ANTENNAS , WAVE PROPAGATION &TV ENGG

Topics to be covered

- Radiation from an electric dipole

2.16 SHORT ELECTRIC DIPOLE (OR HERTZIAN DIPOLE)

A linear antenna can be regarded as a large number of very infinitesimally short cond connected in series (end to end) and hence it is important first to consider the rad properties of such short conductors. A short linear conductor is so short that c may be assumed to be constant throughout its length as shown in Fig. 2.18. Thi of short linear conductor is known as ***"Short dipole"*** or ***"Hertzian dipole"***, aft German physicist Heinrich Hertz.

Definition. *Hertzian dipole is a hypothetical antenna and is defined as a isolated conductor carrying uniform alternating current.*

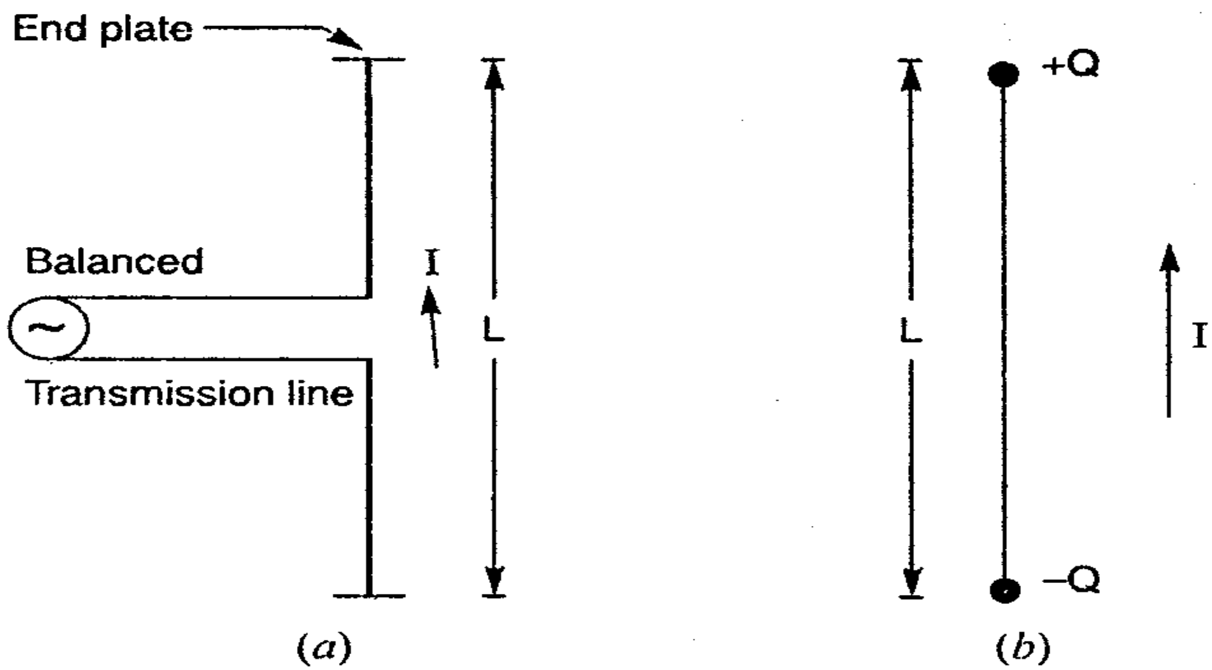

Fig. 2.18. A short dipole and its equivalent

A physical equivalent of short dipole is shown in Fig. 2.18(*b*) in which two ends of the dipole are represented by two spheres where charges are accumulated. If I be the current then it is related to charge as

$$I = \frac{dQ}{dt} \qquad ...(2.161)$$

The electrically short dipole is theoretically the simplest and the most important structure. The term short dipole is commonly applied to any dipole no longer than 0.1λ. A short dipole that does not have a uniform current is known as ***Elemental dipole*** and is generally shorter than $\frac{1}{10}$th λ. Elemental dipole are also known as *elementary dipole, elementary doublet* and *Hertzian dipole.*

When the length of the short dipole is vanishingly small, the term *infinitesimal dipole* is used. If dL be the infinitesimally small length and I be the current, then $\vec{I}\ \vec{dL}$ is called as ***current element.***

Since $I = I_0 \sin \omega t$ or $I_0 \cos \omega t$ ...(2.162*a*)

Current element $IdL = I_0\, dL \sin \omega t$ or $I_0\, dL \cos \omega t$ ...(2.162*b*)

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Current element $IdL = I_0\, dL \sin \omega t$ or $I_0\, dL \cos \omega t$ ...(2.162*b*)

Initially, a short dipole is in neutral condition. When a current (flow of electric charge) starts to flow in one direction, one half of the dipole acquires an excess charge and the other half a deficit, thereby causing a potential difference (voltage) between the two halvs of the dipole. When the current changes its direction this charge unbalance will first be neutralized and then changed.

Thus, the oscillating current will result in an oscillating voltage as well or vice-versa. If the current oscillation is sinusoidal, the voltage oscillation will also be sinusoidal and approximately 90° lagging the current in phase angle, i.e., a short dipole is capacitive in nature from current voltage relation point of view.

As electric charge oscillates in such short dipoles, they may also be called as *oscillating electric dipoles as against oscillating magnetic dipoles.*

RADIATION FROM A SHORT ELECTRIC DIPOLE

2.18 RADIATION FROM A SMALL CURRENT ELEMENT

An alternating current element or oscillating electric dipole possesses electromagnet field and now we will find these fields everywhere around in free space using tl concept of retarded vector potential. Let the elemental length (dL) of the wire l placed at the origin of the spherical co-ordinate and I be current flowing through it a shown in Fig. 2.20. The length is so short that current is constant along the length.

