitors*** In order to calculate the value of colour-coded tantalum capacitors, they are colour coded as resistors as given in Table 2.7. The first and second bands of capacitors are the significant number bands, the third is the multiplier, followed by the percentage tolerance band, through not all tantalum caps have a tolerance band, and the voltage band. If there are only four colours then the last is the voltage and there is no tolerance ID.

- ***Mica Capacitors***

Mica capacitors are coded using coloured dots to represent the value of the capacitance in pF. Mica capacitor coding system is given in Table 2.8.

Three different coding systems for mica capacitors are described below:

- **Three-dot Code** The colour dots must be read in the correct sequence (A, B, C) from left to right in order to correctly interpret the colour code. In order to make certain that the capacitor will be held in the proper position while the dots are being read, manufactures have adopted several 3-dot marking arrangements.



(a) Typical ceramic disk capacitor markings

1 0 0 J

1st and 2nd Fig. of capacitance	Multiplier	Numerical symbol	Tolerance on capacitance	Letter symbol
	1	0		
	10	1		
	100	2	± 5%	J
	1,000	3	± 10%	K
	10,000	4	± 20%	M
	100, 000	5	+ 100%, – 0%	P
		—	+ 80%, – 20%	Z
		—		
	0.01	8		
	0.1	9		

(b) Capacity value and tolerance of ceramic disk capacitors

Z 5 F

Low temp.	Letter symbol	High temp.	Numerical symbol	Max. capacitance change over temp. range	Letter symbol
± 10°C	Z	± 45°C	2	± 1.0%	A
– 30°C	Y	± 65°C	4	± 1.5%	B
– 55°C	X	± 85°C	5	± 1.1%	C
		± 105°C	6	± 3.3%	D
		± 125°C	7	± 4.7%	E
				± 7.5%	F
				± 10.0%	P
				± 15.0%	R
				± 22.0%	S
				± 22%, – 33%	T
				± 22%, – 56%	U
				± 22%, – 82%	V

(c) Temperature range identification of ceramic disk capacitors

Fig. 2.24 *Ceramic capacitor colour codes*

Table 2.7 *Tantalum capacitor colour codes*

Colour	Capacitance in pF		Multiplier (No. of zeros)	Rated voltage
	1st figure	2nd figure		
Black	0	0	–	4
Brown	1	1	1	6
Red	2	2	2	10
Orange	3	3	3	15
Yellow	4	4	4	20
Green	5	5	5	25
Blue	6	6	7	35
Violet	7	7	7	50
Grey	7	8	–	–
White	9	9	–	3

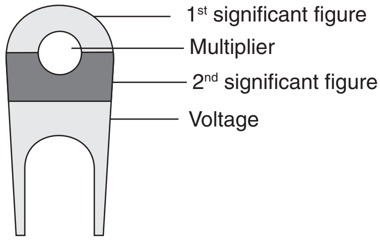


Table 2.8 *Mica-capacitor colour-coding system*

Colour	A First figure	B Second figure	C Number of zeros	D Voltage rating	E Tolerance
Black	0	0	0		
Brown	1	1	1	100	1%
Red	2	2	2	200	2%
Orange	3	3	3	300	3%
Yellow	4	4	4	400	4%
Green	5	5	5	500	5%
Blue	6	6	6	600	6%
Violet	7	7	7	700	7%
Grey	8	8	8	800	8%
White	9	9	9	900	9%
Gold				1000	5%
Silver				2000	10%
No Colour				500	20%

The capacitor must be held so that the name of the manufacturer appears right side up, as shown. Then the dot will be read in the proper sequence if they are read from left to right. Another common arrangement is to have the three coloured dots stamped on an arrow molded in the capacitor case. The arrow always points to the correct direction of reading.

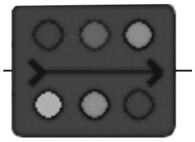
Example *Red, Green, Black = 25 pF = 0.000025 μF*

- **Five-dot Code** Two extra colour dots are included in five-dot colour-coded capacitors, on the face or on the reverse side of the molded case. The colour of the fourth dot (D) indicates the dc voltage rating. No colour in this position implies a voltage rating of 500 volts dc.

