DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB101J-Electromagnetic Theory, Quantum Mechanics, Waves and Optics

Module I

Concept of electric current (conduction and displacement current and current density)

Electric current

Electric Current is defined as the rate of flow of net charge through the conductor with respect to time. It is the flow of charge per unit time.

If Q current is flowing through any cross sectional area of conductor in time t then electric current

$$\mathbf{I = Q/t}$$

The SI unit of charge is Columb. Columb is denoted as C. SI unit of time is second, therefore the SI unit of current is Columb/second. Columb / second is also known as Ampere.

Current density (J)

Current density is defined as the ratio of the current to the surface area whose plane is normal to the direction of charge motion. It is denoted by ***J*** and the current density is given by,

$$\boldsymbol{J} = \frac{dI}{ds} \text{ (or) } dI = \boldsymbol{J} \cdot \boldsymbol{ds}$$

Conduction Current Density (J_1)

The current density due to the conduction electrons in a conductor is known as the conduction current density.

By ohms law, the potential difference across a conductor having resistance R and current I is,

$$V = IR \tag{1}$$

For a length l and potential difference V,

$$V=El \tag{2}$$

where E = electric field intensity.

From equations (1) and (2),

$$IR = El \tag{3}$$

But $$R = \rho \frac{l}{A} = \left(\frac{1}{\sigma}\right)\left(\frac{l}{A}\right) \tag{4}$$

where ρ and σ are the electrical resistivity and conductivity respectively.

Using equation (4) in (3), $$I\left(\frac{l}{\sigma A}\right) = E.l$$

(or) $$\frac{I}{\sigma A} = E \text{ (or) } \left(\frac{I}{A}\right) = \sigma E \text{ (or) } \vec{J}_1 = \sigma \vec{E} \tag{5}$$

$\vec{J}_1$ may be referred to as conduction current density, which is directly proportional to the electric field intensity.

Displacement Current Density $(\vec{J_2})$

There is no direct current in a circuit containing capacitor while an alternating current can flow in it. The conduction current due to the motion of electrons cannot pass through a capacitor as its plates are separated by a dielectric.

As the current does not pass through the capacitor so we have to conclude that in a capacitor a certain process closes the conduction current, i.e. it enables in someway the charge exchange between the capacitor plates without actually transporting a charge between the plates.

The current associated with this process is called as displacement current. The displacement current per unit area is known as displacement current density.

In a capacitor, the current is given by,

$$I_c = \frac{dQ}{dt} = \frac{d(CV)}{dt} = C.\frac{dV}{dt} \qquad (1)$$

where Q, C and V represents charge across the plates, capacity and potential difference across the plates of the capacitor respectively.

In a parallel plate capacitor, the capacitance is given by,

$$C = \frac{\varepsilon A}{d} \qquad (2)$$

where ε, A and d represents electric permittivity, area of the plates of the dielectric filled capacitor and distance between the plates of the capacitor respectively.

Using equation (2) in (1)

$$I_C = \left(\frac{\varepsilon A}{d}\right).\frac{dV}{dt} \, (or) \, \frac{I_C}{A} = \frac{\varepsilon}{d}.\frac{dV}{dt}$$

J_2 = Displacement current density = $\varepsilon\left[\frac{d}{dt}\left(\frac{V}{d}\right)\right] = \varepsilon \frac{dE}{dt} = \frac{d(\varepsilon E)}{dt}$

$$\vec{J_2} = \frac{d\vec{D}}{dt}$$ [since $\vec{D} = \varepsilon\vec{E}$ = electric displacement vector]

This is not a current, which directly passes through a capacitor, and is only an apparent current representing the rate at which the flow of charge takes place from electrode to electrode in the external circuit. Hence the "displacement" is justified.