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Antenna and Wave Propagation

By

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REC–051 : Antenna and Wave Propagation

UNIT 1

Antennas Basics

PART-1

Introduction, Basic Antenna Parameters, Patterns, Beam Area (or Beam Solid Angle) ΩA, Radiation Intensity, Beam Efficiency, Directivity and Resolution, Antenna Aperture, Effective Height.

CONCEPT OUTLINE : PART-1

- Antennas radiate / couple / concentrate/ direct electromagnetic energy in the desired / assigned direction.
- Basic antenna parameters are :
  - i. Radiation pattern
  - ii. Directivity
  - iii. Power density
  - iv Gain
- Radiation intensity is defined as power per unit solid angle.
- The ratio of the main beam area to the total beam area is called the main beam efficiency ϵ_m.
- Beam efficiency, $\epsilon_m = \dfrac{\Omega_m}{\Omega_A}$ (dimensionless)

  where, Ω_m = Main beam area

  Ω_A = Total beam area
- Effective height, $h = \dfrac{V}{E}$ (m)

  where, V = Induced voltage

  E = Incident field

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.1. **What do you understand by term "Antenna" ? Also discuss basic antenna parameters.**

Answer

A. Antenna :

1. A metallic device used for radiating or receiving radio waves is called antenna. Antenna can be used as transmitting antenna or receiving antenna.
2. An antenna may be isotropic (omni-directional) or anisotropic (directional).
3. These are required in wired communication network such as mobile communication, broadcast system, microwave linking and satellite communication etc.
4. It is used to perform following functions :

i. It couples the transmitter output to free space and received input to the receiver.

ii. It is capable of radiating electromagnetic waves.

iii. It converts high frequency current into electromagnetic waves and vice-versa.

B. Basic antenna parameters :

i. **Radiation pattern :** The graph of the received power at a constant radius from transmitting antenna is known as power pattern of antenna whereas the spatial pattern of electric and magnetic field is known as field pattern.

ii. **Power density :** The power density is defined as power per unit area in the field of antenna.

iii. **Directivity :** The directivity of antenna is defined as the ratio of maximum radiation intensity to average radiation intensity of the antenna.

$$D = \frac{\text{Maximum radiation intensity}}{\text{Average radiation intensity}}$$

iv. **Antenna Gain :** Antenna Gain is defined as the ratio of maximum radiation intensity in a given direction to the maximum radiation intensity produced in same direction from a reference antenna.

Que 1.2. **What do you understand by radiation pattern ?**

Answer

1. The radiation of the antenna is represented graphically as a function of direction it is called radiation pattern.
2. Radiation pattern is a graph which shows the variation in actual field strength of electromagnetic field at all points which are at equal distance from the antenna.

3. The radiation pattern is a three dimensional as shown in Fig. 1.2.1, hence spherical co-ordinate system (r, θ, ϕ) are used for it.
4. The antenna is assumed to be located at origin of spherical co-ordinate system and field strength is specified at points on the spherical surface with radius r.
5. For radiation field the direction of field strength (E) is always tangential to the spherical surface of imaginary sphere of radius r and for vertical dipole electric field strength E is in the direction θ and horizontal loop in the direction of ϕ.
6. The radiation field strength may have components E_θ and E_ϕ, mathematically it is represented by

$$E = \sqrt{E_\theta^2 + E_\phi^2}$$

where, E = Total electric field strength

E_θ = Amplitude of θ component

E_ϕ = Amplitude of ϕ component

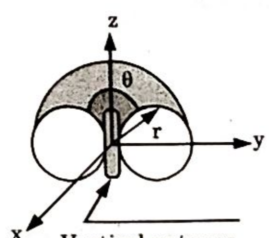
7. A complete radiation pattern is a three dimensional solid and gives the radiation for all angles θ and ϕ. For an elementary dipole antenna the magnitude of radiation term is given by

$$E_\theta = \frac{60\pi Idl}{r\lambda}\sin\theta$$

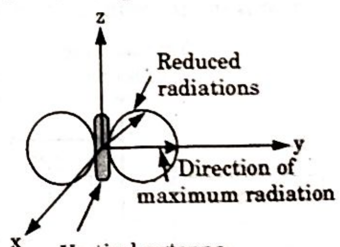
$$E_\theta \propto \sin\theta$$

θ = Angle between the axis of dipole

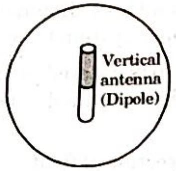
8. Thus, we can draw the field pattern by varying E_θ as shown in Fig. 1.2.1.



(a) Half of the three dimensional pattern (Doughnut shape)



(b) Two dimensional pattern obtained by cutting three dimensional pattern with a vertical plane along the axis of dipole (vertical pattern)



(c) Two-dimensional pattern when cut by a horizontal plane at the center of dipole

Fig. 1.2.1.

Que 1.3. **Describe the method of radiation pattern measurement in the lab.**

AKTU 2013-14, Marks 05

Answer

1. Radiation pattern of a transmitting antenna is described as the field strength or power density at a fixed distance from the antenna, as a function of direction.
2. The radiation pattern of an antenna is three dimensional figure and it needs measurement of field intensity all over the spatial angles.
3. Experimental setup to measure radiation pattern is shown in Fig. 1.3.1.
4. The transmitting antenna is a called as primary antenna while receiving antenna is called as secondary antenna.
5. The transmitting antenna is fixed and the receiving antenna under test is rotated with the help of rotating shaft.

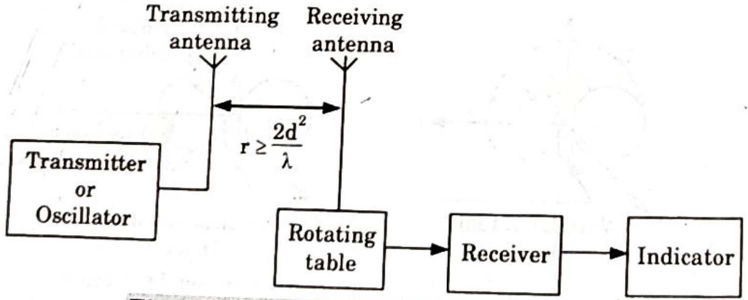


Fig. 1.3.1. Radiation pattern measurement.

6. While carrying out the measurement the distance between transmitting and receiving antenna should be

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

where, d = Maximum linear dimension of either antenna
λ = Wavelength
r = Distance between transmitter and receiver

7. For E_ϕ (θ, $\phi = 90°$) pattern measurement the antenna rotating shaft is rotated with both antennas horizontal and for E_ϕ (θ, $\phi = 0$) pattern, the antenna rotating shift is rotated with both antenna vertical.
8. Indication may be on a direct reading meter calibrated in field intensity.

Que 1.4. **Derive relationship between effective aperture and beam area of an antenna.**

AKTU 2014-15, Marks 05

Answer

1. Effective aperture is the ratio of power radiated in watts to the poynting vector (P) of the incident wave.
2. Consider an antenna with an effective aperture A_e, which radiates all of its power in a conical pattern of beam area Ω_A.
3. Assuming a uniform field E_a over the aperture, the power radiated is

$$P = \frac{E_a^2}{Z_0} A_e \quad \text{(W)} \qquad ...(1.4.1)$$

where Z_0 is intrinsic impedance of medium.

4. Assuming a uniform field E_r in the far field at a distance r, the power radiated is also given by

$$P = \frac{E_r^2}{Z_0} r^2 \Omega_A \quad \text{(W)} \qquad ...(1.4.2)$$

5. From eqs. (1.4.1) and (1.4.2) we get

$$E_r = E_a A_e / r\lambda$$

yields the aperture-beam-area relation

$$\lambda^2 = A_e \Omega_A \quad (m^2) \qquad ...(1.4.3)$$

Eq. (1.4.3) shows Aperture-beam area relation.

where Ω_A = beam area (sr).

Que 1.5. **Define beamwidth of an antenna.**

Answer

1. Antenna beamwidth is defined as angular width in degrees of the major lobes between the two direction at which radiated power or received power is one-half of the maximum power.
2. The relation between directivity and beamwidth is given by

$$D = \frac{4\pi}{\Omega_A} = \frac{4\pi}{\theta_{HP}\,\phi_{HP}} \quad ...(1.5.1)$$

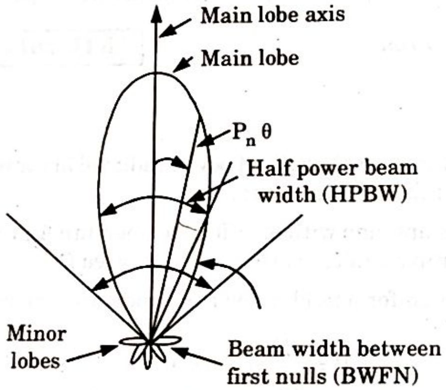


Fig. 1.5.1. Beamwidth measurement.

3. From eq. (1.5.1), it is clear that narrow be the beamwidth higher is the directivity or gain of the antenna.

Que 1.6. **An antenna has a field pattern given by $E(\theta) = \cos\theta \cos 2\theta$ for $0 \le \theta \le 90$. Find the half power beamwidth (HPBW) and the beamwidth between first null (FNBW).**

Answer

Given : $E(\theta) = \cos\theta\cos 2\theta$; $0 \le \theta \le 90°$
To Find : HPBW, FNBW.

1. $E(\theta)$ at half power = 0.707

Thus, $$0.707 = \cos\theta\cos 2\theta = \frac{1}{\sqrt{2}}$$

$$\cos 2\theta = \frac{1}{\sqrt{2}\cos\theta} \Rightarrow 2\theta = \cos^{-1}\left(\frac{1}{\sqrt{2}\cos\theta}\right)$$

and $$\theta = \frac{1}{2}\cos^{-1}\left(\frac{1}{\sqrt{2}\cos\theta'}\right)$$

2. Iterating with $\theta' = 0 \Rightarrow \theta = 22.5°$

$$\theta' = 22.5 \Rightarrow \theta = 20.03°$$

$$\theta = \theta' = 20.47° \cong 20.5°$$

and $$\text{HPBW} = 2\theta = 41°$$

3. For beamwidth between first nulls, $E(\theta) = 0$,

$$0 = \cos\theta\cos 2\theta,$$

so $$\theta = 45°$$

and $$\boxed{\text{FNBW} = 2\theta = 90°}$$

Que 1.7. **How the directivity of an antenna is defined and what is the relation between directivity and gain of an antenna ?**

AKTU 2013-14, Marks 05

Answer

A. Directivity :

1. The maximum directive gain is called as directivity of an antenna and is denoted by D.

$$\text{Directivity, } D = \frac{\text{Maximum radiation intensity of test antenna}}{\text{Average radiation intensity of test antenna}}$$

$$D = \frac{U(\theta,\phi)_{max}}{U(\theta,\phi)_{avg}}$$

2. The directivity of antenna is equal to the ratio of maximum power density $P(\theta, \phi)_{max}$ to its average value over a sphere as observed in the far field of an antenna.

$$D = \frac{P(\theta,\phi)_{max}}{P(\theta,\phi)_{avg.}}$$

Also, $$D = \frac{4\pi}{\iint_{4\pi} P_n(\theta,\phi)\, d\Omega} = \frac{4\pi}{\Omega_A}$$

where, $$P_n(\theta,\phi) = \frac{P(\theta,\phi)}{P(\theta,\phi)_{max}}$$

B. Relation between gain and directivity :

The directivity and gain are related as

$$G = kD$$

where, k = efficiency factor ($0 \le k \le 1$)

Que 1.8. **Calculate the directivity for a unidirectional source whose pattern is $\phi = \phi_m \sin\theta \sin^3 \phi$, where ϕ_m is maximum radiation intensity.**

AKTU 2014-15, Marks 2.5

Answer

Given : $\phi = \phi_m \sin\theta \sin^3 \phi$
To Find : D.

1. Let $0 \le \theta \le \pi$ and $0 \le \phi \le \pi$

We know,

$$D(\theta, \phi) = \frac{4\pi \phi_m}{P_{rad}}$$

where, ϕ_m = maximum radiation intensity

P_{rad} = Total power radiated

2. Hence,

$$D = \frac{4\pi\phi_m}{\int_0^{\pi}\int_0^{\pi}(\phi_m \sin\theta \sin^3 \phi)\, d\phi \times \sin\theta\, d\theta}$$

$$= \frac{4\pi\phi_m}{\phi_m \int_0^{\pi} \sin^2\theta\, d\theta \int_0^{\pi} \sin^3\phi\, d\phi}$$

$$D = \frac{4\pi\phi_m}{\phi_m 2\int_0^{\pi/2} \sin^2\theta\, d\theta \times 2\int_0^{\pi/2} \sin^3\phi\, d\phi}$$

$$= \frac{4\pi}{2\frac{1}{2}\frac{\pi}{2} \times 2\frac{2}{3}} = \frac{4\pi}{2\pi/3} = 2 \times 3 = 6$$

Que 1.9. **A source has a cosine radiation intensity given by $U = U_m \cos\theta$. The radiation intensity has a value only in upper hemisphere. Find the total power radiated and its directivity.**

AKTU 2014-15, Marks 2.5

Answer

Given : $U = U_m \cos\theta$
To Find : Total power radiated and D.

1. For the total power radiated by the cosine source, we apply integration only over the upper hemisphere.

Thus,

$$P = \int_0^{2\pi}\int_0^{\frac{\pi}{2}} U_m \cos\theta \sin\theta\, d\theta\, d\phi = \pi U_m \quad ...(1.9.1)$$

2. If the power radiated by the unidirectional cosine source is same as for an isotropic source, then eq. (1.9.1) may be set equal to $4\pi U_0$ yielding,

$$\pi U_m = 4\pi U_0$$

where U_0 = radiation intensity of isotropic source, Wsr^{-1}

3. ∴ Directivity, $D = \frac{U_m}{U_0} = 4$

Que 1.10. **Define directive gain and power gain in detail and also explain the difference between them.**

AKTU 2017-18, Marks 05

Answer

A. Directive gain :

1. The extent to which a practical antenna concentrates its radiated energy relative to that of some standard antenna is termed as directive gain.
2. Thus the directive gain (G_d) in a given direction is defined as the ratio of the radiation intensity in that direction to the average radiated power *i.e.*,

$$\text{Directive gain} = \frac{\text{Radiation intensity in a particular direction}}{\text{Average radiated power}}$$

$$G_d(\theta, \phi) = \frac{4\pi\phi(\theta, \varphi)}{\int \phi\, d\Omega}$$

In decibels,

$$\text{dB } G_d = 10 \log_{10}\left(\frac{4\pi\phi(\theta,\varphi)}{\int \phi \, d\Omega}\right)$$

3. The directive gain is a qualitative measure of the extent to which the total power radiated is concentrated in one direction.
4. The directive gain solely depends on the distribution of radiated power in space. It does not depend upon the power input to the antenna losses or the power consumed in a terminating resistance.

B. Power Gain :

1. The power gain is defined as the ratio of power density radiated by the test antenna in a particular direction to the power density radiated by isotropic antenna in the same direction; provided that the total input power supplied to both antennas is same.
2. The power gain is denoted by G_p.

$$G_p = \frac{\text{Power density radiated by the test antenna in a particular direction}}{\text{Power density radiated by isotropic antenna in the same direction}}$$

3. The power gain in the given direction is also defined as the ratio of radiation intensity in that direction to the average into power.

C. Difference between directive gain and power gain :

S. No.	Power Gain	Directive Gain
1.	The power gain is the defined ratio of power density radiated by the test antenna in a particular direction to the power density radiated by isotropic antenna in the same direction.	Directive gain (G_d) is defined as the ratio of the radiation intensity in that direction to the average radiated power.

Que 1.11. **Derive the relation between directivity and resolution.**

Answer

1. Resolution of antenna is equal to half of the beamwidth between first null *i.e.*, *FNBW*/2. Half the beamwidth between first null *FNBW*/2 is approximately equal to half power beamwidth (*HPBW*) or

$$\frac{FNBW}{2} \approx HPBW$$

2. Thus, the product of the *FNBW*/2 in the two principal planes of antenna pattern is measure of antenna beam area.

i.e.,
$$\Omega_A = \left(\frac{FNBW}{2}\right)_\theta \left(\frac{FNBW}{2}\right)_\phi$$

3. Thus N number of radio transmitters or point sources of radiation distributed uniformly over the sky which an antenna can resolve is given by

$$N = \frac{4\pi}{\Omega_A} \quad \text{...(1.11.1)}$$

where, Ω_A = beam area

4. Since directivity for beam area Ω_A is given by

$$D = \frac{4\pi}{\Omega_A} \quad \text{...(1.11.2)}$$

5. Then from eq. (1.11.1) and (1.11.2)

$$D = N$$

i.e., number of point source an antenna can resolve is numerically equal to directivity of the antenna.

Que 1.12. **Deduce the relation between effective aperture and gain of an antenna.** **AKTU 2016-17, Marks 10**

OR

Explain the antenna aperture in detail and also derive an expression showing the relation between effective aperture and directivity of an antenna. **AKTU 2017-18, Marks 05**

Answer

1. Consider two antennas as antenna 1 and antenna 2. Let the directivities of these antennas be denoted by D_1 and D_2. Assume that their maximum effective areas are denoted by $(A_{e_1})_{max}$ and $(A_{e_2})_{max}$.
2. The directivity of an antenna is proportional to the maximum effective area. Hence we can write.

$$\therefore \quad \frac{D_1}{D_2} = \frac{(A_{e_1})_{max}}{(A_{e_2})_{max}} \quad \text{...(1.12.1)}$$

3. Let antenna 1 be the isotropic radiator for which the directivity is unity. *i.e.* $D_1 = 1$. Hence we can write,

$$\frac{1}{D_2} = \frac{(A_{e_1})_{max}}{(A_{e_2})_{max}}$$

$$\therefore \quad D_2 = \frac{(A_{e_2})_{max}}{(A_{e_1})_{max}}$$

and $$(A_{e_1})_{max} = \frac{(A_{e_2})_{max}}{D_2} \quad ...(1.12.2)$$

4. Let us assume that antenna 2 be the test antenna which is a short dipole. As we know for the short dipole antenna, maximum effective aperture is $\left(\frac{3}{8\pi}\right)\lambda^2$ and the directivity is $\frac{3}{2}$.

$$\therefore \quad (A_{e_1})_{max} = \frac{\left(\frac{3}{8\pi}\right)\lambda^2}{\left(\frac{3}{2}\right)} = \frac{\lambda^2}{4\pi} \quad ...(1.12.3)$$

5. Putting value of $(A_{e_1})_{max}$ in the expression for D_2, we get,

$$D_2 = \frac{(A_{e_2})_{max}}{\left(\frac{\lambda^2}{4\pi}\right)} = \frac{4\pi}{\lambda^2}(A_{e_2})_{max} \quad ...(1.12.4)$$

6. Hence, in general we can write,

$$D = \frac{4\pi}{\lambda^2}(A_e)_{max} \quad ...(1.12.5)$$

and we know that,

$$G = \eta D \quad ...(1.12.6)$$

where, η = efficiency factor

so, from eq. (1.12.5) and (1.12.6) we get,

$$G = \eta \frac{4\pi}{\lambda^2}(A_e)_{max}$$

Que 1.13. **Explain the antenna efficiency. A directional antenna has an effective radiated power of 1.1 kW, when it is fed with a terminal input power of 90 W. Radiation resistance is 74 Ω at resonance and measured antenna current is 1.088 ampere rms. Find (i) the antenna efficiency, (ii) the antenna power loss, (iii) the directive gain in decibels over an isotropic radiator.**

AKTU 2017-18, Marks 05

Answer

A. **Antenna efficiency :** An efficiency of antenna is denoted by η. It is defined as the ratio of the power radiated by antenna to the total input power supplied to the antenna.

$$\eta = \frac{\text{Power radiated}}{\text{Total input power}} = \frac{P_r}{P_{in}}$$

B. **Numerical :**

Given : P_{eff} = 1.1 kW, P_{in} = 90 W, R_r = 74 Ω, I_{rms} = 1.088 amp.
To Find : η, P_{loss}, $G_{d\,max}$ (dB).

i. Antenna efficiency,

$$\eta = \frac{P_r}{P_{in}} \times 100$$

$$P_r = I_{rms}^2 R = (1.088)^2 \times 74 = 87.59$$

$$\therefore \quad \eta = \frac{87.59}{90} \times 100 = 97.33\%$$

ii. Antenna power loss,

$$P_{in} = P_r + P_{loss}$$

$$P_{loss} = 90 - 87.59 = 2.41 \text{ W}$$

iii. Directive gain is given by

$$G_{d\,max} = \frac{4\pi U_{max}}{P_{rad}}$$

where, $$P_{rad} = \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} U(\theta, \phi) \sin\theta \, d\theta \, d\phi$$

For isotropic radiator, $U(\theta, \phi) = U_{max}$

$$\therefore \quad P_{rad} = \int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} U_{max} \sin\theta \, d\theta \, d\phi$$

$$= U_{max} \int_{\phi=0}^{2\pi} d\phi \int_{\theta=0}^{\pi} \sin\theta \, d\theta$$

$$= U_{max}(2\pi)\left[-\cos\theta\right]_0^{\pi}$$

$$= 4\pi U_{max}$$

so, directive gain, $G_{d\,max} = \frac{4\pi U_{max}}{4\pi U_{max}} = 1$

In decibels, $G_{d\,max}$ (dB) $= 10 \log_{10} G_{d\,max}$

$$= 10 \log_{10}(1) = 0$$

Que 1.14. **Derive the relation between the effective height and effective aperture area. An antenna has a radiation resistance of 100 ohm, a loss resistance of 15 ohm and a power gain of 10 dB. Calculate antenna efficiency and its directivity.**

AKTU 2015-16, Marks 10

Answer

A. Relation between effective height and effective aperture Area

1. Consider an antenna of radiation resistance R_r matched to its load.
2. The power delivered to load,

$$P = \frac{1}{4}\frac{V^2}{R_r} \quad ...(1.14.1)$$

But $h_e = \frac{V}{E}$ = effective height

Using eq. (1.14.1), $P = \frac{h^2 E^2}{4R_r}$ ...(1.14.2)

3. Power in terms of effective aperture is given as

$$P = SA_e \quad ...(1.14.3)$$

where, A_e = effective aperture

But, $S = \frac{E^2}{Z_0}$ = Poynting vector

and Z_0 = intrinsic impedance of space (377 Ω)

Thus, $P = \frac{E^2 A_e}{Z_0}$ ...(1.14.4)

4. Equating eq. (1.14.2) and (1.14.4), we get

$$h_e = 2\sqrt{\frac{R_r A_e}{Z_0}} \text{ m}$$

and $A_e = \frac{h_e^2 Z_0}{4R_r} \text{ m}^2$

B. Numerical :

Given : $R_r = 100\ \Omega$, $R_{Loss} = 15\ \Omega$
To Find : η, D.

1. Power gain $(G_P) = 10\text{ dB} = 10 \log (G_P) \Rightarrow G_P = 10$
2. Antenna efficiency, $\eta = \frac{R_r}{R_{Loss} + R_r} = \frac{100}{15 + 100} = 0.869 = 86.9\ \%$
3. Directivity, $D = \frac{G_P}{\eta} = \frac{10}{0.869}$

$$D = 11.5$$

$$(D)_{dB} = 10 \log (11.5) = 10.61 \text{ dB}$$

Que 1.15. **A transmitting antenna having effective height of 61.4 m takes a current of 50 A, at a wavelength of 625 m. Find radiation resistance, power radiated by an antenna and antenna efficiency for $R_A = 50\ \Omega$.**

AKTU 2016-17, Marks 10

Answer

Given : $l_e = 61.4$ m, $I_{rms} = 50$ A, $\lambda = 625$ m, $R_A = 50\ \Omega$
To Find : R_r, P, η.

1. $R_r = \frac{160\pi^2(61.4)^2}{(625)^2} = \frac{32 \times \pi^2 \times (61.4)^2}{125 \times 625}$

$\therefore$ $R_r = 15.24\ \Omega$

2. $P = I^2_{rms} R_r$

$= (50)^2 \times 15.24 = 2500 \times 15.24 = 38100$ **watts**

$= 38.10$ kW.

$$\eta = \frac{R_r}{R_r + R_A} = \frac{15.24}{50 + 15.24} = 23.36\ \%$$

PART-2

The Radio Communication Link, Fields from Oscillating Dipole, Signal to Noise Ratio (SNR), Antenna Temperature, Antenna Impedance.

CONCEPT OUTLINE : PART-2

- **Friis transmission formula :**

$$\frac{P_r}{P_t} = \frac{A_{er} A_{et}}{r^2 \lambda^2}$$

where, P_r = Received power in watt
P_t = Transmitted power in watt
A_{et} = Effective aperture of transmitting antenna, m^2
A_{er} = Effective aperture of receiving antenna, m^2
r = Distance between antennas, m
λ = Wavelength, m

- The ratio of signal (fed to the network) and noise (N) is termed as signal to noise ratio (S/N).
- Antenna temperature is the fictitious temperature at the input of an antenna, which would result in noise ΔN at the output.
- ΔN is the additional noise introduced by antenna itself.
- Antenna terminal impedance is the impedance that is measured at the input terminals of antenna.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.16. **Derive Friis's transmission formula.**

AKTU 2014-15, Marks 2.5

AKTU 2016-17, Marks 10

OR

Write short notes on the following :
i. Directivity and resolution
ii. The radio communication link

AKTU 2017-18, Marks 05

Answer

i. **Directivity and resolution :** Refer Q. 1.11, Page 1–11D, Unit-1.

ii. **The radio communication link (Friis's Formula) :**

1. Fig. 1.16.1 shows a radio communication link. Let the transmitter feed a power P_t to a transmitting antenna of effective aperture A_{et}.
2. At a distance r, a receiving antenna of effective aperture A_{er} intercepts some of the power radiated by the transmitting antenna and delivers it to the receiver R.
3. Assuming that the transmitting antenna is isotropic, the power per unit area available at the receiving antenna is

$$S_r = \frac{P_t}{4\pi r^2} \text{ (W)} \quad \text{...(1.16.1)}$$

4. If the antenna has gain G_t, the power per unit area available at the receiving antenna will be increased in proportion as given by

$$S_r = \frac{P_t G_t}{4\pi r^2} \text{ (W)} \quad \text{...(1.16.2)}$$

5. Now the power collected by the lossless, matched receiving antenna of effective aperture A_{er} is

$$P_r = S_r A_{er} = \frac{P_t G_t A_{er}}{\lambda^2} \text{ (W)} \quad \text{...(1.16.3)}$$

6. The gain of the transmitting antenna can be expressed as

$$G_t = \frac{4\pi A_{et}}{\lambda^2} \quad \text{...(1.16.4)}$$

7. Substituting this in eq. (1.16.3) we get,

$$\frac{P_r}{P_t} = \frac{A_{er} A_{et}}{r^2 \lambda^2} \text{ (dimensionless)} \quad \text{...(1.16.5)}$$

8. Eq. (1.16.5) is known as Friis transmission formula

where,

P_r = received power, W
P_t = transmitted power, W
A_{et} = effective aperture of transmitting antenna, m²
A_{er} = effective aperture of receiving antenna, m²
r = distance between antennas, m
λ = wavelength, m

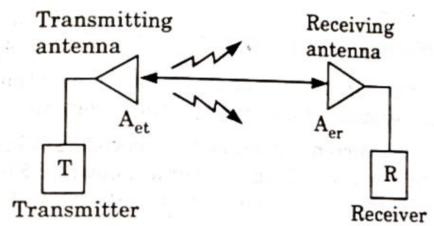
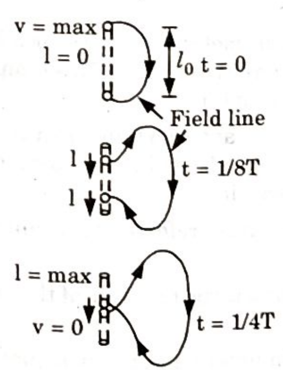


Fig. 1.16.1.

