Electric Circuit and circuit element

As we know that the electric current is the rate of flow of electric charge (electrons). It is denoted by **I** and its unit is Ampere (A) and a complete path which consist one or more circuit elements and connecting wire and allows flowing electric current is known as electric circuit.

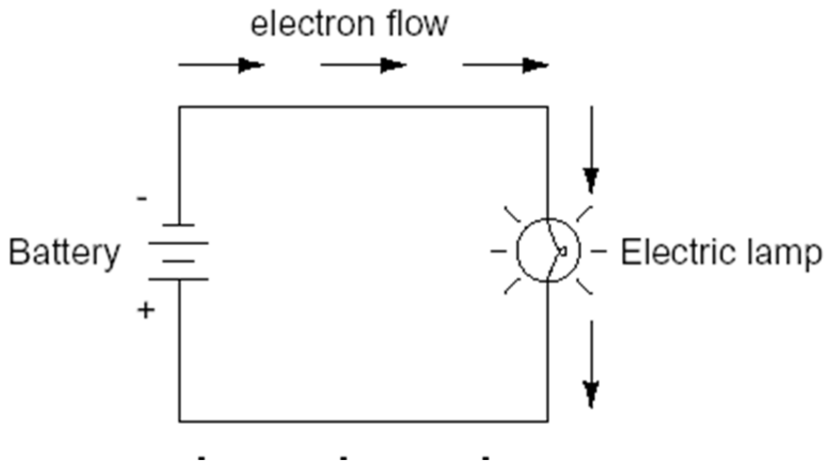


Fig. 1.6 A simple electric Circuit

In this circuit, battery and electric lamp are the circuit elements. Any individual electric component (lamp, battery, generators etc.) with terminals by which it can be connected to other electric components is known as circuit elements. They may be active elements or passive elements. Active elements are capable of delivering electric power to some external devices e.g. current source, voltage source etc. while passive elements are capable of receiving electric power from active elements e.g. resistor, capacitor, inductor etc.

Resistance

It is the property of material to oppose the flow of electric current through it. The opposition of flow of current is due to the presence of large no of atom or molecules of the material through which electrons flow. During the movement of electrons collide with these atoms or molecules. Unit of resistance is ohm (Ω).The most common schematic symbol for a resistor is a zigzag line:

Fig. 1.7 Symbol of resistance

The resistance of a conducting material is found

- To be directly proportional to its length l

- To be inversely proportional to its area of cross-section A
- Depends upon the nature of conducting material and
- Depends upon the temperature.

$$\therefore R \propto \frac{l}{A} \quad \text{Or} \quad R = \rho\frac{l}{A}$$

Where ρ (rho) is a constant of material, called specific resistance or resistivity
For a conductor of length 1m and cross-sectional area $1m^2$, R = ρ.

Hence the resistivity of a material offered by 1m of its length and having cross-sectional area $1m^2$. Its unit is ohm-meter (Ω-m). The reciprocal of resistivity is known as conductivity (σ) and the reciprocal of resistance is known as conductance (G).

The resistance of every material is affected by temperature change. Resistance of metallic conductors increases with rise in temperature. If R_0 and R_t are respectively the resistance of a material at 0^oC and at t^oC, then it has to be found that the change in resistance $(R_t - R_0)$ is directly proportional to:

- Its initial resistance R_0 and
- Rise in temperature t^oC

Thus:

$$\begin{aligned}(R_t - R_0) &\propto R_o t \\ (R_t - R_0 &= \alpha R_0 t\end{aligned} \qquad (0.1)$$

Where α is a constant called temperature coefficient of resistance, and is numerically equal to 'the change in resistance of a unit resistance for unit rise in temperature'

From Eq. 1.1 we get:

$$\alpha = \frac{R_t - R_0}{R_0.t} \qquad (0.2)$$

Or

$$R_t = R_0(1+\alpha t) \qquad (0.3)$$

Effect of temperature on resistivity: Since resistivity (ρ) is the resistance of unit cube of material, so temperature affects the resistivity in the same way as on resistance. The effect of temperature on resistivity may be depicted as:

$$\rho_{t_1} = \rho_0(1+\alpha t_1) \qquad (0.4)$$

$$\rho_{t_2} = \rho_{t_1}(1+\alpha_1(t_2 - t_1)) \qquad (0.5)$$

Where ρ_0,ρ_t, ρ_{t1} and ρ_{t2} are the respective resistivity at 0^0C, t^0C, $t1^0C$, and $t2^0C$, and α_0 and α_1 are the respective temperature coefficient of resistance at 0^0C and in $t1^0C$ and $t2^0C$ temperature range.