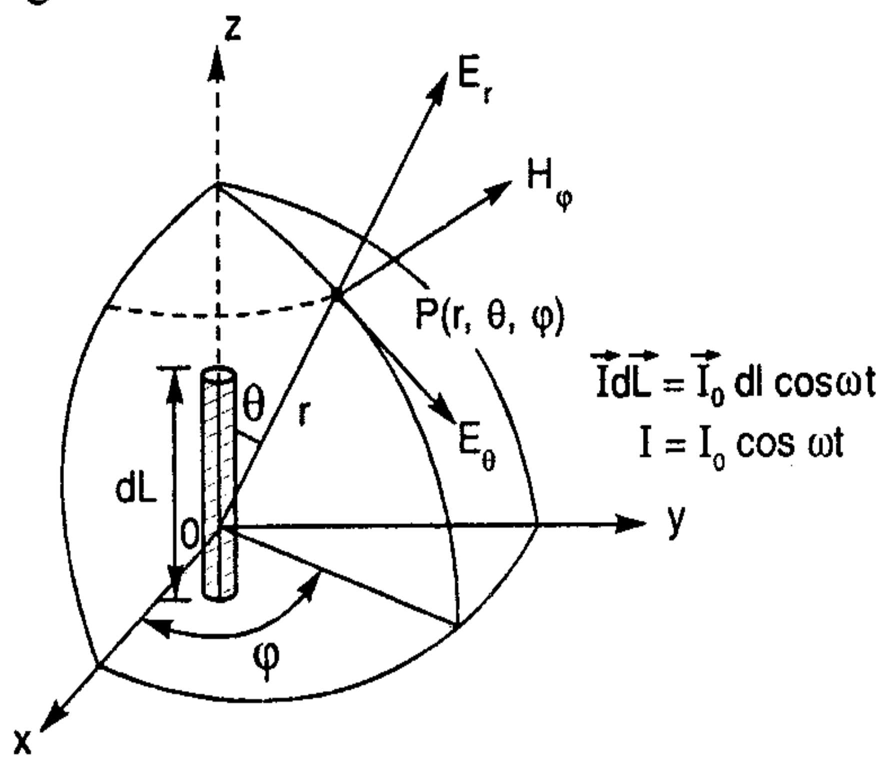

Fig. 2.20. Current element (IdL) at the origin of

2.18.1 Magnetic Field Components

To find the electromagnetic field at any arbitrary point $P(r, \theta, \phi)$, first we will calcul the vector potential $\vec{\mathbf{A}}$. The general expression for magnetic vector potential is giv by

i.e.,
$$\vec{\mathbf{A}}(r) = \frac{\mu}{4\pi} \int \frac{\vec{\mathbf{J}}\left(t - \frac{r}{c}\right)}{r} \, dv \qquad \text{...(2.16}$$

The vector potential $\vec{\mathbf{A}}$ is acting along z direction so it will have only z compon e.g., A_z retarded in time by (r/c) seconds. Since the current element is excited **by t** current $I = I_0 \cos \omega t$, so $\int_V \vec{\mathbf{J}} \, dv$ in Eqn. (2.169) may be replaced by $I \, dl$, **thus**

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$$\vec{\mathbf{A}}_z = \frac{\mu}{4\pi} \int \frac{I_0\, dL \cos\omega\left(t - \frac{r}{c}\right)}{r} \qquad \text{...(2.17}$$

$$\because \qquad A_z = \frac{\mu}{4\pi} \int_V \frac{\vec{\mathbf{J}}\left(t - \frac{r}{c}\right) dv}{r}$$

$$= \frac{\mu}{4\pi} \int_V \frac{\vec{\mathbf{J}}\left(t - \frac{r}{c}\right)\, \vec{ds}\ \vec{d\mathbf{l}}}{r} = \frac{\mu}{4\pi} \int \frac{I\left(t - \frac{r}{c}\right)\, \vec{d\mathbf{l}}}{r}$$

$$= \frac{\mu}{4\pi} \int \frac{I_0 \sin \omega \left(t - \frac{r}{c}\right) \; d\vec{\mathbf{l}}}{r}$$

$$= \frac{\mu}{4\pi} \frac{I_0}{r} \int \sin \omega \left(t - \frac{r}{c}\right) dL \qquad \because I = \int \vec{\mathbf{J}} \; d\vec{\mathbf{s}}$$

$$= \frac{\mu}{4\pi} \int \frac{I_0 \cos \omega \left(t - \frac{r}{c}\right) dL}{r}$$

Now the magnetic field intensity $\vec{\mathbf{H}}$ is obtained from the magnetic vector potential.

$$\boxed{\vec{\mathbf{B}} = \nabla \times \vec{\mathbf{A}} = \mu \vec{\mathbf{H}}} \qquad \text{...(2.171)}$$

As field is symmetrical in X-Y plane and so, $\frac{\partial}{\partial \varphi} = 0$. From Figs. 2.20 and 2.21 it is seen that components of $\vec{\mathbf{A}}$ are

$$\left.\begin{aligned} \frac{\partial}{\partial \varphi} &= 0 \\ A_\varphi &= 0 \\ A_r &= A_z \cos \theta \\ A_0 &= -A_z \sin \theta \end{aligned}\right\} \qquad ...(2.172)$$

where A_z is given by Eqn. (2.170).

