Chapter 5

Basics of Antennas

CHAPTER HIGHLIGHTS

- *Wire Antennas*
- *Aperture Antennas*
- *Parabolic Dish Reflector*
- *Dipoles*
- *Regions*
- *Radiation Pattern*
- *Gain*
- *Radiation Efficiency* η_r
- *N – element Array*
- *Antenna Arrays*
- *Friis Transmission Formula*
- *Effective Length*

Introduction

The electric charges are the sources of electromagnetic (EM) fields. If the sources are time varying, then EM waves propagate away from the sources and radiation is said to have taken place. Radiation may be thought of as the process of transmitting electric energy. The radiation or launching of wave into space is efficiently accomplished with the aid of conducting or dielectric structures called 'antennas'. Theoretically any structure can radiate EM waves but not all structures can serve as efficient radiation mechanisms.

An antenna may also be viewed as a transducer used in matching the transmission line or wave guide (used in guiding the wave to be launched) to the surrounding medium or vice versa. The below figure shows how an antenna is used to accomplish a match between the line or guide and the medium. The antenna is needed for the following two main reasons:

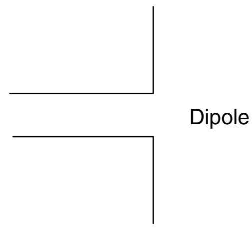
1. Efficient radiation
2. Matching wave impedances in order to minimize reflection

The antenna uses voltage and current from the transmission line (or the EM fields from the waveguide) to launch an EM wave into the medium.

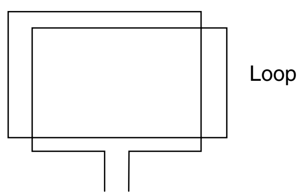
An antenna may be used for either transmitting or receiving EM energy.

Wire Antennas

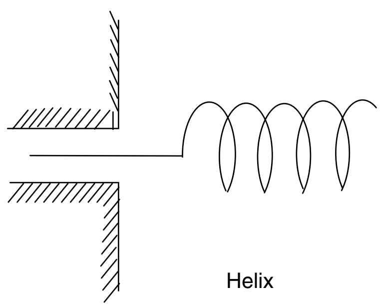
1. **Dipole antennas:** It consists of two straight wires along same axis.



2. **Loop antennas:** It consists of one or more turns in a wire.



3. **Helical antenna:** It consists of a wire in the form of a helix backed by a ground plane.



Wire antennas are used in automobiles, building, ships, etc.

Aperture Antennas

1. **Horn antenna:** It is an example of aperture antenna. It is a tapered section of waveguide providing a transition between a waveguide and the surroundings.

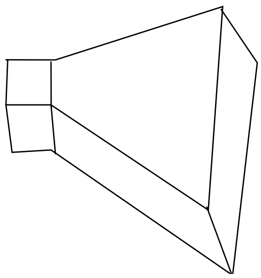
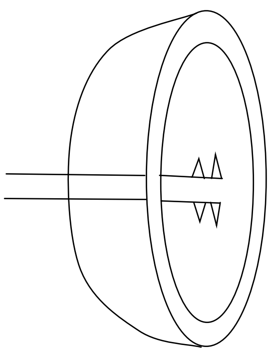


Figure 1 Pyramidal horn.

It is useful in variant applications such as aircraft.

Parabolic Dish Reflector

The EM waves are reflected by a conducting sheet. When used as a transmitting antenna, a feed antenna such as a dipole or horn is placed at the focal point. The radiation from the source is reflected by the dish (acting like a mirror) and a parallel beam results. Parabolic dish antennas are used in communications, radar, and astronomy.



Dipoles

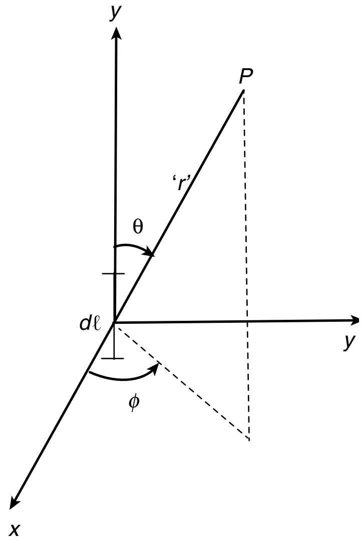
Hertzian Dipole

Hertzian dipole means an infinitesimal current element Idl(current element with differential length). Although such a current element does not exist in real life, it serves as building block from which the field of a practical antenna can be calculated.

Considering a Hertzian dipole at the origin of a co-ordinate system and that it carries a uniform current (constant throughout the dipole),

$$I = I_o \cos\omega t$$

The retarded magnetic vector potential at the field point 'P', due to dipole is given by



$$A = \frac{\mu[I]d\ell}{4\pi r} a_z$$

[I] is the retarded current given by

$$[I] = I_0 \cos \omega \left(t - \gamma/u\right)$$

$$= I_0 \cos(\omega t - \beta r)$$

$$= \mathrm{Re}[I_o{}^{j(\omega t - \beta r)}]$$

Current is said to be retarded at point P because there is a propagation delay r/u or phase delay βr.

From origin to point P,

$$A_{zs} = \frac{\mu I_o d\ell}{4\pi r} e^{-j\beta r}$$

Transforming into spherical co-ordinates

$A_{rs} = A_{zs} \cos\theta$
$A_{\theta s} = -A_{zs} \cos\theta$
$A_{\phi s} = 0$

Obtaining E and H using Maxwell equations,

$$H_{rs} = H_{\phi s} = 0$$

$$H\phi s = \frac{I_0 d\ell}{4\pi}\left[\frac{j\beta}{r} + \frac{1}{r^2}\right]e^{-j\beta\gamma}$$

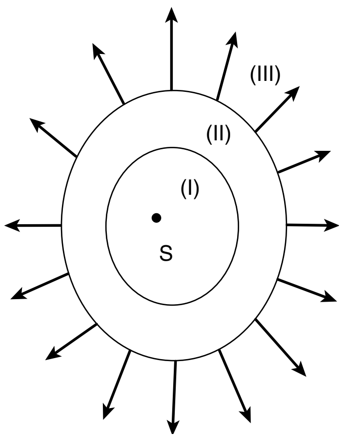
$$Ers = \frac{\eta I_o dl}{4\pi}\cos\theta\left[\frac{1}{r^2} - \frac{j}{\beta r^3}\right]e^{-j\beta r}$$

$$E\theta s = \frac{\eta I_o dl}{4\pi}\sin\theta\left[\frac{j\beta}{r} + \frac{1}{r^2} - \frac{j}{\beta r^3}\right]e^{-j\beta r}$$

$$E_{\phi s} = 0$$

Regions

Region I: It is called as oscillatory field region, and it is very close to source, that is, the region is within $1/r^3$.