Que 1.17. **Write a note on field from oscillating dipoles.**

Answer

1. Let us consider that the dipole shown in Fig. 1.17.1(a) has two equal charge of opposite sign oscillating up and down with harmonic motion with instantaneous separation l while focusing on the electric field.



(a) Electric field line or wave front with charges at ends of dipole.

(b) Wave front moves out as charges go in.

(c) As charges pass the midpoint the field lines cut loose.

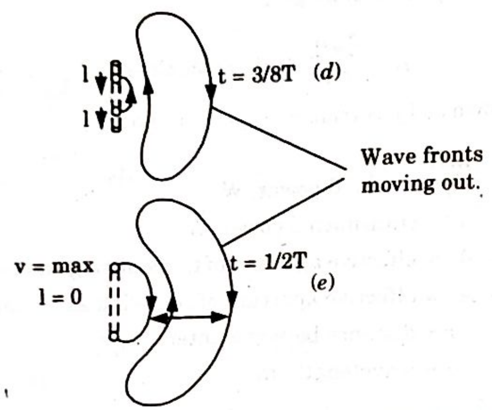


Fig. 1.17.1. Oscillating electric dipole consisting of two electric charges.

2. At time $t = 0$ the charges are at maximum separation and undergo maximum acceleration as they reverse the direction.
3. At this instant the current I is zero when t becomes 1/8 of total time the charges are moving towards each other as shown in Fig. 1.17.1(*b*) and at a period of 1/4 they pass the midpoint as shown in Fig. 1.17.1(*c*).
4. As this occur the field line detach and new ones of opposite sign are formed. At this time equivalent current I is a maximum and charge acceleration is zero.
5. As the time progresses to 1/2 T period, the field continues to move out as shown in Fig. 1.17.1(*d*) and Fig. 1.17.1(*e*).

Que 1.18. **Explain antenna temperature and antenna impedance.**

Answer

A. Antenna temperature :

1. Antenna temperature (T_A) is a parameter that describes how much noise an antenna produces in a given environment. This temperature is not the physical temperature of the antenna.
2. An antenna does not have an intrinsic antenna temperature associated with it, rather the temperature depends on its gain pattern and the thermal environment that it is placed in.
3. Antenna temperature is also sometimes referred to as antenna noise temperature.
4. The temperature of an ideal antenna is the measure of the noise power received by the antenna.
5. The noise power received from an antenna at temperature T_A can be expressed in terms of the bandwidth (B)

$$P = kT_AB \quad ...(1.18.1)$$

where, k = Boltzmann's constant (1.38×10^{-23} J/K)

B = receiver bandwidth, Hz

6. Let the antenna has an effective aperture A_e. Then, the power received from the source is given by

$$P = SA_eB \text{ watts}$$

where, S = power density per unit bandwidth.

A_e = effective aperture in m²

7. From eq. (1.18.1), we get,

$$\therefore \quad SA_eB = kT_AB$$

or,

$$S = \frac{kT_A}{A_e}$$

B. Antenna impedance :

1. An antenna impedance is the impedance at the point where the transmission line carrying R.F. power from the transmitter is connected.
2. Since, at this point input to the antenna is supplied, therefore it is called as antenna input impedance or since at this impedance the R.F. power from the transmitter is fed so this is also known as feed point impedance.
3. Also, at this impedance the transmission line operates; so this is known as driving point impedance or terminal impedance.
4. Now, if the antenna is lossless and isolated, then the antenna terminal impedance (Z_L) is same as the self-impedance (Z_{11}) of the antenna. Mathematically,

$$Z_{11} = R_{11} + jX_{11}$$

where R_{11} = self resistance or radiation resistance

X_{11} = self reactance

5. The self impedance of antenna is always positive. The value of self impedance is same for antenna used either as transmitting antenna or receiving antenna.
6. The self impedance of the antenna is nothing but the impedance measured at input terminals of an antenna with all other antennas isolated from it.
7. Mutual impedance is a measure of coupling between two circuits (antennas). In circuits it is defined as the negative of the ratio of the emf induced in the second circuit due the current flowing in the first circuit or vice versa :

$$Z_{21} = -\frac{V_{21}}{I_1}$$

8. In other words, actual impedance of an antenna element is the sum of its self-impedance the impedance when all other antennas removed and its mutual impedance with all antennas present in the nearby.

Que 1.19. **Write a short note on antenna temperature, directivity and antenna impedance.** **AKTU 2015-16, Marks 10**

OR

What is antenna gain, directivity, beam efficiency, and antenna impedance ? **AKTU 2017-18, Marks 10**

OR

Define signal to noise ratio (SNR). Also define front to back ratio.

Answer

A. **Antenna temperature :** Refer Q. 1.18, Page 1–19D, Unit-1.

B. **Directivity :** Refer Q. 1.7, Page 1–8D, Unit-1.

C. **Antenna impedance :** Refer Q. 1.18, Page 1–19D, Unit-1.

D. **Antenna gain :** Refer Q. 1.1, Page 1–2D, Unit-1.

E. **Beam efficiency :**

1. Beam efficiency is the parameter that is frequently used to judge the quality of transmitting and receiving antenna. For an antenna with its major lobe coincident with z-axis ($\theta = 0$), the beam efficiency is defined as

$$\text{Beam efficiency} = \frac{\text{power transmitted (or received) within cone angle } \theta_1}{\text{power transmitted (or received) by antenna}} \quad ...(1.19.1)$$

where, θ_1 = half angle of the cone within which the percentage of the total power is to be found.

2. In the term of beam area, the beam efficiency is defined as the ratio of main beam area (Ω_M) to the total beam area (Ω_A) *i.e.*,

$$\text{Beam efficiency} = \epsilon_M = \frac{\Omega_M}{\Omega_A} = \frac{\text{Main beam area}}{\text{Total beam area}} \quad ...(1.19.2)$$

3. Total beam area = Main beam area + Minor lobe area

$$\Omega_A = \Omega_M + \Omega_m \quad ...(1.19.3)$$

Dividing eq. (1.19.3) by Ω_A

$$1 = \frac{\Omega_M}{\Omega_A} + \frac{\Omega_m}{\Omega_A}$$

$$1 = \epsilon_M + \epsilon_m$$

where, $\epsilon_m = \dfrac{\Omega_m}{\Omega_A}$ = Stray factor

And, $\epsilon_M = \dfrac{\Omega_M}{\Omega_A}$ = Beam efficiency

F. **SNR :** If an electrical signal is fed in a network. The signal to noise ratio is defined as ratio of signal power to the noise power. It is most important parameter used to measure the detection capability of the system.

G. **Front to back ratio :** This is the ratio of power radiated in the desired direction to the power radiated in the opposite direction. This ratio has significance when antennas are to be located to illuminate areas in opposite directions and are in close proximity as in case of line of sight communication.

Que 1.20. **Derive the expression for power radiated by an alternating current element.** **AKTU 2014-15, Marks 05**

Answer

1. The total power radiated by the alternating current element can be obtained by integrating the radial Poynting vector over a spherical surface.

2. Consider a spherical shell with the current element IdL placed at the centre of the spherical co-ordinate system as shown in the Fig. 1.20.1.

3. The point P at which power radiated is to be calculated is independent of an azimuthal angle ϕ, so the element of area ds on the spherical shell is considered as strip.

4. The element of area ds is given by

$$ds = 2\pi r^2 \sin\theta\, d\theta \quad ...(1.20.1)$$

and radial power is given as :

$$P_r = \frac{\eta_0}{2}\left(\frac{\omega IdL \sin\theta}{4\pi rc}\right) \quad ...(1.20.2)$$

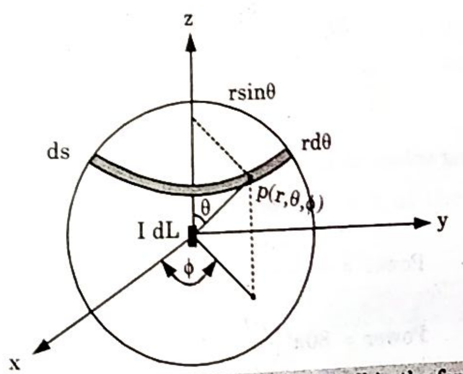


Fig. 1.20.1. Element of area on spherical shell in the form of strip.

6. The total power radiated is calculated by integrating average radial power over the spherical surface.

$$\text{Power} = \oint P_r \, ds = \oint \left[\frac{\eta_0}{2} \left(\frac{\omega \, IdL \sin\theta}{4\pi rc} \right)^2 (2\pi r^2 \sin\theta \, d\theta) \right]$$

$$= \oint \frac{\eta_0 \omega^2 I^2 dl^2}{16 \pi c^2} \sin^3 \theta \, d\theta$$

$$= \frac{\eta_0 \, \omega^2 \, I^2 \, dL^2}{16\pi c^2} \oint \sin^3 \theta \, d\theta \quad ...(1.20.3)$$

7. In spherical co-ordinate system, θ varies from 0 to π. Hence putting limits of integration as,

$$\text{Power} = \frac{\eta_0 \omega^2 I^2 dL^2}{16\pi c^2} \int_0^{\pi} \sin^3 \theta \, d\theta$$

$$= \frac{\eta_0 \omega^2 I^2 dL \times 2}{16\pi c^2} \int_0^{\pi/2} \sin^3 \theta \, d\theta$$

$$\therefore \quad \text{Power} = \frac{\eta_0 \omega^2 I^2 dL^2}{12\pi c^2} \quad ...(1.20.4)$$

8. The power represented by eq. (1.20.4) is in terms of the maximum or peak current. We know that,

$$I_{\text{eff}} = \frac{I_m}{\sqrt{2}}$$

or $$I_m = \sqrt{2} \, I_{\text{eff}}$$

Substitute in eq. (1.20.4), we get

$$\text{Power} = \frac{\eta_0 \omega^2 (\sqrt{2} \, I_{\text{eff}})^2 dL^2}{12\pi c^2}$$

$$\therefore \quad \text{Power} = \frac{\eta_0 \omega^2 I_{\text{eff}}^2 dL^2}{6\pi c^2} \quad ...(1.20.5)$$

9. For free space, $\eta_0 = 120\pi$ and

$$\frac{\omega}{c} = \frac{2\pi}{\lambda} \quad i.e., \quad \frac{\omega^2}{c^2} = \frac{4\pi^2}{\lambda^2}$$

Substituting values of η_0 and $\frac{\omega^2}{c^2}$ in eq. (1.20.5), we get

$$\text{Power} = \frac{(120\pi)\left(\frac{4\pi^2}{\lambda^2}\right) I_{\text{eff}}^2 dL^2}{6\pi}$$

$$\therefore \quad \text{Power} = 80\pi^2 \left(\frac{dL}{\lambda}\right)^2 I_{\text{eff}}^2 \quad ...(1.20.6)$$

Eq. (1.20.6) is the power radiated in terms of the effective current.

Que 1.21. **Explain in detail induction field (near-field) and radiation field (far-field) (magnetic field only) applicable to alternating current element.** **AKTU 2015-16, Marks 10**

Answer

1. There is only one component for the magnetic field, in $\hat{a}_\phi$ direction given by

$$H_\phi = \frac{Idl \sin\theta}{4\pi} \left[\frac{\omega \sin \omega t'}{rv} - \frac{\cos \omega t'}{r^2} \right] \quad ...(1.21.1)$$

2. The magnitude of two bracketed terms in eq. (1.21.1) will become equal if the following condition is satisfied

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

$$\therefore \quad r = \frac{v}{\omega} = \frac{f\lambda}{2\pi f} = \frac{\lambda}{6}$$

3. For $r < \lambda/6$, the induction field will dominate where as for $r > \lambda/6$, the radiation field will dominate.
4. The term inversely proportional to r^2 represent induction or near field.
5. The term inversely proportional only to r represent radiation (distant or far) field. It is also called far field which represent radiation of E.M. waves from a conductor. This radiation has a great significance at large distance.
6. When distance is small the induction field term is dominating. This term indicates the energy stored in magnetic field which surrounds the current element.
7. Radiation field term indicates flow of energy away from the current element while induction field term indicates the energy stored in the field during one quarter of cycle which is returned back during next cycle.

Que 1.22. **A transmitting antenna having an effective height of 100 meters has a current at the base 100 A at the frequency of 300 kHz. Calculate :**

i. The field strength at a distance of 100 km

ii. The value of radiation resistance. **AKTU 2013-14, Marks 05**

Answer

$$\therefore \quad \lambda = \frac{300}{0.300} = 1000 \text{ m}$$

$$r = 100 \text{ km}$$

i. $$|E| = \frac{120\,\pi\, l_e\, I_{rms}}{\lambda r} = \frac{120\,\pi \times 100 \times 100}{1000 \times 100 \times 10^3}$$

$$= 37.68 \text{ mV/m.}$$

ii. $$R_r = \frac{160\,\pi^2 l_e^2}{\lambda^2} = \frac{160\,\pi^2\,(100)^2}{(1000)^2} = 15.78\ \Omega.$$

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Describe the method of radiation pattern measurement in the lab.

Ans. Refer Q. 1.3.

Q. 2. How the directivity of an antenna is defined and what is the relation between directivity and gain of an antenna ?

Ans. Refer Q. 1.7.

Q. 3. Calculate the directivity for a unidirectional source whose pattern is $\phi = \phi_m \sin\theta \sin^3\phi$, where ϕ_m is maximum radiation intensity.

Ans. Refer Q. 1.8.

Q. 4. Deduce the relation between effective aperture and gain of an antenna.

Ans. Refer Q. 1.12.

Q. 5. Derive Friis's transmission formula.

Ans. Refer Q. 1.16.

Q. 6. Write a short note on antenna temperature, directivity and antenna impedance.

Ans. Refer Q. 1.19.

☺☺☺

2 UNIT

Point Sources and Array

PART-1

Application of an Isotropic Source, Radiation Intensity, Array of two Isotropic Point Sources, Non-Isotropic but Similar point Sources and the Principle of Pattern Multiplication.

CONCEPT OUTLINE : PART-1

- Point source is an isotropic charge source that radiates energy in all direction.
- **Radiation intensity :** It is defined as power per unit solid angle.
- **The total field due to :**

i. Two isotropic point sources of same amplitude and phase is

$$E = \cos\left(\frac{\pi}{2}\cos\phi\right)$$

ii. Two isotropic point sources of same amplitude but opposite phase is

$$E = \sin\left(\frac{\pi}{2}\cos\phi\right)$$

iii. Two isotropic point sources of same amplitude and in phase quadrature is

$$E = \cos\left(\frac{\pi}{4}+\frac{\pi}{2}\cos\phi\right)$$

- **Principle of pattern multiplication :** The field pattern of an array of non-isotropic but similar point sources is the product of the pattern of the individual source and the pattern of an array of isotropic point sources having the same locations, relative amplitude, and phase similar to non-isotropic point sources.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.1. **Write a note on point source.**

Answer

1. The idea of point source used for describing antenna is based on looking upon the antenna as a volumeless emitter located at a point from a large distance where only the far field exists.
2. The ratio of the distance between the antenna and the point of observation of the field to the physical size of an antenna is the deciding factor for considering an antenna to be point source.
3. If the ratio is much greater than unity, an antenna may be considered to be point source.
4. It is an isotropic charge source that radiates energy in all direction.
5. At a sufficient distance in the far field of an antenna the radiated field is transverse in nature and the power flow is radial at point O at a distance R on the observation circle as shown in Fig. 2.1.1.

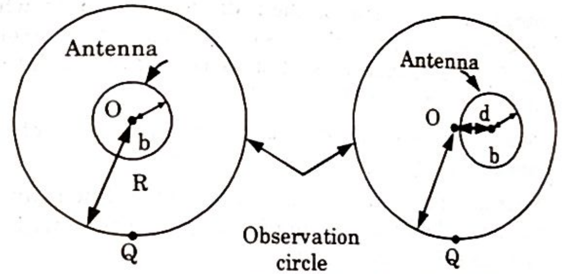


Fig. 2.1.1. Antenna and observation circle.

6. In many analysis it is assumed that field of antenna are everywhere of this type, if we assume, by extrapolating inward along the radii of circle, that the waves originate at a fictitious volumeless emitter at center O of the observation circle.
7. The actual field variation in near field region of the antenna is ignored and source of waves can be described in terms of far field only that it produces.
8. The equivalent effect can be obtained by making measurements at fixed points Q on the circle and rotating the antenna around the center O instead of making field measurement around the observation circle with the fixed antenna.
9. Usually, this is more convenient procedure for small antenna.
10. As in Fig. 2.1.1 the center O of antenna coincides with the centre of the observation circle.
11. If the center of antenna is displaced from center O to an extent such that O lies outside the antenna, the distance d between the two centers has a negligible effect on field pattern at the observation circle.

12. However, the phase pattern will generally differ, depending on d. If $d = 0$, the phase shift around the observation circle is minimum. As d is increased the observed phase shift becomes larger.

Que 2.2. **What is Antenna Array ? Also, give types of Antenna array. Explain advantages of the Antenna array.**

Answer

A. Antenna array :

1. To increase the field strength in the desired direction by a using group of antennas excited simultaneously. Such a group of antennas is called array of antennas or simply antenna array.
2. Thus antenna array can be defined as the system of similar antennas directed to get required high directivity in the desired direction.
3. In general, antenna array is the radiating system in which several antennas are spaced properly so as to get greater field strength at a far distance from the radiating system by combining radiations at point from all the antennas in the system.
4. The antenna array is said to linear if the elements of the antenna array are equally spaced along a straight line.
5. The linear antenna array is said to be uniform linear array if all the elements are fed with a current of equal magnitude with progressive uniform phase shift along the line.

B. Types of Antenna ray :

i. **Broadside array antenna :** Broadside array antenna is the array of identical parallel antennas. Antennas are setup along a line perpendicular to their respective axis.

ii. **Endfire array antenna :** The endfire array is the array of identical antennas and is spaced equally along a line and individual elements are feed with currents of equal magnitude but their phase varies progressively along the line of array.

iii. **Parasitic arrays antenna :** Multielement array having number of parasitic elements are called parasitic arrays. A parasitic element lengthened by 5 % with respect to driven element acts as a reflector and shortened by 5 % acts as director.

C. Advantage of Antenna Array :

i Increase in the overall gain.

ii. Provides diversity reception.

iii. Cancels out interference from a particular set of directors.

iv. Steer the array such that it is more sensitive in a particular direction.

v. Used to determine the direction of arrival of incoming signal.

Que 2.3. **Design a four element broadside array of λ/2 spacing between elements. Consider unit element as λ/2 length antenna. Draw its radiation pattern and calculate its HPBW.**

AKTU 2013-14, Marks 05

Answer

Given : $n = 4$, $d = \lambda/2$.
To Find : HPBW
To draw : Radiation pattern.

1. Major lobe : $\Psi = d_r \cos\phi - \delta = 0$

   Hence with $\delta = -d_r$, $\phi = \pm 0°, \pm 180°$

2. Magnitude of major lobe :

$$|\text{Major lobe}| = n = 4$$

3. Nulls :
The direction of nulls are given by,

$$\phi_{min} = \cos^{-1}\left[1 - \frac{m\lambda}{nd}\right], \text{ where } m = 1,2,3...$$

For $m = 1$,
$$\phi_{min1} = \cos^{-1}\left[1 - \frac{(1)\lambda}{4(\lambda/2)}\right] = \cos^{-1}\left[1 - \frac{1}{2}\right]$$
$$= \cos^{-1}\left(\frac{1}{2}\right) = \pm 60°$$

For $m = 2$,
$$\phi_{min2} = \cos^{-1}\left[1 - \frac{(2)\lambda}{4(\lambda/2)}\right] = \cos^{-1}[1-1]$$
$$= \cos^{-1}(0) = \pm 90°$$

For $m = 3$,
$$\phi_{min3} = \cos^{-1}\left[1 - \frac{3(\lambda)}{4(\lambda/2)}\right] = \cos^{-1}\left[1 - \frac{3}{2}\right]$$
$$= \cos^{-1}(-0.5) = \pm 120°$$

4. **Subsidiary maxima (side lobes) :**
Directions of side lobe are given by,

$$\phi = \cos^{-1}\left[1 - \frac{(2m+1)\lambda}{2nd}\right] = \cos^{-1}\left[1 - \frac{(2m+1)\lambda}{2(4)(\lambda/2)}\right]$$
$$= \cos^{-1}\left[1 - \frac{(2m+1)}{4}\right]$$

For $m = 1$,
$$\phi_1 = \cos^{-1}\left[1 - \frac{(2+1)}{4}\right] = \cos^{-1}\left(\frac{1}{4}\right) = \pm 75.52°$$

For $m = 2$,
$$\phi_2 = \cos^{-1}\left[1 - \frac{(4+1)}{4}\right] = \cos^{-1}\left(-\frac{1}{4}\right) = \pm 104.47°$$

For $m = 3$, $\phi_3 = \cos^{-1}\left[1 - \frac{(6+1)}{4}\right] = \cos^{-1}\left(\frac{-3}{4}\right) = \pm 138.59°$

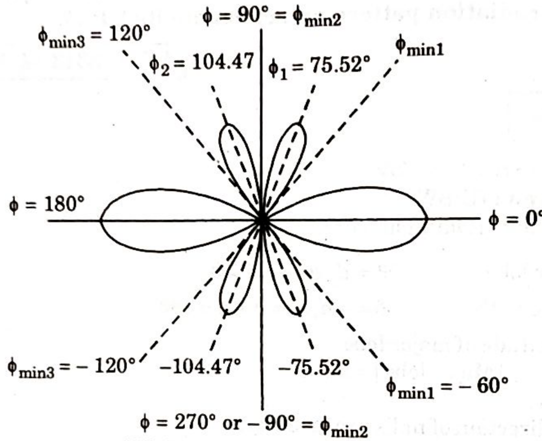


Fig. 2.3.1. Radiation pattern.

5. Now, we know that,

$$BWFN = \frac{114.6°}{\left(\frac{nd}{\lambda}\right)} = \frac{114.6}{\left[\frac{4(\lambda/2)}{\lambda}\right]} = 57.3°$$

and
$$HPBW = \frac{BWFN}{2} = \frac{57.3°}{2} = 28.65°$$

Que 2.4. **What is end-fire array ? Deduce an expression for th radiation pattern of an end-fire array with *n* vertical dipoles.**

AKTU 2013-14, Marks 05

Answer

A. Endfire array :

1. The endfire array is nothing but broadside array except that individu elements are fed in, out of phase (usually 180°).
2. In the endfire array, a number of identical antennas are spaced equal along a line and individual elements are fed with currents of equ magnitude but their phases varies progressively along the line in su a way as to make the entire arrangement substantially unidirectiona
3. Endfire array may be defined as the arrangement in which the princip direction of radiation coincides with the direction of the array axis.

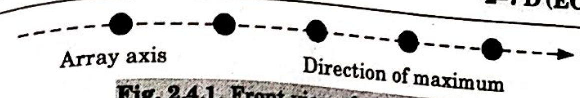


Fig. 2.4.1. Front view of endfire array.

B. Expression for radiation pattern :

1. For an array to be end fire, the phase angle is such, that makes the maximum radiation in the line of array *i.e.*, $\theta = 0°$ or $180°$.
2. Thus for an array to be endfire, $\psi = 0$ and $\theta = 0°$ or $180°$. This requires,

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

i.e.,
$$0 = \beta d \cos 0° + \alpha$$
$$\alpha = -\beta d = -\frac{2\pi}{\lambda}d$$

3. This indicates that the phase difference between the sources of an endfire is retarded progressively by same amount as the spacing between the sources.

a. Direction of pattern maxima :

1. Pattern maxima can be obtained when

$$\sin\left(n\frac{\psi}{2}\right) = 1, \text{ if } \sin\psi/2 \neq 0$$

or
$$n\frac{\psi}{2} = \pm(2N+1)\frac{\pi}{2}$$
$$\psi = \frac{\pm(2N+1)}{n}\pi$$

2. For endfire case, $\alpha = -\beta d$, $\psi = 0$

$$\psi = \beta d \cos(\theta_{max})_{min} + \alpha = \frac{\pm(2N+1)}{n}\pi$$

$$(\theta_{max})_{minor} = \cos^{-1}\left[\pm\frac{(2N+1)\pi}{\beta nd} + 1\right]$$

b. Direction of pattern minima :

$$\alpha = -\beta d$$

$$\beta d \cos(\theta_{min}) + \alpha = \pm\frac{2N\pi}{n}$$

On solving, we get $\theta_{min} = 2\sin^{-1}\left(\pm\sqrt{\frac{N\lambda}{2nd}}\right)$

c. Beam width of major lobes :

1. Beam width = 2 × Angle between first nulls and maximum of major lobes.

$$BW = 2 \times \theta_1$$

2. Since,
$$\theta_{min} = 2\sin^{-1}\left(\pm\sqrt{\frac{N\lambda}{2nd}}\right)$$

$$\therefore \quad \sin\theta_{min} \approx \theta_{min} = 2\left(\pm\sqrt{\frac{N\lambda}{2nd}}\right) \Rightarrow \theta_{min} = \pm\sqrt{\frac{2N\lambda}{nd}}$$

3. Beam width between first nulls

$$BWFN = 2 \times \theta_{min}$$

$$BWFN = 2 \times \left(\pm\sqrt{\frac{2N\lambda}{nd}}\right)$$

4. If $L = nd$ and $N = 1$

then, $$BWFN = \pm 114.6\sqrt{\frac{2}{L/\lambda}}$$

d. Directivity of endfire array :

1. The directivity is given by $D = \frac{\phi_{max}}{\phi_o}$

But $\phi_{max} = 1$ at $\theta = 90°$

2. $\therefore$ $$D = \frac{2n\beta d}{\pi} = 2n.\frac{2\pi}{\lambda}.\left(\frac{d}{\pi}\right) = 4n\left(\frac{d}{\lambda}\right) = 4\left(\frac{L}{\lambda}\right)$$

where, $L = nd$ = array length

Que 2.5. **Explain Radiation Intensity.**

Answer

1. Radiation intensity is defined as the power radiated from an anten per unit solid angle.
2. It is denoted by U (watts per steradian or per square degree).
3. The normalized power pattern can be expressed in terms of radiati intensity.

$$P_n(\theta, \phi) = \frac{U(\theta, \phi)}{U(\theta, \phi)_{max}} = \frac{S(\theta, \phi)}{S(\theta, \phi)_{max}}$$

where, $P_n(\theta, \phi)$ = Normalized power pattern,

$U(\theta, \phi)$ = Radiation intensity as a function of angle,

$U(\theta, \phi)_{max}$ = Maximum radiation intensity.