The colour of the fifth dot (E) indicates the percent of tolerance on the accuracy of the capacity rating. No colour in this position indicates a tolerance of ±20% in the capacity value.

- **Six-dot Code** A 6-dot colour code is employed when there are three significant figures in the capacity value and the voltage rating and tolerance information is also to be represented.

When six dots are marked on capacitors, the upper three (A, B, B1) indicate the capacity and the lower right hand dot (C) indicates the number of zeros to be added. The remaining two dots (D) and (E) indicate the dc working voltage rating and the capacity tolerance respectively, as shown in the illustration.



Example *Brown, Red, Green, Orange, Green, Brown = 1250 pF, 300 dc working voltage ± 5%, tolerance*

- **Chip Capacitors** Chip capacitors or surface mount capacitors do not have leads. They are used in aerospace, automotive, general-purpose, high voltage, high-frequency, microwave, and telecommunication applications. Most chip capacitors are packed in tape reel assemblies, carbon-powder trays or rails, and shipping tubes or stick magazines. Bulk pack parts are distributed as individual products. Some chip capacitors are polarized or self-healing.

There are three popular colour coding systems used by the different manufacturers of chip capacitors. The values represented in all three systems are in pF.

As shown in Fig. 2.25, a two-place system in which a letter indicates first and second digits of the capacitance value and a number indicates the multiplier (number of zeros to be appended). Thirty-three symbols consisting of 24 uppercase letters and 9 lowercase letters are used to represent the two significant figures. For example, L3 represents 2700 pF.

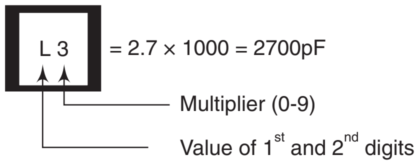


Fig. 2.25 *A two-place system*

Value (33 Value Symbols)—Uppercase and Lowercase Letters				Multiplier	
A = 1.0	H–2.0	b–3.5	f–5.0	X–7.5	0 = × 1.0
B = 1.1	J–2.2	P–3.6	T–5.1	t–8.0	1 = × 10
C = 1.2	K–2.4	Q–3.9	U–5.6	Y–8.2	2 = × 100
D = 1.3	a–2.5	d–4.0	m–6.0	y–8.0	3 = × 1000
E = 1.5	L–2.7	R–4.3	V–6.2	Z–9.1	4 = × 10000
F = 1.6	M–3.0	e–4.5	W–6.8		5 = × 100000
G = 1.8	N–3.3	S–4.7	n–7.0		etc.

As shown in Fig. 2.26, values below 100 pF are marked using two numbers from which the capacitance value is read directly. The values above 100 pF are indicated by a letter and a number. In this system, only 24 uppercase letters are used to represent the first two digits in the capacitance value and the number represents the number of zeros to be appended. For example, U1 represents 560 pF and J3 represents 22000 pF.

Value (24 Value Symbols)—Uppercase Letters Only				Multiplier	
A–10	F–16	L–27	R–43	W–68	1 = × 10
B–11	G–18	M–30	S–47	X–75	2 = × 100
C–12	H–20	N–33	T–51	Y–82	3 = × 1000
D–13	J–22	P–36	U–56	Z–91	4 = × 10000
E–15	K–24	G–39	V–62		5 = × 100000
					etc.