Region II: ($\beta r << 1$) called as near radiation field zone or Fresnel field or inductive field where the region is within $1/r^3$ < region II < $1/r^2$ range.

Region III: It is called Far field or ($\beta r >> 1$) Fraunhofer field or radiation zone. $1/r$ term fields are associated with radiation zone.

Therefore, at the radiation zone ($\beta r >> 1$) or ($2\pi r >> \lambda$), the term in $1/r^3$ and $1/r^2$ can be neglected.

$$\therefore\ H\phi s = \frac{jI_o \beta d\ell}{4\pi r}\sin\theta e^{-j\beta r}$$

$$E_{\theta s} = \eta H\phi s$$

$$E_{rs} = H_{\theta s} = E_{\phi s} = H_{rs} = 0$$

The distance where Fresnel and Fraunhofer fields are equal is

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

The boundary between near and far zones is given by

$$r = \frac{2d^2}{\lambda}$$

d – largest dimension of antenna.

Time – average power density

$$P_{avg} = \frac{1}{2}\text{Re}(E \times H^*)$$

$$= \frac{1}{2}\text{Re}(E\theta s H^* \phi s).\hat{a}_r$$

$$P_{avg} = \frac{1}{2}\eta |H\phi s|^2 a_r .$$

Time average radiated power as

$$P_{rad} = \int P_{avg}.ds$$

$$P_{rad} = \int \frac{1}{2}\eta |H\phi s|^2 a_r$$

After simplification, we get

$$P_{rad} = \frac{I_0^2 \eta\pi}{3}\left[\frac{d\ell}{\lambda}\right]^2$$

If the medium is free space $\eta = 120\pi$

$$\therefore\ P_{rad} = 40\left[\frac{\pi d\ell}{\lambda}\right]^2 I_o^2$$

The power is equivalent to the dissipated in fictitious resistance R_{rad} by current

$$I = I_o \cos \omega t$$

is

$$P_{rad} = I^2_{rms} R_{rad}$$

$$P_{rad} = \frac{1}{2} I_o^2 R_{rad}$$

$$R_{rad} = 80\left[\frac{\pi d\ell}{\lambda}\right]^2$$

The resistance R_{rad} is a characteristic property of the Hertzian dipole antenna and is called radiation resistance.

To deliver large amounts of power to space, we needed antennas with largest radiation resistances.

For example, if

$$d\ell = \lambda/20$$

Then $R_{rad} \cong 2\ \Omega$

which is very small and it can deliver relatively small amounts of power.

Assumptions:

(i) $\beta d\ell << 1$ (or) $d\ell \le \lambda/10$

(ii) Uniform current

Our analysis will be valid and useful for $d\ell \le \lambda/10$.

Half-wave Dipole Antenna

The half-wave dipole derives its name from the fact that its length is half a wavelength, that is, $\ell = \lambda/2$. It consists of a thin wire fed or excited at the middle point by a voltage source connected to the antenna via a transmission line. The field due to dipole can be easily obtained if we consider it as consisting of a chain of Hertzian dipoles. The magnetic vector potential due to differential length dl at P of the dipole carrying a phasor current

$I_\delta = I_o \cos \beta z$ is given by

$$dA_{zs} = \frac{\mu I_o \cos\beta z(dz)}{4\pi r^1} e^{-j\beta r1}$$

We have assumed a sinusoidal current distribution because the current must vanish at both the ends of the dipole. The actual current distribution is not precisely known. It is determined by Maxwell equations and subjected to boundary conditions on the antenna. However, the sinusoidal current assumption approximates the distribution obtained by solving boundary value problem and is commonly used in antenna theory.

If $r >> \ell$

$$r - r^1 = z\cos\theta$$

$$r^1 = r - z\cos\theta$$

Thus, we may substitute $r^1 \approx r$ in denominator of dA_{zs}, whereas in phase term, βr and βr^1 difference is significant.

$$A_{zs} = \frac{\mu I_o}{4\pi r}\int_{-\lambda/4}^{\lambda/4} e^{-j\beta(r - z\cos\theta)}$$

$$= \frac{\mu I_o}{4\pi r}.e^{-j\beta r}\int_{-\lambda/4}^{\lambda/4} e^{-j\beta z\cos\theta}\cos\beta z dz$$

$$A_{zs} = \frac{\mu I_o}{2\pi r\beta\sin^2\theta}\times\cos(\pi/2\cos\theta)$$

By using Maxwell equations and discarding $1/r^2$ and $1/r^3$ terms, we get

$$H_{\phi s} = \frac{jI_0 e^{-j\beta r}\cos\left(\pi/2\cos\theta\right)}{2\pi r\sin\theta}$$

$$E_{\theta s} = \eta H_{\phi s}$$

Time average power density as

$$P_{avg} = \frac{1}{2}\eta|H\phi s|^2\, ar$$

$$\frac{\eta I_o^2\cos^2\left(\pi/2\cos\theta\right)}{8\pi^2 r^2\sin^2\theta}$$

$\therefore$ Radiated power $= \int P_{avg}.ds$

$$= \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi}\frac{\eta I_o^2\cos^2\left(\pi/2\cos\theta\right)}{8\pi^2 r^2\sin^2\theta}.\hat{a}_r$$

$$P_{rad} = \frac{\eta I_o^2}{8\pi^2}2\pi\int_0^{\pi}\frac{\cos^2\left(\pi/2\cos\theta\right)}{\sin\theta}d\theta$$

$\eta = 120\pi$ (in free – space)

and simplifying further, we get

$$P_{rad} = 36.56 I_o^2$$

$$R_{rad} = \frac{2P_{rad}}{I_o^2}$$

$$R_{rad} = 73\ \Omega$$

Therefore, there is significant increase in the radiation resistance of the half-wave dipole over that of Hertzian dipole. Thus, half-wave dipole is capable of delivering greater amounts of power to space than the Hertzian dipole.

This value of radiation resistance of $\lambda/2$ dipole antenna is easy to match to transmission lines.

Quarter-wave Monopole Antenna

Basically, the quarter-wave monopole antenna consists of one half of a half wave dipole antenna located as a conducting ground plane.

The monopole antenna is perpendicular to the plane, which is usually assumed to be infinite and perfectly conducting. It is fed by a co-axial cable connected to its base.