Que 2.6. **Derive the total far field for an array of two isotrop point sources of equal amplitude and phase. Find out the maximu minimum and half power point directions of radiation pattern fo this case.**

AKTU 2017-18, Marks 0

Answer

1. Let the two isotropic point sources 1 and 2 be separated by a distance and located symmetrically with respect to the origin of the co-ordinat as shown in Fig. 2.6.1.

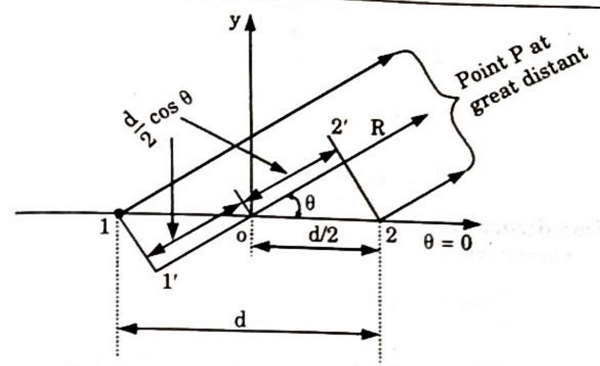


Fig. 2.6.1. Two isotropic point sources located symmetrically with respect to origin O with same amplitude and phase.

2. As seen from Fig. 2.6.1, the fields due to source 1 lags while that due to source 2 leads and the path difference between the two waves is (1′ 2′) and is given as,

$$\text{Path difference} = \left(\frac{d}{2}\cos\theta + \frac{d}{2}\cos\theta\right)$$

$$= d\cos\theta \quad ...(2.6.1)$$

$$= \frac{d}{\lambda}\cos\theta \text{ wavelengths} \quad ...(2.6.2)$$

3. We know that,

Phase angle $(\psi) = 2\pi$ (Path difference) ...(2.6.3)

$$\psi = 2\pi\left(\frac{d}{\lambda}\cos\theta\right)$$

$$\psi = \beta\, d\cos\theta \left[\text{If } \beta = \frac{2\pi}{\lambda}\right] \quad ...(2.6.4)$$

4. The total far field at distant point P in the direction θ is given by,

$$E = E_1 e^{-j\psi/2} + E_2 e^{+j\psi/2} \quad ...(2.6.5)$$

where, $E_1 e^{-j\psi/2}$ = Field component due to source 1

$E_1 e^{+j\psi/2}$ = Field component due to source 2.

5. Here, it is assumed that the amplitudes of the fields are same, therefore

$$E_1 = E_2 = E_0$$

$$E = e_0(E_1 e^{-j\psi/2} + E_1 e^{-j\psi/2})$$

$$= 2E_0\left(\frac{e^{-j\psi/2} + e^{j\psi/2}}{2}\right) = 2E_0\cos\frac{\psi}{2}$$

$$= 2E_0\cos\left[\frac{\beta d\cos\theta}{2}\right] \quad [\because \psi = \beta d\cos\theta] \quad ...(2.6.6)$$

Eq. (2.6.6) is the equation of far field pattern of two isotropic point sources of same amplitude and phase.

6. The total amplitude is $2E_0$ whose maximum value is 1.

By putting $2E_0 = 1$, then eq. (2.6.6) becomes,

$$E = \cos\left[\frac{\beta d \cos\theta}{2}\right] \quad ...(2.6.7)$$

$$= \cos\left[\frac{2\pi}{\lambda} \times \frac{\lambda \cos\theta}{2}\right]$$

$$E = \cos\left[\frac{\pi}{2}\cos\theta\right]$$

A. Maxima direction :

E is maximum when

$$\cos\left(\frac{\pi}{2}\cos\theta\right) = \pm 1$$

$$\frac{\pi}{2}\cos\theta_{max} = \pm n\pi \qquad \text{where,} \qquad n = 0, 1, 2...$$

$$\frac{\pi}{2}\cos\theta_{max} = 0$$

$$\cos\theta_{max} = 0$$

i.e., $\theta_{max} = 90°$ and $270°$

B. Minima direction :

E is minimum when $\cos\left(\frac{\pi}{2}\cos\theta\right) = 0$

i.e., $\frac{\pi}{2}\cos\theta_{min} = \pm(2n+1)\frac{\pi}{2}$ where, $n = 0, 1, 2...$

i.e., $\cos\theta_{min} = \pm 1$

$\theta_{min} = 0°$ and $180°$

C. Half power point direction :

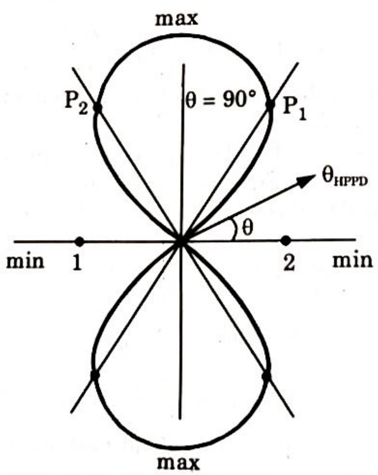


Fig. 2.6.2. Radiation pattern for two isotropic point sources with same amplitude and phase.

At half power points, power is $\frac{1}{2}$ or voltage or current is $\frac{1}{\sqrt{2}}$ times the maximum value of voltage or current.

$$\therefore \quad \cos\left(\frac{\pi}{2}\cos\theta\right) = \pm\frac{1}{\sqrt{2}}$$

$$\frac{\pi}{2}\cos\theta_{HPP} = \pm(2n+1)\frac{\pi}{4} \qquad \text{where,} \qquad n = 0, 1, 2...$$

$$\frac{\pi}{2}\cos\theta_{HPP} = \pm\frac{\pi}{4}$$

i.e., $\cos\theta_{HPP} = \pm\frac{1}{2}$

i.e., $\theta_{HPP} = 60°$ or $120°$

Que 2.7. **Derive and hence plot the radiation pattern for two isotropic point sources of same amplitude but opposite phase.**

AKTU 2014-15, Marks 05

Answer

1. Let the 2 isotropic point sources be separated by distance d and located symmetrically with respect to origin.
2. Then the total field in the direction ϕ at a large distance r is given by
$$E = E_0 e^{+j\Psi/2} - E_0 e^{-j\Psi/2}$$
from which
$$E = 2jE_0 \sin\frac{\Psi}{2} = 2jE_0 \sin\left(\frac{dr}{2}\cos\phi\right) \quad ...(2.7.1)$$
3. Putting $2jE_0 = 1$ and considering the special case of $d = \lambda/2$, then eq. (2.7.1) becomes
$$E = \sin\left(\frac{\pi}{2}\cos\phi\right) \quad ...(2.7.2)$$
4. The directions ϕ_m of maximum field are obtained by setting the argument of eq. (2.7.2) equal to $\pm(2k+1)\pi/2$. Thus,
$$\frac{\pi}{2}\cos\phi_m = \pm(2k+1)\frac{\pi}{2} \quad ...(2.7.3)$$
where $k = 0, 1, 2, 3$ .... For $k = 0$, $\cos\phi_m = \pm 1$ and $\phi_m = 0°$ and $180°$.
5. The null directions ϕ_0 are given by
$$\frac{\pi}{2}\cos\phi_0 = \pm k\pi \qquad \text{For } k = 0, \phi_0 = \pm 90°. \quad ...(2.7.4)$$
6. The half-power directions are given by
$$\frac{\pi}{2}\cos\phi = \pm(2k+1)\frac{\pi}{4} \quad ...(2.7.5)$$
For $k = 0$, $\phi = \pm 60° \pm 120°$.

7. The field pattern given by eq. (2.7.3), (2.7.4) and (2.7.5) is shown in Fig. 2.7.1. The pattern is a relatively broad figure-of-eight with the maximum field in the same direction as the line joining the sources.

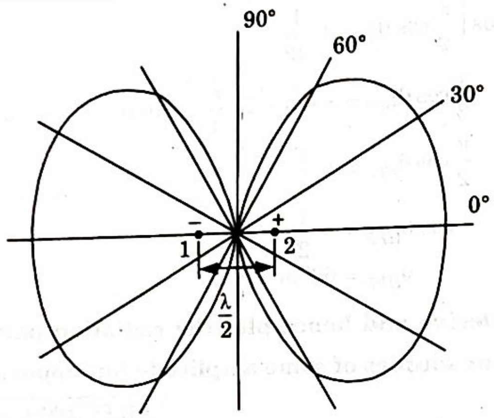


Fig. 2.7.1.

Que 2.8. **Calculate the directivity of an endfire array of two identical isotropic point source in phase opposition, spaced λ/2 apart along the polar axis, the relative field pattern being given by $E = \cos(d_r/2 \cos\theta)$.**

AKTU 2016-17, Marks 12

Answer

Given : $E = \cos(d_r/2 \cos\theta)$
To Find : D.

1. The general expression for directivity is given by

$$D = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} P_n(\theta,\phi)\sin\theta\, d\theta\, d\phi} \quad ...(2.8.1)$$

where, $P_n(\theta, \phi)$ = normalized power pattern = $[E_n(\theta, \phi)]^2$

$$E_n(\theta,\phi) = \frac{E(\theta,\phi)}{E(\theta,\phi)_{max}}$$

2. Now eq. (2.8.1) becomes

$$D = \frac{4\pi E^2(\theta,\phi)_{max}}{\int_0^{2\pi}\int_0^{\pi} E^2(\theta,\phi)\sin\theta\, d\theta\, d\phi} \quad ...(2.8.2)$$

3. $$E(\theta,\phi) = \cos\left(\frac{d_r}{2}\cos 0\right) = \cos\left(\frac{\psi}{2}\right)$$

where, $\psi = d_r \cos\theta$; for broadside case

so, $$E^2(\theta,\phi) = \cos^2\left(\frac{\psi}{2}\right) = \frac{1+\cos\psi}{2} \quad ...(2.8.3)$$

at $\psi = 0$,

$$E^2(\theta,\phi)_{max} = \frac{1}{2}$$

4. Now eq. (2.8.2) becomes

$$D = \frac{4\pi \frac{1}{2}}{\int_0^{2\pi}\int_0^{\pi} E^2(\theta,\phi)\sin\theta\, d\theta\, d\phi}$$

5. Let the denominator be denoted by

$$I = \int_0^{2\pi}\int_0^{\pi} E^2(\theta,\phi)\sin\theta\, d\theta\, d\phi$$

$$= [\phi]_0^{2\pi}\int_0^{\pi} E^2(\theta,\phi)\sin\theta\, d\theta = 2\pi\int_0^{\pi}\cos^2\frac{\psi}{2}\sin\theta\, d\theta$$

$$= 2\pi\int_0^{\pi}\left(\frac{1+\cos\psi}{2}\right)\sin\theta\, d\theta$$

$$I = \left[\int_0^{\pi}\sin\theta\, d\theta + \int_0^{\pi}\cos\psi\sin\theta\, d\theta\right]$$

$$= \pi\,[I_1 + I_2]$$

where $$I_1 = \int_0^{\pi}\sin\theta\, d\theta = [-\cos\theta]_0^{\pi} = [1+1] = 2$$

and $$I_2 = \int_0^{\pi}\cos\psi\sin\theta\, d\theta$$

$$= \int_0^{\pi}\cos(d_r\cos\theta)\sin\theta\, d\theta \quad (\because\ \psi = d_r\cos\theta) \quad ...(2.8.4)$$

6. Let $z = d_r\cos\theta$
then $dz = d_r(-\sin\theta\, d\theta)$

or $$\sin\theta\, d\theta = -\frac{dz}{d_r}$$

when, $\theta = 0,\ z = +d_r$
$\theta = 0,\ z = -d_r$

7. Hence, $$I_2 = \int_{+d_r}^{-d_r}\cos z\left(\frac{-dz}{d_r}\right) = +\int_{-d_r}^{d_r}\frac{\cos z\, dz}{d_r}$$

$$= \frac{1}{d_r}[+\sin z]^{+d_r}_{-d_r} = \frac{1}{d_r}[\sin d_r - \sin(-d_r)]$$

and $$I_2 = \frac{2 \sin d_r}{d_r}$$

Therefore, $$D = \frac{4\pi \frac{1}{2}}{\pi\left[2 + \frac{2\sin d_r}{d_r}\right]}$$

$$D = \frac{1}{1 + \frac{\sin d_r}{d_r}}$$

Que 2.9. **Explain the principle of pattern multiplication. Draw the radiation pattern of 2 half wave linear antenna separated at a distance of λ/4 with zero initial phase.**

Answer

1. The total field pattern of an array of non-isotropic but similar sources is the product of the individual source pattern and the pattern of an array of isotropic point sources each located at the phase center of the individual source and having the same relative amplitude and phase.
2. While the total phase pattern is the sum of the phase patterns of the individual source and the array of isotropic point sources.
3. The total phase pattern is referred to the phase center of the array. The total field E is then,

$$E = f(\theta, \phi)\, F(\theta, \phi) \angle f_p(\theta, \phi) + F_p(\theta, \phi)$$

where,
$f(\theta, \phi)$ = Field pattern of individual source
$f_p(\theta, \phi)$ = Phase pattern of individual source
$F(\theta, \phi)$ = Field pattern of array of isotropic sources
$F_p(\theta, \phi)$ = Phase pattern of array of isotropic source

4. Radiation pattern of 2-half wave linear antenna :

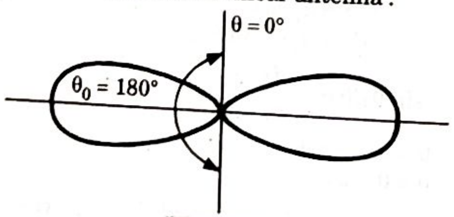


Fig. 2.9.1.

Que 2.10. **Explain the radiation pattern of 4-isotropic elements fed in phase, spaced λ/2 apart.**

Answer

1. Let the 4-elements of isotropic radiators are in a linear arrays in which elements are placed at a distance of λ/2 and are fed in phase *i.e.*, $\alpha = 0$ as shown in Fig. 2.10.1.

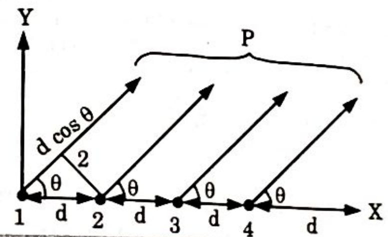


Fig. 2.10.1. Linear arrays of 4-isotropic elements spaced λ/2 apart, fed in phase.

2. It is already seen that two isotropic point sources spaced λ/2 apart are fed in phase provides a bi-directional pattern. The radiation pattern of two isotropic radiators spaced λ apart, fed in phase is shown Fig. 2.10.2.

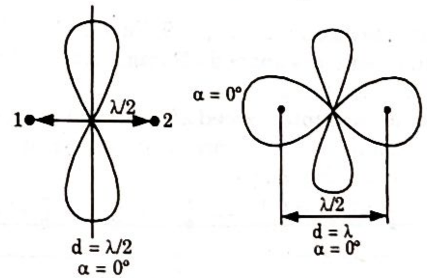
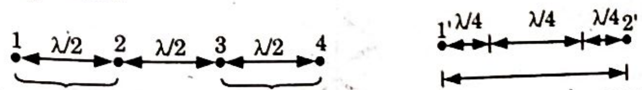


Fig. 2.10.2. Radiation pattern.

3. In this case, 2-isotropic elements are assumed to be one unit and then find the radiation pattern of two such units, spaced λ apart, as shown in Fig. 2.10.3.



(*a*) 4-isotropic elements spaced λ/2. (*b*) 2-units array, where one unit (O = 0 ← λ/2 → 0) spaced λ.

Fig. 2.10.3.

4. Then according to the multiplication of pattern, the resultant radiation pattern of 4 elements is obtained by multiplying the radiation pattern of

individual element and array of two units spaced λ apart as shown in Fig. 2.10.4.

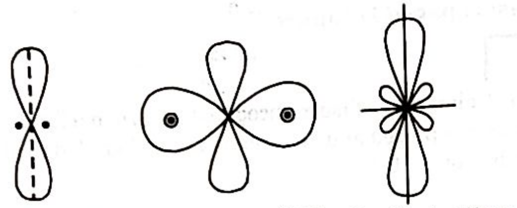


Fig. 2.10.4. Resultant radiation pattern of 4-isotropic elements by pattern multiplication.

Que 2.11. **Explain the principle of pattern multiplication. Synthesize the pattern using this principle for the two case (i) Four isotropic elements spaced λ/2 apart and fed in phase. (ii) Eight isotropic elements spaced λ/2 and fed in phase.**

AKTU 2017-18, Marks 05

Answer

A. Pattern multiplication : Refer Q. 2.9, Page 2–14D, Unit-2.

B. Four isotropic elements spaced λ/2 apart and fed in phase : Refer Q. 2.10, Page 2–15D, Unit-2.

C. Eight isotropic elements spaced λ/2 and fed in phase :

1. The principle can be applied to broadside linear array of 8-isotropic elements as shown in Fig. 2.11.1.

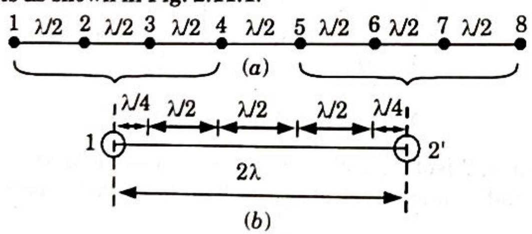


Fig. 2.11.1. (*a*) Linear arrays of 8-isotropic elements spaced λ/2. (*b*) Equivalent two units array spaced 2λ.

2. In this case 4-isotropic elements are assumed to be one unit and then to find the radiation pattern of two such units spaced at a distance 2λ apart, fed in phase can be calculated as

$$E = E_o(1 + e^{j\psi} + e^{2j\psi} + \ldots\ldots) = E_o\sum_{n=1}^{N} e^{j(n-1)\psi}$$

where, $\psi = \beta\, d \cos\theta + \alpha$ $(\alpha = 0)$

$$\psi = \beta\, d \cos\theta \qquad (d = 2\lambda)$$

$$\psi = 4\,\pi \cos\theta \qquad \left(\beta = \frac{2\pi}{\lambda}\right)$$

3. Thus the radiation pattern of 8-isotropic elements is obtained by multiplying the unit pattern of 4 individual elements and group pattern of two isotropic radiators spaced 2λ is shown in Fig. 2.11.2.

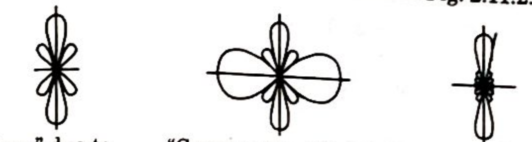


Fig. 2.11.2. Resultant radiation pattern of 8-isotropic elements by pattern multiplication.

Que 2.12. **Show that linear array of *N*-isotropic point source of equal amplitude and spacing $E_{norm} = 1/\lambda \dfrac{\sin \lambda\phi/2}{\sin \phi/2}$**

AKTU 2016-17, Marks 10

Answer

1. An array is said to be linear, if the individual elements of the array are spaced equally along a line and are uniform, and they are fed with currents of equal amplitude and having a uniform progressive phase shift along the line.
2. Consider a linear array of *N*-isotropic point sources as shown in Fig. 2.12.1.

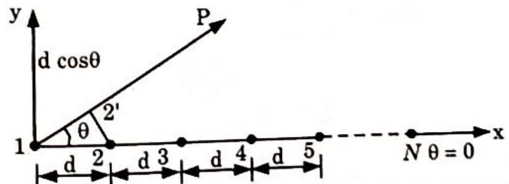


Fig. 2.12.1. Linear array with *N* isotropic point sources with equal amplitude and spacing.

3. The total far field pattern at a distant point *P* is obtained by adding vertically the fields of individual source as :

$$E_t = E_o\,[1 + e^{j\phi} + e^{2j\phi} + \ldots\ldots + e^{j(N-1)\phi}] \qquad \ldots(2.12.1)$$

where, $\phi = \beta d \cos\theta + \alpha$

= Total phase difference of fields at point *P*.

and α = Phase difference in adjacent point sources or progressive phase shift between two point sources.

4. Now, multiplying eq. (2.12.1) by $e^{j\phi}$ gives

$$E_t e^{j\phi} = E_o (e^{j\phi} + e^{2j\phi} + \ldots\ldots + e^{Nj\phi}) \quad \ldots(2.12.2)$$

5. Subtracting eq. (2.12.2) from (2.12.1), we get,

$$E_t(1 - e^{j\phi}) = E_o(1 - e^{jN\phi})$$

$$E_t = \frac{E_o\,(1 - e^{jN\phi})}{(1 - e^{j\phi})} \quad \ldots(2.12.3)$$

6. Eq. (2.12.3) can be written as

$$E_t = E_0 \frac{e^{jN\phi/2}}{e^{j\phi}} \left(\frac{e^{jN\phi/2} - e^{-jN\phi/2}}{e^{j\phi/2} - e^{-j\phi/2}} \right)$$

from which,

$$E_t = E_0\, e^{j\psi} \frac{\sin (N\phi/2)}{\sin (\phi/2)} = E_0 \frac{\sin (N\phi/2)}{\sin (\phi/2)} \angle\psi \quad \ldots(2.12.4)$$

where, $\psi = \left(\frac{N-1}{2}\right)\phi$

7. If the phase is referred to the centre point of array, then eq. (2.12.4) becomes.

$$E_t = \frac{E_0 \sin (N\phi/2)}{\sin (\phi/2)}$$

8. For $\phi = 0$, we have the relation that

$$E_{t\,max} = E_0 N$$

Hence the normalized value of the total field is

$$E_{norm} = \frac{E_t}{E_{t\,max}}$$

$$= \frac{E_0}{E_0 N} \frac{\sin N\phi/2}{\sin \phi/2}$$

$$= \frac{1}{N} \frac{\sin N\phi/2}{\sin \phi/2}$$

PART-2

Linear Array of n Isotropic Point Sources of Equal Amplitude and Spacing, Linear Broadside Array with Non-Uniform Amplitude Distortions, General Considerations.

CONCEPT OUTLINE : PART-2

- A short linear conductor is after called a short dipole.
- A short dipole is always of finite length even though it may be very short.
- Magnetic fields (General case)

$$|H| = H_\phi = \frac{I_o\, L \cos\theta\, e^{j\omega\left(t - \frac{r}{c}\right)}}{2\pi\varepsilon_o} \left(\frac{j\omega}{cr} + \frac{1}{r^2}\right)$$

$$H_r = H_\theta = 0$$

- Radiation resistance of short electric dipole :

$$R_r = 80\,\pi^2 \left(\frac{L}{\lambda}\right)^2$$

- Radiation resistance of $\frac{\lambda}{2}$ antenna = 73 Ω

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.13. **Explain the linear array of n-isotropic point sources of equal amplitude and spacing. Derive the expressions of direction of pattern maxima, direction of minimum field pattern, beam width of major lobe and directivity for a broadside array of n-isotropic sources.**

AKTU 2017-18, Marks 10

Answer

A. Linear array of n-isotropic point sources : Refer Q. 2.12, Page 2–17D, Unit-2.

B. Directions of pattern maxima :

1. $$E_t = E_0 \frac{\sin n\psi/2}{\sin \psi/2} \quad \ldots(2.13.1)$$

For array of n-isotropic point sources of equal amplitude and spacing eq. (2.13.1) may be used.

2. This is maximum when numerator is maximum *i.e.*, $\sin n\,\psi/2$ is maximum provided $\sin \psi/2 \neq 0$.

$$\therefore \quad \sin \frac{n\psi}{2} = 1$$

or $\dfrac{n\psi}{2} = \pm (2N + 1)\, \pi/2$

where $N = 1, 2, 3, 4$ ....

while $N = 0$ corresponds to major lobe maxima

$\psi/2 = \pm (2N + 1)\, \pi/2 \,.\, 1/n$

or $\psi = \pm (2N + 1)\, \pi/n$

and $\beta d \cos (\theta_{max})_{min} + \alpha = \pm (2N + 1)\dfrac{\pi}{n}$

$$\cos (\theta_{max})_{minor} = \left\{\frac{1}{\beta d}\left[\pm\frac{(2N+1)\pi}{n} - \alpha\right]\right\}$$

$$(\theta_{max})_{minor} = \cos^{-1}\left\{\frac{1}{\beta d}\left[\pm\frac{(2N+1)\pi}{n} - \alpha\right]\right\} \qquad ...(2.13.2)$$

where $(\theta_{max})_{minor}$ = minor lobe maxima.