Example: 1

A coil consisting of 2000 turns of copper wire has cross-sectional area of $0.8mm^2$. The mean length per turn is 200cm and resistivity of copper is $2x10^{-8}$Ω-m. Calculate the resistance of the coil.

Ans:

Here, $N = 2000$

$A = 8 \times 10^{-7}$ m

$\rho = 2 \times 10^{-8}$ Ω-m

$l = 0.2$ m

Total length L= N x mean length (l) = 2000 x 0.2 = 400 m

$R = \rho \frac{L}{A} = 2x10^{-8} x \frac{400}{8x10^{-7}}$ = **10 Ω**.

Example: 2

The length of a conductor is doubled by stretching it. Calculate the change in resistance of conductor.

Ans:

Let R_1, R_2, $\rho_1, \rho_2, l_1, l_2, A_1$ and A_2 are the resistance, resistivity, length and cross-sectional area of conductor before and after respectively.

We know that $R_1 = \rho_1 \frac{l_1}{A_1}$ and $R_2 = \rho_2 \frac{l_2}{A_2}$

But the total volume of the conductor must be same, so:

$l_1 A_1 = l_2 A_2$ And if $l_2 = 2l_1$, then $A_2 = \frac{A_1}{2}$

$$\therefore R_2 = \rho \frac{l_2}{A_2} = \rho \frac{2l_1}{A_1 / 2} = 4\rho \frac{l_1}{A_1} = 4R_1$$

The resistance of the conductor after doubled by stretching it is **four times** of its initial value.

Example: 3

A silver wire has a resistance of 5.85Ω at 20^{o}C. Calculate its resistance at 50^{o}C. Given that the temperature coefficient of silver is 0.004 /^{o}C at 0^{o}C.

Ans:

For temperature 20^{o}C

$$R_1 = R_0(1 + \alpha t_1)$$

or

$$5.85 = R_0(1 + 0.004x20).........(1)$$

For temperature 50^{o}C

$$R_2 = R_0(1 + 0.004x50).........(2)$$

Then dividing eq. 2 by eq. 1, we get

$$\frac{R_2}{5.85} = \frac{1 + 0.004x50}{1 + 0.004x20}$$

or

$$R_2 = \frac{1.2}{1.08} x 5.85$$
$$\therefore R_2 = 6.5\Omega$$

Example: 4

The resistance of the conductor is 3.60Ω at 20^{0}C. What will the resistance at 80^{o}C? Given that the temperature coefficient of silver is 0.00393 /^{o}C at 20^{o}C.

Ans:

We have

$$R_2 = R_1(1+\alpha(t_2 - t_1))$$

or

$$R_2 = 3.6[1+0.00393(80-20)]$$
$$\therefore \text{R2} = \mathbf{4.45\Omega}$$

Resistor:

The circuit component which has the properties of resistance is called resistor. In other words the resistor is the manufactured version of resistance.

Types of Resistors:

Carbon resistor: They are made of finely ground particles of carbon mixed with ceramic material and enclosed in an insulating material. They are compact, easy to manufacture and cheap. They are widely used in electronic devices and circuits e.g. radio, TV, telephone set etc.

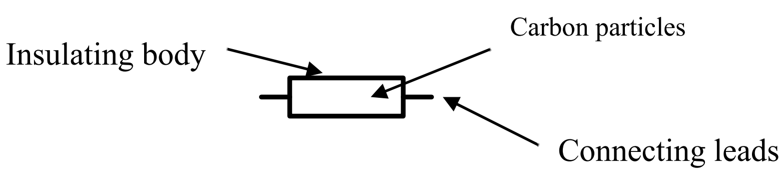


Fig. 1.7 Carbon resistor

Wire wound resistors: They consist of uniform wire wound insulating material. The resistance of this kind of resistor is very accurate. Rheostat used in laboratory is the example of wire wound resistors.