Using image theory, we replace infinite, the perfectly conducting ground plane with the image of monopole. The field produced in the region above the ground plane due to the monopole with its image is same as the field due to a $\lambda/2$ wave dipole. The field equation for quarter-wave monopole is same as half-wave dipole except the limits of integration, that is, θ = zero to $\pi/2$ because monopole radiates in only through that surface. Hence, monopole radiates half-power of half-wave dipole.

$$P_{rad} = 12.28\, I_0^2$$

$$R_{rad} = \frac{2P_{rad}}{I_o^2}$$

$$R_{rad} = 36.5\ \Omega$$

Radiation Pattern

An antenna pattern or a radiation pattern is a three-dimensional plot of its radiation at far field.

When the amplitude of a specified field component of the *E*-field in plotted, it is called the field pattern or voltage pattern.

When the square of the amplitude of *E* is plotted, it is called the power pattern.

***E*-plane pattern or vertical pattern:** Normalized $|E_s|$ versus θ for a constant ϕ.

***H*-plane pattern or horizontal patterns:**

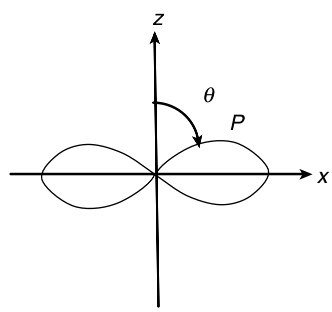
Normalized $|E_s|$ versus ϕ for a constant 'θ' = $\pi/2$.

Es is the normalized value of *E* with respect to its maximum value of *E*. Hence, that the maximum value of Es is unity.

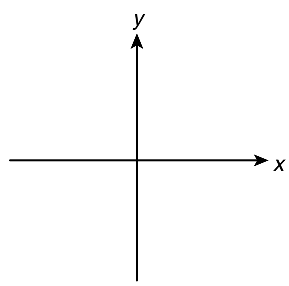
Case I: Hertzian dipole:

The normalized $|E_s|$

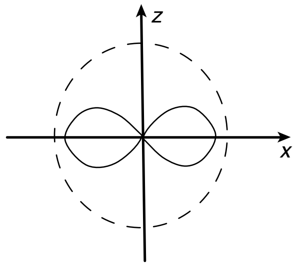
$$f(\theta) = |\sin\theta|$$



E-plane (or) vertical pattern

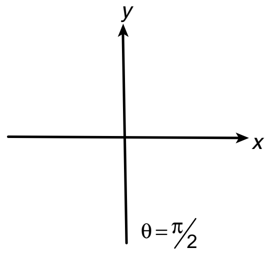


H-plane (or) horizontal pattern



ϕ = constant = 0

Power pattern $(f^2) = \sin^2\theta$



Power pattern

Radiation Intensity

It is defined as $u(\theta, \phi) = r^2 P_{avg}$.

Total radiated power can be expressed as

$$P_{rad} = \oint_s P_{avg}.ds.$$

$$= \int_s \frac{u(\theta,\phi)}{r^2} r^2 \sin\theta d\theta d\phi$$

$$= \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} u(\theta,\phi) d\Omega$$

$d\Omega = \sin\theta\, d\theta\, d\phi$ is the differential solid angle in steradian. Hence, the intensity is measured in watts/ steradian.

$$u_{avg} = \frac{P_{rad}}{4\pi}$$

Gain

The directive gain $G_d(\theta,\phi)$ of an antenna is a measure of the concentration of the radiated power in particular direction (θ,ϕ).

$$G_d(\theta, \phi) = \frac{u(\theta,\phi)}{u_{avg}} = \frac{4\pi.u(\theta,\phi)}{P_{rad}}$$

$$P_{avg} = \frac{G_d(\theta,\phi)}{4\pi.r^2} \times P_{rad}$$

For Hertzian dipole and $\lambda/4$ monopole,

P_{avg} is maximum at $\theta = \pi/2$

P_{avg} is minimum at $\theta = 0$ or π

Therefore, the Hertzian dipole radiates power in a direction broadside to its length.

For an isotropic antenna cone that radiates equally in all directions,

$$G_d = 1$$

However, such antenna is not a practical but an ideality.

Directivity

The directivity D of an antenna is the ratio of the maximum radiation intensity to the average radiation intensity.

That is, directivity is the maximum directivity gain.

$$D = \frac{U_{max}}{U_{avg}} = G_{d\,max}$$

$$U = \frac{4\pi U_{max}}{P_{rad}}$$

Antenna	*D*
Isotropic antenna	1
$\lambda/2$ dipole	1.64
Hertzian dipole	1.5

Power Gain

The total input power to the antenna P_{in}

$$P_{in} = P_\ell + P_{rad}$$

$$= \frac{1}{2}|I_{in}|^2 (R\ell + R_{rad})$$

I_{in} is input current at the input terminals and R_ℓ is the loss or ohmic resistance of the antenna.

P_{rad} is the power radiated by the antenna.

The difference between the P_{in} and P_{rad} is P_l.

P_l is the power dissipated within the antenna.

$$GP(\theta,\phi) = \frac{4\pi.u(\theta,\phi)}{p_{in}}$$

GP (θ, ϕ) is the power gain.

Radiation Efficiency γ_r

The ratio of power gain in any specified direction to the directive gain in that direction is referred to as the radiation efficiency (η_r).

$$\eta_r = \frac{Gp}{Gd} = \frac{P_{rad}}{P_{in}}$$

$$\eta_r = \frac{P_{rad}}{P_{rad} + P_L}$$

For maximum antennas, $\eta_r \approx 100\%$.

That is, GP ≅ Gd

D (dB) = $10\log_{10}^{D}$

G (dB) = $10\log_{10}^{G}$

It should be mentioned at this point that the radiation patterns of an antenna are usually measured in far-field region.

The far-field region of an antenna is commonly taken to exist at distance $r \geq r_{min}$ where

$$r_{min} = \frac{2d^2}{\lambda}$$

d – largest dimension of an antenna.

Resultant pattern = (single element pattern) × Array factor
= unit pattern × group pattern

N-Element Array

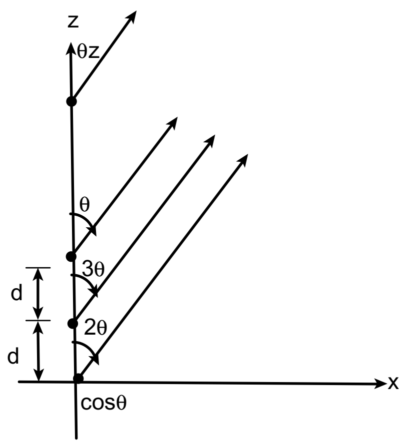
Array Factor (AF)

$$= \frac{\sin\frac{n\psi}{2}}{\sin\frac{\psi}{2}}$$

where $\psi = \beta d \cos\theta + \alpha$

α is the phase difference between the consecutive array elements.