3. For a broadside array $\alpha = 0$

$$\therefore \quad (\theta_{max})_{minor} = \cos^{-1}\left\{\frac{1}{\beta d}\left[\pm\frac{(2N+1)\pi}{n}\right]\right\}$$

$$= \cos^{-1}\left\{\frac{\lambda}{2\pi d}\left[\pm\left(\frac{(2N+1)}{n}\right)\pi\right]\right\}$$

$$(\theta_{max})_{minor} = \cos^{-1}\left\{\pm\frac{(2N+1)\lambda}{2nd}\right\} \qquad ...(2.13.3)$$

C. Direction of pattern minima :

1. $$E_t = E_0 \frac{\sin n\psi/2}{\sin \psi/2} = 0$$

or $\sin n\,\psi/2 = 0$ provided $\sin \psi/2 \neq 0$

or $n\,\psi/2 = \pm N\pi$

or $\psi = \pm \dfrac{2N\pi}{n}$

$\beta d\,(\cos \theta_{min})_{minor} + \alpha = \pm \dfrac{2N\pi}{n}$

or $$(\theta_{min})_{minor} = \cos^{-1}\left[\frac{1}{\beta d}\left\{\pm\frac{2N\pi}{n} - \alpha\right\}\right]$$

2. For broad side, $\alpha = 0$

$$(\theta_{min})_{minor} = \cos^{-1}\left[\frac{1}{\beta d}\left(\pm\frac{2N\pi}{n}\right)\right]$$

$$= \cos^{-1}\left[\frac{\lambda}{2\pi d}\left(\pm\frac{2N\pi}{n}\right)\right]$$

$$(\theta_{min})_{minor} = \cos^{-1}\left[\pm\frac{N\lambda}{nd}\right] \qquad ...(2.13.4)$$

D. Beam width of major lobe :

1. Beam width of major lobe

= 2 × Angle between first null and maximum of major lobe

$BWFN = 2 \times \gamma$

2. From eq. (2.13.4) $(\theta_{min}) = \cos^{-1}\left[\pm\dfrac{N\lambda}{nd}\right]$ $[\because\ 90 - \theta_m = \gamma \text{ or } 90 - \gamma = \theta_m]$

or $(90 - \gamma) = \pm \cos^{-1}\left[\pm\dfrac{N\lambda}{nd}\right]$

or $\cos (90 - \gamma) = \sin \gamma = \pm \dfrac{N\lambda}{n\,d}$

$\because$ γ is very small $\therefore$ $\sin \gamma \cong \gamma$

$$\gamma = \pm\frac{N\lambda}{nd}$$

3. First null occurs when $N = 1$

$$\therefore \quad \gamma_1 = \frac{+\lambda}{nd}$$

$$\therefore \quad BWFN = 2 \times \gamma_1 = \frac{2\lambda}{nd}$$

4. If the broadside array is large, so that $N\lambda >> nd$, then

$$2\,\gamma_1 = \frac{2\lambda}{nd} = \frac{2\lambda}{L}$$

where L = Total length of the array in metre

$= (n - 1)\, d = nd$ [if n is large]

$$\therefore \quad 2\,\gamma_1 = \frac{2\lambda}{L}$$

$$\frac{2}{L/\lambda} \text{ radian} = \frac{2 \times 57.3}{L/\lambda} \text{ degree}$$

or $$2\,\gamma_1 = \frac{114.6°}{L/\lambda} = BWFN$$

E. Directivity :

$$D = \frac{n\beta d}{\pi} = \frac{nd}{\pi}\frac{2\pi}{\pi}$$

$$= 2n\left(\frac{d}{\lambda}\right)$$

Total length of array is

$$L = (n-1)\,d \approx nd$$

Hence, $$D = 2\left(\frac{L}{\lambda}\right)$$

Que 2.14. **For endfire array consisting of several half wavelength long isotropic radiators is to have a directive gain of 30. Find array length and width of the minor lobe (*i.e.*, beamwidth between first nulls). What will be these values for a broadside array ?**

Answer

Given : Directivity $(D) = 30$
To Find : Array length, $BWFN$ (for endfire)
Array length, $BWFN$ (for broadside)

A. For endfire case :

$$D = \frac{4L}{\lambda}$$

$$30 = \frac{4L}{\lambda}$$

$$\frac{L}{\lambda} = 7.5$$

$$L = 7.5\lambda = \text{array length}$$

$$BWFN = 114.6\sqrt{\frac{2}{L/\lambda}} = 114.6\sqrt{\frac{2}{7.5}} = 59.18^\circ$$

B. For broadside case :

$$D = \frac{2L}{\lambda} = 30$$

$$L = 15\lambda = \text{array length}$$

and $$BWFN = \frac{114.6}{L/\lambda} = \frac{114.6}{15} = 7.64^\circ$$

Que 2.15. **What is meant by Dolph-Chebyshev distribution for a linear array ? Show that such a distribution gives a minimum side lobe level for a given beam-width of major lobe.**

AKTU 2013-14, Marks 05

Answer

1. In the antenna design, it is often desired to achieve the narrowest beam width, besides low side level.
2. C.L. Dolph proposed that for a linear in phase broadside arrays, it is possible to minimize the beam width of main lobe (between first nulls) for a specified side lobe level and vice-versa.
3. Since for a specified side lobe level, narrowest beam width is achieved by Dolph-Chebyshev distribution and hence it is considered to be optimum.
4. Assuming n number of sources, the steps for calculation of Dolph-Chebyshev distribution are given below :

i. Calculate the value of r.

$$r = \frac{\text{Main lobe maximum}}{\text{Side lobe level}}$$

This value of r is calculated from following formula, side lobe level below main lobe maximum in dB = $20\log_{10} r$.

ii. Now, select Chebyshev polynomial of the same degree as the array polynomial *i.e.*,

$$T_{n-1}(x_o) = r$$

and solve for x_o.

x_o may be calculated from equation

$$x_o = \frac{1}{2}\left[\left\{r + \sqrt{r^2 - 1}\right\}^{1/m} + \left\{r + \sqrt{r^2-1}\right\}^{1/m}\right]$$

where, $m = n - 1$.

iii. Choose array polynomial E_t from following equation :

$E_{te} = a_0 z + a_1\,[4z^3 - 3z] + a_2\,[16z^5 - 20z^3 + 5z] + \ldots$

$E_{t0} = a_0 + a_1\,[2z^2 - 1] + a_2\,[8z^4 - 8z^2 + 1] + \ldots$

iv. Equate Chebyshev polynomial $T_{n-1}(x)$ with array polynomial E_t, *i.e.*,

$$T_{n-1}(x) = E_t$$

and calculate the coefficients $a_0, a_1, a_2, \ldots$etc., and take ratios of relative amplitudes. This gives optimum amplitude distribution for specified side lobe level.

Que 2.16. **What is tapering ? Explain it using suitable example.**

Answer

1. The techniques used in reduction of side lobe level are called as tapering which means that the current or amplitudes in the sources of a linear array is non-uniform.

2. It is found that minor lobes are reduced if the centre source radiates more strongly than the end sources and hence the tapering is done from the centre to end according to some prescription. It is the prescription which derives the name of the array.
3. For example, if the tapering follows coefficients of binomial series then the arrays are known as binomial arrays.

Example :

1. To reduce the Side-Lobe-Level (SLL) of linear in-phase broadside arrays, the sources have amplitudes proportional to the coefficients of a binomial series of the form

$$(a+b)^{n-1} = a^{n-1} + (n-1)a^{n-2}b + \frac{(n-1)(n-2)}{2!} a^{(n-3)} b^2 + \ldots \quad ...(2.16.1)$$

where n is the number of sources.

2. Thus, for arrays of three to six sources the relative amplitudes are given in such a way that the amplitudes are arranged as in Pascal's triangle.
3. Applying the binomial distribution to the array of five sources spaced $\lambda/2$ apart, the resulting pattern, designated as binomial.
4. The pattern has no minor lobes, but this has been achieved at the expense of an increased beamwidth.

Que 2.17. **Briefly explain Binomial Array.**

Answer

1. In this array, the amplitude of the radiating sources is arranged according to the coefficients of successive terms of the binomial series.
2. This was proposed by John Stone in 1929 that if the side lobes in the linear array (broadside) are to be eliminated totally then the radiating sources must have current amplitudes proportional to the coefficients.
3. As the array length is increased to increase the directivity, the minor lobes also appear.
4. But for certain applications, it is highly desirable that secondary lobes should be eliminated totally or reduced to minimum desired level in comparison to main lobes.
5. To eliminate the side lobes, the following conditions are necessarily satisfied in binomial array :

i. Spacing between two consecutive radiating sources does not exceed $\lambda/2$.

ii. The current amplitude in radiating sources is proportional to the coefficients of the successive terms of binomial series.

iii. The elimination of secondary lobes takes place at the cost of directivity.

iv. Half Power Beam Width of Binomial array is more than that of uniform array for the same length of an array.

v. Thus in uniform array secondary lobes appear but main lobe is sharp and narrow whereas in Binomial array, width of beam widens but without secondary lobes.

Que 2.18. **Derive the expression of field binomial array and also write its disadvantages.**

Answer

A. Derivation of binomial array :

1. In derivation of binomial array, the principle of multiplicity of pattern is utilized. The far field pattern of two point sources of same amplitude and phase is given by eq. (2.18.1) and (2.18.2) and its pattern has no minor lobe as shown in Fig. 2.18.1.

$$E = 2E_o \cos\left(\frac{\psi}{2}\right) \quad ...(2.18.1)$$

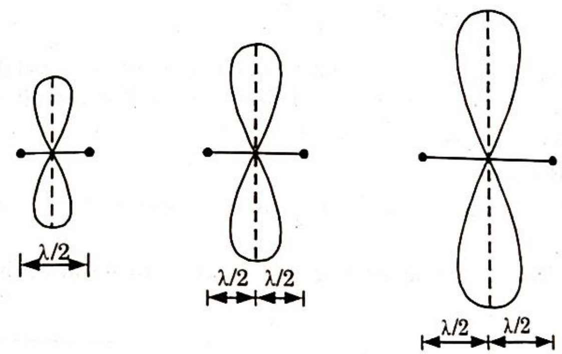


Fig. 2.18.1. Radiation pattern.

$$E_{nor} = \cos\left(\frac{\pi}{2}\cos\theta\right) \quad ...(2.18.2)$$

$$\therefore \quad \left[d = \frac{\lambda}{2} \text{ or } E_o = \frac{1}{2}\right]$$

2. If another identical array of two point sources is superimposed on above array, then the array will take the shape as shown in Fig. 2.18.1, and the far field pattern by principle of multiplicity of pattern is,

$$E_{nor} = \cos^2\left(\frac{\pi}{2}\cos\theta\right)$$

3. The superimposition of two sources at the centre increases its current amplitude to just double in comparison to sources at the edges. Therefore, the array now has the three effective sources with amplitude ratio 1 : 2 : 1.

4. Similarly, if these three sources array are superimposed with another identical array, then an array of effective four sources with current amplitude ratio 1:3:3:1 is obtained as shown in Fig. 2.18.2. in which there is no minor lobes.
5. The far pattern, again by principle of multiplicity of pattern is given by,

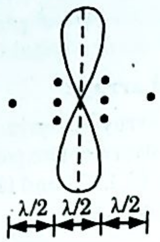


Fig. 2.18.2. 4 sources with amplitude ratio 1 : 3 : 3 : 1.

$$E_{nor} = \cos^2\left(\frac{\pi}{2}\cos\theta\right)$$

6. In this way, it is possible to have a pattern of any desired directivity without any minor lobe provided that the current amplitude source corresponds to the coefficients of said binomial series.

B. Disadvantages :

i. HPBW (Half Power Beam Width) increases and hence the directivity decreases.

ii. For design of a larger array, large amplitude ratio of sources is required.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Design a four element broadside array of λ/2 spacing between elements. Consider unit element as λ/2 length antenna. Draw its radiation pattern and calculate its HPBW.

Ans. Refer Q. 2.3.

Q. 2. Derive the total far field for an array of two isotropic point sources of equal amplitude and phase. Find out the maximum, minimum and half power point directions of radiation pattern for this case.

Ans. Refer Q. 2.6.

Q. 3. Calculate the directivity of an end fire array of two identical isotropic point source in phase opposition, spaced λ/2 apart along the polar axis, the relative field pattern being given by $E = \cos(d_r/2 \cos\theta)$.

Ans. Refer Q. 2.8.

Q. 4. Explain the principle of pattern multiplication. Synthesize the pattern using this principle for the two case (i) Four isotropic elements spaced λ/2 apart and fed in phase. (ii) Eight isotropic elements spaced λ/2 and fed in phase.

Ans. Refer Q. 2.11.

Q. 5. Explain the linear array of *n*-isotropic point sources of equal amplitude and spacing. Derive the expressions of direction of pattern maxima, direction of minimum field pattern, beam width of major lobe and directivity for a broadside array of *n*-isotropic sources.

Ans. Refer Q. 2.13.

Q. 6. What is meant by Dolph-Chebyshev distribution for a linear array ? Show that such a distribution gives a minimum side lobe level for a given beam-width of major lobe.

Ans. Refer Q. 2.15.

☺☺☺

3 UNIT

Thin Linear Antennas and Arrays of Dipoles

PART-1

The Short Electric Dipole, The Fields of a Short Dipole, Radiation Resistance of Short Electric Dipole, Thin Linear Antenna, Radiation Resistance of λ/2 Antenna.

CONCEPT OUTLINE : PART-1

- A short dipole is always of finite length even though it may be very short.
- Magnetic fields (General case)

$$|H| = H_\phi = \frac{I_o L \cos\theta \, e^{j\omega\left(t - \frac{r}{c}\right)}}{2\pi\varepsilon_o}\left(\frac{j\omega}{cr} + \frac{1}{r^2}\right)$$

$$H_r = H_\theta = 0$$

where 'L' is length of dipole, c is the velocity of light and r is the distance.

- Radiation resistance of short electric dipole :

$$R_r = 80\,\pi^2\left(\frac{L}{\lambda}\right)^2$$

- Radiation resistance of $\frac{\lambda}{2}$ antenna = 73 Ω

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.1. **Briefly explain short electric dipoles.**

Answer

1. A short linear conductor is so short that current may be assumed to be constant throughout its length, such short conductor is often called as short dipole.
2. A physical approximation is shown in which two ends of the dipole are represented by two spheres where charges are accumulated. A short dipole that does have a uniform current will be known as elemental dipole.
3. When the length of the short dipole is vanishingly small, the term infinitesimal dipole is used. A short dipole is initially in neutral condition

and the moment a current starts to flow in one direction, one half of the dipole acquire an excess of charge and the other a deficit.

4. Because a current is a flow of electrons, then there will be a voltage between two halves of dipole. Hence an oscillating current will result in an oscillating voltage as well.
5. 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.
6. Since in such dipoles, electric charge oscillates, it may also be called as oscillating electric dipole.

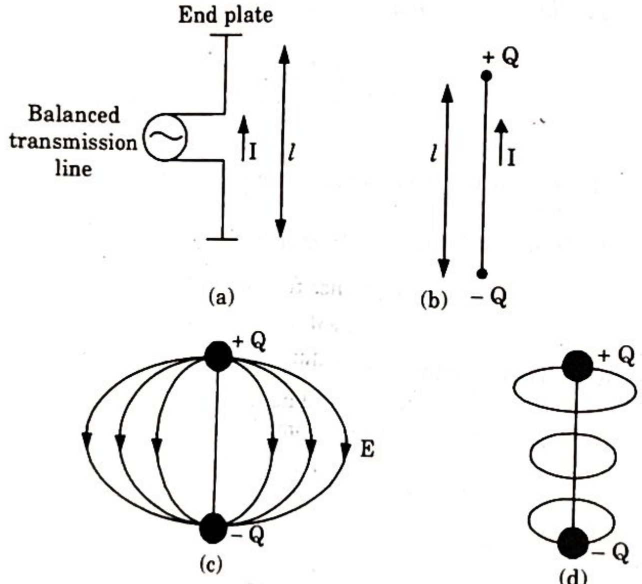


Fig. 3.1.1.

7. Again, a current in a wire is accompanied by a magnetic field surrounding the wire and so the dipole antenna will be surrounded by an electric and a magnetic field.

Que 3.2. Derive the expressions of potential, electric and magnetic field of a short electric dipole. **AKTU 2017-18, Marks 10**

Answer

1. Let us consider a short dipole located as shown in Fig. 3.2.1. The retarded vector potential of electric current has only one component A_z *i.e.*, the current is entirely in *z*-direction.

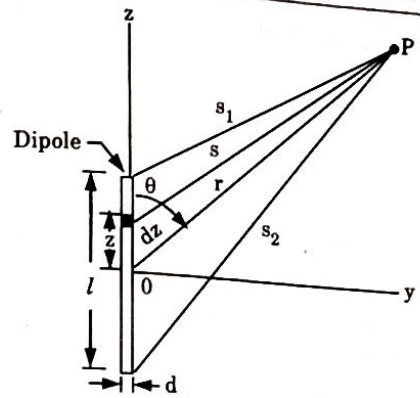


Fig. 3.2.1. Geometry for short dipole.

2. Then the *z* components of retarded vector potential is given by

$$|\vec{A}| = A_z = \frac{\mu}{4\pi}\int_{-l/2}^{l/2}\frac{[I]}{S}dz \qquad ...(3.2.1)$$

where, $[I] = I_m e^{j\omega\left(t-\frac{s}{c}\right)}$

z = Distance to a point on dipole.

I_m = Peak value in time of current.

μ_o = Permeability of free space.

3. If $r >> l$ and $\lambda >> l$ then $s = r$ and neglecting the amplitude and phase difference of field contribution from different parts of the wire.
4. Hence, eq. (3.2.1) can be reduced as

$$A_z = \frac{\mu_o}{4\pi}\int_{-l/2}^{l/2}\frac{I_m e^{j\omega\left(t-\frac{r}{c}\right)}}{r}dz$$

$$= \frac{\mu_o}{4\pi}\int_{0}^{l/2}\frac{2I_m e^{j\omega\left(t-\frac{r}{c}\right)}}{r}dz$$

$$= \frac{\mu_o I_m 2e^{j\omega\left(t-\frac{r}{c}\right)}}{4\pi r}[z]_0^{l/2}$$

$$= \frac{\mu_o I_m l e^{j\omega\left(t-\frac{r}{c}\right)}}{4\pi r}$$

$$= \frac{\mu_o I_m l e^{j(\omega t-\beta r)}}{4\pi r} \qquad ...(3.2.2)$$

where, β = Phase constant.

5. The retarded scalar potential V of a charge distribution is

$$V = \frac{1}{4\pi \epsilon_o}\int_v \frac{[\rho]}{s}\, dt \quad ...(3.2.3)$$

where, ρ = Retarded charge density given by

$$\rho = \rho_o e^{j\omega(t - s/c)} \quad ...(3.2.4)$$

dV = Infinitesimal volume element.

ϵ_o = Permittivity of free space.

6. Since the region of charge in case of dipole under consideration is confined at the points at the end. Then eq. (3.2.3) becomes

$$V = \frac{1}{4\pi \epsilon_o}\left[\frac{Q}{s_1} - \frac{Q}{s_2}\right] \quad ...(3.2.5)$$

$$Q = \int I dt = \int I_m e^{j\omega\left(t - \frac{r}{c}\right)} dt = \frac{I_m e^{j\omega\left(t - \frac{r}{c}\right)}}{j\omega} = \frac{I}{j\omega} \quad ...(3.2.6)$$

7. Substituting the value of eq. (3.2.6) in eq. (3.2.5), we get

$$V = \frac{I_m}{4\pi \epsilon_o j\omega}\left[\frac{e^{j\omega\left(t - \frac{s_1}{c}\right)}}{s_1} - \frac{e^{j\omega\left(t - \frac{s_2}{c}\right)}}{s_2}\right] \quad ...(3.2.7)$$

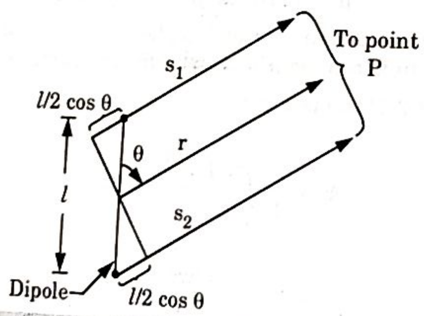


Fig. 3.2.2. Relations for short dipole when $r >> l$.

8. When $r >> l$, the lines connecting the ends of dipole and point P can be considered as parallel such that

$$s_1 = r - \frac{l}{2}\cos\theta$$

$$s_2 = r + \frac{l}{2}\cos\theta$$

9. Substituting the value of s_1 and s_2 in eq. (3.2.7) and solving the equation, we get

$$E_r = \frac{I_m l \cos\theta\, e^{j\omega\left(t - \frac{r}{c}\right)}}{2\pi \epsilon_o}\left[\frac{1}{cr^2} + \frac{1}{j\omega r^3}\right] \quad ...(3.2.8)$$

$$E_\theta = \frac{I_m l \sin\theta\, e^{j\omega\left(t - \frac{r}{c}\right)}}{4\pi \epsilon_o}\left[\frac{j\omega}{c^2 r} + \frac{1}{cr^2} + \frac{1}{j\omega r^3}\right] \quad ...(3.2.9)$$

10. Since, $\mu \vec{H} = \nabla \times \vec{A}$

where, $$\nabla \times \vec{A} = \frac{\hat{r}}{r\sin\theta}\left[\frac{\partial(\sin\theta)A_\phi}{\partial\theta} - \frac{\partial A_\theta}{\partial\phi}\right] + \frac{\hat{\theta}}{r\sin\theta}\left[\frac{\partial A_r}{\partial\phi} - \frac{\partial(r\sin\theta)A_\phi}{\partial r}\right] + \frac{\hat{\phi}}{r}\left[\frac{\partial\, rA_\theta}{\partial r} - \frac{\partial A_r}{\partial\theta}\right] \quad ...(3.2.10)$$

11. Since, $A_\phi = 0$ here first and fourth term in eq. (3.2.10) is zero and only last two terms contributed so that $\nabla \times \vec{A}$ and hence H have only ϕ component. Thus

$$H_\phi = \frac{I_m l \sin\theta\, e^{j\omega\left(t - \frac{r}{c}\right)}}{4\pi}\left[\frac{j\omega}{cr} + \frac{1}{r^2}\right] \quad ...(3.2.11)$$

Thus, field from dipole have only three components E_r, E_θ, and H_ϕ.

Que 3.3. **Derive the radiation resistance of a short electric dipole.**

AKTU 2014-15, Marks 2.5

Answer

1. The radiation resistance of the short dipole can be determined by integrating Poynting vector of the far-field over a large sphere to obtain the total power radiated. This power is then equated to $I^2 R$ where I is the rms current on the dipole and R is a resistance, called the radiation.
2. The average Poynting vector is given by

$$S = \frac{1}{2}\text{Re}(E \times H^*) \quad ...(3.3.1)$$

3. The far-field components are E_θ and H_ϕ so that the radial component of the Poynting vector is

$$S_r = \frac{1}{2}\text{Re } E_\theta H_\phi^* \quad ...(3.3.2)$$

where E_θ and H_ϕ^* are complex.

4. The far-field components are related by the intrinsic impedance of the medium. Hence,

$$E_\theta = H_\phi Z = H_\phi \sqrt{\frac{\mu}{\varepsilon}} \quad ...(3.3.3)$$

Thus, eq. (3.3.2) becomes

$$S_r = \frac{1}{2} \text{Re } ZH_\phi H_\phi{}^* = \frac{1}{2} |H_\phi|^2 \text{ Re } Z = \frac{1}{2} |H_\phi|^2 \sqrt{\frac{\mu}{\varepsilon}} \quad ...(3.3.4)$$

5. The total power P radiated is then given by

$$P = \iint S_r \, dS = \frac{1}{2}\sqrt{\frac{\mu}{\varepsilon}} \int_0^{2\pi}\int_0^{\pi} |H_\phi|^2 r^2 \sin\theta \, d\theta \, d\phi \quad ...(3.3.5)$$

where, $$|H_\phi| = \frac{\omega I_0 L \sin\phi}{4\pi\varepsilon r} \quad ...(3.3.6)$$

6. Substituting eq. (3.3.6) into eq. (3.3.5), we have

$$P = \frac{1}{32}\sqrt{\frac{\mu}{\varepsilon}} \frac{\beta^2 I_0^2 L^2}{\pi^2} \int_0^{2\pi}\int_0^{\pi} \sin^3\theta \, d\theta \, d\phi \quad ...(3.3.7)$$

7. The double integral equals $8\pi/3$ and eq. (3.3.7) becomes

$$P = \sqrt{\frac{\mu}{\varepsilon}} \frac{\beta^2 I_0^2 L^2}{12\pi} \quad ...(3.3.8)$$

8. This is the average power or rate at which energy is streaming out of a sphere surrounding the dipole. Hence, it is equal to the power radiated. Assuming no losses, it is also equal to the power delivered to the dipole.
9. Therefore, P must be equal to the square of the rms current I flowing on the dipole times a resistance R_r called the radiation resistance of the dipole. Thus,

$$\sqrt{\frac{\mu}{\varepsilon}} \frac{\beta^2 I_0^2 L^2}{12\pi} = \left(\frac{I_0}{\sqrt{2}}\right)^2 R_r$$

Solving for R_r,

$$R_r = \sqrt{\frac{\mu}{\varepsilon}} \frac{\beta^2 I_0^2 L^2}{6\pi} \quad ...(3.3.9)$$

10. For air or vacuum $\sqrt{\mu/\varepsilon} = \sqrt{\mu_0/\varepsilon_0} = 377 = 120\pi\,\Omega$ so eq. (3.3.9) becomes

$$R_r = 80\pi^2 \left(\frac{L}{\lambda}\right)^2 = 80\pi^2 L_\lambda^2 = 790 L_\lambda^2 \,\Omega$$

Que 3.4. **Define the expression of far fields for thin linear antenna.**

Answer

1. Consider the thin linear antenna of length that is symmetrically fed at the center by a balanced two-wire transmission line.
2. The antenna may be of any length but it is assumed that the current distribution is sinusoidal.
3. Now, for far-field expression the retarded value of current at any point z at distance s, given by

$$[I] = I_0 \sin\left[\frac{2\pi}{\lambda}\left(\frac{l}{2} \pm z\right)\right] e^{j\omega\left(t - \frac{r}{c}\right)} \quad ...(3.4.1)$$

where, $\sin\left[\frac{2\pi}{\lambda}\left(\frac{l}{2} \pm z\right)\right]$ = form factor for current on the antenna.

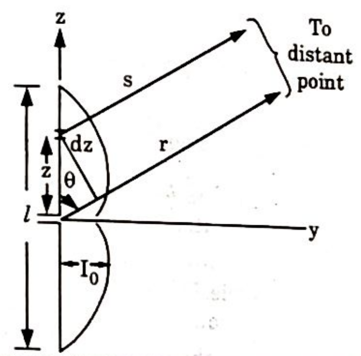


Fig. 3.4.1. Relations for symmetrical, thin linear, center-fed antenna of length l.