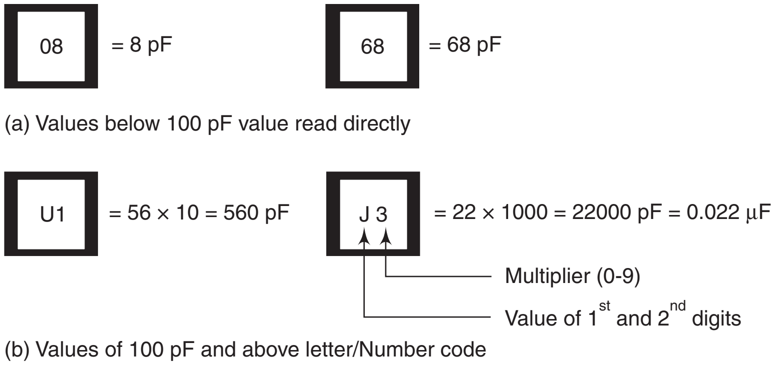


Fig. 2.26 *Alternate two-place code*

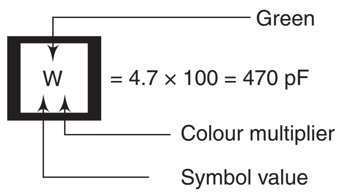


Fig. 2.27 *Standard single place code*

As shown in Fig. 2.27, a single letter or number is used to designate the first two digits in the capacitance value. The multiplier is determined by the colour of the letter. For example, a green-coloured W represents a capacitance of 470 pF. Similarly, an orange-coloured *R* represents 33 pF and a blue coloured 7 represents 8200 pF.

Value (24 Value Symbols)—Uppercase Letters and Numerals					Multiplier
A–1.0	H–1.6	N–2.7	V–4.3	3–6.8	Orange = × 1.0
B–1.1	I–1.8	O–3.0	W–4.7	4–7.8	Black = × 10
C–1.2	J–2.0	R–3.3	X–5.1	7–8.2	Green = × 100
D–1.3	K–2.2	S–3.6	Y–5.6	9–9.1	Blue = × 1000
E–1.5	L–2.4	T–3.9	Z–6.2		Violet = × 10000
					Red = × 100000
					etc.

2.3.5 Connecting Capacitors

- ***Capacitors in Parallel*** Figure 2.28 shows *n*-capacitors connected in parallel. Here, as the effective area of the plates increases, the total equivalent capacitance of the parallel circuit C_{TP} increases with plate area (more charge is stored in the capacitor). Hence, C_{TP} is equal to the sum of the individual capacitances, i.e.,

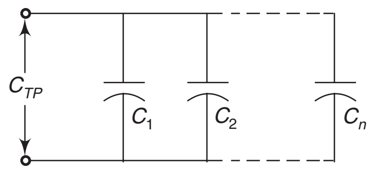


Fig. 2.28 *n-capacitors connected in parallel*

$$C_{TP} = C_1 + C_2 + \cdots + C_n$$

When all capacitors are equal then $C_{TP} = nC$. The relationship for C_{TP} is similar to that for resistors in series.

- ***Capacitors in Series*** Figure 2.29 shows *n*-capacitors connected in series. Here, as the separation of the outer plates of the combination increases, the total equivalent capacitance of the series circuit C_{TS} will be less than the smallest capacitance of the individual capacitors. The value of C_{TS} can be calculated by

$$\frac{1}{C_{TS}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$$

The relationship for C_{TS} is similar to that for resistors in parallel. Considering two capacitors, C_1 and C_2, connected in series, the total equivalent capacitance of the series circuit C_{TS} is equal to their product divided by their sum, i.e.,

$$C_{TS} = \frac{C_1 C_2}{C_1 + C_2}$$

When equal valued capacitors are connected in series, then $C_{TS} = \frac{C}{n}$.

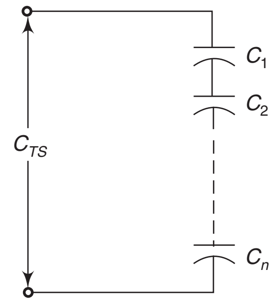


Fig. 2.29 *n-capacitors connected in series*

2.3.6 Characteristics and Applications

The characteristics and applications of various types of capacitors are summarized in Table 2.9.