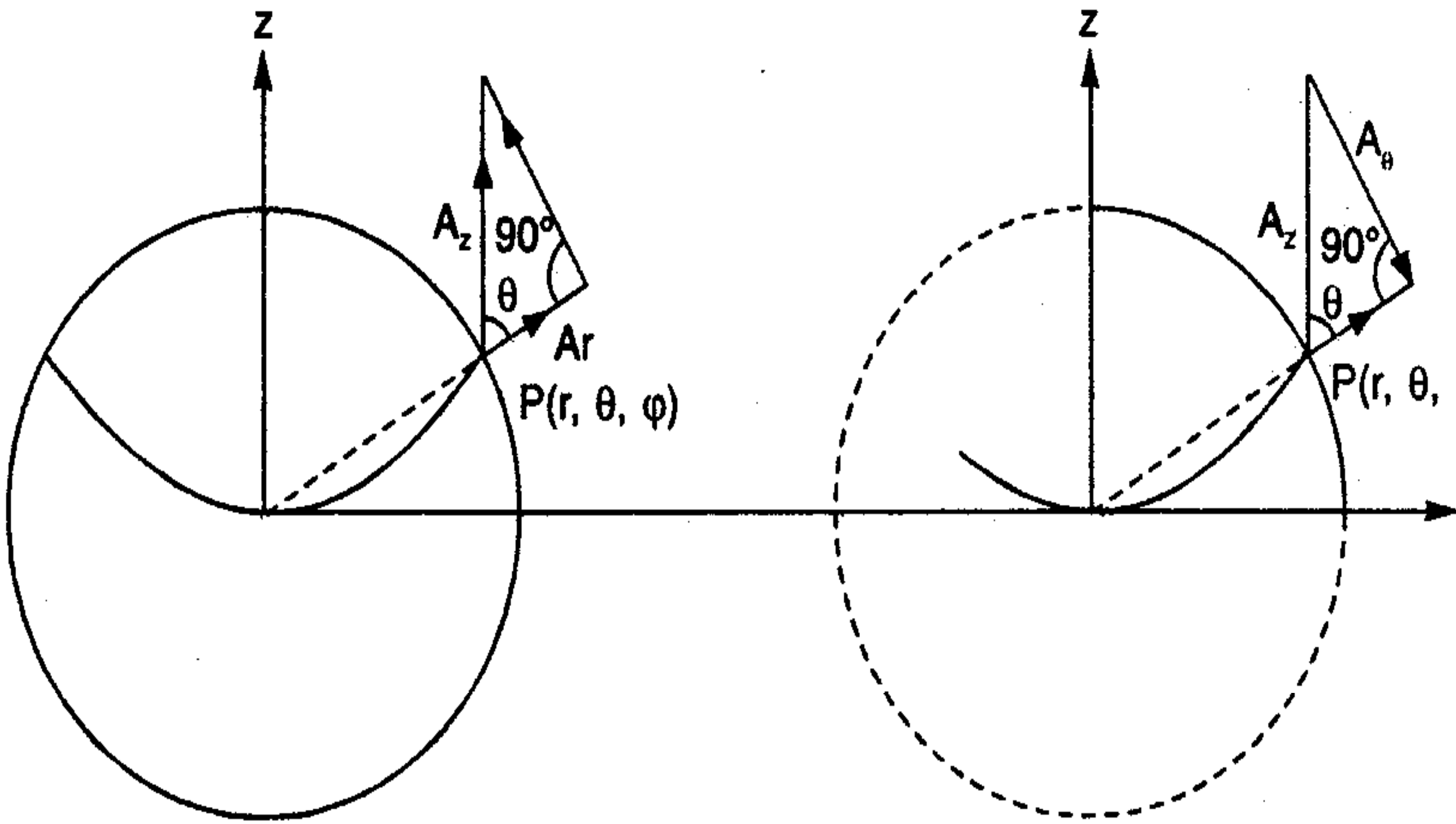


Fig. 2.21. Resolution of vector potential at point $P(r, \theta, \varphi)$ of Fig. 2.20.

Now from $(\nabla \times A)$ in its polar component and using eqn. (2.172), we get

$$(\nabla \times \vec{\mathbf{A}})_r = \mu H_r = 0 \quad i.e., \quad \boxed{H_r = 0} \qquad ...(2.173a)$$

$$(\nabla \times \vec{\mathbf{A}})_\theta = \mu H_\theta = 0 \quad i.e., \quad \boxed{H_\theta = 0} \qquad ...(2.173b)$$

and $$(\nabla \times \vec{\mathbf{A}})_\varphi = \frac{1}{r}\left[\frac{\partial}{\partial r}\left(A_\theta\, r - \frac{\partial A_r}{\partial \theta}\right)\right] = \mu\, H_\varphi$$

or $$\mu\, H_\varphi = \frac{1}{r}\left[\frac{\partial}{\partial r}\{-A_z \sin\theta, r\} - \frac{\partial}{\partial \theta}\{A_z \cos\theta\}\right]$$

Now solving the bracket terms :