4. When, $z < 0$, the expression $\left(\frac{l}{2} + z\right)$ is used and when $z > 0$, $\left(\frac{l}{2} - z\right)$ is used. Considering the antenna is made up of a series of infinitesimal dipole of length dz.
5. Therefore, field for entire antenna can be obtained by integrating the fields from all of the dipoles which is given by

$$H_\phi = \frac{j[I_0]}{2\pi r}\left[\frac{\cos[(\beta l \cos\theta)/2] - \cos(\beta l/2)}{\sin\theta}\right] \quad ...(3.4.2)$$

$$E_\theta = \frac{j60[I_0]}{r}\left[\frac{\cos[(\beta l \cos\theta)/2] - \cos(\beta l/2)}{\sin\theta}\right] \quad ...(3.4.3)$$

where, $$[I_0] = I_0 e^{j\omega\left(t - \frac{r}{c}\right)}$$

6. Eq. (3.4.2) ad (3.4.3) gives far-fields H_ϕ and E_θ of a symmetrical center fed thin linear antenna of length l.

Que 3.5. **Prove that the radiation resistance of half wave dipole antenna is 73 ohms.** **AKTU 2013-14, Marks 05**

OR

Evaluate the radiation resistance of a λ/2 antenna element operating at a frequency of 20 MHz. **AKTU 2014-15, Marks 2.5**

Answer

1. The elemental surface area of a spherical shell is given by

$$ds = 2\pi r^2 \sin\theta \, d\theta \quad ...(3.5.1)$$

2. Hence, the total power radiated from λ/2 antenna is given by the surface integral of Poynting vector over surrounding surface.

$$P = \oint P_{av} \, ds \quad ...(3.5.2)$$

3. The average Poynting vector is given by,

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

$$= \frac{1}{2}\text{Re}(E_\theta H_\phi^*) = \frac{1}{2}|H_\phi|^2 \times 120\pi \quad ...(3.5.3)$$

But, $$H_\phi = \frac{j[I_o]}{2\pi r}\left[\frac{\cos[(\beta L\cos\theta)/2] - \cos\left(\frac{\beta L}{2}\right)}{\sin\theta}\right]$$

For, $$L = \frac{\lambda}{2}$$

$$H_\phi = \frac{jI_0}{2\pi r}\left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right]$$

4. Using eq. (3.5.3), $$P_{av} = \frac{1}{2}\frac{I_o^2}{(2\pi r)^2}\frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin^2\theta} \times 120\pi$$

$$P_{av} = 30\frac{I_{rms}^2}{(\pi r^2)}\cos^2\left(\frac{\frac{\pi}{2}\cos\theta}{\sin^2\theta}\right) \quad ...(3.5.4)$$

5. Using eq. (3.5.4) in eq. (3.5.2), we get

$$P = \int_0^\pi \frac{30\, I_{rms}^2}{(\pi r^2)}\left\{\frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{(\sin\theta)^2}\right\} 2\pi r^2 \sin\theta \, d\theta$$

$$= 60 I_{rms}^2 \int_0^\pi \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} d\theta$$

$$= 30 I_{rms}^2 \int_0^\pi \frac{1+\cos(\pi\cos\theta)}{\sin\theta} d\theta = 60 I_{rms}^2 \times 1.219$$

$$P = 73.140 \; I_{rms}^2 \quad ...(3.5.5)$$

6. Since, $$P = I_{rms}^2 \times R_r \quad ...(3.5.6)$$

Comparing eq. (3.5.5) and (3.5.6) we get

$$R_r = 73.14 = 73\ \Omega \quad ...(3.5.7)$$

Que 3.6. **Explain the thin linear antenna and also derive the radiation resistance of λ/2 antenna.** **AKTU 2017-18, Marks 10**

Answer

A. **Thin Linear Antenna :** Refer Q. 3.4, Page 3–7D, Unit-3.

B. **Radiation resistance of λ/2 antenna :** Refer Q. 3.5, Page 3–9D, Unit-3.

Que 3.7. **A thin dipole antenna is λ / 15 long. If it's R_L = 1.5 Ω, find R_r and its efficiency.** **AKTU 2016-17, Marks 03**

Answer

Given : $dl = \lambda/15$, $R_L = 1.5\ \Omega$
To Find : R_r, η.

$$R_r = 80\pi^2\left(\frac{dl}{\lambda}\right)^2 = 80\pi^2\left(\frac{\lambda}{15\lambda}\right)^2 = 3.5\ \Omega$$

$$\text{Efficiency, } \eta = \frac{R_r}{R_r + R_L} = \frac{3.5}{3.5 + 1.5} = 0.7 = 70\ \%$$

PART-2

Array of Two Driven λ/2 Elements : Broadside Case and End-Fire Case, Horizontal Antennas Above a Plane Ground, Vertical Antennas Above a Plane Ground, Yagi-Uda Antenna Design, Long-Wire Antennas, Folded Dipole Antennas.

CONCEPT OUTLINE : PART-2

- **Array of two driven λ/2 elements :**

1. **Broadside case :** In this case two elements are fed with equal in phase currents.
2. **Endfire case :** Two elements are fed with equal currents in opposite phase.

- The fields of most antennas are affected by the presence of the ground and also the impedance relation may also be different if the array is very close to the ground.
- A dipole antenna with a set of one or more directors and reflector is called Yagi-Uda antenna.

  Yagi-Uda antennas are high gain antennas.
- When the antenna is more than a half wave long then it is called as long wire antenna.
- Folded dipole antenna consists of two closely spaced λ/2 elements connected together at the outer end.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.8. **Derive the expression for field pattern for broad side array of two driven λ/2 elements.**

Answer

1. Consider elements that are center fed and arranged side by side with a spacing d. In this case the two elements are fed with equal in phase current.
2. To obtain a field pattern for two driven λ/2 elements let the element be vertical as shown in Fig. 3.8.1. It is assumed that array is in free space *i.e.*, at an infinite distance from the ground or other object. Then the field intensity $E_1(\phi)$ from the ground single element as a function ϕ and at a large distance d in horizontal plane is given by

$$E_1(\phi) = KI_1 \quad \text{...(3.8.1)}$$

where, K = Constant involving the distance D.

I_1 = Terminal current,

3. Eq. (3.8.1) is the expression for a field pattern in horizontal plane. Since it is independent of ϕ, hence the relative pattern is a circle. If the elements are replaced by isotropic point source with equal amplitude, then the field pattern is given as

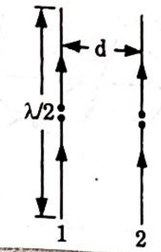


Fig. 3.8.1. Broadside array of 2 in-phase λ/2 elements.

$$E_{iso}(\phi) = 2E_0 \cos\left(\frac{d_r \cos\phi}{2}\right) \quad \text{...(3.8.2)}$$

where, $d_r = \dfrac{2\pi}{\lambda} d$, distance between sources expressed in radians.

4. Applying the principle of pattern multiplication considering E_0 is the field intensity from a single element at distance D. Then,

$$E_o = E_1(\phi) = KI_1 \quad \text{...(3.8.3)}$$

5. Putting the value of E_o in eq. (3.8.2) we get

$$E(\phi) = E_1(\phi)\, 2\cos\left(\frac{d_r \cos\phi}{2}\right)$$

$$= 2\,KI_1 \cos\left(\frac{d_r \cos\phi}{2}\right)$$

6. This is the required expression for field intensity $E(\phi)$ as a function of ϕ in horizontal plane. Fig. 3.8.2 shows the shape of this pattern.
7. The field intensity, $E_1(\theta)$ as a function of θ from single λ/2 element at a distance in vertical plane is given by

$$E_1(\theta) = KI_1 \frac{\cos(\pi/2\cos\theta)}{\sin\theta}$$

8. Then, the pattern $E_{iso}(\theta)$ for two isotropic sources in place of two element in vertical plane as

$$E_{iso}(\theta) = 2E_o$$

9. By applying principle of pattern multiplication

$$E_0 = E_1(\theta)$$

10. Therefore, the field intensity in vertical plane is given by

$$E(\theta) = 2\,KI_1 \frac{\cos(\pi/2\cos\theta)}{\sin\theta}$$

11. This may be called as absolute field pattern in the vertical plane.

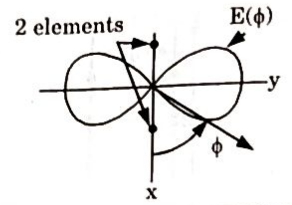


Fig. 3.8.2. Field pattern of 2-element array.

Que 3.9. **Derive the expression for field pattern for endfire array of λ/2 driven elements.**

Answer

1. Consider the Fig. 3.9.1, showing a center fed array of two elements in free space that are arranged side by side with a spacing d and equal current in opposite phase as shown in Fig. 3.9.1.

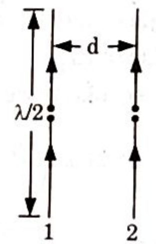


Fig. 3.9.1. Endfire array of 2 linear λ/2 elements with currents of equal magnitude but opposite phase.

2. Now, for the field pattern the field intensity $E_1(\phi)$ as function of at distance d in horizontal plane from a single element is given by

$$E_1(\phi) = KI_1$$

where, K = Constant involving distance D

I_1 = Terminal current.

3. Replacing the elements by isotropic sources of equal amplitude, the pattern $E_{iso}(\phi)$ for such sources is given by

$$E_{iso}(\phi) = 2E_o \sin\left(\frac{d_r \cos\phi}{2}\right)$$

By applying principle of pattern multiplication,

$$E_o = E_1(\phi) = KI_1$$

4. Therefore, field intensity $E(\phi)$ for horizontal plane at large distance D from the array is

$$E(\phi) = 2KI_1 \sin\left(\frac{d_r \cos\phi}{2}\right)$$

5. This is the absolute field pattern in horizontal plane. The relative pattern for spacing λ/2 is shown in Fig. 3.9.2. (*a*). Then, the field intensity $E_1(\theta)$ as a function of θ from a single λ/2 elements at distance D in vertical plane as given by

$$E_1(\theta) = \frac{KI_1 \cos(\pi/2 \cos\theta)}{\sin\theta}$$

6. The pattern $E_{iso}(\theta)$ as a function of θ in vertical plane for two isotropic sources is given by

$$E_{iso}(\theta) = 2E_o \sin\left(\frac{d_r \sin\theta}{2}\right)$$

7. Putting $E_o = E_1(\theta)$ the field intensity $E(\theta)$ in vertical plane at large distance D from an array is

$$E(\theta) = \frac{2KI_1 \cos(\pi/2 \cos\theta)}{\sin\theta} \sin\left(\frac{d_r \sin\theta}{2}\right)$$

8. This is the absolute field pattern in vertical plane and the relative pattern is shown in Fig. 3.9.2. (*b*), (*c*).

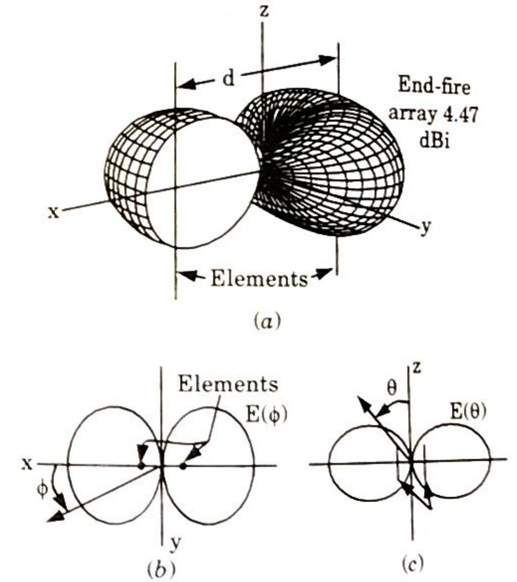


Fig. 3.9.2. Field patterns for end-fire array of 2 linear out-of-phase λ/2 elements with spacing d = λ/2.

Que 3.10. **Write a note on horizontal antenna above planar ground.**

Answer

1. Consider the horizontal antenna that is located at height h above plane ground of infinite extent as shown in Fig. 3.10.1. Because of presence of ground, the field at distant point P is resultant of a direct wave and reflected wave from the ground.
2. If the ground is perfectly conducting then the tangential component of electric field must be zero at the surface. To fulfill this boundary condition, the reflected wave must have a phase reversal of 180° at the point of reflection.

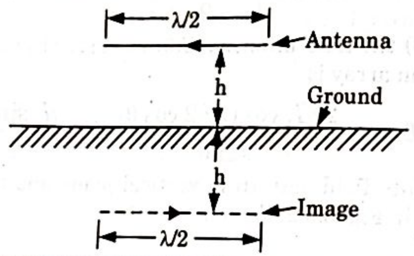


Fig. 3.10.1. Horizontal λ/2 antenna at height h above ground with image at equal distance below ground.

3. To obtain the field at point P method of images is utilized. In this method, the ground is replaced by an image of the antenna situated at distance h below the ground plane as shown in Fig. 3.10.2.
4. Then by considering the current in the image equal in magnitude but reversed in phase by 180° with respect to antenna current, the condition of zero tangential electric field is met at all points along a plane everywhere equidistant from the antenna and the image.
5. This is the plane of ground which the image replaces. In this way the problem of horizontal antenna above perfectly conducting ground of infinite extent can be transformed in endfire array.

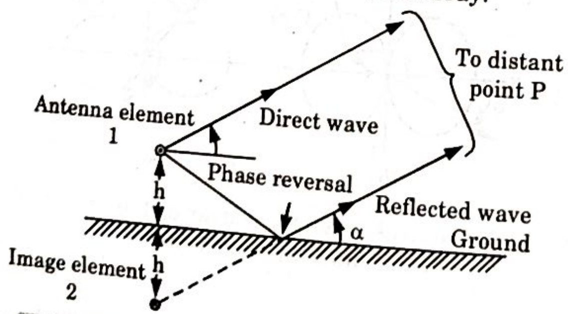


Fig. 3.10.2. Antenna above ground with image showing direct and reflected waves.

Que 3.11. **Explain the effect of ground (earth) on vertical pattern of antenna.**

Answer

1. An antenna located at about 5λ length above the ground may be considered to be in free space. However, in practice, this is not always true and hence the radiation patterns are found to be much affected by reflection from ground.
2. Influence of ground depends on the fact, whether the antenna is actually grounded or merely situated near the ground. So, there are two types of antennas:

A. Ungrounded antennas (ground assumed to be a perfect conductor) :

1. If a source of radiation is put near a reflecting surface, the radiation received at any distant point is the vector sum of the direct and indirect (*i.e.*, reflected from the ground) radiations.
2. Using the principle of image, simplify the situation to a great extent. It is assumed that an image antenna is existing below the ground and is true mirror image of the actual antenna as shown in Fig. 3.11.1.
3. The currents flowing in the image now have the same magnitude as that of actual antenna. The overall radiation is calculated on the basis of being caused by an array of two nearby antennas.
4. These are identical in length having equal currents in magnitudes and are spaced by twice the height of actual antenna above ground.
5. The direction of current flow in vertical antennas is same as that of actual antenna, while in case of horizontal antenna it is in opposite phase.
6. In practice, the ground is an imperfect conductor and hence reflection coefficient of the ground is an important factor. For a perfect conductor, reflection coefficient of earth is unity.

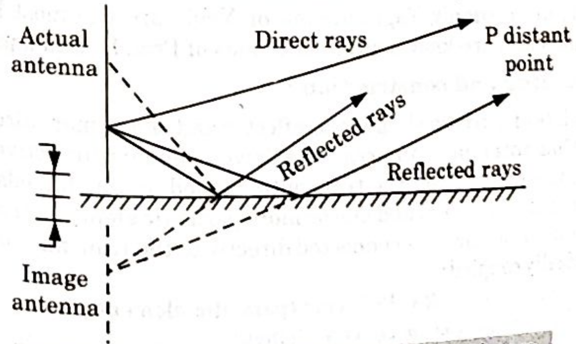


Fig. 3.11.1. Ungrounded antenna and its image.

B. Grounded antennas :

1. When an antenna is close to the ground, then regardless of whether the antenna is grounded or not, the earth acts as a mirror and becomes part of radiating system.
2. There is one difference in the resulting behaviour, whereas the ungrounded with its image forms an array, the bottom of the grounded antenna is joined to the top of the image antenna and acts as an antenna of double size.
3. Hence in case of grounded antenna the effective size of the actual antenna is just double. For example, a $\lambda/4$ antenna effectively has a $\lambda/4$ added to it by its image. Such $\lambda/2$ grounded antenna is known as the basic Marconi antenna.
4. The voltage and current distribution remains the same as in that of the $\lambda/2$ dipole in space.
5. The Marconi antenna has one important advantage over the ungrounded (Hertz antenna) that only half height of the antenna is now required in comparison to ungrounded (Hertz antenna) to produce the same radiation pattern.
6. Ground plays an important role in producing required characteristics and hence conductivity must be accounted.

Que 3.12. **With a neat sketch explain the construction and working of Yagi-Uda antenna.**

AKTU 2016-17, Marks 07

OR

What is Yagi-Uda antenna ? Explain its construction and properties with special reference to directivity pattern for this case.

AKTU 2017-18, Marks 05

Answer

A. Yogi-Uda antenna :

1. Yagi-Uda or simply Yagi antenna or Yagis are the most high gain antennas and are known after the names of Prof. S. Uda and H. Yagi.

B. Its working and construction :

1. It consists of a driven element, a reflector and one or more directors *i.e.*, Yagi-Uda antenna is an array of a driven element (or active element where the power from the transmitter is fed or which feeds received power to the receiver) and one or more parasitic elements (*i.e.*, passive elements which are not connected directly to the transmission line but electrically coupled).

R = Reflector (parasitic element);
D_R = Driven element;
D = Director (parasitic element)

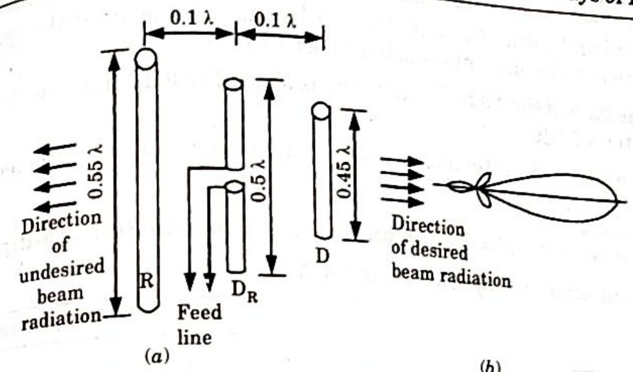


Fig. 3.12.1. (*a*) Yagi-uda antenna, (*b*) Its radiation pattern.

2. The driven element is a resonant half wave dipole of metallic rod at the frequency of operation. The parasitic elements of continuous metallic rods are arranged parallel to the driven element at the same line of sight level. They are arranged collinearly and close together as shown in Fig. 3.12.1 with one reflector and one director.
3. The parasitic elements receive their excitation from the voltages induced in them by the current flow in the driven element. The phase and currents flowing due to the induced voltage depend on the spacing between the elements and upon the reactance of the elements (*i.e.*, length).
4. The reactance may be varied by dimensioning the length of the parasitic element. The spacing between driven and parasitic elements that are usually used, in practice, are of the order of $\lambda/10$ *i.e.*, 0.10 λ to 0.15 λ.
5. The parasitic element in front of driven element is known as director and its number may be more than one, whereas the element in back of it is known as reflector.
6. The length of the arrangement is such that the reflector is 5 % more and director is 5 % less than the driven elements which is $\lambda/2$ at resonant frequency.

i. Reflector length = $\dfrac{500}{f\text{ (MHz)}}$ feet

ii. Driven element length = $\dfrac{475}{f\text{ (MHz)}}$ feet

iii. Director length = $\dfrac{455}{f\text{ (MHz)}}$ feet

C. Properties :

1. It is generally a fixed frequency operated unit. This antenna is frequency sensitive and the bandwidth of 3 % can be easily obtained. Such bandwidth is sufficient for television reception.

2. The bandwidth of 2 % to 3 % can be easily achieved if the spacing between the elements is between 0.1 λ to 1.5 λ.
3. The gain of the Yagi-Uda antenna is about 7 to 8 dB. Its front to back ratio is 20 dB.
4. The Yagi-Uda antenna is light weight, low cost and simple in feeding with signal.

Que 3.13. **Explain Yagi-Uda antenna and design a 5-dipoles Yagi-Uda array for operation at 500 MHz.**

AKTU 2015-16, Marks 10

Answer

A. **Yagi-Uda antenna :** Refer Q. 3.12, Page 3–17D, Unit-3.

B. **Numerical :**

Given : $f = 500$ MHz.
To Design : 5-dipole Yagi-Uda Antenna.

1. At 500 MHz frequency, the wavelength is

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{500\times10^6} = 0.6 \text{ m}$$

2. The dimensions of the elements and the spacings are given as :

i. Length of the reflector = $0.475\lambda \Rightarrow 0.475 \times 0.6 = 0.285$ m

ii. Length of the driven element

$$= 0.46\lambda \Rightarrow 0.46 \times 0.6 = 0.276 \text{ m}$$

iii. Length of each of the director

$$= 0.44\lambda \Rightarrow 0.44 \times 0.6 = 0.264 \text{ m}$$

iv. Spacing between the driven element and the reflector

$$= 0.25\lambda \Rightarrow 0.25 \times 0.6 = 0.15 \text{ m}$$

v. Spacing between the driven element and the first director

$$0.31\lambda = 0.31 \times 0.6 = 0.186 \text{ m}$$

vi. Spacing between consecutive directors

$$= 0.31\lambda \Rightarrow 0.31 \times 0.6 = 0.186 \text{ m}$$

vii. Diameter of element = $0.01\lambda = 0.01 \times 0.6 = 6$ mm.

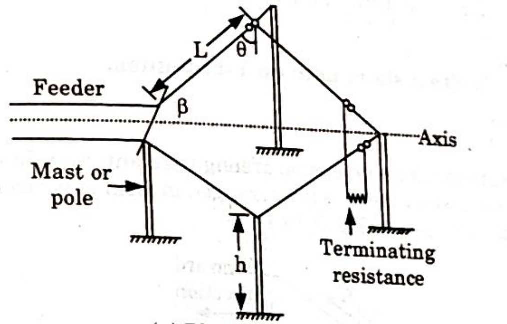
Que 3.14. **What is a rhombic antenna ? Describe its construction and properties with special reference to directivity and bandwidth.**

AKTU 2013-14, Marks 05

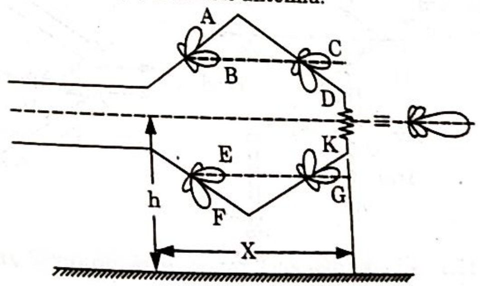
Answer

A. **Rhombic antenna and its construction :**

1. It is a *HF* (higher frequency) transmission and reception antenna. It operates over a broad frequency range *i.e.,* nearly 3 to 30 MHz. It consists of non-resonant elements arranged like a rhombus in the same plane as shown in Fig. 3.14.1(*a*).
2. The length of the radiators is equal and may range from 2λ to 8λ. The angle of tilt θ varies from 40° to 75°.
3. The four radiators are considered as non-resonant antennas terminated in its characteristic impedance *R*.
4. The terminating resistance is often in the range of 800 Ω and the input impedance varies from 650 to 700 Ω.



(*a*) Rhombic antenna.



(*b*) Radiation pattern.

Fig. 3.14.1.

5. When the rhombic antenna is used for transmission, it is fed through a balanced transmission line and the terminating characteristic impedance is so adjusted that travelling waves are set up in the four legs of the rhombus.
6. The maximum gain from the rhombic antenna is along the direction of main axis which passes through feed point to termination in free space.
7. The rhombic antenna generates horizontal polarised waves with a little elevation in the upward direction due to the presence of earth.

8. The radiation pattern of the rhombic antenna is shown in Fig. 3.14.1(*b*). The radiation pattern is unidirectional and is formed due to addition of four lobes of four legs one on each leg.
9. The other lobes formed on each of the leg get cancelled, as they have opposite directions.
10. The unidirectional radiation pattern can be made bi-directional by removing the terminating resistance.
11. **Uses :** It is used in commercial point to point communication system.

B. Properties :

i. It is highly directional broadband antennas with greatest radiated or received power along the main axis or longer diagonal.

ii. Rhombic antennas are untuned and are useful wideband antenna suitable for a rapid switching from one working frequency to another frequency.

Que 3.15. **Write a short note on *V*-antennas.**

Answer

1. The *V*-antenna is an extension of long wire antenna. In this antenna the two long wire antennas are arranged in form of horizontal *V*, fed at the apex, as shown in Fig. 3.15.1.

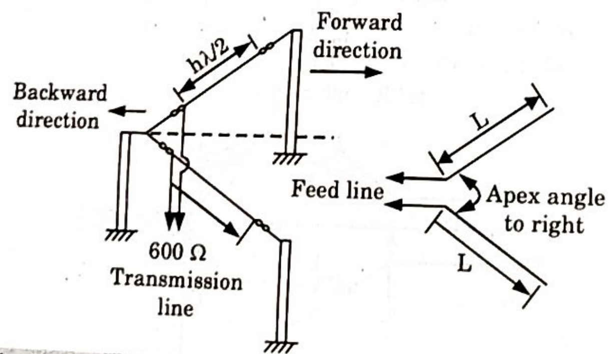


Fig. 3.15.1. A high frequency tuned or resonant *V* antenna.

2. Basically, there are two types of *V*-antennas one is resonant and the other is non-resonant.

i. Resonant V-antenna :

1. In resonant *V*-antenna the radiation is concentrated in the plane of *V* and in the direction of the bisector of the apex angle.
2. If the angle between the two sides of *V* is equal to twice the angle of that the cone of maximum radiation of each wire makes with the axis of that wire, then the two cones will add up in the direction of line bisecting the apex angle of *V* and thereby produce a maximum lobe of radiation.

3. The two wires are fed 180° out of phase with each other.

ii. Non resonant V-antenna :

1. Non-resonant antennas are the antennas in which the source is matched to the load (*i.e.*, they don't have open circuit).
2. A non-resonant antenna is like a properly terminated transmission line, produces no standing waves.
3. They are suppressed by the use of a correct termination resistor and no power is reflected, ensuring that only forward travelling waves will present.
4. In a correctly matched transmission line, all the transmitted power is dissipated in the terminating resistance.

Que 3.16. **Derive the impedance of a folded dipole antenna.**

AKTU 2016-17, Marks 10

Answer

1. Folded dipole antenna consists of two closely spaced $\lambda/2$ elements connected together at the outer ends.
2. In folded dipole two half wave dipoles are folded and joined together in parallel at the ends.
3. It is fed at the centre by a balanced transmission line.

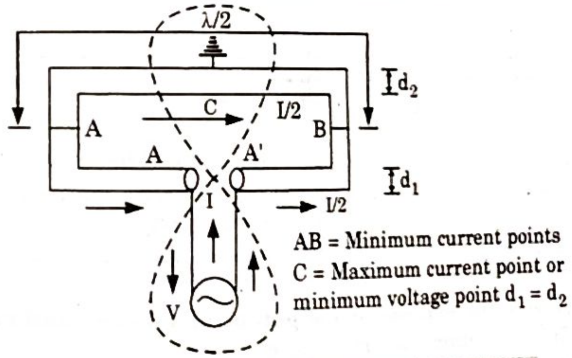


Fig. 3.16.1. Two-wire folded dipole with current distribution and radiation pattern.

4. Therefore, the two dipoles have same voltages at their ends. The radiation pattern of conventional half wave dipole and folded dipole is same but input impedance of folded dipole is higher.
5. Let us assume, in folded dipole both the conductors have same diameter. If *V* is emf applied to the antenna terminals that are divided between the two dipoles as shown in Fig. 3.16.1.

Then, $$\frac{V}{2} = I_1 Z_{11} + I_2 Z_{12}$$

where, I_1 = Current at terminals of dipole 1

I_2 = Current at terminal of dipole 2

Z_{11} = Self impedance of dipole 1

Z_{12} = Mutual impedance of dipole 1 and 2

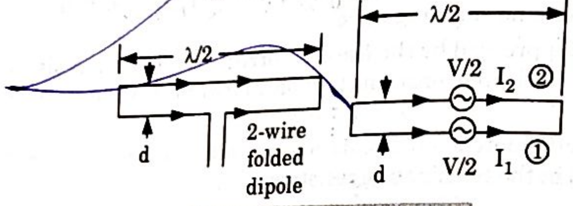


Fig. 3.16.2. Folded dipoles.