Table 2.9 *Characteristics and applications of capacitors*

	Type	Approximate capacitance range and tolerance	Power factor	Maximum working voltage (in volts)	Operating temperature	Typical applications
1.	Aluminium electrolytic	(i) 2 µF – 100 µF – 15%	0.02 – 0.2	600	85°C – 125°C	Rectifier filters and smoothing
		(ii) 50 µF – 1000 µF – 15%		50 – 200	-do-	Decoupling and bypassing in a.f.
2.	Tantalum electrolytic	1 µF – 2000 µF – 2.5%	-do-	6 – 150	-do-	Coupling, decoupling, bypassing in amplifiers
3.	Silvered ceramic	2 pF – 0.001 µF 1 – 20%	0.001	350	85°C – 150°C	RF amplifiers, RF bypass, decoupling and resonant circuit
4.	Ceramic with high dieletric constant	50 pF – 0.01 µF – 20%	0.001	350	-do-	-do-
5.	Polystyrene	100 pF – 0.5 µF – 1/2 – 5%	0.002	125 – 500	65°C – 85°C	Resonant, coupling, measuring and ac applications
6.	Polyester	0.005 – 2 µF – 10 – 20%	0.005	500	65°C – 125°C	Coupling, decoupling, smoothing and dc applications
7.	Stacked mica	50 pF – 0.01 µF – 2 – 20%	0.001 – 0.005	2000	85°C – 120°C	RF coupling, bypassing circuits
8.	Silvered mica	10 pF – 0.1 µF – 1/2 – 20%	0.001 – 0.005	1000	85°C – 150°C	RF resonant and measuring circuits
9.	Tubular rolled paper	0.005 µF – 10 – 20%	0.004 – 0.01	1000	85°C – 125°C	AF coupling and decoupling, bypass, filter, motor-start
10.	Metallized paper	0.005 µF – 25%	0.005 – 0.015	400	-do-	-do-
11.	Air/polystyrene variable capacitance	15 pF – 500 pF	1000.0	1000	-do-	Tuning circuits in receivers and transmitters
12.	Mica trimmers and padders	4 pF – 70 pF 100pF – 600pF	—	500	80°C	Tracking and alignment of receivers
13.	Air trimmers	8 pF – 100 pF	—	-do-	-do-	-do-

2.4 INDUCTORS

This is the third passive component used in electronic circuits. It stores energy in the form of magnetic field and delivers it as and when required.

Whenever current passes through a conductor, lines of magnetic flux are generated around it. This magnetic flux opposes any change in current due to the induced e.m.f. This opposition to the change in current is known as inductance and the component producing inductance is known as inductor. The unit of inductance is Henry (symbol H). The induced e.m.f. is actually given by

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Represent induced emf mathematically.

$$e = -L\frac{di}{dt}$$

where e = induced e.m.f. in volts at any instant, L = inductance in Henry, and di/dt = rate of change of current.

The negative sign in the above equation indicates that the induced e.m.f. opposes the cause for the change in current.

An inductor is usually a coil of copper wire wound around a core made up of a ferromagnetic material, as shown in Fig. 2.30. The inductance (L) of the coil is given by

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

where μ_o = permeability of free space = $4\pi \times 10^{-7}$ H/m

= 1.257×10^{-6} H/m

μ_r = relative permeability of the core material

A = area of cross-section of the core

N = number of turns of the coil

l = length of the core

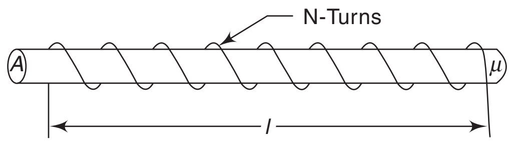

Fig. 2.30 *Inductance of a coil*

Hence, the value of the inductor depends upon the following factors: (i) number of turns, (ii) permeability of the core material, and (iii) size of core.

Inductors can be divided into two categories: (i) fixed inductors, and (ii) variable inductors.

2.4.1 Fixed Inductors

Fixed type inductors can be further divided into three categories depending on the type of core used. They are (i) air-core inductors, (ii) iron-core inductors, and (iii) ferrite-core inductors.