Since $A_\theta = -A_z \sin\theta = -\dfrac{\mu\, I_0\, dL \cos\omega\,[t-(r/c)]}{4\pi r}\,.\sin\theta$ [from Eqn. **(2.17**

or $$\frac{\partial}{\partial r}(r\, A_\theta) = -\frac{\partial}{\partial r}\left[\frac{\mu\, I_0\, dL \cos\omega\,[t-(r/c)]\sin\theta}{4\pi}\right]$$

$$= +\frac{\mu\, I_0\, dL \sin\theta}{4\pi}\,.\,\frac{\partial}{\partial r}\left[\cos\omega\left(t-\frac{r}{c}\right)\right]$$

$$= \frac{\mu\, I_0\, dL \sin\theta}{4\pi}\left[-\sin\omega\left(t-\frac{r}{c}\right)\left(-\frac{\omega}{c}\right)\right]$$

$$= \frac{\mu\, I_0\, dL \sin\theta}{4\pi}\left[-\sin\omega\left(t-\frac{r}{c}\right)\left(-\frac{\omega}{c}\right)\right]$$

$$\boxed{\frac{\partial}{\partial r}(r\, A_\theta) = \left[\frac{-\mu\, I_0\, dL \sin\theta\omega\, \sin\omega\left(t-\frac{r}{c}\right)}{4\pi c}\right]} \qquad \text{...(2.17}$$

$$A_r = A_z \cos\theta = \frac{\mu\, I_0\, dL \cos\omega\left(t-\frac{r}{c}\right)\cos\theta}{4\pi r}$$

$$\boxed{\frac{\partial}{\partial\theta}(A_r) = \frac{\mu I_0 dL}{4\pi r}\cos\omega\, t_1\, \{-\sin\theta\}}$$

or

$$\frac{\partial}{\partial r}(A_r) = -\frac{\mu I_0 dL}{4\pi r}\cos\theta\cos\omega\, t_1 \qquad \text{...(2.17}$$

or $$\frac{\partial}{\partial r}(A_r) = -\frac{\mu I_0 dL}{4\pi r}\cos\theta\cos\omega t_1 \qquad \text{...(2.1}$$

$$[\vec{\mathbf{H}}] = H_\varphi = \frac{1}{\mu r}\left[-\frac{\mu I_0 dL\omega}{4\pi c}(\sin\theta\sin\omega t_1) - \left\{\frac{-\mu I_0 dL}{4\pi r}\times\sin\theta\cos\omega t_1\right.\right.$$

$$\boxed{H_\varphi = \frac{I_0 dL\sin\theta}{4\pi}\left[-\frac{\omega\sin\omega t_1}{cr} + \frac{\cos\omega t_1}{r^2}\right]} \qquad \text{...(2.1}$$

where $t_1 = t - \frac{r}{c}$.

2.18.2 Electric Field Components

To calculate the components of $\vec{\mathbf{E}}$ $(E_r, E_\theta, E_\varphi)$ we will use Maxwell's equation,

$$\nabla\times\vec{\mathbf{H}} = \frac{\partial\vec{\mathbf{D}}}{\partial t} = \varepsilon\frac{\partial\vec{\mathbf{E}}}{\partial t} \qquad [\because\ \vec{\mathbf{D}} = \varepsilon$$

Now writing the above equation in its components form we get

$$\varepsilon \frac{\partial E_r}{\partial t} = (\nabla \times \vec{\mathbf{H}})_r = \frac{1}{r\sin\theta}\left[\frac{\partial}{\partial\theta}(H_\varphi \sin\theta) - \frac{\partial}{\partial\theta}(H_\theta)\right] \qquad \text{...(2.177}a\text{)}$$

$$\varepsilon \frac{\partial E_\theta}{\partial t} = (\nabla \times \vec{\mathbf{H}})_\theta = \frac{1}{r}\left[\frac{1}{\sin\theta}\left(\frac{\partial Hr}{\partial\theta}\right) - \frac{\partial}{\partial r}(H_\phi r)\right] \qquad \text{...(2.177}b\text{)}$$

$$\varepsilon \frac{\partial E_\varphi}{\partial t} = (\nabla \times \vec{\mathbf{H}})_\varphi = \left[\frac{\partial}{\partial r}(H_\theta r) - \frac{\partial H_r}{\partial\theta}\right] \qquad \text{...(2.177}c\text{)}$$

Putting Eqn. (2.173) (a, b) into eqn. (2.177), we get

$$\varepsilon \frac{\partial E_r}{\partial t} = (\nabla \times \vec{\mathbf{H}})_r = \frac{1}{r\sin\theta}\left[\frac{\partial}{\partial\theta}(H_\phi \sin\theta)\right] \qquad \text{...(2.178}a\text{)}$$

$$\varepsilon \frac{\partial E_r}{\partial t} = (\nabla \times \vec{\mathbf{H}})_r = \frac{1}{r\sin\theta}\left[\frac{\partial}{\partial\theta}(H_\phi \sin\theta)\right] \qquad \text{...(2.178}a\text{)}$$

$$\varepsilon \frac{\partial E_r}{\partial t} = \frac{1}{r\sin\theta}\left[\frac{\partial}{\partial\theta}\left\{\frac{I_0 dL \sin^2\theta}{4\pi}\left(\frac{-\omega\sin\omega t_1}{cr} + \frac{\cos\omega t_1}{r^2}\right)\right\}\right]$$

or
$$\varepsilon \frac{\partial E_r}{\partial t} = \frac{1}{r\sin\theta}\left[\frac{I_0 dL}{4\pi}\left\{\frac{-\omega\sin\omega t_1}{cr} + \frac{\cos\omega t_1}{r^2}\right\}\frac{\partial}{\partial\theta}(\sin^2\theta)\right]$$