6. Since, $I_1 = I_2$

so, $V = 2I_1 (Z_{11} + Z_{12})$

7. Since the two dipoles are close together *i.e.*, d is order of $\lambda/100$, therefore, $Z_{12} \approx Z_{11}$. Thus, the terminal impedance Z of the antenna is given by

$$Z = \frac{V}{I_1} \approx 4Z_{11}$$

8. For $\lambda/2$ dipole, consider $Z_{11} \approx 70 + j0\ \Omega$, then terminal impedance of 2-wire folded dipole becomes $Z \approx 280\ \Omega$.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Derive the expressions of potential, electric and magnetic field of a short electric dipole.

Ans. Refer Q. 3.2.

Q. 2. Prove that the radiation resistance of half wave dipole antenna is 73 ohms.

Ans. Refer Q. 3.5.

Q. 3. With a neat sketch explain the construction and working of Yagi-Uda antenna.

Ans. Refer Q. 3.12.

Q. 4. What is a rhombic antenna ? Describe its construction and properties with special reference to directivity and bandwidth.

Ans. Refer Q. 3.14.

Q. 5. Derive the impedance of a folded dipole antenna.

Ans. Refer Q. 3.16.

☺☺☺

UNIT 4

Loop Antenna and Reflector Antenna

PART-1

The Loop Antenna : Design and its Characteristics Properties, Application of Loop Antennas, Far Field Patterns of Circular Loop Antenna with Uniform Current, Slot Antennas, Horn Antennas, Helical Antennas, The Log-Periodic Antenna, Micro-Strip Antennas

CONCEPT OUTLINE : PART-1

- A loop antenna is a radiating coil of convenient cross section of one or more turns carrying radio frequency current. It can be of any shape *i.e.*, rectangular, square, circular, triangular etc.
- Application of loop antenna is that it can be used as direction finder.
- Slot antennas are useful in many applications, especially where low profile or flush mountings are required as, for example, on high speed aircrafts.
- A horn antenna may be regarded as a flared out (or opened out) waveguide.
- Microstrip antenna is popular for low profile applications at frequencies above 100 MHz.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.1. What do you understand by loop antenna ?

Answer

1. A loop antenna is a radiating coil of convenient cross-section of one or more turns carrying radio frequency current.
2. It can be of any shape *i.e.*, it may be rectangular, square, triangular and circular etc. A loop having more than one turn is called frame.
3. In loop antenna, ordinarily loop is designed in such way that its dimensions are small as compare to wavelength.
4. Hence the current flowing through the loop has same magnitude and phase throughout the loop. Fig. 4.1.1 shows the various types of loop used as a loop antenna.

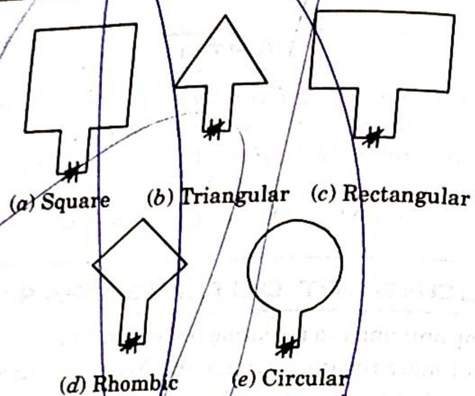


Fig. 4.1.1. Loop antennas of different shapes.

Que 4.2. **Derive necessary equations for the loop antenna.**

Answer

1. The field pattern of a small circular loop of radius r can be determined by considering a square loop of same area, that is

$$d^2 = \pi r^2$$

where, d = side length of square loop.

2. The loop discussed so far is of low dimension compared to wavelength so that the magnitude and phase remain the same throughout the loop.
3. If the loop antenna is used for transmission purpose, its field pattern can be analysed by treating loop as four short linear dipoles AC and BD in YZ plane.

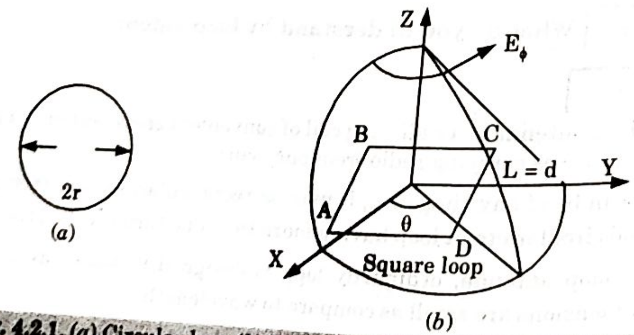


Fig. 4.2.1. (a) Circular loop (b) Relation of square loop to coordinate.

The loop here is circular shape of radius r where $r << \lambda$.

4. The radiation pattern of AC and BD dipoles is circular in YZ plane as shown in Fig. 4.2.2(b). This means that they are radiating uniformly in all directions.

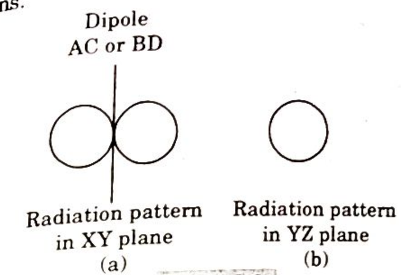


Fig. 4.2.2.

5. Now, the far field radiation pattern due to isotropic source AC and BD with reference to centre point O, we have

E_ϕ = Field component due to AC + field component due to BD.

$$E_\phi = -E_0\, e^{j\psi/2} + E_0\, e^{-j\psi/2}$$

$$E_\phi = -2jE_0\left[\frac{e^{j\psi/2} - e^{-j\psi/2}}{2j}\right]$$

$$E_\phi = -2E_0 j \sin(\psi/2)$$

where, E_0 = electric field amplitude of short dipole

where,
$$\psi = \frac{2\pi}{\lambda}\, d \cos(90 - \theta) = \text{Phase difference}$$

$$\psi = \beta\, d \sin\theta$$

$$\therefore \quad E_\phi = -2j\, E_0 \sin\left(\frac{\beta d \sin\theta}{2}\right) = j\, E_0 \beta d \sin\theta$$

6. The term j indicates that total field E_ϕ is in phase quadrature with the individual dipole field E_0. The equation of a individual dipole is given as :

$$E_0 = \frac{j60\pi[I]\sin 90^\circ}{r} \times \frac{L}{\lambda}$$

$$E_0 = \frac{j60\pi[I]L}{r\lambda}$$

$$E_\phi = \frac{120\pi^2[I]\sin\theta A}{r\lambda^2}$$

Que 4.3. **Derive the expression for voltage induced in the loop.**

Answer

1. To derive the expression for induced emf in loop we have to find actual value of phase difference between the two vertical sides, the plane of loop is at an angle θ with respect to direction of inco waves.
2. As from Fig. 4.3.1 the plane of loop makes an angle with the incre waves.

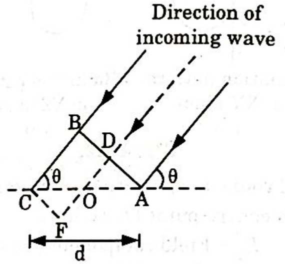


Fig. 4.3.1. Loop antenna and signal wave arrival.

3. From Fig. 4.3.1, path difference between the two waves is given b

Path difference $= OD = \frac{d}{2}\cos\theta$

Phase difference $= \frac{2\pi}{\lambda} \times$ path difference

$$\alpha = \frac{2\pi}{\lambda}\frac{d}{2}\cos\theta$$

$$\alpha = \frac{\pi d\cos\theta}{\lambda} \quad ...(4.$$

4. The electric field at point A is given by,

$$= E_m \sin(\omega t + \alpha)$$

And field at point C is given by

$$= E_m \sin(\omega t - \alpha)$$

5. Hence emf induced in vertical side AD and BC of loop are given by

$$E_1 = E_m h \sin(\omega t + \alpha) \quad \text{(In side } AD) \quad ...(4.$$

$$E_2 = E_m h \sin(\omega t - \alpha) \quad \text{(In } BC) \quad ...(4.$$

6. Resultant emf is given by, $e = E_1 - E_2$
7. Putting the values of E_1 and E_2 from eq. (4.3.2) and (4.3.3) we get,

$$e = E_m h [\sin(\omega t + \alpha) - \sin(\omega t - \alpha)]$$

$$e = 2E_m h \cos\omega t \sin\alpha$$

$$= 2E_m h \cos\omega t \sin\left(\frac{\pi d\cos\theta}{\lambda}\right)$$

8. Since α is very small *i.e.*, $\sin\alpha \cong \alpha$

$$\left(\frac{\pi d\cos\theta}{\lambda}\right) \cong \left(\frac{\pi d\cos\theta}{\lambda}\right)$$

$$e = \frac{2\pi h d\cos\theta}{\lambda} E_m \cos\omega t$$

If,

N = Number of turns in the loop

$A = hd$ = Area of the loop

9. Then instantaneous emf of loop is given by

$$e_\phi = \frac{2\pi AN\cos\theta}{\lambda} E_m \sin\left(\frac{\pi}{2} + \omega t\right) \quad ...(4.3.4)$$

10. The eq. (4.3.4) shows the instantaneous value of emf at the centre of loop having 90° phase between emf induced and the electromagnetic field being received.

Que 4.4. **A loop aerial for use at 500 kHz is of height 0.5 meter, width 0.5 meter and 25 turns, when directed to receive a maximum signal. The emf induced in the loop is 150 µV. What is the field strength of the signal picked up ?**

AKTU 2013-14, Marks 05

Answer

Given : f = 500 kHz, h = 0.5 m, d = 0.5 m, N = 25, V_{rms} = 150 µV

To Find : Field strength, (E_{rms}).

1. $$\lambda = \frac{300}{0.5} = 600 \text{ m}$$

$$A = 0.5 \times 0.5 = 0.25 \text{ m}^2$$

2. We know, $$V_{rms} = \frac{2\pi E_{rms} AN}{\lambda}\cos\theta$$
3. For maxima, $\theta = 0°$

$$\therefore \quad E_{rms} = \frac{V_{rms}\lambda}{2\pi AN} = \frac{150 \times 10^{-6} \times 600}{2\pi \times 0.25 \times 25} = 2.29 \text{ V/m}$$

Que 4.5. **Discuss about the applications of loop antenna and what is 180° ambiguity ? How it arise and how is it removed ?**

AKTU 2014-15, Marks 05

Answer

A. Applications of loop antenna :

1. A small loop antenna is used as a source for paraboloid in many applications.
2. Large loop antenna can be used as direction finder.
3. In many applications, loops are mounted at the top of the towers and can be used as omnidirectional systems.
4. For line of sight communication, an array of loops with different dimensions is used.

B. 180° ambiguity :

1. When the loop is rotated to either null or maximum signal position, there is still uncertainty whether the signal is arriving from the left or right (*i.e.*, front or back) directions of the loop.
2. This uncertainty exists because there are two positions of the loop for zero signal and is known as 180° ambiguity.
3. This means loop antenna (or frame antenna) when used as direction finder is unable to distinguish between bearing of a distant transmitter and its reciprocal bearing.
4. The 180° ambiguity in the sense of the bearing can be resolved by employing an open wire or vertical antenna in conjunction with the loop antenna.
5. To determine the sense of the reading of the loop (*i.e.*, which of the two possible directions is correct one in which the unknown transmitter lies) vertical antenna popularly known as sense antenna is used. The apparatus used for finding sense is known as sense finder.

Que 4.6. **Discuss applications of loop antenna as direction finder. What are disadvantages of loop direction finders ? Also explain 180 degree ambiguity and how is it resolved.** **AKTU 2015-16, Marks 10**

OR

Describe the principle of direction finding by means of a closed loop antenna and give the expression for the induced voltage and field strength for short loop and large loop. **AKTU 2017-18, Marks 10**

Answer

A. Loop antenna as a direction finder :

1. Consider a loop antenna of area $A = lb$ used as a receiver as shown in Fig. 4.6.1.

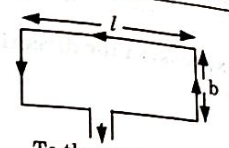


Fig. 4.6.1. Loop antenna as a direction finder.

2. The equation for induced emf in loop is given by

$$V = \frac{2\pi E_{rms} An \cos\theta}{\lambda} \quad ...(4.6.1)$$

3. Eq. (4.6.1) indicates that loop antenna has a directional property. This property is used for direction finding of an unknown transmitter.
4. When the loop antenna associated with receiver is rotated 360°, there are two minimas at $\theta = 90°$ and $270°$ and two maximum at $\theta = 0°$ and $180°$.
5. Because of this nature of radiation pattern of the receiving loop antenna, maximum signal strength will be picked up when the receiving loop antenna is along the direction of transmitting loop antenna, whereas there will be no minimum or no signal strength picked by the receiving loop antenna when it is at right angle to the transmitting antenna.

B. 180° ambiguity : Refer Q. 4.5, Page 4–6D, Unit-4.

C. Disadvantage of loop direction finder :

1. It is suitable for only low and medium frequencies.
2. Transmission efficiency is poor.
3. Spurious induced voltages are produced if nearby loop, wires and conductors are present.
4. It is subjected to antenna effect and night effect which can be minimized by balancing and using Adcock antenna.

D. Expression for field strength :

a. Small loop :

1. Electric field component is given by

$$E_\phi = \frac{120\pi^2 [I] \sin\theta A}{\lambda^2 r}$$

2. Magnetic field component is given by

$$H_\theta = \frac{\pi[I] \sin\theta A}{\lambda^2 r}$$

b. Large loop :

1. Electric field component is given by

$$E_\phi = \frac{60\pi(\beta)\, a[I]\, J_1(\beta a \sin\theta)}{r}$$

2. Magnetic field component is given by

$$H_\theta = \frac{\beta[I]\, aJ_1(\beta a \sin\theta)}{2r}$$

Que 4.7. **Derive an expression for directivity of a loop antenna with uniform current ?**

Answer

1. The directivity D of an antenna is defined as the ratio of maximum radiation intensity to the average radiation intensity *i.e.*,

$$D = \frac{\text{Maximum radiation intensity}}{\text{Average radiation intensity}} = \frac{(P_r)(r^2)}{(P/4\pi)}$$

2. The maximum radiation intensity for a loop antenna is;

$$P_r = \frac{15\pi(\beta a I_m)^2 J_1^2(\beta a \sin\theta)}{r^2}$$

3. Now, the average radiation intensity is given by :

$$P_{avg} = 30\pi^2(\beta a I_m)^2 \int_2^{\pi} J_1^2(\beta a \sin\theta)\sin\theta\, d\theta$$

$$D = \frac{\left\{\dfrac{r^2 \times 15\pi(\beta a I_m)^2 J_1^2(\beta a \sin\theta)}{r^2}\right\}_{max}}{\dfrac{30\pi^2(\beta a I_m)^2 \int_2^{\pi} J_1^2(\beta a \sin\theta)\sin\theta\, d\theta}{4\pi}}$$

$$D = \frac{[2J_1^2(\beta a \sin\theta)]_{max}}{\int_2^{\pi} J_1^2(\beta a \sin\theta)\sin\theta\, d\theta}$$

$$= \frac{2[J_1^2(\beta a \sin\theta)]_{max}}{\dfrac{1}{\beta a}\int_0^{2\beta a} J_1^2(\beta a \sin\theta)\sin\theta\, d\theta}$$

$$D = \frac{2\beta a[J_1^2(\beta a \sin\theta)]_{max}}{\int_0^{2\beta a} J_1^2(\beta a \sin\theta)\sin\theta\, d\theta}$$

4. But, $\beta a = \dfrac{C}{\lambda}$

$$D = \frac{2\dfrac{C}{\lambda}\left[J_1^2\left(\dfrac{C}{\lambda}\sin\theta\right)\right]_{max}}{\int_0^{2C/\lambda} J_1^2\left(\dfrac{C}{\lambda}\sin\theta\right)\sin\theta\, d\theta} = \frac{2\dfrac{C}{\lambda}\left[J_1^2\left(\dfrac{C}{\lambda}\sin\theta\right)\right]_{max}}{\int_0^{2C/\lambda} J_2(y)dy}$$

5. This expression is known as foster's expression for the directivity of a circular loop with uniform phase current of any circumference C/λ.

Case I : $\dfrac{C}{\lambda} < \dfrac{1}{3}$

$$D = \frac{2[J_1^2(\beta a \sin\theta)]_{max}}{\int_0^{\pi} J_1^2(\beta a \sin\theta)\sin\theta\, d\theta}$$

Applying the condition for small loop

So, $D = J_1(x) = \dfrac{x}{2};\ J_1^2(\beta \sin\theta) = \dfrac{(\beta\sin\theta)^2}{2}$

$$D = \frac{2\left[\dfrac{(\beta a)^2}{4}\sin^2\theta\right]_{max}}{\int_0^{\pi}\dfrac{(\beta a)^2}{4}\sin^2\theta\sin\theta\, d\theta} = \frac{2[\sin^2\theta]_{max}}{\int_0^{\pi}\sin^3\theta\, d\theta} = \frac{2(1)}{2\int_0^{\pi}\sin^3\theta\, d\theta}$$

or, $D = \dfrac{3}{2}$

Thus the directivity is same for a small short electric dipole because the pattern of short dipole is same as for a small loop.

Case II : $\left(\dfrac{C}{\lambda} \geq 5\right)$ for a large loop.

$$D = \frac{2\dfrac{C}{\lambda}\left[J_1^2\left(\dfrac{C}{\lambda}\sin\theta\right)\right]_{max}}{\int_0^{2V/\lambda} J_2(y)dy}$$

$$D = 2\frac{C}{\lambda}\left[J_1^2\left(\frac{C}{\lambda}\sin\theta\right)\right]_{max}$$

The maximum value of $J_1\left(\dfrac{C}{\lambda}\sin\theta\right)$ is equal to 0.584 when the loop size is restricted to $C/\lambda \geq 1.84$. Then,

$$D = 2\frac{C}{\lambda}[0.584]^2 = 2\frac{C}{\lambda}[0.341056]$$

$$D = 0.682\left(\frac{C}{\lambda}\right)$$

Que 4.8. **Explain the far field pattern of circular loop antenna.**

Answer

1. The radiation pattern of a loop of any radius is given by following equations :

$$E_\phi = \frac{60\pi\beta a[I]}{r} J_1(\beta a \sin\theta)$$

And,
$$H_\theta = \frac{\beta a[I]}{2r} J_1(\beta a \sin\theta)$$

2. For every loop since βa is constant therefore far field pattern is given as a function of θ

$$= J_1(\beta a \sin\theta)$$

$$= J_1\left(\frac{2\pi}{\lambda} r \sin\theta\right) \qquad \left(\because \beta = \frac{2\pi}{\lambda}\right)$$

$$= J_1\left(\frac{C}{\lambda}\sin\theta\right) \qquad [\because C = \text{Circumference} = 2\pi r] \quad ...(4.8.1)$$

$$\frac{C}{\lambda} = \beta r$$

3. From eq. (4.8.1) it is clear that the value of $\sin\theta$ is a function of θ which ranges from 0 to 1 in magnitude.

When, $\theta = 90°$

$$J_1\left(\frac{C}{\lambda}\sin 90°\right) = J_1\left(\frac{C}{\lambda}\right) \qquad [\because \sin 90° = 1] \quad ...(4.8.2)$$

Similarly when $\theta = 0°$

$$J_1\left(\frac{C}{\lambda}\sin 0°\right) = 0 \qquad [\because \sin 0° = 0] \quad ...(4.8.3)$$

4. From eq.(4.8.2) and (4.8.3) it is clear that relative field varies in accordance with J_1 curve from $J_1\left(\frac{C}{\lambda}\right)$ to 0 as shown in Fig. 4.8.1.

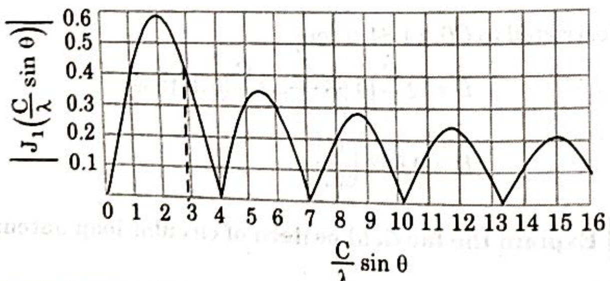


Fig. 4.8.1. Pattern chart for loop antennas with uniform current as given by first order Bessel curve as function.

Que 4.9. Explain the slot antenna used in communication with its application.

AKTU 2017-18, Marks 05

Answer

A. Slot antenna :

1. Basically a slot antenna is nothing but an aperture of any size and shape made in a conducting metallic sheet, forming a suitable radiator above 300 MHz.
2. Every slot antenna has its complementary dipole formed in the form of wires or strip such that the information about the pattern and impedance of slot can be easily obtained from the same properties of the complementary dipole.
3. The antenna shown in Fig. 4.9.1(a), consisting of two resonant $\lambda/4$ stubs connected to a 2-wire transmission line, is an inefficient radiator.
4. The long wires are closely spaced ($w \ll \lambda$) and carry current of opposite phase so that their fields tend to cancel.
5. The end wires carry current in the same phase, but they are too short to radiate efficiently. Hence, enormous currents may be required to radiate appreciable amounts of power.
6. The antenna in Fig. 4.9.1(b), on the other hand, is a very efficient radiator. In this arrangement a $\lambda/2$ slot is cut in flat metal sheet.
7. Although the width of the slot is small ($w \ll \lambda$), the currents are not confined to the edges of the slot but spread out over the sheet. This is a simple type of slot antenna.

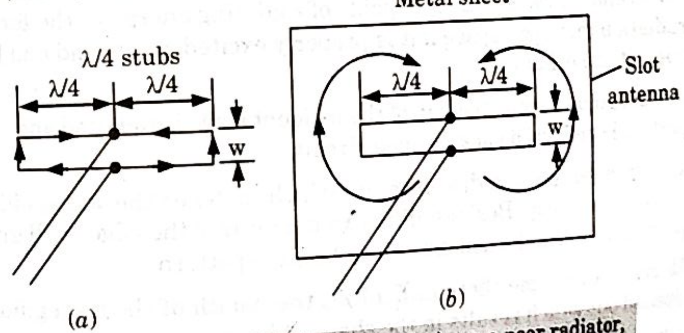


Fig. 4.9.1 Whereas the stubs of (a) are a poor radiator, (b) is a good, efficient radiator because the currents can spread out on the metal sheet.

8. Radiation occurs equally from both sides of the sheet. If the slot is horizontal, the radiation normal to the sheet is vertically polarized.
9. A slot antenna may be conveniently energized with a coaxial transmission line as in Fig. 4.9.2(a). The outer conductor of the cable is bonded to the metal sheet.

10. Since the terminal resistance at the center of a resonant $\lambda/2$ slot in a large sheet is about 500 Ω and the characteristic impedance of coaxial transmission lines is usually much less, an off-center feed such as shown in Fig. 4.9.2(b) may be used to provide a better impedance match.

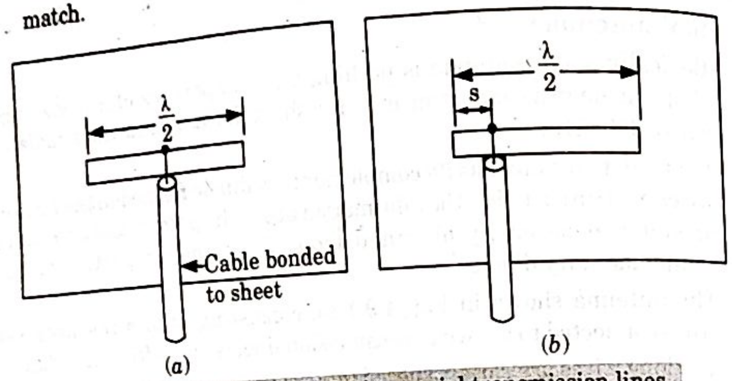


Fig. 4.9.2. Slot antennas fed by coaxial transmission lines.

B. Application : Slot antennas are useful where low-profile or flush mountings are required as, for example, on high-speed aircraft.

Que 4.10. **Explain horn antenna and write it features.**

Answer

A. Horn antenna :

1. A horn antenna can be regarded as opened-out (or flared-out) waveguide. A waveguide is capable of radiating energy in the form of radiation into open space if it is properly excited at one end and kept open at the other end.
2. In waveguide a small portion of the incident wave is radiated and large portion is reflected back by open circuit.
3. The open circuit is a discontinuity which matches the waveguide to space very poorly. Besides, diffraction improves the edges will give a poor radiation and a non directive radiation pattern.
4. Hence to overcome these difficulties the mouth of the waveguide is opened out which results in the shape of horn.
5. When a waveguide is terminated by a horn, the abrupt discontinuity that existed is replaced by gradual transformation then, all energy incident in the forward direction in the waveguide will be radiated, provided the impedance matching is proper.
6. This improves the directivity and reduces diffraction.

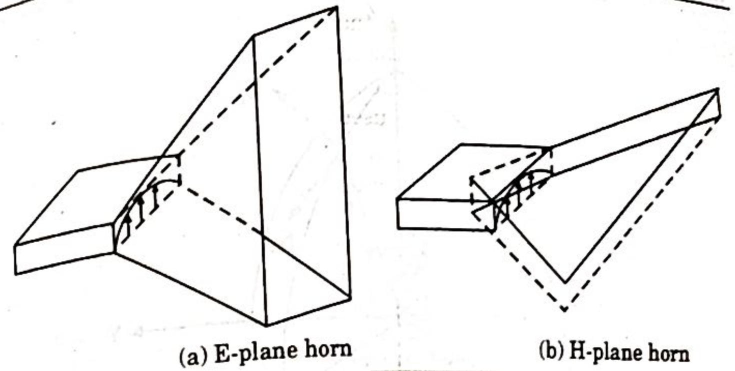


Fig. 4.10.1.

B. Feature :

1. The gain of horn antennas often increases as the frequency of operation is increased.
2. This is because the size of the horn aperture is always measured in wavelengths, a higher frequency has a smaller wavelength.
3. Since the horn antenna has a fixed physical size, the aperture is more wavelengths across at higher frequencies.
4. Horn antennas have very little loss, so the directivity of a horn is roughly equal to its gain.

Que 4.11. **Explain the important features of the horn antenna and the principle of its working. Describe helical antenna in normal mode of operation.**

AKTU 2013-14, Marks 05

Answer

A. Horn antenna : Refer Q. 4.10, Page 4–13D, Unit-4.

B. Helical antenna :

1. In normal mode of helical antenna, the radiation is maximum in broadway direction *i.e.*, normal or perpendicular to the axis of the helix, hence the mode in called normal or perpendicular mode of radiation.
2. The radiation in the direction normal to the helix axis is circularly polarized wave.
3. This mode of radiation can be obtained if the helix dimensions are made very small as compared with radiation is $N.S << \lambda$.
4. But with this mode of radiation, the bandwidth of antenna becomes narrow and the radiation efficiency also becomes very less.
5. Consider a helix in spherical coordinate system as shown in the Fig. 4.11.1.