1. $(AF)_{max} = N$
   ∴ Principal maximum occurs
   When $\psi = 0$, that is,
   $0 = \beta d \cos\theta + \alpha$
   $\cos\theta = \frac{-\alpha}{\beta d}$
2. AF has nulls when AF = 0
   That is, $\frac{N\psi}{2} = \pm k\pi$
   k is not multiple of N.
3. **Broadside array:** It has its maximum radiation directed along the axis of the array.
   That is,
   $\psi = 0°$ and $\theta = 90°$, so that $\alpha = 0$.
4. **End-fire array:** It has its maximum radiation directed perpendicular to the axis of the array.



Antenna Arrays

An antenna array is used to obtain greater directivity than can be obtained with a single antenna element.

It is a group of radiating elements arranged to produce some particular radiation characteristics.

Element Array

$$r_1 = r - \frac{d}{2}\cos\theta$$

$$r_2 = r + \frac{d}{2}\cos\theta$$

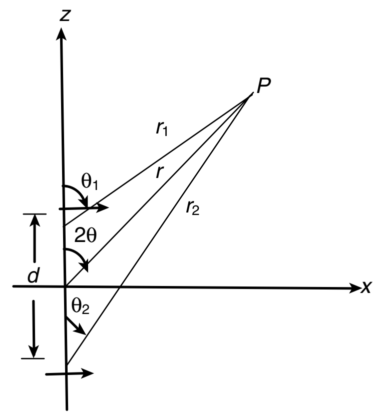
The total electric field at 'p' is

$$Es = \frac{jn\beta Iodl}{4\pi r}\cos\theta e^{-j\beta r}\, 2.\cos\left[\frac{1}{2}(\beta d\cos\theta + \alpha)\right].e^{j\alpha/2} a\theta$$

Comparing this with the expression of dipoles, we get that the total field is equal to the field of single element located at the origin multiplied by an array factor given by

$$\text{AF} = 2\cos\left[\frac{1}{2}(\beta d\cos\theta + \alpha)\right].e^{j\alpha/2}$$

$$E(\text{total}) = [E \text{ due to single element at origin}] \times [\text{aray factor}]$$



Principle of Pattern Multiplication

According to this principle, the total electric field due to the array of N-element is equal to the field due to a single element located at origin multiplied by the array factor, which is also called group pattern.

That is, $\psi = 0$

$\theta = 0 - \pi$

$\alpha = -\beta d$ to βd

Effective Area (Ae)

The effective area Ae of an antenna is the ratio of time average power received P_r to the time average power density p_{avg} of the incident wave at the antenna.

$$Ae = P_r / \text{Power density}$$

$$Ae = \frac{\lambda^2}{4\pi}.D$$

For any antenna

$$Ae = \frac{\lambda^2}{4\pi}.G_d(\theta, \phi)$$

Friis Transmission Formula

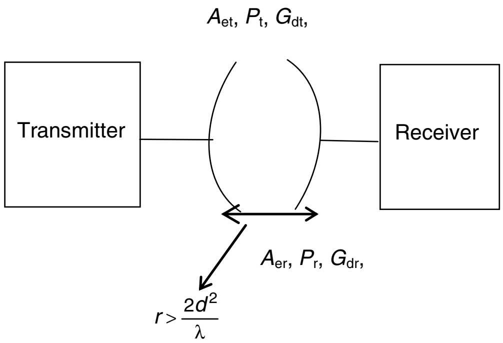
It relates the received power by an antenna to the power transmitted by the other, provided that the two antennas are separated by

$$r > \frac{2d^2}{\lambda}$$

$$\therefore P_r = G_{dr} \cdot G_{dt} \left[\frac{\lambda}{4\pi r}\right]^2 P_t$$

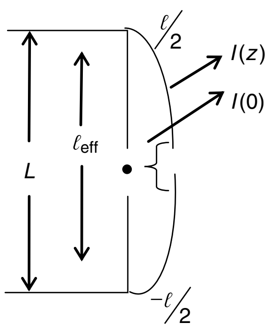
$$\text{if } G_{dt} = G_{gr} = G$$

$$P_r = P_t \left[\frac{\lambda G}{4\pi r}\right]^2$$



Effective Length (ℓ_{eff})

It is used to indicate the effectiveness of the antenna as a radiator or collector of elector magnetic energy.



The effective length of a transmitting antenna is that length of equivalent antenna that has a current $I(0)$ at all points along its length and that radiates the same field strength as the actual antenna in the direction perpendicular to its length.

$$\therefore I(0)\, \ell_{eff} = \int_{-\ell/2}^{\ell/2} I(z)\, dz$$

$$L_{eff}\, T_x = \frac{1}{\text{I}(0)} \int_{-\ell/2}^{\ell/2} I(z)\, dz$$

$$L_{eff}\, R_x = \frac{-Voc}{E}$$

Solved Examples

Example 1

Which of the following is NOT true about antennas?
(A) It is used for matching between transmission line and the medium.
(B) It is used for efficient radiation.
(C) It is used as a reciprocal device.
(D) It is used as circulator.

Solution

Antenna cannot be used as circulator.

Example 2

The term associated with radiation in the expression of electric field is

(A) $1/r$ term (B) $1/r^2$ term
(C) $1/r^3$ term (D) All of the above

Solution

The radiation field means far field region.

$\therefore$ βr >> 1

$\therefore$ $1/r^2$ and $1/r^3$ term can be neglected.

Example 3

If the amplitude of the time harmonic current distribution on a thin centre fed short z-directed dipole antenna of length ℓ ($<<\lambda$) is given by

$\text{I}(z) = \text{I}_0 \left(1 - \frac{2|z|}{\ell}\right)$. which one of the following represents radiation resistance of the antenna?

(A) $302\left(\frac{\pi\ell}{\lambda}\right)^2$ (B) $80\left(\frac{\pi\ell}{\lambda}\right)^2$
(C) $40\left(\frac{\pi\ell}{\lambda}\right)^2$ (D) $20\left(\frac{\pi\ell}{\lambda}\right)^2$

Solution

The radiation resistance is derived for length $d\ell$

$$R_{rad} = 80\left(\frac{\pi d\ell}{\lambda}\right)^2$$

Example 4

A magnetic field strength of 5 μA/m is required at a point on $\theta = \pi/2$, 1 km from an antenna in air. Neglecting ohmic losses, how much power must the antenna transmit if it is Hertzian dipole of length $\lambda/20$.