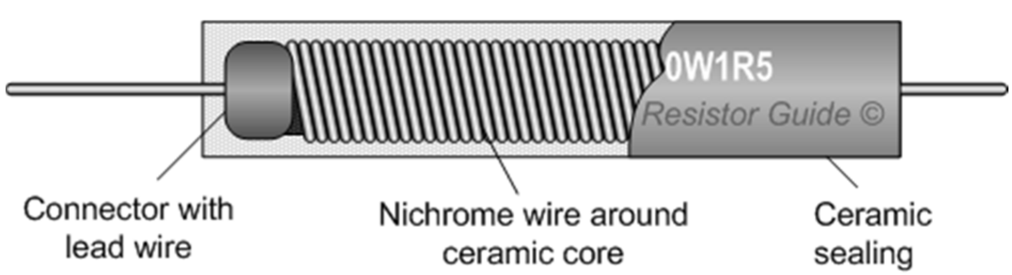


Fig. 1.8 wire wound resistor

Film resistors: Thin layer of resistive material (carbon composition) is deposited on the insulating base to make a film resistor. Film resistors are very compact and accurate. They are widely used in integrated circuits (**IC**s).

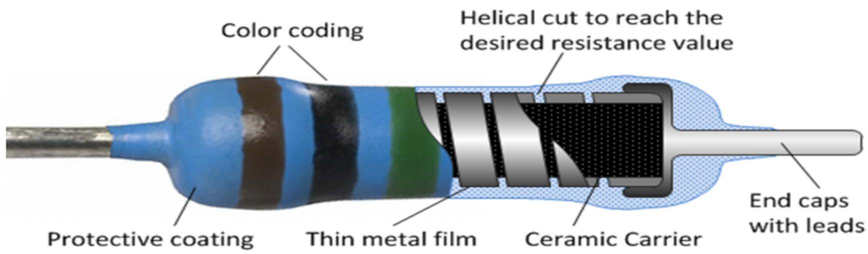


Fig. 1.9 Film Resistor

Variable resistor (Potentiometer): They are made of thin layer of carbon composition deposited on an insulating base. A third contact called slider is provided to vary the resistance between fixed terminal and slider terminals. They may be sliding type (as equalizer in cassette player) or rotary type (as volume controller of radio).

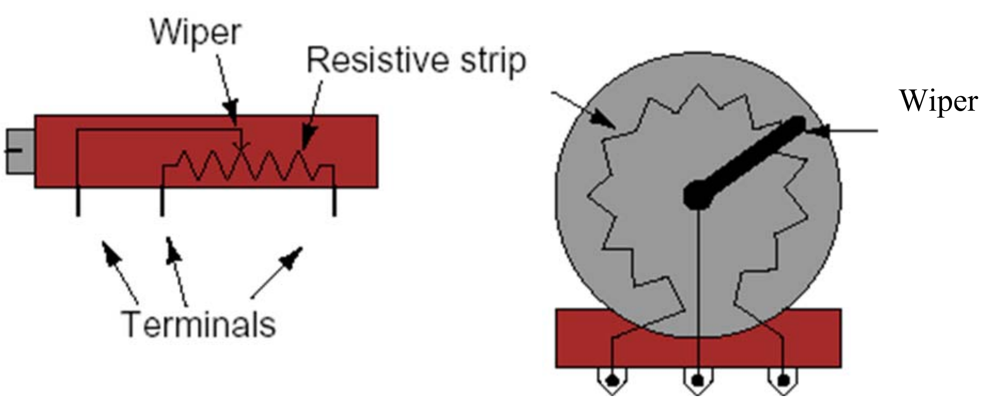
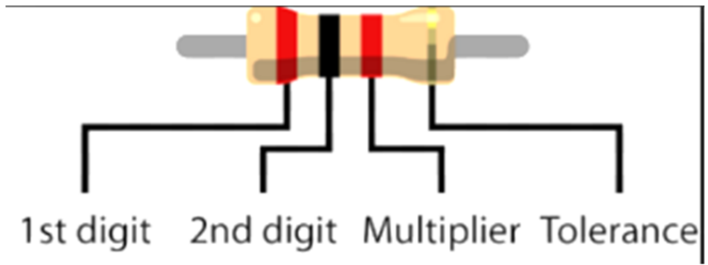