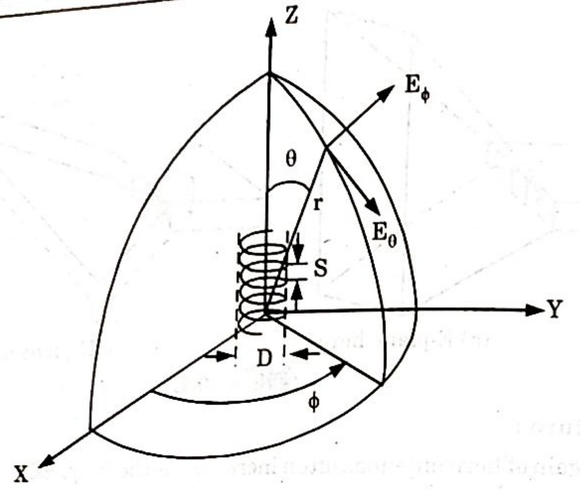


Fig. 4.11.1. Helical antenna with spherical coordinates.

6. Considering that the helical antenna is made up of number of small loops and short dipoles arranged in series such that loop diameter equal to helix diameter D and length of the short dipole equal to the spacing between two helix S.
7. The far field of a small loop is given by,

$$E_\phi = \frac{120\pi^2 [I] \sin\theta}{r} \frac{A}{\lambda^2}$$

where $[I]$ = Retarded current, r = Distance at a point in m

$$A = \text{Area of loop} = \pi\left(\frac{D}{2}\right)^2, \lambda = \text{Wavelength in m.}$$

8. Similarly the far field of the short dipole is given by,

$$E_\theta = j\frac{60\pi [I] \sin\theta}{r} \frac{S}{\lambda} \quad ...(4.11.1)$$

where $S = dL$ = Length of the dipole

9. From eq. (4.11.1), it is clear that two fields are in phase quadrature (phase of 90°).
10. To get axial ratio (AR) of the elliptical polarization, we should take ratio of magnitudes of the field due to short dipole to that due to the loop.
11. Hence the axial ratio is given by,

$$AR = \frac{|E_\theta|}{|E_\phi|} = \frac{\left|j\frac{60\pi [I]\sin\theta}{r}\frac{S}{\lambda}\right|}{\left|j\frac{120\pi^2 [I]\sin\theta}{r}\frac{A}{\lambda^2}\right|} = \frac{S\lambda}{2\pi A} \quad ...(4.11.2)$$

12. Substituting value of A as $\frac{\pi D^2}{4}$ in eq. (4.11.2), we get,

$$AR = \frac{S\lambda}{2\pi\left(\frac{\pi D^2}{4}\right)} = \frac{4S\lambda}{2\pi^2 D^2}$$

$$\therefore \quad AR = \frac{2S\lambda}{\pi^2 D^2}$$

13. Now depending on values of AR, we get three conditions.

Condition 1 : When $AR = 0$, the elliptical polarization becomes linear horizontal polarization.

Condition 2 : When $AR = \infty$, the elliptical polarization becomes linear vertical polarization.

Condition 3 : When $AR = 1$, the elliptical polarization becomes circular polarization.

14. Thus the condition for the circular polarization is given by,

$$AR = 1 = \frac{|E_\theta|}{|E_\phi|} = \frac{2S\lambda}{\pi^2 D^2} \quad i.e., \ |E_\theta| = |E_\phi|$$

15. Hence, we can write,

$$2S\lambda = \pi^2 D^2$$

i.e., $$S = \frac{\pi^2 D^2}{2\lambda} = \frac{C^2}{2\lambda}$$

where, C = Circumference = πD

16. Hence the pitch angle for the circular polarization is given by,

$$\alpha = \tan^{-1}\left(\frac{S}{\pi D}\right) = \tan^{-1}\left(\frac{\frac{\pi^2 D^2}{2\lambda}}{\pi D}\right)$$

$$\therefore \quad \alpha = \tan^{-1}\left(\frac{\pi D}{2\pi}\right) = \tan^{-1}\left(\frac{C}{2\lambda}\right)$$

where, C = Circumference = πD

17. Thus the resultant radiation pattern for the helical antenna in the normal mode can be obtained by superposing the field patterns of the loop and the dipole for circular polarization as shown in the Fig. 4.11.2.

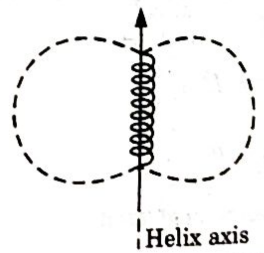


Fig. 4.11.2. Normal mode radiation pattern with circular polarization for helical antenna.

Que 4.12. **How a horn antenna produces a uniform phase front with a large aperture in comparison to waveguide ? Mention one antenna system when a horn is used as a feed system.**

AKTU 2017-18, Marks 05

Answer

1. A horn antenna can be regarded as opened-out (or flared-out) waveguide. The function of the electromagnetic horn is to produce a uniform phase front with a larger aperture in comparison to waveguide and thus the directivity is greater.

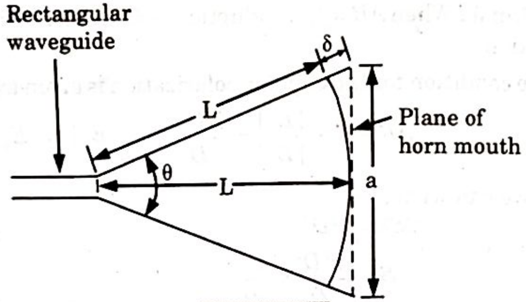


Fig. 4.12.1.

2. From Fig. 4.12.1

$$\cos\frac{\theta}{2} = \frac{L}{L+\delta}$$

$$\sin\frac{\theta}{2} = \frac{a}{2(L+\delta)} \quad ...(4.12.1)$$

$$\tan\frac{\theta}{2} = \frac{a}{2L}$$

where, θ = Flare angle (θ_E for E plane, θ_H for H plane), deg
a = Aperture (a_E for E plane, a_H for H plane), m
L = Horn length, m
δ = Path length difference, m

3. From Fig. 4.12.1 we get,

$$(L+\delta)^2 = L^2 + \left(\frac{a}{2}\right)^2$$

or, $L^2 + \delta^2 + 2L\delta = L^2 + \frac{a^2}{4}$

If δ is small then δ^2 can be neglected.

$$\therefore \quad 2L\delta = \frac{a^2}{4}$$

$$L = \frac{a^2}{8\delta} \quad (\because \ \delta << L) \quad ...(4.12.2)$$

and

$$\theta = 2\tan^{-1}\left(\frac{a}{2L}\right) = 2\cos^{-1}\left(\frac{L}{L+\delta}\right) \quad ...(4.12.3)$$

The eq. (4.12.3) and (4.12.3) gives the design equation of horn antenna.

4. When the flare angle (2θ) is small, the aperture area for a specified length L becomes small. Thus at the mouth of the horn, the uniform phase front is resulted, which increases directivity with increase in the beamwidth.
5. Cassegrain antenna is a system where a horn is used as a feed system.

Que 4.13. **Explain with suitable diagram the working of axial mode of operation of a helical antenna.**

AKTU 2014-15, Marks 05

Answer

1. In axial mode of radiation, the radiation field is maximum in the end fire direction *i.e.*, along the helix axis.
2. With the axial mode radiation, the polarization of the wave is either circular or nearly circular.
3. The ground plane may be flat (either circular or square) with a diameter or side dimension of at least $3\lambda/4$ or the ground plane may be cup-shaped forming a shallow cavity.

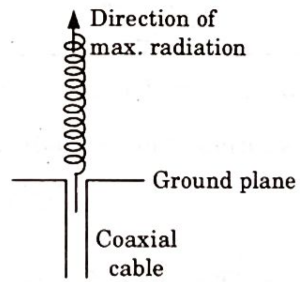


Fig. 4.13.1. Helical antenna in axial mode.

4. This mode is possible in the helical antenna if the circumference is selected of the order of one wavelength and spacing is selected approximately equal to $\frac{\pi}{4}$.
5. For the axial mode, the pitch angle α varies from 12° to 18°. The optimum pitch angle is 14°. The terminal impedance is resistive at the resonant frequency and it becomes reactive at higher and lower frequencies. The terminal impedance is given by,

$$R = \frac{140\,C}{\lambda}$$

6. In the axial mode, the antenna gain and beam width both depend on the length of helix *i.e.*, *NS*. The beamwidth between half power points is given by

$$HPBW = \frac{52}{C}\sqrt{\frac{\lambda^3}{NS}} \text{ degrees}$$

7. Beam width between first nulls is given by

$$BWFN = \frac{115}{C}\sqrt{\frac{\lambda^3}{NS}} \text{ degrees}$$

8. The maximum directive gain in the axial mode is given by,

$$G_D = \frac{15\,NSC^2}{\lambda^3}$$

9. The axial ratio (AR) is given by,

$$AR = 1 + \frac{1}{2N}$$

10. The radiation pattern for axial mode is as shown in the Fig. 4.13.2.

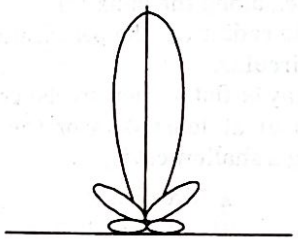


Fig. 4.13.2. Radiation pattern of helical antenna in axial mode.

Que 4.14. Explain operation of log periodic antenna in detail.

AKTU 2015-16, Marks 10

OR

Illustrate with neat diagram and design equations the working of log periodic antenna.

AKTU 2016-17, Marks 08

OR

Write the short note on log periodic antenna with proper mathematical expression.

AKTU 2017-18, Marks 05

Answer

1. Log periodic antennas are broadband antennas. The basic concept is that a gradually expanding periodic structure array radiates most effectively when the array elements (dipoles) are near resonance so that with change in frequency the active (radiating) region moves along the array.

2. The log periodic dipole array is a popular design. The dipole lengths increase along the antenna so that the included angle α is a constant, and the lengths l and spacings s of adjacent element are scaled so that

$$\frac{l_{n+1}}{l_n} = \frac{s_{n+1}}{s_n} = k \qquad \text{...(4.14.1)}$$

where k is a constant

3. At a wavelength near the middle of the operating range, radiation occurs primarily from the central region of the antenna (Fig. 4.14.2). The elements in this active region are about $\lambda/2$ long.
4. The small currents in elements 9, 10 and 11 mean that the antenna is effectively truncated at the right of the active region.

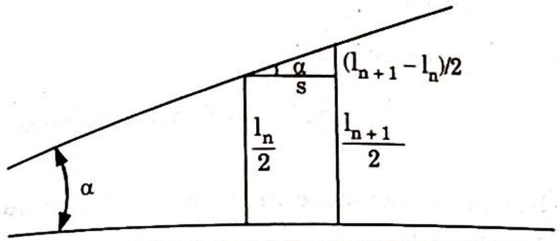


Fig. 4.14.1. Log-periodic array geometry for determining the relation of parameters.

5. The elements at the left (1, 2, 3, etc.) are less than $\lambda/2$ long and present a large capacitive reactance to the line. Hence, currents in these elements are small and radiation is small.

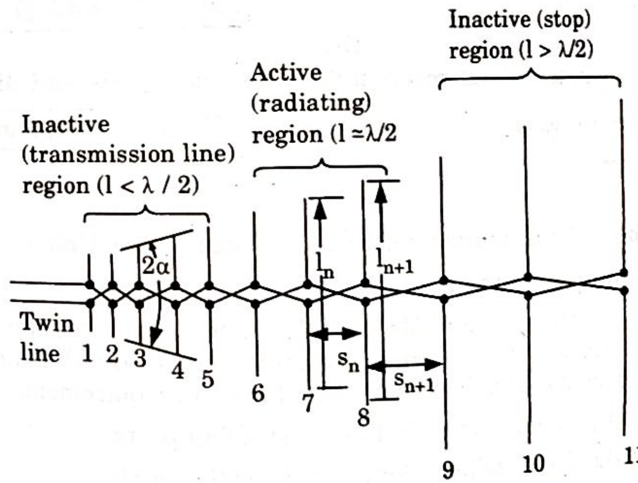


Fig. 4.14.2. Log periodic antenna structure.

6. Thus, at a wavelength λ, radiation occurs from the middle portion where the dipole elements are $\lambda/2$ long.

7. When the wavelength is increased, the radiation zone moves to the right and when the wavelength is decreased, it moves to the left with maximum radiation towards the apex or feed point of the array.
8. From the geometry of Fig. 4.14.1, we have

$$\tan \alpha = \frac{(l_{n+1} - l_n)/2}{s}$$

and from eq. (4.14.1),

$$\tan \alpha = \frac{[1-(1/k)](l_{n+1}/2)}{s}$$

9. Taking $l_{n+1} = \lambda/2$ (when active), we have

$$\tan \alpha = \frac{1-(1/k)}{4s_\lambda}$$

where, α = Apex angle
k = Scale factor
s_λ = Spacing in wavelengths shortward of $\lambda/2$ element

Que 4.15. **Design log-periodic antenna of your own defined parameter. Describe microstrip antenna. What are its advantage and disadvantage ? Describe any one feed method.**

AKTU 2013-14, Marks 05

OR

Design log periodic antenna. What are the advantages of microstrip antennas ?

AKTU 2014-15, Marks 05

OR

Describe in brief about microstrip antennas types and different feeding techniques.

AKTU 2016-17, Marks 10

Answer

A. **Log-periodic antenna :** Refer Q. 4.14, Page 4–19D, Unit-4.

B. **Microstrip antenna :**

1. The microstrip antenna (MSA) is also called as patch antenna. The microstrip antenna is generally preferred where thickness and conformability to the host surface are the main requirements.
2. Mircostrip antenna are basically consist of four parts :
   i. A very thin flat metallic region often called the patch.
   ii. A dielectric substrate.
   iii. A ground plane, which is usually much larger than the patch.
   iv. Feed network which distributes the R.F. power to the different elements

3. A patch antenna basically is a metal patch suspended over a ground plane. They are constructed on a dielectric substrate.
4. The microstrip antenna is constructed on a thin dielectric sheet using a printed circuit board and etching techniques.
5. Its configuration employs a metallic patch which is positioned on the top surface of a dielectric substrate.
6. The dielectric substrate has the bottom surface coated with a suitable metal to form a ground plane. A hole is formed through the ground plane and through the dielectric to allow access to the bottom surface of the patch.
7. The patch is generally made of conducting material such as gold or copper. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.
8. Microstrip antenna has radiating elements on one side of a dielectric substrate and thus may be fed by a coaxial cable lines or microstrip transmission lines.
9. The MSAs may have a square, rectangular, circular, triangular or elliptical shape. Fig. 4.15.1 illustrates three different shapes of MSAs along with the feed arrangements and coordinate systems.

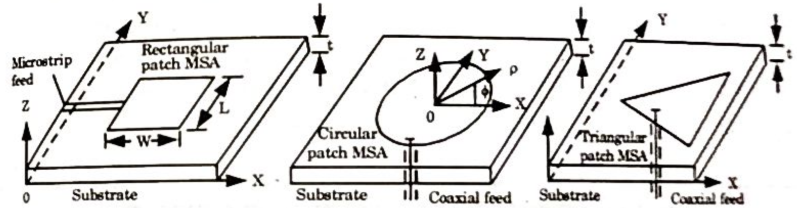


Fig. 4.15.1. Configurations of rectangular, circular and triangular patch MSA.

10. The size of MSA is inversely proportional to its frequency.

C. **Advantages of microstrip antennas :**

1. They are low cost, have a low profile and are easily fabricated.
2. These antennas are of smaller size, light weight which occupies very less volume.
3. These can support both linear as well as circular polarization and are capable of dual and triple frequency operations.
4. They are mechanically robust when mounted on rigid surfaces.
5. With MSA, it is easy to form large arrays with half wavelength of lesser spacings.

D. **Disadvantages of microstrip antenna :**

1. These are low bandwidth, low efficiency and low gain antennas with low power handling capacity.

2. The design complexity gets enhanced due to their smaller size.
3. These antennas suffer from the effects of radiation from feeds and junctions.
4. These are poor end fire radiators.

E. Applications :

1. They are compatible for embedded antennas in handheld wireless devices such as cellular phones and pagers.
2. They are used in satellite communication.
3. They are used in military applications.
4. They have been employed in aircraft or spacecraft systems because of their low profile.

F. Feed method : Microstrip antennas may be fed by a coaxial cable line or microstrip transmission lines.

PART-2

Reflector Antennas : Flat Sheet Reflectors, Corner Reflectors, The Parabola General Properties, A Comparision Between Parabolic and Corner Reflector, The Paraboidal Reflector, Patterns of Large Circular Apertures with uniform Illumination, Reflectors Types (Summarized), Feed Methods for Parabolic Reflector

CONCEPT OUTLINE : PART-2

- Reflectors are widely used to modify the radiation pattern of a radiating element.
- A plane sheet reflector of large enough dimensions can be used to eliminate the backward radiation.
- A parabolic reflector has a directional feed while a corner reflector does not require a directional feed.
- The surface generated by the revolution of a parabola around its axis is called a paraboloid or a parabola of revolution.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.16. **Write a note on flat sheet reflector.**

Answer

1. Reflectors are used to modify the radiation pattern of a radiating element. Generally there are two types of flat reflectors :
   i. Large flat sheet reflector.
   ii. Small flat sheet reflector.

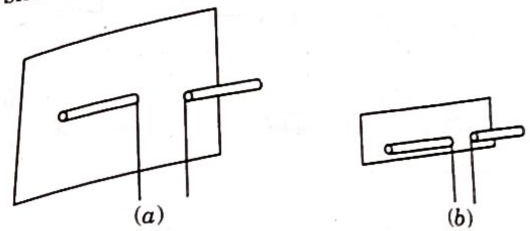


Fig. 4.16.1. (*a*) Large flat sheet (*b*) Small flat sheet.

2. In method of images of flat sheet reflector the problem of an antenna at a distance S from a perfectly conducting plane sheet reflector of infinite extent can be readily handled. Fig. 4.16.2 shows the method of image for flat sheet reflector.

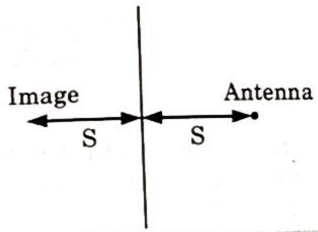


Fig. 4.16.2. Method of images.

3. In this method the reflector is replaced by an image of the antenna at a distance $2S$ from the antenna.
4. Consider a dipole antenna with zero reflector losses. Then the expression for dipole antenna gain at distance S from infinite plane reflector is given by

$$G = 2\sqrt{\frac{R_{11} + R_L}{R_{11} + R_L - R_{12}}}\,|\sin (S_r \cos\phi)| \quad \text{...(4.16.1)}$$

where, $S_r = \dfrac{2\pi S}{\lambda}$ = spacing

5. Eq. (4.16.1) expresses the gain relative to antenna in free space with the same power input. The field pattern of $\lambda/2$ antenna at various spacing such as $S = \lambda/4$, $\lambda/8$ and $\lambda/16$ from the flat sheet reflector are shown in Fig. 4.16.3.
6. These field patterns are calculated using eq. (4.16.1) when R_L is equal to zero.

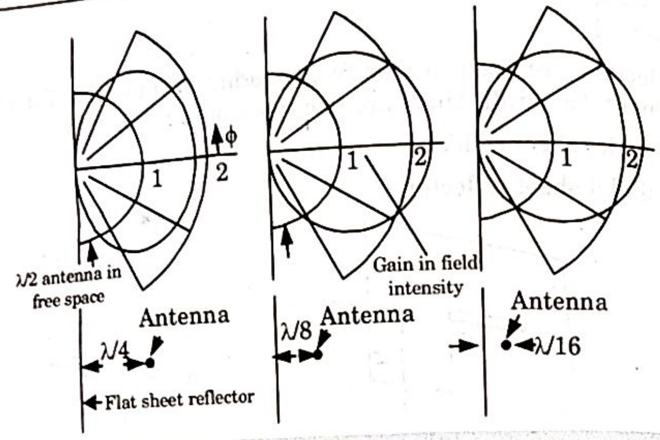


Fig. 4.16.3. Field patterns of a $\lambda/2$ antenna at spacing of $\lambda/4$, $\lambda/8$ and $\lambda/16$ from an infinite flat sheet reflector. Patterns give gain in field intensity over a $\lambda/2$ antenna in free space with same power input.

Que 4.17. **Explain principle angular regions of a flat sheet reflector.**

AKTU 2014-15, Marks 05

Answer

1. **Region 1 (above or in front of the sheet) :** In this region the radiated field is given by the resultant of the direct field of the dipole and the reflected field from the sheet.

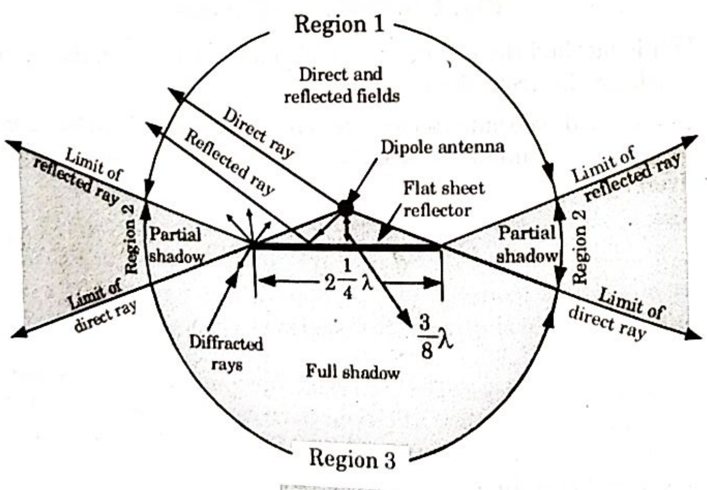


Fig. 4.17.1.

2. **Region 2 (above and below at the sides of the sheet) :** In this region there is only the direct field from the dipole. This region is in the shadow of the reflected field.
3. **Region 3 (below or behind the sheet) :** In this region the sheet acts as a shield, producing a full shadow (no direct or reflected fields, only diffracted fields).

Que 4.18. **Write a note on corner reflector antenna.**

Answer

1. The corner reflector antenna is a driven antenna, generally a half wave dipole associated with a reflector constructed of two flat conducting sheet which meet at a corner or angle to form a corner. This arrangement of corner reflector is shown in Fig. 4.18.1.
2. If the corner angle β is equal to 90° then the two flat sheet meeting at a right angle forms a square corner reflector.

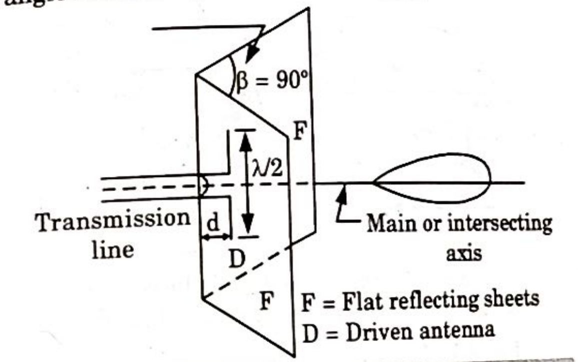


Fig. 4.18.1. Vertical corner reflector antenna with field pattern along main axis.

3. Corner angle $\beta = \pi$ radian or 180° may be considered as limiting case of corner reflector which is equivalent to a flat sheet.
4. The corner antennas are analyzed using method of images for corner angle

$$\beta = \frac{180°}{n}$$

where, n = Positive integer

If $n = 1$, $\beta = 180°$ Flat sheet reflector
If $n = 2$, $\beta = 90°$ Square corner reflector
If $n = 3$, $\beta = 60°$ Corner angle 60°
If $n = 4$, $\beta = 45°$ Corner angle 45°

Que 4.19. **Describe the parabolic antenna used at microwave frequencies. Describe the methods of feeding a paraboloid reflector in which the primary antenna is located at the focal point.**

AKTU 2013-14, Marks 05

OR

Explain parabolic reflector and corner reflector antenna.

AKTU 2015-16, Marks 15

Answer

A. Parabolic reflector :

1. In parabolic reflector, when the point source is placed at the focus or focal point, then the rays reflected by the parabolic reflector form parallel wave front as shown in the Fig. 4.19.1(*a*). This principle is used in the transmitting antenna.
2. Similarly when the beam of parallel rays is incident on a parabolic reflector, the radiations focus at a focal point as shown in the Fig. 4.19.1(*b*). This principle is used in the receiving antenna.

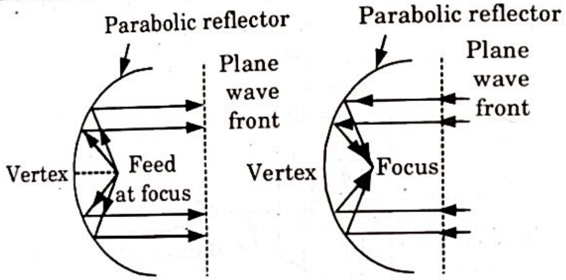


Fig. 4.19.1. Parabolic reflector principle.

3. Consider a parabolic reflector as shown in Fig. 4.19.1(*a*). When the point source is kept at the focus or focal point of the parabola, the radiations striking the parabolic reflector are reflected parallel to the axis of parabola irrespective of the angle at which the radiations strike the reflector.
4. This means the rays which are reflected by the parabolic reflector travel same distance to reach near the mouth of the reflector. The open end of the parabolic reflector is called aperture.
5. The time taken by the reflected rays to travel a distance upto the directrix of the parabola is same. That means all the reflected rays are in phase and thus very strong and concentrated beam is obtained along the axis.
6. Thus parabolic reflector is the most effective microwave antenna which produces concentrated radiation beam along the axis of parabola.

B. Corner reflector antenna : Refer Q. 4.18, Page 4–26D, Unit-4.

Que 4.20. **Make a detailed comparison between corner reflector and parabolic reflector.**

AKTU 2014-15, Marks 05

Answer

S. No.	Parabolic reflectors	Corner reflectors
1.	A parabolic reflector has a directional feed which radiates all or most of the energy into the parabola.	Corner reflector does not require a directional feed since the direct and reflected waves are properly combined.
2.	Difficult to construct.	Easy to construct.
3.	Parabolic reflectors have a specific focal point.	Corner reflectors do not have a specific focal point.
4.	For large aperture, parabolic reflectors are used.	For a large parabola of many λ aperture, corner reflectors are used as a feed.

Que 4.21. **What do you understand by paraboloid ? Derive the expression for field distribution across the aperture of a parabolic reflector.**

Answer

A. Paraboloid :

1. The surface generated by the revolution of parabola about its own axis is called paraboloid or parabola of revolution.
2. If an isotropic source is placed at the focus of paraboloid reflector as shown in Fig. 4.21.1.