or
$$\varepsilon \frac{\partial E_r}{\partial t} = \frac{1}{r\sin\theta}\left[\frac{I_0 dL}{4\pi}\left\{\frac{-\omega\sin\omega t_1}{cr} + \frac{\cos\omega t_1}{r^2}\right\}2\sin\theta\cos\theta)\right]$$

or
$$\frac{\partial E_r}{\partial t} = \frac{2 I_0 dL\cos\theta}{4\pi\varepsilon}\left[\frac{-\omega\sin\omega\, t_1}{cr^2} + \frac{\cos\omega\, t_1}{r^3}\right]$$

or
$$\int \partial E_r = \frac{2 I_0 dL\cos\theta}{4\pi\varepsilon}\int\left[\frac{-\omega\sin\omega\, t_1}{cr^2} + \frac{\cos\omega\, t_1}{r^3}\right]dt$$

or
$$E_r = \frac{2I_0 dL\cos\theta}{4\pi\varepsilon}\left[\frac{+\omega\sin\omega\, t_1}{cr^2\omega} + \frac{\sin\omega\, t_1}{\omega r^3}\right]$$

or
$$E_r = \frac{2I_0 dL\cos\theta}{4\pi\varepsilon}\left[\frac{\cos\omega\, t_1}{cr^2} + \frac{\sin\omega\, t_1}{\omega r^3}\right] \qquad ...(2.179)$$

$$\varepsilon\frac{\partial E_\theta}{\partial t} = (\nabla \times \vec{\mathbf{H}})_\theta = \frac{1}{r}\left[-\frac{\partial}{\partial r}(H_\phi r)\right] \qquad ...(2.180)$$

$$\varepsilon\frac{\partial E_\theta}{\partial t} = -\frac{1}{r}\frac{\partial}{\partial r}\left[\frac{I_0 dL\sin\theta}{4\pi}\left(\frac{\omega\sin\omega\, t_1}{cr} + \frac{\cos\omega\, t_1}{r^3}\right)r\right]$$

$$= \frac{1}{r}\frac{\partial}{\partial r}\left[\frac{I_0 dL\sin\theta}{4\pi}\left(+\frac{\omega\sin\omega\, t_1}{c} + \frac{\cos\omega\, t_1}{r}\right)\right]$$

$$\varepsilon\frac{\partial E_\theta}{\partial t} = \frac{I_0 dL\sin\theta}{4\pi r}\left[\frac{\partial}{\partial r}\left(\frac{\omega\sin\omega\, t_1}{c}\right) - \frac{\partial}{\partial r}\left(\frac{\cos\omega\, t_1}{r}\right)\right]$$

$$\varepsilon\frac{\partial E_\theta}{\partial t} = \frac{I_0 dL\sin\theta}{4\pi r}\left[+\frac{\omega}{c}\cos\omega\, t_1\left(-\frac{\omega}{c}\right) - \frac{\left\{r\frac{\partial}{\partial r}\cos\omega\, t_1 - \cos\omega\, t_1\right\}}{r^2}\right]$$

or

$$\frac{\partial E_\theta}{\partial t} = \frac{I_0 dL\sin\theta}{4\pi\varepsilon r}\left[-\frac{\omega^2}{c^2}\cos\omega\, t_1 - \left\{\frac{-r\sin\omega\, t_1\left(-\frac{\omega}{c}\right) - \cos\omega t_1}{r^2}\right\}\right].$$

$$\int\partial E_\theta = \int\frac{I_0 dL\sin\theta}{4\pi\varepsilon r}\left[-\frac{\omega^2}{c^2}\cos\omega\, t_1 - \frac{\omega}{cr}\sin\omega\, t_1 + \frac{\cos\omega\, t_1}{r^2}\right]dt$$

$$E_\theta = \frac{I_0 dL \sin\theta}{4\pi\varepsilon}\left[-\frac{\omega^2 \sin\omega\, t_1}{c^2 \omega r} + \frac{\omega}{cr^2}\,\frac{\cos\omega\, t_1}{\omega} + \frac{\sin\omega\, t_1}{r^3 \omega}\right]$$

$$\boxed{E_\theta = \frac{I_0 dL \sin\theta}{4\pi\varepsilon}\left[-\frac{\omega \sin\omega\, t_1}{c^2 r} + \frac{\cos\omega\, t_1}{cr^2} + \frac{\sin\omega\, t_1}{\omega r^3}\right]} \qquad \text{...(2.181)}$$

and $$\varepsilon \frac{\partial E_\theta}{\partial t} = (\nabla \times \vec{\mathbf{H}})_\varphi = 0$$

or $$\boxed{E_\varphi = \mathbf{0}} \qquad \text{...(2.182)}$$

Thus, we have calculated all the three components of electric field intensity vector $\vec{\mathbf{E}}$ (E_r, E_θ, E_φ) given by Eqns. (2.179), (2.180), (2.181). Hence, we conclude here that *out of six components of electromagnetic field* (H_r, H_θ, H_φ and $\mathbf{E_r}$, $\mathbf{E_\theta}$, $\mathbf{E_\varphi}$) *only three components e.g.,* E_r, E_θ *and* H_ϕ *exist in the current element and remaining components* E_φ, H_r *and* H_θ *are everywhere zero.*

$$E_\theta = \frac{I_0 \sin\theta \, dL}{4\pi\varepsilon}\left[-\frac{\omega \sin\omega \, t_1}{c^2 r}\right] \qquad (1/r^2 \text{ and } 1/r^3 \text{ terms neglected})$$

