8.3 CONDUCTION CURRENT AND DISPLACEMENT CURRENT

Physical Interpretation

Consider a parallel plate capacitor is connected to an alternating generator through a resistance in series circuit as shown in fig. (1). We know that in a series circuit, the

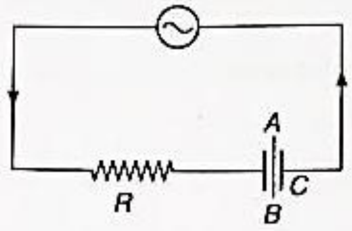

Fig. (1)

current has the same value at all cross-sections. The conduction current which is due to electrical charges is same at all cross-sections of the circuit except at all cross-sections (such as AB) of the dielectric inside capacitor. The dielectric is air with permittivity ε_0. It is important to mention here that conduction electrons (free electrons) are flowing into one plate of the capacitor and forcing other free electrons out of the second plate. Therefore, *there is no flow of free electrons through the dielectric.* In other words, we can say that there is a discontinuity of the current in the space between the plates of a capacitor. Now the question is that how this discontinuity of the current can be explained. In order to remove this discontinuity J.C. Maxwell revised and extended the definition of current by introducing the idea of *displacement current.*

Let at any particular instant, q be the charge on capacitor plate. The conduction current (i_c) is defined as the time rate of flow of charge; *i.e.*,

$$i_c = \frac{dq}{dt} \qquad ...(1)$$

We have studied the electrical displacement D in dielectrics. The electrical displacement D is given by

$$D = \sigma = \frac{q}{A} \qquad ...(2)$$

where σ is the surface charge density and A is the area of each plate.

From eq. (2), $q = DA$ ...(3)

Substtituting the value of q from eq. (3) in eq. (1), we get

$$i = \frac{d}{dt}(DA) = A\frac{dD}{dt} \qquad ...(4)$$

Maxwell suggested that the term $A\,(dD/dt)$ should be considered as the current inside the dielectric. This current is called as *displacement current* and is denoted by i_d. Therefore,

$$\boxed{i_d = A\frac{dD}{dt}} \qquad ...(5)$$

Consequently, the displacement current density $\mathbf{J}_d$ is given by

$$\boxed{\mathbf{J}_d = \frac{d\mathbf{D}}{dt}} \qquad ...(6)$$

The vector **D** may vary with space, hence

$$\boxed{\mathbf{J}_d = \frac{\partial \mathbf{D}}{\partial d}} \qquad \text{...(7)}$$

Thus, inside the dielectric, there will be a displacement current i_d which is equal to conduction current i in the line.

Important points

(1) The concept of conduction current and displacement current are shown in fig. (2).

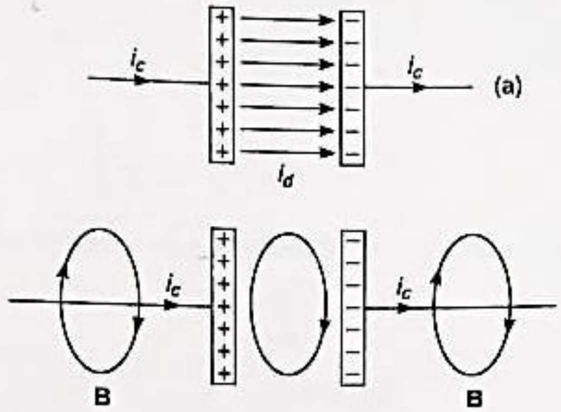

Fig. (2) Concepts of conduction and displacement current

(2) The conduction current i_c flows from one plate to another plate of the capacitor through conducting wires. Maxwell suggested that during time varying electric field between the plates of the capacitor, an electric current, called the displacmeent current i_d, also flows across the space between the plates of the capacitor.

(3) The displacement current density $\mathbf{J}_d$ does not represent a current which directly passes through the capacitor. It is only the apparent current representing the rate at which flow of charge takes place from one plate to another plate. Hence, the term displacement is justified.

(4) The conduction current and displacement current are equal, *i.e.*,

$$i_c = i_d$$

(5) Like conduction current, the displacement current is also a source of magnetic field.

(6) In good conductors, the displacement current is negligible small as compared to conduction current at frequencies less than optical frequencies. At ultra high frequencies, the displacement current in conductors become quite important.

(7) The displacement current exists only so long as electric field **E** is changing with time, *i.e.*, displacement **D** is changing with time. When the capacitor is fully charged upto the value of applied e.m.f., the current in the line drops to zero. Now, the electric field **E** between the plates of the capacitor attains as steady value. As a result, $(d\mathbf{E}/dt)$ and $(d\mathbf{D}/dt)$ becomes zero.

(8) The displacement current is called a current in the sense that it has the same dimensions as that of current.