These three types of inductors are shown in Fig. 2.31.

- ***Air-core inductors*** In radio-frequency applications where very low values of inductance (from a fraction of a μH to a few μH) is required, air core inductors are generally used. Air-core inductors consist of a few turns of wire wound on a hollow former.

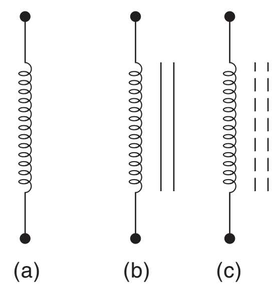

Fig. 2.31 *(a) Air-core inductor, (b) Iron-core inductor, (c) Ferrite-core inductor*

- ***Iron-core inductors*** They have a coil containing a number of turns of copper wire wound on a hallow former and the core material passes through the former in such a way that it forms a closed magnetic path for the magnetic flux. The former is made up of paper or plastic material. The core is generally made up of silicon steel (a ferromagnetic material having high permeability) in the form of thin laminated sheets. Laminated sheets are used instead of solid mass to reduce the hysteresis and eddy-current losses. Iron core transformers are used in low-frequency applications such as filter circuits in power supplies, chokes in fluorescent tubes or as a reactive element in ac circuits. The value of inductors are generally in the order of a few henries.

- ***Ferrite-core Inductors*** Iron-core inductors are not suitable for high-frequency applications (because of enormous increase in hysteresis and eddy-current losses). This difficulty is overcome by the use of ferrite materials as the core. A ferrite is basically an insulator having very high permeability.

Ferrite is made up of non-metallic compounds consisting mainly of ferric oxide in combination with one or two bivalent metal oxides. They are hard, dense ceramics and because of their high resistivity they can be used in the form of solid cores. The values of such inductors is in the range of few μH to few mH.

The typical applications of ferrite-core inductors are in (i) RF chokes for supply decoupling purposes, (ii) switching regulated type dc power supplies, and (iii) various types of filters used in communication equipment.

2.4.2 Variable Inductors

In certain applications such as tuned circuits, it is required to vary the inductance from a minimum value to a maximum value. Ferrite-core variable inductors are generally used for this purpose. In such inductors the hollow former on which the coil is wound has screw threads in the inner hollow portion. Similar matching threads are provided on the ferrite-core which can be screwed in or out of the former. Because of the change of the position of the ferrite-core, the value of the inductance changes. It is maximum when the ferrite-core is fully in. The variable ferrite-core inductor is shown in Fig. 2.32.

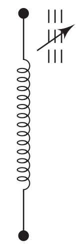

Fig. 2.32 *Variable inductor*

2.4.3 Inductive Reactance

The reactance of an inductor of inductance L at frequency f is given by

$$X_L = 2\pi f L$$

The value of inductive reactance offered by a coil is not constant but depends on frequency of the alternating current passing through it. At higher frequencies, the inductive reactance X_L is large and at lower frequencies, X_L is small. For dc current, i.e., at $f = 0$, $X_L = 0$. Therefore, the inductor allows very low-frequency currents more easily than higher frequency currents. Also, for a given frequency, X_L depends directly on coil inductance L.

2.4.4 Energy Stored in a Magnetic Field

In an inductor, the strength of the magnetic flux is directly proportional to the amount of current flowing through it. If the current flowing through an inductor increases, the strength of the magnetic flux also increases. This increase in flux represents energy taken from the circuit or the applied voltage source. When the current flowing through the inductor decreases, the magnetic flux also decreases. The decrease in magnetic flux returns energy stored in the magnetic field to the circuit. The amount of energy stored is

$$W = \frac{1}{2} L I^2 \text{ (joules)}$$

where L = self-inductance of an inductor, and I = current flowing through an inductor.

The inductor does not dissipate power like resistor. Only when the value of current flowing through the inductor changes, the energy storage in the inductor takes place.