(A) $2\pi^2$ mw (B) $4\pi^2$ mw
(C) $6\pi^2$ mw (D) $8\pi^2$ mw

Solution

$$H_{\phi s} = \frac{I_o \beta (d\ell) \sin\theta}{4\pi r}$$

$$\beta d\ell = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{20} = \frac{\pi}{10}$$

$$H_{\phi s} = 5\ \mu\text{A/m}$$

$$5 \times 10^{-6} = \frac{I_o \frac{\pi}{10}}{4\pi \times 10^{-3}}$$

$$5 \times 10^{-6} = \frac{I_o}{4 \times 10^4}$$

$$I_o = 0.2\ \text{A}$$

$$P_{rad} = 40\pi^2 \left(\frac{d\ell}{\lambda}\right)^2 . I_o^2 = 40\ \pi^2 \times \frac{1}{400} \times 0.04 = 4\pi^2\ \text{mW}$$

Example 5

A very small wire of length $\lambda/_{80}$ has a radiation resistance of

(A) $\frac{\pi^2}{6400}\Omega$ (B) $\frac{\pi^2}{1600}\Omega$

(C) $\frac{\pi^2}{80}\Omega$ (D) $\frac{\pi^2}{4800}\Omega$.

Solution

$$R_{rad} = 80\left(\frac{\pi\ell}{\lambda}\right)^2$$

$$\ell = \lambda/_{80}$$

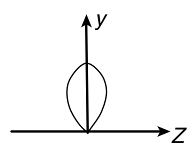
$$\frac{\ell}{\lambda} = \frac{1}{80}$$

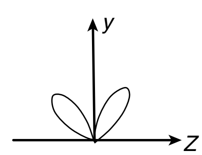
$$R_{rad} = \frac{\pi^2}{80}\Omega$$

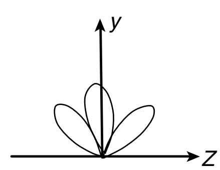
Exercises

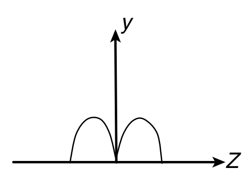
Practice Problems I

Direction for questions 1 to 12: Select the correct alternative from the given choices.

1. An antenna having a gain of 10 dB radiates 3-W power in free space. The electric field intensity at a distance of 1 km from the antenna is given by ($\eta_o = 120\pi$)
   (A) $30\ \text{m}\,\text{V}/_{\text{m}}$ (B) $30\sqrt{2}\text{m}\,\text{V}/_{\text{m}}$
   (C) $15\ \text{m}\,\text{V}/_{\text{m}}$ (D) $15\sqrt{2}\text{m}\,\text{V}/_{\text{m}}$
2. The electric field intensity at a distance of 10 km from an antenna having a directive gain of 10 dB and radiating a total power of 60 kw is
   (A) $0.6\,\text{V}/_{\text{m}}$ (B) $1.2\,\text{V}/_{\text{m}}$
   (C) $0.36\,\text{V}/_{\text{m}}$ (D) $13.3\,\mu\,\text{W}/_{\text{m}^2}$
3. An antenna having a directivity of 2 at a frequency of 300 MHz will have a maximum effective aperture of
   (A) $\frac{1}{80\pi}\text{m}^2$ (B) $\frac{1}{4\pi}\text{m}^2$
   (C) $\frac{1}{2\pi}\text{m}^2$ (D) $\frac{1}{\pi}\text{m}^2$
4. A mast antenna consisting of a 50-metre long vertical conductor operates over a perfectly ground plane. It is base-fed at a frequency of 600 kHz. The radiation resistance of the antenna is
   (A) $8\pi^2$ (B) $\pi^2/_5$
   (C) $4\pi^2/_5$ (D) $20\pi^2$
5. A medium wave radio transmitter operating at a wavelength of 500 m and the height of tower antenna in 125 m, then the radiation resistance of the antenna is
   (A) 73 Ω (B) 36.5 Ω (C) 50 Ω (D) 25 Ω
6. In a uniform linear array four isotropic elements are placed $\lambda/_2$ apart. The progressive phase shift between the elements required for forming the main beam at 60° off the end-fire is
   (A) $-\pi$ (B) $-\pi/_2$
   (C) $-\pi/_4$ (D) $-\pi/_8$
7. A transmitting antenna radiates 251 W isotropically, and a receiving antenna 100 m away from the transmitting antenna has an effective aperture of 500 cm^2. The total received power by the antenna is
   (A) 10 μW (B) 1 μW
   (C) 20 μW (D) 100 μW
8. The radiation pattern of an antenna in spherical co-ordinates is given by $U(\theta) = \cos^4\theta$; $0 \le \theta \le \pi/_2$. Directivity of the antenna is
   (A) 10 dB (B) 12.6 dB
   (C) 11.5 dB (D) 18 dB
9. A $\lambda/_2$ dipole is kept horizontally at a height of $\lambda/_2$ above a perfectly conducting infinite ground plane. The radiation pattern in the plane of the dipole is
   (A)
   

   (B)
   

   (C)
   

   (D)
   

10. The maximum effective area of a $\lambda/2$ wire dipole operating at 30 MHz and how much power is received with an incident wave of strength 2 m V/m is, respectively

(A) 6.525 m^2, 70 nW (B) 13.05 m^2, 35.8 nW
(C) 13.05 m^2, 71.62 nW (D) 6.525 m^2, 35.8 nW

Direction for questions 11 and 12:

11. In the radiation pattern of the three element array of isotropic radiators equally spaced at distance of $\frac{\lambda}{4}$, it is required to place a null at an angle of 33.56° of the end-fire direction. Calculate the progressive phase shifts to be applied to the elements.

(A) $\frac{\pi}{4}$ rad (B) $\frac{\pi}{2}$ rad
(C) 3π (D) π rad

12. For the above Q. No. 11, calculate the angle at which the main beam is placed for this phase distribution?

(A) $\phi_{max} = 120°$
(B) $\phi_{max} = 60°$
(C) $\phi_{max} = 30°$
(D) $\phi_{max} = 10°$

Practice Problems 2

Direction for questions 1 to 11: Select the correct alternative from the given choices.

Direction for questions 1 and 2:

Strength of 5 μA/m is required at a point on $\theta = \frac{\pi}{2}$, 1 km from an antenna in air, neglecting ohmic losses.