$$= -\frac{\omega \, I_0 \, dL \sin\theta \sin\omega \, t_1}{4\pi\varepsilon c \, . \, cr}$$

$$= -\frac{2\pi f \; I_0 \, dL \sin\theta \sin\omega \, t_1}{4\pi\varepsilon \, . \, \frac{1}{\sqrt{\mu\varepsilon}} \, cr} \qquad \left(c = \frac{1}{\sqrt{\mu\varepsilon}}; \quad \frac{f}{c} = \frac{1}{\lambda} \right)$$

$$E_\theta = -\frac{I_0 \, dL \sin\theta \sin\omega \, t_1}{2\sqrt{\frac{\varepsilon}{\mu}} \lambda r} = -\frac{\eta \, I_0 \, dL \sin\theta \sin\omega \, t_1}{2\lambda}$$

$$\left(\because \eta = \sqrt{\frac{\mu}{\varepsilon}} = 120\pi \right)$$

$$\boxed{E_\theta = -\frac{60\pi \, I_0 \, dL \sin\theta \sin\omega\left(t - \frac{r}{c}\right)}{\lambda r}} \qquad \text{...(2.184)}$$

or

$$\boxed{|E_\theta| = \frac{60\pi \, I_0 \, dL}{\lambda r}} \qquad \text{...(2.185)}$$

Similarly, at a distance $r >> \lambda$

$$H_\varphi = \frac{I_0\, dL \sin\theta}{4\pi}\left[-\frac{\omega \sin \omega\, t_1}{cr}\right] = -\frac{2\pi f\, I_0\, dL \sin\theta \sin\omega\, t_1}{4\pi cr}$$

or
$$H_\varphi = -\frac{I_0\, dL \sin\theta \sin\omega\left(t - \frac{r}{c}\right)}{2\lambda r} \quad ...(2.186$$

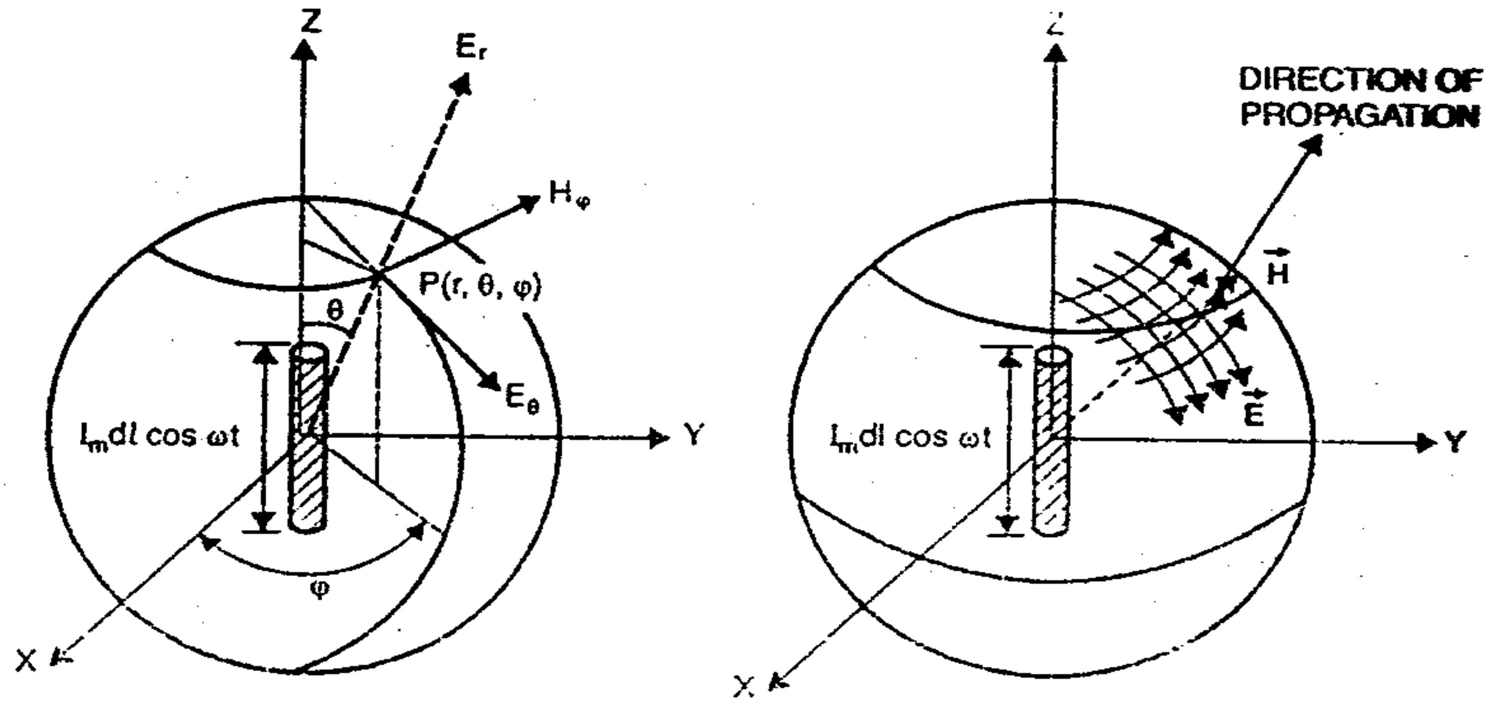
or
$$|H_\varphi| = \left|\frac{I_0\, dL \sin\theta \sin\omega\, t_1}{2\lambda r}\right|$$