2.4.5 *Q* of an Inductor

Though there is no power loss in an ideal inductor, losses do occur in a practical inductor. These losses are of two types (i) I^2R loss (ohmic loss in the copper wire), and (ii) hysteresis and eddy-current losses in the core.

An equivalent circuit of a practical inductor is shown in Fig. 2.33 in which R_s is the effective resistance of the inductor which accounts for the total losses. The value of impedance (Z) of the practical inductor is given by

Fig. 2.33 *Equivalent circuit of an inductor*

$$Z = \sqrt{R_s^2 + X_{L_s}^2} = \sqrt{R_s^2 + \omega^2 L_s^2}$$

The quantity $$Q = \frac{\omega L_s}{R_s}$$

which is the ratio of the inductive reactance (ωL_s) to the effective resistance is known as the Q of an inductor. This is also called as the quality factor or figure of merit of an inductor.

2.4.6 Mutually Coupled Coils

When two coils are placed very near to each other as shown in Fig. 2.34, the changing magnetic flux of one coil, linking with the other, produces an induced e.m.f. in the other coil. These two coils are then set to have mutual inductance (M), which is expressed in henries (H).

$$M = \frac{\mu_0 \, \mu_r \, A N_1 N_2}{l}$$

where l is the length of the magnetic path.

Let the rate of current change through the first coil be $\frac{di}{dt}$. This changing current will produce a changing magnetic flux through it which will link partly or fully with the second coil. Hence, an induced e.m.f. e_2 will be produced in the second coil, which is given by

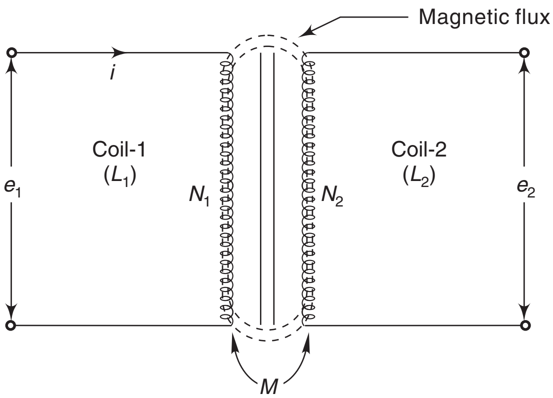

Fig. 2.34 *Mutually coupled coils*

$$e_2 = M \frac{di}{dt}$$

The mutual inductance of a coil depends upon the self-inductances of the coils and the coefficient of coupling between them. The mutual inductance (M) between the two coils can be computed from the equation

$$M = k\sqrt{L_1 L_2}$$

where k = coupling coefficient (there are no units for k), L_1 = self-inductance of coil 1, and L_2 = self-inductance of coil 2.

From the above equation, we get the coupling coefficient,

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

If the magnetic flux produced by one coil does not link with the other coil, then $k = 0$. If all the flux produced by one coil links with the other, then $k = 1$. A coupling coefficient of 1, or 100 per cent coupling is approached only in well-designed iron-core transformers and chokes. In air-core transformers and coils it is very much less but increases in transformers with iron-power and ferrite cores. Air-core coils have k value of 0.05 to 0.3.

2.4.7 Connecting Inductors

- ***Inductors in Series*** The combined inductance of any two coils connected in series aiding and having self-inductances of L_1 and L_2, respectively, will be given by

$$L = L_1 + L_2 + 2M$$

But if the coils are connected in series opposing, their combined inductance will be

$$L = L_1 + L_2 - 2M$$

- ***Inductors in Parallel*** If two coils are connected in parallel with fields aiding, then