1. If the antenna is half-wave dipole, then the radiated power is

(A) 36 mw (B) 144 mw
(C) 72 mw (D) 108 mw

2. If the antenna is quarter-wave monopole, then the radiated power is

(A) 18.25 mw (B) 36.5 mw
(C) 73 mw (D) 18 mw

3. The radiation intensity of a certain antenna is $u(\theta,\phi) = \begin{cases} 2\sin\phi & 0 \le \theta \le \pi \\ 0 & 0 \le \phi \le \pi \end{cases}$. Then the radiated power is

(A) 2 W (B) 4 W
(C) zero (D) 8 W

4. The directivity of an antenna with normalized radiation intensity is

$$U(\theta, \phi) = \begin{cases} 2\sin\phi & 0 \le \phi \le \pi \\ 0 & \text{else} \end{cases}$$

(A) 1.273 (B) 2.546
(C) $4/\pi$ (D) $16/\pi$

5. The electric field intensity at a distance of 10 km from an antenna having a directive gain of 10 dB and radiating a total power of 80 kW is

(A) 1.08 v/n (B) 10.8 v/n
(C) 1.04 (D) None of the above

6. The maximum radiation for an end-fire array occur

(A) at perpendicular to the line of array
(B) along the line of array
(C) 45° to the line of array
(D) in both perpendicular and along the axis of array

7. For taking antenna far field pattern, what must be the distance R between transmitting and receiving antennas?

(A) $R > \frac{2d^2}{\lambda}$ (B) $R > \frac{4D^2\lambda^2}{3}$
(C) $R > \frac{D^2}{2\lambda^2}$ (D) $R > \frac{2D^2}{\lambda^2}$

8. A transmitting antenna has a gain of 10 dB. If it is fed with a signal power of 10 W assuming free space propagation, what power would be captured by a receiving antenna of effective area 1 m^2 in the broadside direction at a distance of 1 m?

(A) 0.8 W (B) 8 W
(C) 0.2 W (D) 2 W

9. Which of the following is not a $\frac{\lambda}{2}$ dipole antenna?

(A) Yagi-Uda antenna
(B) Rhombic antenna
(C) Parabolic antenna
(D) Horn antenna

10. The gain G of an antenna of effective area A is given by

(A) $G = \frac{4\pi\lambda}{A^2}$ (B) $G = \frac{4\pi A}{\lambda}$
(C) $G = \frac{4\pi}{\lambda^2} A$ (D) $G = \frac{4\pi \lambda^2}{A}$

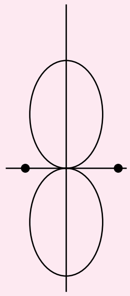
11. An end-fire array consisting of several half-wavelength long isotropic radiators has a directive gain of 30 dB. Beam Width between First null (BWFN) is given by

(A) 47.3° (B) 59.4°
(C) 71.3° (D) 90°

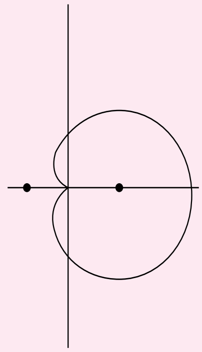
Previous Years' Questions

1. Two identical and parallel dipole antennas are kept apart by a distance of $\frac{\lambda}{4}$ in the H-plane. They are fed with equal currents but the right-most antenna has a phase shift of $+90°$. The radiation pattern is given as **[2005]**

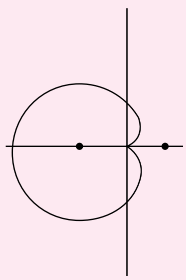
(A)



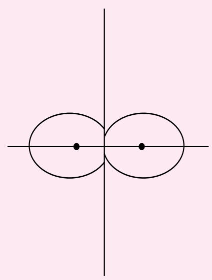
(B)



(C)



(D)



2. A transmission line is feeding 1 watt of power to a horn antenna having a gain of 10 dB. The antenna is matched to the transmission line. The total power radiated by the horn antenna into the free space is **[2006]**

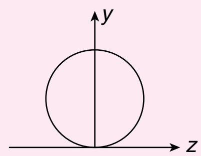
(A) 10 watts (B) 1 watt
(C) 0.1 watt (D) 0.01 watt

3. A mast antenna consisting of a 50-metre long vertical conductor operates over a perfectly conducting ground plane. It is base fed at a frequency of 600 kHz. The radiation resistance of the antenna in Ohms is **[2006]**

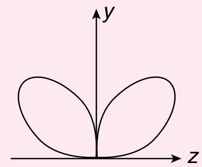
(A) $\frac{2\pi^2}{5}$ (B) $\frac{\pi^2}{5}$
(C) $\frac{4\pi^2}{5}$ (D) $20\pi^2$

4. A $\frac{\lambda}{2}$ dipole is kept horizontally at a height of $\frac{\lambda_0}{2}$ above a perfectly conducting infinite ground plane. The radiation pattern in the plane of the dipole $\left(\vec{E} \text{ plane}\right)$ looks approximately as **[2007]**

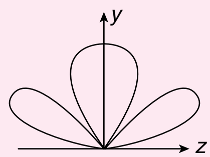
(A)



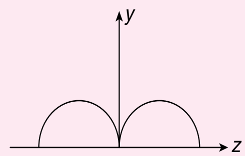
(B)



(C)



(D)



5. For a Hertz dipole antenna, the half-power beam width (HPBW) in the E-plane is **[2008]**

(A) 360° (B) 180°
(C) 90° (D) 45°

6. At 20 GHz, the gain of a parabolic dish antenna of 1 metre diameter and 70% efficiency is **[2008]**

(A) 15 dB (B) 25 dB
(C) 35 dB (D) 45 dB

7. Match Column A with Column B.

Column A	Column B
1. Point electromagnetic source	P. Highly directional
2. Dish antenna	Q. End fire
3. Yagi-Uda antenna	R. Isotropic

[2014]

(A) $1 \rightarrow P, 2 \rightarrow Q, 3 \rightarrow R$
(B) $1 \rightarrow R, 2 \rightarrow P, 3 \rightarrow Q$
(C) $1 \rightarrow Q, 2 \rightarrow P, 3 \rightarrow R$
(D) $1 \rightarrow R, 2 \rightarrow Q, 3 \rightarrow P$

8. The directivity of an antenna array can be increased by adding more antenna elements, as a large number of elements **[2015]**

(A) improves the radiation efficiency
(B) increases the effective area of the antenna
(C) results in a better impedance matching
(D) allows more power to be transmitted by the antenna

9. An antenna pointing in a certain direction has a noise temperature of 50K. The ambient temperature is 290K. The antenna is connected to a pre-amplifier that has a noise figure of 2dB and an available gain of 40dB over an effective band width of 12MHz. The effective input noise temperature T_e for the amplifier and the noise power P_{a0} at the output of the preamplifier, respectively, are **[2016]**