($\because$ max. value of sine is unity when $\theta = 90°$)

or
$$H_\varphi = \frac{I_0\, dL}{2\lambda r} \quad ...(2.187$$

Eqn. (2.184, 2.186) constitute the fields present in the radiating wave **from th** current element $I_0\, dL \cos \omega t$. The geometry of the situation is shown **in Fig. 2.22. H_φ** is **tangent to a parallel latitude on a sphere and E_θ is tangent to the meridi**[Fig. 2.22(*a*)]. They both lie on the spherical surface and for a small **area would appe** as a plane wave travelling outward as shown in Fig. 2.22(*b*). Now taking **the ratio o** E_θ to H_φ, we will get the intrinsic impedance, at point P, which is same as **was in ca** of plane wave *e.g.*,

$$\frac{E_\theta}{H_\varphi} = \frac{1}{c\varepsilon} = \eta_0 = 120\,\pi \qquad \text{from eqn. (2.185)} \qquad \text{...(2.18}$$



(*a*) Radiation from current element $I_0 dL \cos \omega t$ in shape

(*b*) Spherical wave from the dipole

Fig. 2.22

2.18.4 Distance at which Induction and Radiation Fields are Equal

As the distance from the current element increases, both induction and radiation fields emerge and start decreasing. Since induction field varies inversely as square of the

distance $\left(i.e. \frac{1}{r^2}\right)$, so it diminishes rapidly and hence is important near the conductor but the radiation field which varies inversely as distance $\left(i.e. \frac{1}{r}\right)$ diminishes relatively less rapidly and is in position to propagate to a larger distance.

However, a distance reaches from the conductor at which both induction and radiation fields become equal and the particular distance depends on the wavelength (or frequency) used.

The two fields will, thus, have equal amplitude at that particular distance. Thus, from eqn. (2.176)

$$\textbf{Induction field} = \frac{I_0\, dL \sin\theta}{4\pi}\left(\frac{\cos\omega\, t_1}{r^2}\right) \quad \text{...(2.189}a\text{)}$$

$$\textbf{Radiation field} = \frac{I_0\, dL \sin\theta}{4\pi}\left(-\frac{\omega \sin\omega t}{cr}\right) \quad \text{...(2.189}b\text{)}$$

distance $\left(i.e. \frac{1}{r^2}\right)$, so it diminishes rapidly and hence is important near the conductor but the radiation field which varies inversely as distance $\left(i.e. \frac{1}{r}\right)$ diminishes relatively less rapidly and is in position to propagate to a larger distance.

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$$\textbf{Induction field} = \frac{I_0\, dL \sin\theta}{4\pi}\left(\frac{\cos\omega\, t_1}{r^2}\right) \quad ...(2.189a)$$

$$\textbf{Radiation field} = \frac{I_0\, dL \sin\theta}{4\pi}\left(-\frac{\omega \sin\omega t}{cr}\right) \quad ...(2.189b)$$

The distance at which both induction and radiation fields are equal is obtained by taking modulus of eqn. (2.189*a* and *b*) and equating the amplitudes of both fields

$$\left|\frac{I_0\, dL \sin\theta}{4\pi}\left(\frac{\cos\omega\, t_1}{r^2}\right)\right| = \left|\frac{I_0\, dL \sin\theta}{4\pi}\left(-\frac{\omega \sin\omega\, t_1}{cr}\right)\right|$$

Since maximum values of *sine* or *cosine* is unity so

$$\frac{1}{r^2} = \frac{\omega}{cr}$$

or

$$\frac{1}{r} = \frac{\omega}{c} = \frac{2\pi f}{c} = \frac{2\pi}{\lambda}$$

∴

$$r = \frac{\lambda}{2\pi} \approx \frac{\lambda}{6}$$

∴

$$\boxed{r = 0.159\,\lambda} \quad \text{...(2.190)}$$

$$\therefore \qquad \boxed{r = 0.159\,\lambda} \qquad \text{...(2.190)}$$

Hence, at a distance of approximately 1/6th wavelength from the current element, the two fields are equal. Beyond this distance radiation field predominates while before this induction field and after a considerable distance beyond λ/6 induction field vanishes altogether and radiation field contribute significantly to radio wave propagation.