$$\frac{1}{L} = \frac{1}{(L_1 + M)} + \frac{1}{(L_2 + M)}$$

And for two coils in parallel with fields opposing, then

$$\frac{1}{L} = \frac{1}{(L_1 - M)} + \frac{1}{(L_2 - M)}$$

Key Terms

Air-core inductors
Barrier-layer capacitors
Capacitors
Carbon-film resistor
Carbon potentiometer
Carbon-composition resistor
Ceramic capacitors
Ceramic disk capacitors
Chip capacitors
Conductors
Connecting capacitors
Connecting inductors
Connecting resistors
Disc capacitor
Dissipation factor
Electrolytic capacitors
Ferrite-core inductors
Film-type capacitors
Five-dot code
Fixed capacitors
Fixed inductors
Impregnated paper capacitor
Inductive reactance
Inductors
Insulators
Iron-core inductors
Metal-film resistor
Metallized paper capacitor
Mica capacitors
Monolithic capacitor
Multiturn wire-wound potentiometer
Mutually coupled coils
Non-polarized electrolytic capacitor
Paper capacitors
Plastic capacitors
Polarized electrolytic capacitor
Polycarbonate capacitors
Polyester capacitors
Polystyrene capacitors
Potentiometer
Q of an inductor
Rheostat
Silvered mica capacitor
Single-turn wire-wound potentiometer
Six-dot code
Specific resistance
Specific resistivity
Stacked mica capacitor
Tantalum capacitors
Thick-film resistor
Thin-film resistor
Three-dot code
Tolerance
Trimmer
Tubular capacitor
Variable capacitors
Variable inductors
Variable resistors
Wire-wound potentiometers
Wire-wound resistor

Review Questions

1. What is meant by resistance? Describe the various types of resistors. ○○●
2. What are the uses of resistors in electronic circuits? ○●●
3. Write short notes on wire-wound resistors. ○●●
4. Describe different types of potentiometers. ○●●
5. Explain the tapering of potentiometers. ○●●
6. Why is colour coding used in resistors? Briefly explain its significance. ●●●
7. What is meant by tolerance in resistors? ○○●
8. Write short notes on: (a) Film resistors (b) Rheostat, and (c) Trimmer. ○●●
9. Explain the action of capacitor for dc and ac voltages. ○●●
10. Define the dielectric strength referred to a capacitor. ○○●
11. List the various capacitors used in electronic circuits and state uses of each type. ○●●
12. Compare the constructional features and characteristics of (a) paper, (b) mica, (c) ceramic, and (d) plastic capacitors. ○●●
13. Describe briefly polarized and non-polarized electrolytic capacitors. ○●●
14. Compare the constructional features and characteristics of aluminium and tantalum electrolytic capacitors. ○●●
15. What are the specifications of a capacitor? State the factors affecting the capacitance of a capacitor. ○●●
16. Explain the various losses of a capacitor. ○●●
17. What is meant by dissipation factor of a capacitor? Explain. ○○●
18. Write short notes on variable capacitors. ○●●
19. Why is colour coding used in capacitors? Briefly explain its significance. ●●●
20. What is meant by tolerance in capacitors? ○○●
21. How is the value of film-type capacitor calculated using colour codes? ●●●
22. How is the value of ceramic disk capacitor determined using colour codes? ●●●
23. How is the value of tantalum capacitor found out using colour codes? ●●●
24. How is the value of mica capacitor represented using colour codes? ●●●
25. Write a short note on the chip capacitors and explain the three popular coding systems used by the different manufacturers of chip capacitors. ○●●
26. What are the factors that influence the value of inductance in an inductor? ○●●
27. Explain fixed inductors in detail. ○●●
28. Write down the applications of various types of inductors. ○●●
29. What are the losses that occur in an inductor? ○○●
30. Explain the quality factor of an inductor. ○●●
31. Classify the inductors and explain briefly. ○●●
32. Inductors and capacitors are energy storage elements—justify. ●●●

Note: ○○● Level 1 & Level 2 category
○●● Level 3 & Level 4 category
●●● Level 5 & Level 6 category

Objective-Type Questions

1. Which one of the following has the ability to act as an open circuit for dc and a short circuit for ac at high frequency?
(a) An inductor (b) A capacitor (c) A resistor (d) None of the above

2. When copper is added to silver in small quantity so as to form an alloy, the resistivity of such an alloy is
(a) equal to the resistivity of copper (b) equal to the resistivity of silver
(c) greater than the resistivity of copper (d) in between the resistivity of silver and copper.