Fig. 1.10 linear and rotary type potentiometers

Color Coding of resistance



Color	Digit	Multiplier	Tolerance (%)
Black	0	10^0 (1)	
Brown	1	10^1	1
Red	2	10^2	2
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	0.5
Blue	6	10^6	0.25
Violet	7	10^7	0.1
Grey	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
(none)			20

A resistor colored **Yellow-Violet-Orange-Gold** would be 47 kΩ with a tolerance of +/- 5%.
47×10^3 +/- 5% or 47 kΩ +/- 5%.

A resistor colored Green-Red-Gold-Silver would be 5.2 Ω with a tolerance of +/- 10%.

A resistor colored Brown-Green-Grey-Silver-Red would be 1.58 Ω with a tolerance of +/- 2%.

Inductance

Inductance is the property of a coil which opposes any change in current flowing through the coil. It is denoted by L and its unit is Henry (H).

Inductor:

It is a two terminal circuit element which has the capacity to store energy in the form of magnetic field. Inductors are made by winding the conductor around a core. The core may be magnetic or non-magnetic material. The value of inductance of the inductor depends upon the geometry of the coil and the permeability μ of the core.

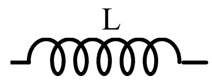


Fig.1.11 Symbol of inductor

Capacitance

Capacitance is the property of a system of insulated conductors in which energy can be stored in the form of electric charge. It is denoted by C and unit of capacitance is Farad (F).

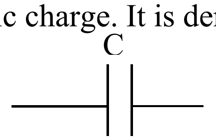


Fig.1.12 Symbol of capacitor

Capacitor:

It is the electrical device that can shows the properties of capacitance. It consists of two conducting plates separated by insulator. The capacitance of a capacitor is directly proportional to the area of the plate and inversely proportional to the distance between them.

$$C \propto \frac{A}{d} \Rightarrow C = \varepsilon \frac{A}{d} \text{ Farad}$$

One Farad is the capacitance of a capacitor that can store 1 Coulomb of charge when applied potential difference to capacitor is 1 Volt.

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

According to types of the dielectric material used in capacitor, they are classified as air capacitor, mica capacitor, ceramic capacitor, paper capacitor, electrolytic capacitor etc.

Air Capacitor: It has two sets of metal plates; one set is fixed; while other is movable. Air is the dielectric medium between the plates. The capacitance of this type of capacitor range 10μF to 400μF. The capacitance can be varied easily by moving the knob of the set of movable plates.

Paper Capacitor: Two rolls of tin, aluminum or copper foil conductors are separated by a tissue paper are rolled into a compact cylindrical form to make a paper capacitor. The capacitance of these capacitors range from 500pF to 1000pF.They can be used for both ac and dc circuit.

Mica Capacitor: In these capacitors thin mica sheets are staked between two aluminum or tin foils, to provide required capacitance. The entire unit is generally molded in the Bakelite case. They are used for greater accuracy and high voltage. Their capacitance ranges from 5pF to 500pF.

Ceramic Capacitor: It consists of disc of ceramic material (usually barium titanate, or talk or hydrous silicate), whose parallel surface are coated with metallic silver. These capacitors are very versatile, since they possess very low power factor. There capacitance range from 3pF to 2µF. They can be used for both ac and dc circuit.

Electrolytic Capacitors: They employ an electrolyte as a dielectric. They consist of an aluminum cylinder containing an electrolyte like ammonium borate which also acts as cathode. An aluminum anode is suspended inside the electrolyte. When current is passed through two electrodes a thin film of aluminum oxide (Al2O3) is formed on the surface of the aluminum cathode. The oxide film acts as a dielectric. These capacitors are mainly used where very high value of capacitance is required.