Radiation pattern of a Current Element or Elemental Dipole

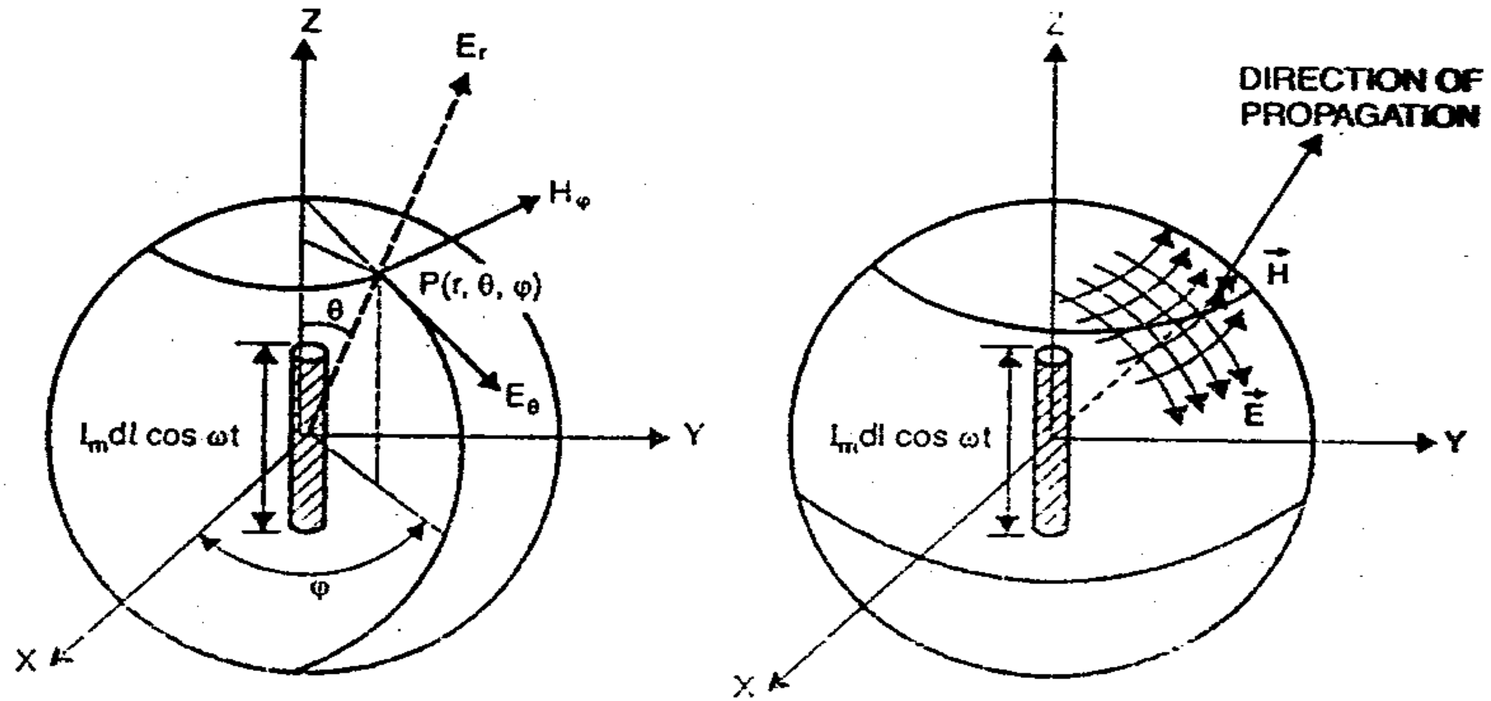
As
$$E_\theta = -\frac{60\pi\, I_0\, dL \sin\theta \sin\omega\left(t - \frac{r}{c}\right)}{\lambda r}$$

and
$$H_\phi = -\frac{I_0\, dL \sin\theta \sin\omega\left(t - \frac{r}{c}\right)}{2\lambda r}$$

Therefore, it is observed.

Eqn. (2.184, 2.186) constitute the fields present in the radiating wave **from th** current element $I_0\ dL \cos \omega t$. The geometry of the situation is shown in **Fig. 2.22.** H_φ **is tangent to a parallel latitude on a sphere and** E_θ **is tangent to the meridi** [Fig. 2.22(*a*)]. They both lie on the spherical surface and for a small area would **appea** as a plane wave travelling outward as shown in Fig. 2.22(*b*). Now taking **the ratio o** E_θ to H_φ, we will get the intrinsic impedance, at point *P*, which is same as **was in ca** of plane wave *e.g.*,

$$\frac{E_\theta}{H_\varphi} = \frac{1}{c\varepsilon} = \eta_0 = 120\,\pi \qquad \text{from eqn. (2.185)} \qquad \ldots(2.18$$



(*a*) Radiation from current element $I_0 dL \cos \omega t$ in shape

(*b*) Spherical wave from the dipole

1. Both E_θ and H_ϕ are in time phase in far field as it has the dimension of **pure** resistance

$$\because \quad \frac{E_\theta}{H_\phi} = \eta_0 = 120\,\pi = 377\ \Omega$$

2. Both the components, E_θ and H_ϕ are proportional to sin θ.
3. The pattern is independent of ϕ. This leads us to conclude that the **pattern** is ***doughnut shaped*** (figure of eight) about the axis of the **dipole** (Fig. 2.23). The maximum is along perpendicular to the axis (sin **90° = 1)** and the minimum (0) is along the axis of the dipole.

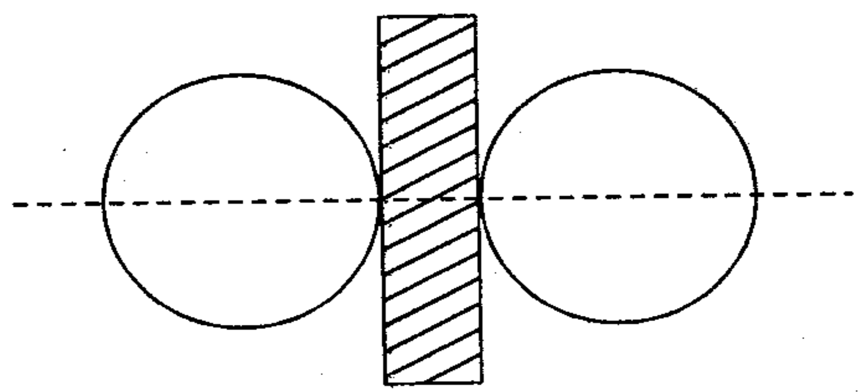


Fig. 2.23. Radiatoin pattern of the elemental dipole

4. H_ϕ is tangent to a parallel latitude on a sphere and E_ϕ is tangent **to th** meridian. They both lie on the spherical surface and for a **small area** approximates to a plane wave travelling outward.