(A) $T_e = 169.36K$ and $P_{a0} = 3.73 \times 10^{-10}W$
(B) $T_e = 170.8K$ and $P_{a0} = 4.56 \times 10^{-10}W$
(C) $T_e = 182.5K$ and $P_{a0} = 3.85 \times 10^{-10}W$
(D) $T_e = 160.62K$ and $P_{a0} = 4.6 \times 10^{-10}W$

10. Two lossless X band horn antennas are separated by a distance of 200λ The amplitude reflection coefficients at the terminals of the transmitting and receiving antennas are 0.15 and 0.18, respectively. The maximum directivities of the transmitting and receiving antennas (over the isotropic antenna) are 18dB and 22dB respectively. Assuming that the input power in the lossless transmission line connected to the antenna is 2 W and that the antennas are perfectly aligned and polarization matched, the power (in mw) delivered to the load the receiver is ___________ . **[2016]**

11. The far zone power density radiated by a helical antenna is approximated as

$$\vec{W}_{\text{rad}} = \vec{W}_{\text{average}} = \approx \hat{a}_r C_0 \frac{1}{r^2} \cos^4\theta.$$

The radiated power density is symmetrical with respect to f and exists only in the upper hemisphere; $0 \le \theta \le \frac{\pi}{2}$; $0 \le \phi \le 2\pi$; C_0, is a constant. The power radiated by the antenna (in watts) and the maximum directivity of the antenna, respectively are: **[2016]**

(A) $1.5C_0$, 10dB
(B) $1.256C_0$, 10dB
(C) $1.256C_0$, 12dB
(D) $1.5C_0$, 12dB

12. A radar operating at 5GHz uses a common antenna for transmission and reception. The antenna has a gain of 150 and is aligned for maximum directional radiation and reception to a target 1 km away having radar cross section of 3 m^2. If it transmits 100kW, then the received power (in mW) is___________ . **[2016]**

Answer Keys

Exercises

Practice Problems 1

1. B	**2.** A	**3.** C	**4.** C	**5.** B	**6.** B	**7.** D	**8.** A	**9.** C	**10.** C
11. A	**12.** A								

Practice Problems 2

1. A	**2.** A	**3.** D	**4.** B	**5.** C	**6.** B	**7.** A	**8.** B	**9.** D	**10.** C
11. B									

Previous Years' Questions

1. A	**2.** B	**3.** A	**4.** B	**5.** C	**6.** D	**7.** B	**8.** B	**9** A
10. 3 mW		**11.** B	**12.** 0.06m					

Test

Electromagnetics

Time: 60 Minutes

Direction for questions 1 to 30: Select the correct alternative from the given choices.

1. A vector field A is said to be solenoidal (or divergence-less) if

(A) $\nabla \times A = 0$ (B) $\nabla \cdot A = 0$
(C) $\nabla \cdot A = 1$ (D) $\nabla \times A = 1$

2. The potential difference V_{LM}, the potential at M with reference to L, is

(A) $V_{LM} = -\int_L^M E \cdot dl$ (B) $V_{LM} = \int_L^M E \cdot dl$
(C) $V_{ML} = -\int_L^M E \cdot dl$ (D) $V_{ML} = \int_L^M E \cdot dl$

3. Identify which of the following expressions are not Maxwell's equation for time-varying fields.

(A) $\nabla \cdot D = \rho_v$ (B) $\nabla \cdot J + \dfrac{\rho_v}{t} = 0$
(C) $\nabla \times E = \dfrac{-\partial B}{\partial t}$ (D) $\nabla \times H = J + \dfrac{\partial D}{\partial t}$

4. If a plane electromagnetic wave satisfies the equation $\dfrac{\partial^2 E_x}{\partial z^2} = c^2 \dfrac{\partial^2 E_x}{\partial t^2}$, then the wave propagates in the

(A) X-direction
(B) Z-direction
(C) Y-direction
(D) XY plane at an angle of 45° between the X and Z directions.

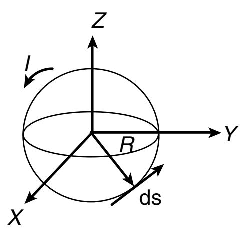
5. The Brewster angle is given by

(A) $\tan\theta = \sqrt{\epsilon_1 \epsilon_2}$ (B) $\tan\theta = (\epsilon_1 - \epsilon_2)$
(C) $\tan\theta \dfrac{1}{\sqrt{\epsilon_1 \epsilon_2}}$ (D) $\tan\theta = \sqrt{\dfrac{\epsilon_2}{\epsilon_1}}$

6. For a good conductor, the depth of penetration 'δ' is

(A) $\sqrt{\dfrac{1}{\pi f \mu \sigma}}$ (B) $\sqrt{\dfrac{\pi f \mu}{\sigma}}$
(C) $\sqrt{\dfrac{2}{\pi f \mu \sigma}}$ (D) $\sqrt{\dfrac{1}{2\pi f \mu \sigma}}$

7. Find the field at the centre of a circular loop shown in the below figure.



(A) $\dfrac{I}{2R}\hat{z}$ (B) $\dfrac{I}{2R}\hat{y}$ (C) $\dfrac{I}{2R}\hat{x}$ (D) $\dfrac{2R}{I}\hat{z}$

8. The average power flow per unit area in a uniform plane wave in an electric field of maximum voltage E_0 and impedance Z_0 is

(A) $\dfrac{E_0^3}{Z_0}$ (B) $I_0 E_0$ (C) $\dfrac{E_0^2}{2Z_0}$ (D) $I_0^2 Z_0$

9. In the presence of both electric and magnetic fields, the charge Q moving with velocity V given by $F = Q(E + V \times B)$ is known as

(A) Lorentz force equation
(B) Coulomb's force equation
(C) Faraday's force equation
(D) Gauss's force equation

10. Current changing from 4 to 6 A in 1 s induces 40 V in a coil. Its inductance is

(A) 40 mH (B) 4 H (C) 6 H (D) 20 H

11. When electric field is parallel to the plane of incidence, the electromagnetic wave is said to be

(A) Linearly polarized
(B) Circularly polarized
(C) Elliptically polarized
(D) Parallely polarized

12. Let $\overline{D} = 1.\hat{a}_r$ c/m^2. Hence, calculate the amount of flux leaving the cylindrical surface $r = 1$.

(A) π C (B) 2π C (C) 6π C (D) 4π C

13. A point charge of 6 nc is located at the origin in the free space. Find VQ if Q is located at (0.2, – 0.4, 0.4) mt, given that $V = 0$ at infinity.