3. Resistors will always __________________energy.
(a) dissipate (b) generate (c) both (d) depends on source

4. If two resistors having same resistance of value R are connected in parallel, what will be the equivalent resistance?
(a) R (b) $2R$ (c) $R/2$ (d) $3R$

5. Resistance of a conductor depends on
(a) length of the conductor (b) resistivity of the material
(c) width of the conductor (d) all of the above

6. If the frequency of ac supply voltage increases, what will happen to impedance offered by the capacitor?
(a) Increase (b) Decrease (c) Remain constant (d) Independent of frequency

7. If two capacitors having same capacitance value C are connected in series, what will be the equivalent capacitance?
(a) $2C$ (b) C (c) $C/2$ (d) $3C/2$

8. For dc voltages, the capacitor will act as
(a) open circuit (b) short circuit (c) normal capacitor (d) none of the above

9. What is the relation between quality factor and dissipation factor of a capacitor?
(a) Linear (b) Quadratic (c) Exponential (d) Inverse

10. The energy consumed by a coil is stored in the form of
(a) an electric field (b) a force field (c) an electrostatic field (d) magnetic field

11. Which of the following is a type of variable resistor?
(a) Potentiometer (b) Resistor (c) Both a and b (d) Wire-wound resistor

12. A capacitor will store energy in the form of
(a) magnetic field (b) electromagnetic field(c) electric field (d) none of these

13. Which of the following is a variable type of capacitor?
(a) Electrolyte capacitor (b) Varicap capacitor
(c) Tuning capacitor (d) All

14. Quality factor of an inductor is
(a) $\dfrac{\omega R}{L}$ (b) $\dfrac{\omega}{RL}$ (c) ωLR (d) $\dfrac{\omega L}{R}$

15. If two inductors L_1 and L_2 are connected in series aiding way, what is the combined inductance?
(a) $L_1 + L_2 - 2M$ (b) $L_1 + L_2 + M$ (c) $L_1 + L_2 - M$ (d) $L_1 + L_2 + 2M$

16. The capacitive reactance X_C is equal to
(a) $\dfrac{1}{2(fC)}$ (b) $2\pi fC$ (c) πfC (d) $\dfrac{1}{\pi fC}$

17. In high-permittivity ceramic capacitors, the permittivity ranges from
(a) 6 to 400 (b) 500 to 4000 (c) 5000 to 30000 (d) 50000 onwards

18. In high-permittivity ceramic capacitors, the capacitance value is limited up to
(a) 0.001 µF (b) 0.01 µF (c) 0.47 µF (d) 2.2 µF

19. The power factor of a capacitor is given by

(a) $\frac{R}{X_c}$ (b) $\frac{R}{\sqrt{R_s^2 + X_c^2}}$ (c) $\frac{X_c}{R}$ (d) $\frac{\sqrt{R_s^2 + X_c^2}}{R}$

20. The dissipation factor of a capacitor is given by

(a) $\frac{R_s}{X_c}$ (b) $\frac{1}{\omega C R_s}$ (c) $\frac{X_c}{R_s}$ (d) $\frac{\sqrt{R_s^2 + X_c^2}}{R}$

21. The quality factor of a capacitor is given by

(a) $\frac{R_s}{X_c}$ (b) $\omega C R_s$ (c) $\frac{X_c}{R_s}$ (d) $\frac{\sqrt{R_s^2 + X_c^2}}{R}$

State whether the following statements are TRUE or FALSE.

22. Trimmer is a type of fixed resistor.
23. Low-permittivity ceramic capacitors can be made to exhibit zero temperature coefficient.
24. Tubular capacitors are used to isolate the antennas in receivers.
25. Ceramic capacitors cannot be used as bypass capacitors.
26. The monolithic capacitor is a type of ceramic capacitor.