(A) 30 V (B) 60 V (C) 90 V (D) 120 V

14. What factor will decide whether a medium is free space, lossless dielectric, lossy dielectric, or good dielectric?

(A) Reflection coefficient
(B) Loss tangent
(C) Constitutive parameters (σ, ϵ, μ)
(D) Attenuation constant.

15. Given $E = 10\cos(10^8 t - 3y)a_x$ v/m in a certain medium. What type of medium is it?

(A) Lossless dielectric (B) Perfect conductor
(C) Free space (D) Perfect dielectric

16. For electricity field, the boundary conditions between dielectric and dielectric interface for E–field are

(A) E_{tan} is continuous and E_{normal} is discontinuous.
(B) E_{tan} is discontinuous and E_{nor} is continuous.
(C) Both E_{tan} and E_{nor} are continuous.
(D) Both E_{tan} and E_{nor} are discontinuous.

17. $\vec{B} = \nabla \times \vec{A}$ because

(A) $\nabla\ \vec{B} = 0$ (B) $\nabla \cdot \vec{B} = 0$

(C) $\nabla \times \vec{B} = 0$ (D) None of the above

18. Maxwell's Curl equation for static magnetic fields is given by

(A) $\nabla \times B = \mu J$ (B) $\nabla \times B = 0$

(C) $\nabla \cdot B = \mu J$ (D) $\nabla \times B = \dfrac{\mu}{J}$

19. The magnitude of the electric field strength at a distance r from a charge q is equal to:

(A) $\dfrac{q}{4\pi r^2}$ (B) $\dfrac{q}{4\pi \in r^2}$

(C) $\dfrac{q}{4 \in r^2}$ (D) $\dfrac{1}{4\pi \in r}$

20. In a circularly polarized wave traveling in Z-direction,

(A) E_x and E_y are in phase.

(B) E_x and E_y are 90° out-of-phase and unequal in magnitude.

(C) E_x and E_y are 90° out-of-phase and equal in magnitude.

(D) $E_x = -E_y$

21. A material has $\sigma = 10^{-2}$s/m and $\in = 3\in_0$. At what frequency will the conduction current equal to the displacement current.

(A) 60 MHz (B) 120 MHz

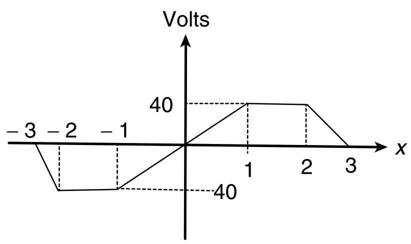
(C) 30 MHz (D) 90 MHz

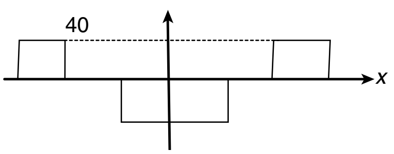
22. A UPW propagating in the x-direction has no

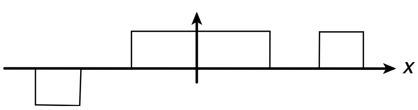
(A) x-component (B) y-component

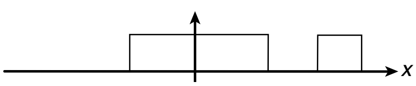
(C) z-compound (D) None of the above

23. In a certain region, the potential field distribution as function of x is shown in figure. Sketch the corresponding electric field.



(A) 

(B) 

(C) 

(D) None of the above

24. UPW propagating in a conducting medium, the wave equation E is given by

(A) $\nabla^2 E - \mu \in \dot{E} - \mu\sigma \dot{E} = 0$

(B) $\nabla E - \mu \in \dot{E} - \mu\sigma E = 0$

(C) $\nabla^2 E - \mu \in \dot{E} + \mu\sigma \dot{E} = 0$

(D) $\nabla^2 E - \mu \in \dot{E} + \mu\sigma \dot{E} = 0$

25. Relation existing between electric field E and electric potential V is given by

(A) $E = -\nabla V$ (B) $E = \nabla V$

(C) $E = -\nabla \cdot V$ (D) $E = -\nabla \times V$

26. Plane defined by $Z = 0$ carry surface current density $2\hat{a}_x$ A/m. The magnetic intensity 'H_y' in the two regions $-\alpha < Z < 0$ and $0 < Z < \alpha$ are, respectively.

(A) $\hat{a}_y$ and $-\hat{a}_y$ (B) $-\hat{a}_y$ and $\hat{a}_y$

(C) $\hat{a}_x$ and $-\hat{a}_x$ (D) $-\hat{a}_x$ and $\hat{a}_x$

27. The electric field across a dielectric-air interface is shown in the given figure. Then electric field is

$$\in = 1 \uparrow \bar{E} = \hat{a}x$$
$$\in = 2 \uparrow \bar{E} = 2\hat{a}x$$

(A) $4\in_0$ (B) $3\in_0$ (C) $2\in_0$ (D) $-\in_0$

28. The magnetic flux through each turn of a 100 coil is $(t^3 - 2t)$ mWb where t is in seconds. The induced emf at $t = 2$ s is

(A) 1 v (B) –1 v (C) 0.4 v (D) –0.4 v

Direction for questions 29 and 30:

In a medium, $\sigma = 0$, $\mu = \mu_0$, $\in = \in_0$, and

$\bar{E} = 20\sin(10^8 t - \beta z)\,\hat{a}_y$ v/m

29. Calculate β

(A) $+\dfrac{1}{3}$ rad/m (B) $-\dfrac{1}{3}$ rad/m

(C) $\pm\dfrac{1}{3}$ rad/m (D) ± 3 rad/m

30. From Q29. Find $\bar{H}$.

(A) $\bar{H} = +\dfrac{20}{120\pi}\sin(10^8 t + 0.33\,Z)\,\hat{a}_x$

(B) $\bar{H} = -\dfrac{20}{120\pi}\sin(10^8 t - 0.33\,Z)\,\hat{a}_x$

(C) $\bar{H} = \pm\dfrac{20}{120\pi}\sin(10^8 t \pm 0.33Z)\,\hat{a}_x$

(D) $\bar{H} = \pm\dfrac{20}{120\pi}\sin(10^8 t \pm \dfrac{6.2}{3}Z)\,\hat{a}_x$

Answer Keys

1. B	**2.** A	**3.** B	**4.** B	**5.** D	**6.** A	**7.** A	**8.** C	**9.** A	**10.** D
11. D	**12.** B	**13.** C	**14.** C	**15.** A	**16.** A	**17.** B	**18.** A	**19.** B	**20.** C
21. A	**22.** A	**23.** A	**24.** A	**25.** A	**26.** A	**27.** A	**28.** B	**29.** A	**30.** C