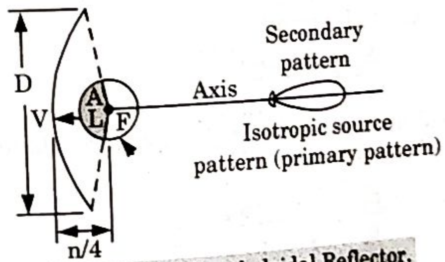


Fig. 4.21.1. Paraboloidal Reflector.

3. Then the portion A of the source radiation that is intercepted by paraboloid is reflected as a plane wave of circular cross section provided that the reflector surface deviates from true parabolic surface by a small fraction of wavelength.

B. Derivation :

1. Let us consider a cylindrical parabolic reflector with a line source as shown in Fig. 4.21.2.

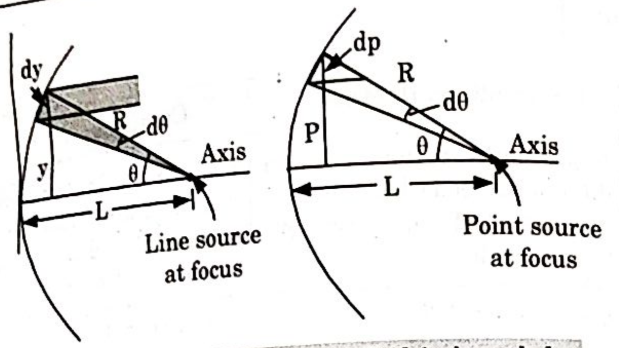


Fig. 4.21.2. Cross sections of cylindrical parabola.

2. The line source is isotropic in a plane perpendicular to its axis. Then for unit distance along z direction the power P in a strip of width dy is given by

$$P = dy\, S_y$$

Where, S_y = Power density at y in W/m².

Since $P = d\theta\, U'$

where, U' = Power per unit angle per unit length in the z direction.

3. Then, $S_y\, dy = U' d\theta$

$$\frac{S_y}{U'} = \frac{1}{\left(\frac{d}{d\theta}\right)(R \sin \theta)}$$

where, $R = \frac{2L}{1 + \cos \theta}$

$$\therefore \quad S_y = \frac{1 + \cos \theta}{2L} U'$$

4. Then power density is given by

$$\frac{S_\theta}{S_0} = \frac{1 + \cos \theta}{2}$$

Whereas field intensity ratio in the aperture plane is equal to the square root of power ratio.

$$\frac{E_\theta}{E_0} = \sqrt{\frac{1 + \cos \theta}{2}}$$

where, $\frac{E_\theta}{E_0}$ = Relative field intensity at distance y

5. Then the total power P through angular section of radius ρ and width $d\rho$ is given by

$$P = 2\pi\rho\, d\rho\, S_\rho$$

Where, S_ρ = Power density at distance ρ

6. This power must be equal to power radiated by isotropic source over solid angle.

Thus, $P = 2\pi \sin \theta\, d\theta\, U$

where, U = Radiation intensity

Then, $\rho d\rho\, S_\rho = \sin \theta\, d\theta\, U$

or, $$\frac{S_\rho}{U} = \frac{\sin \theta}{\rho(d\rho / d_\theta)}$$

where, $$\rho = R \sin \theta = \frac{2L \sin \theta}{1 + \cos \theta}$$

Thus, $$S_\rho = \frac{(1 + \cos \theta)^2}{4L^2} U$$

7. These ratio of power density S_θ at angle θ to power density S_0 at θ = 0 is given by

$$\frac{S_\theta}{S_0} = \frac{(1 + \cos \theta)^2}{4}$$

Whereas the field intensity ratio is given by

$$\frac{E_\theta}{E_0} = \frac{1 + \cos \theta}{2}$$

Where $\frac{E_\theta}{E_0}$ is the relative field intensity at radius ρ from the axis given by $\rho = R \sin \theta$.

Que 4.22. **Explain the radiation pattern of large circular aperture with uniform illumination.**

OR

Derive BWFN, HPBW, directivity and gain of large circular Aperture with uniform illumination.

Answer

1. The radiation field pattern for uniformly illuminated aperture can be calculated using Huygens principle. The normalized field pattern as a function of ϕ and D is given by :

$$E(\phi) = \frac{2\lambda}{\pi D} \frac{J_1[(\pi D / \lambda) \sin \phi]}{\sin \phi}$$

where, D = Diameter of aperture.

λ = Free space wavelength.

ϕ = Angle with respect to normal to aperture.

J_1 = First order Bessel function.

2. The angle ϕ_0 of the first null of radiation pattern is given by

$$\frac{\pi D}{\lambda} \sin \phi_0 = 3.83$$

Since, $J_1(x) = 0$ at $x = 3.83$

Hence, $$\phi_0 = \text{arc} \sin \frac{3.83\lambda}{\pi D} = \text{arc} \sin \frac{1.22\lambda}{D}$$

If ϕ_0 is very small

$$\phi_0 = \frac{1.22}{D_\lambda} \text{ (rad)} \approx \frac{70}{D_\lambda} \text{ (deg)}$$

Where, $D_\lambda = \dfrac{D}{\lambda}$ = Diameter of aperture

3. For large circular apertures, beamwidth between first nulls is given by,

$$BWFN = \frac{140}{D_\lambda} \text{ (deg)}$$

Whereas the directivity D for large uniformly illuminated aperture is given by,

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

4. For a circular aperture,

$$D = 4\pi \frac{\pi D^2}{4\lambda^2} = 9.87 D_\lambda^2$$

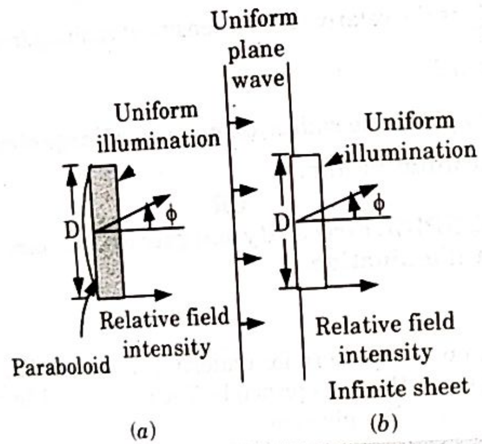


Fig. 4.22.1. (a). Large paraboloid with uniformaly illuminated aperture and (b) Equivalent uniformaly illuminated aperture of same diameter D in finite flat sheet

where, D_λ = Diameter of aperture.

Whereas the power gain G of a circular aperture over $\lambda/2$ dipole antenna is given by,

$$G = 6D_\lambda^2$$

5. If an antenna with illuminated circular aperture 10 λ in diameter has a gain of 600 or nearly 28 dB with respect to $\lambda/2$ dipole antenna is shown in Fig. 4.22.2.

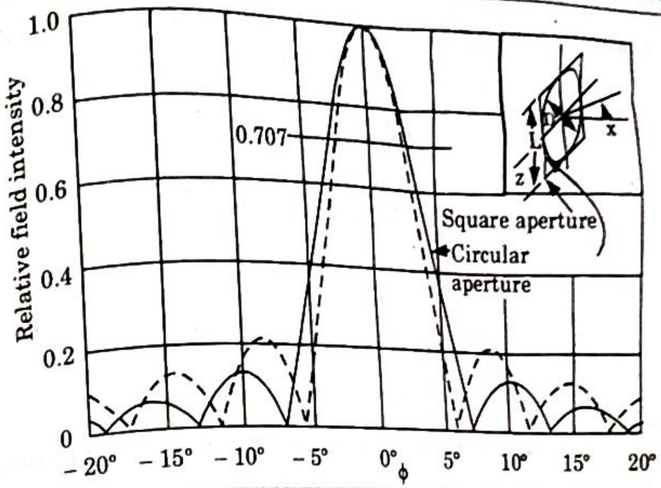


Fig. 4.22.2. Relative radiation patterns of circular aperture of diameter $D = 10\ \lambda$ and of square aperture of side length $L = 10\ \lambda$.

6. The $HPBW$ for a large circular aperture is given by

$$HPBW = \frac{58}{D_\lambda} \text{ degree}$$

where, $D_\lambda = \dfrac{D}{\lambda}$ = Diameter of aperture, (λ)

Que 4.23. **Write a note on various types of reflector.**

Answer

i. **Parabolic cylinder :**

1. This is generated by moving parabolic contour parallel to itself.
2. It provides a rectangular mouth and has a line instead of point as the focus. This may be fed by a line source of dipoles that are directing their radiation to the cylindrical surface.
3. Fine beam with large aspect ratio are generated by this configuration.

ii. **Parabolic reflector :** Fig. 4.23.1(*b*) shows the most commonly used paraboloid reflector. It is fed by a point source normally a wave guide horn. It generates a pencil beam. It has a three dimensional curved surface generated by rotating parabola about its own axis.

iii. **Truncated paraboloid :** This reflector is a unsymmetrical section cut from a parabolic surface. These are used to generate fine beams in azimuth or elevation direction depending on location of asymmetry.

iv. **Pill box antenna :** Fig. 4.23.1(*d*) represents a cylinder that is short in axial direction and are provided with conducting end plates. It can be fed by a waveguide horn or wave guide or it can be fed by a probe or by extending the inner conductor of a coaxial cable to the space between the plates.

v. **Cheese antenna :** It is a combination of pill box and parabolic cylinder.

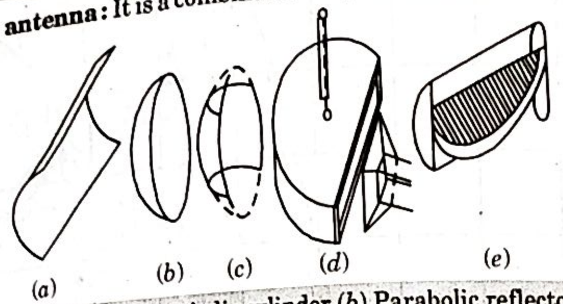


Fig. 2.23.1. (a) Parabolic cylinder (b) Parabolic reflector (c) Truncated paraboloid (d) Pill box antenna (e) Cheese antenna.

Que 4.24. **Narrate in details about Cassegrain feed of a parabolic reflector and explain different reflector types.**

AKTU 2016-17, Marks 10

Answer

A. Cassegrain feed :

1. Cassegrain feed system employs a hyperboloid secondary reflector whose one of the foci coincides with the focus of paraboloid.
2. The feed radiator is aimed at the secondary hyperboloid reflector or sub-reflector.
3. As such, the radiations emitted from feed radiator are reflected from Cassegrain secondary reflector which illuminates the main paraboloid reflector as if they had originated from the focus.
4. Then the paraboloid reflector colliminates the rays as usual.
5. Sometimes, it becomes important to minimise the length of transmission line or waveguide connecting the feed radiator with receiver or transmitter. This is needed specially to avoid losses.

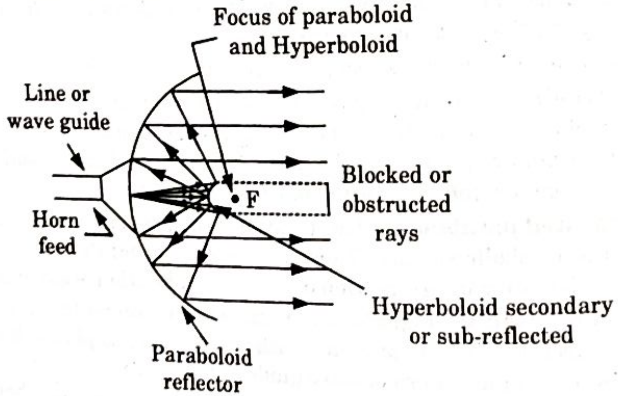


Fig. 4.24.1.

6. Although, there could be a solution of this problem by placing the RF amplifier stage of R_x near the focus which minimises the losses on reception. But this is not practicable for transmitters, as the RF amplifier of a transmitter is bulky or heavy.
7. Hence, the practical solution in such cases is Cassegrain feed when the transmission line or waveguide length between feed and transmitter and receiver, is required to be short.
8. The disadvantage of the Cassegrain feed is that some of the radiation from the paraboloid reflector is obstructed. This is tolerable in greater dimension paraboloid but becomes problem with small dimension paraboloid.

B. Reflector types :

1. In Fig. 4.24.2(a) has a large flat sheet reflector near a linear dipole antenna to reduce the backward radiation.

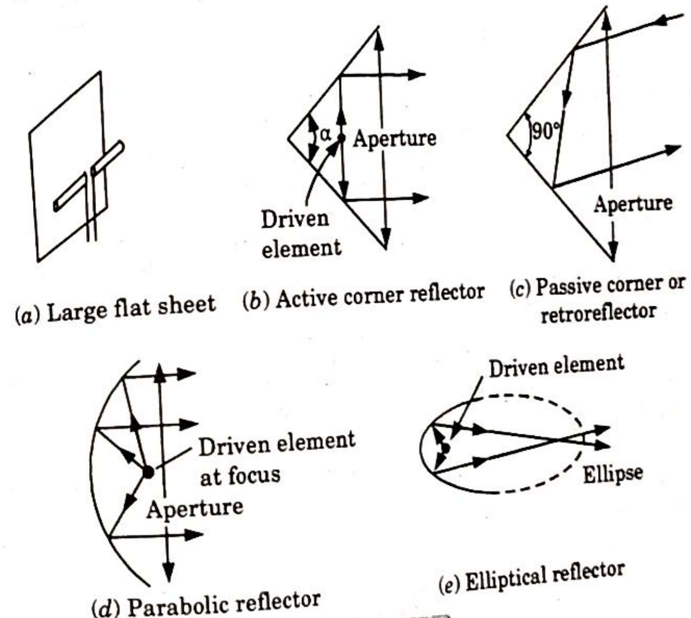


Fig. 4.24.2.

2. With two flat sheets intersecting at an angle α (< 180°) as Fig. 4.24.2(b) sharper radiation pattern than from a flat sheet reflector (α = 180°) can be obtained. This arrangement, called an active corner reflector antenna.
3. A corner reflector without an exciting antenna can be used as a passive reflector or target for radar waves. In this application the aperture may be many wavelengths, and the corner angle is always 90°.
4. Reflectors with this angle have the property that an incident wave is reflected back toward its source as in Fig. 4.24.2(c), the corner acting as a retroreflector.

5. When it is feasible to build antennas with apertures of many wavelengths, parabolic reflectors can be used to provide highly directional antennas. A parabolic reflector antenna is shown in Fig. 4.24.2(*d*).
6. The parabola reflects the waves originating from a source at the focus into a parallel beam, the parabola transforming the curved wave front from the feed antenna at the focus into a plane wave front.
7. With an antenna at one focus, the elliptical reflector Fig. 4.24.2(*e*) produces a diverging beam with all reflected waves passing through the second focus of the ellipse.

Que 4.25. **What are the various feeding methods used for reflector antenna ?**

AKTU 2014-15, Marks 05

OR

What is helical antenna and explain different type of feed method for parabolic reflector.

AKTU 2017-18, Marks 05

Answer

A. Helical antenna : Refer Q. 4.11, Page 4–14D, Unit-4.

B. Types of feed method for parabolic reflector :

i. Rear feed :

1. In this feed method, transmission line is not in the center hence results in asymmetrical pattern.
2. If transmission line is at the center as in dual aperture feed waveguide is in the center of dish and energy is made to bend 180° at the end of waveguide by a properly designed reflecting plate.
3. It forms a compact system.
4. It requires minimum length of transmission line that results in less line loss.

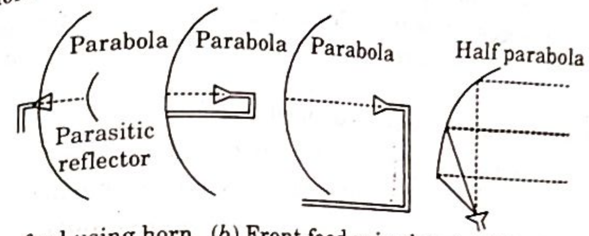
ii. Front feed :

1. Obstructs aperture.
2. Impedance mismatch in feed results.
3. Reflection from dish cause standing waves in transmission line which again cause impedance mismatch and degrade performance of transmitter.
4. By using impedance matching and apex matching plates mismatch can be reduced, results in lower gain.

iii. Offset feed :

1. Only half of the parabola is used.
2. In this feed system instead of pyramidal horn, hog horn is employed.
3. No aperture blocking.

4. No impedance mismatch.
5. Seriously affects performance.
6. More difficult to scan.



(*a*) Rear feed using horn (*b*) Front feed using horn (*c*) Offset feed using horn

Fig. 4.25.1.

Que 4.26. **What are antenna measurement ranges ? Explain any two gain measurement techniques.**

AKTU 2014-15, Marks 05

Answer

A. Antenna measurement range :

1. The measurements on antenna are carried out in the antenna ranges that are well equipped for the testing and evaluation of antenna systems.
2. For measurement of certain antenna, the choice of the best suitable range type depends on the physical size of the antenna and the frequency of antenna.
3. A typical antenna range includes a source antenna to illuminate the AUT (Antenna Under Test) positioners to support and the electronic instrumentation along with interface and the physical space between and around antennas.
4. For far field measurement, the antenna to be tested is operated in the receiving mode and antenna whose radiation pattern is known may be used as source antenna for transmission.

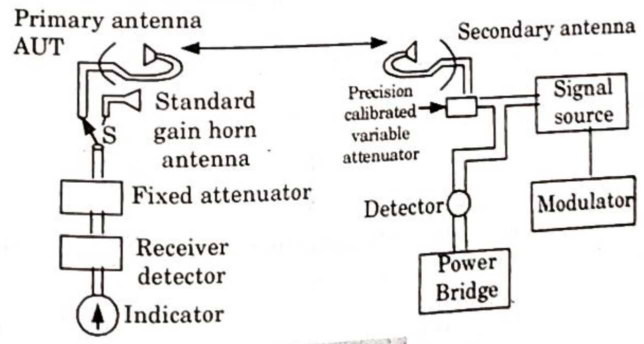


Fig. 4.26.1.

B. Antenna ranges are of two types :

i. **Indoor ranges :** In these ranges, there is a constraint on the space availability. They are protected from environmental variations.

ii. **Outdoor ranges :** For far field measurement, outdoor ranges are used. However, outdoor ranges are not protected from environmental variations.

C. Gain measurement : Gain is defined as :

$$\text{Gain} = \frac{\text{Maximum radiation intensity by test antenna}}{\text{Maximum radiation intensity by reference antenna}}$$

a. Measurement of gain by direct comparison method :

1. At higher frequencies, the comparison method is one which is commonly used.
2. In comparison method, measurement of gain is done by comparing the signal strengths transmitted or received with the unknown gain antenna and a standard gain antenna.
3. A standard gain antenna is that antenna whose gain is accurately known so that it can be used in measurement of other antenna.
4. In primary antenna there will be two antennas, one the subject antenna under test (AUT) and the other a standard antenna at a considerable distance so that coupling or interaction between two antennas could be avoided.
5. The distance between primary and secondary antennas must satisfy the condition $r \geq \frac{2d^2}{\lambda}$.

b. Absolute gain of identical antennas :

1. Let,

W_t = Transmitted power

W_r = Received power

A_{et}, A_{er} = Effective apertures of transmitting and receiving antenna

Since antennas are identical so, $A_{et} = A_{er} = \frac{G_0\lambda^2}{4\pi}$

2. From the Friis's transmission equation

$$\frac{W_r}{W_t} = \frac{A_{er}A_{et}}{\lambda^2 r^2} = \left(\frac{G_0\lambda^2}{4\pi}\right)\left(\frac{G_0\lambda^2}{4\pi}\right) \times \frac{1}{\lambda^2 r^2}$$

where r = Distance between transmitting and receiving antenna.

and λ = wavelength

$$\frac{W_r}{W_t} = \left(\frac{G_0\lambda}{4\pi r}\right)^2$$

or
$$\sqrt{\frac{W_r}{W_t}} = \frac{G_0\lambda}{4\pi r}$$

$\therefore$
$$G_0 = \frac{4\pi r}{\lambda}\sqrt{\frac{W_r}{W_t}}$$

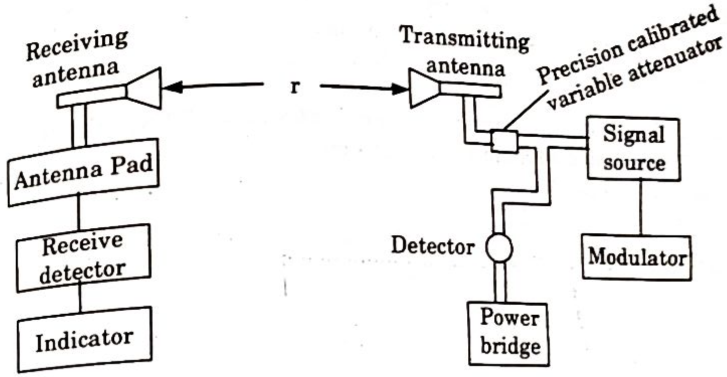


Fig. 4.26.2.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. A loop aerial for use at 500 kHz is of height 0.5 meter, width 0.5 meter and 25 turns, when directed to receive a maximum signal. The emf induced in the loop is 150 μV. What is the field strength of the signal picked up ?

Ans. Refer Q. 4.4.

Q. 2. Describe the principle of direction finding by means of a closed loop antenna and give the expression for the induced voltage and field strength for short loop and large loop.

Ans. Refer Q. 4.6.

Q. 3. Explain the slot antenna used in communication with its application.

Ans. Refer Q. 4.9.

Q. 4. Explain operation of log periodic antenna in detail.

Ans. Refer Q. 4.14.

Q. 5. Describe the parabolic antenna used at microwave frequencies. Describe the methods of feeding a paraboloid reflector in which the primary antenna is located at the focal point.

Ans. Refer Q. 4.19.

Q. 6. What is helical antenna and explain different type of feed method for parabolic reflector.

Ans. Refer Q. 4.25.

Q. 7. What are antenna measurement ranges ? Explain any two gain measurement techniques.

Ans. Refer Q. 4.26.

☺☺☺

5 UNIT

Wave Propagation

PART-1

Ground Wave Propagation : Plane Earth Reflection, Space Wave and Surface Wave, Space Wave Propagation : Introduction, Effects of Curvature of Earth

CONCEPT OUTLINE : PART-1

- The ground wave is a wave that is guided along the surface of earth.
- The space wave consists of direct component and indirect component *i.e.*, ground reflected components.
- Space wave propagation is also known as line of sight (LOS) communication or propagation and takes place above 30 MHz.
- Field strength for space wave propagation is given by,

$$|E_r| = \frac{E_0\, 4\pi\, h_t\, h_r}{\lambda d}$$

where, d is the distance between transmitter and receiver.
h_t and h_r are the height of transmitter and receiver respectively.
λ is the wavelength.

- The earth's curvature causes divergence of the reflected wave and the received signal strength at the receiver, becomes weaker.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.1. **Discuss the phenomenon of ground wave propagation at long and medium waves.** **AKTU 2013-14, Marks 05**

Answer

1. The ground wave or surface wave is important for medium waves and long waves.
2. The ground wave is a wave that is guided along the surface of the earth, just as an EM wave is guided by a waveguide or transmission line.
3. Surface wave permits the propagation around the curvature of the earth. This mode of propagation exist when the transmitting and receiving antennas are close to the surface of earth and is supported at its lower edge by the presence of ground.

4. The ground wave propagation along the surface of the wave induces charge in the earth, which travel with the wave and hence constitute a current.
5. When the surface wave glides over the surface of the earth, energy is abstracted from the surface wave to supply the losses in the earth.
6. Thus while passing over the surface of the earth, the surface wave losses some of its energy by absorption.
7. The ground wave suffers varying amount of attenuation while propagating along the curvature of the earth, depending upon frequency, surface irregularities, permittivity and conductivity.
8. Earth's attenuation increases as the frequency increases and hence the mode of propagation is suitable for low and medium frequency *i.e.*, up to 2 MHz only.
9. At higher frequency, wave attenuation by ground is much more than at low frequency over the same ground. It is also called as medium wave propagation and is used invariably in local broadcasting.
10. Besides ground attenuation, there is still another way in which surface wave is attenuated *i.e.*, due to diffraction and tilt in wavefront.

Que 5.2. **Write the advantages and disadvantages of ground wave propagation.**

Answer

A. Advantages of Ground Wave Propagation :

1. The atmospheric conditions do not affect the ground wave propagation too much.
2. If transmitted power is large, it can be used to communicate between any two points of the world.

B. Disadvantages :

1. Limited range for higher operating frequencies.
2. High transmission power is required for adequate range.
3. At low frequencies, very tall antennas are required.

Que 5.3. **Write a short note on plane earth reflection.**

Answer

1. The wave propagation can be obtained by means of space wave propagation when the transmitting and receiving antennas are elevated.
2. When the two antennas are within the site of each other then the resultant signal obtained is the combination of space wave and surface

wave. These two waves have same amplitude, if the earth is considered as a perfect conductor having infinite conductivity.

3. If the surface of earth is smooth and has finite conductivity then the amplitude and phase of reflected wave can be obtained using concept of reflection at a perfect dielectric.
4. But if the surface of earth is rough then the reflected waves will be scattered and their amplitude will reduce as compared to amplitude of smooth surface.
5. This scattering of reflected waves is obtained due to Rayleigh's criterion that states, if reflecting surface is rough, then the reflection is similar to smooth surface provided large angle of incidence. It is given by

$$R = \frac{4\pi\sigma \sin\theta}{\lambda}$$

where, R = Measure of Roughness

σ = Standard deviation of surface irregularities from mean height

θ = Angle of incidence

λ = Wavelength

6. If value of R is less than 0.1 then surface is considered to be smooth and if the value of R is greater than 10 then surface is rough that leads to scattering of reflected waves.

Que 5.4. **Explain space wave and surface wave.**

Answer

A. Surface Wave (Ground Wave) : Refer Q. 5.1, Page 5–2D, Unit-5.

B. Space Wave :

1. When the frequency of the EM wave is between 30 MHz to 300 MHz, the space wave propagation mode is of importance.
2. The EM waves in the space wave propagation mode reach the receiving antenna either directly from the transmitting antenna or after reflection from the region of the atmosphere above the earth's surface around 16 km of height called troposphere.
3. Thus the space wave consists of two components *i.e.*, direct wave and indirect wave.
4. Eventhough, both the wave namely direct wave and indirect wave are transmitted at the same time, with same phase, at the receiving end they may reach in phase or out of phase depending on the different path lengths.
5. Thus at the receiving end, the signal strength is the vector addition of the strengths of the direct and indirect waves. When the two waves are in phase, the strength of the signal at the receiver will be stronger.

6. Similarly if the two waves are out of phase, the strength of the signal at the receiver will be weaker.
7. The space wave propagation is mainly used in VHF (Very High Frequency) band as both previous modes namely ground wave propagation and sky wave propagation both fail at very high frequencies.

Que 5.5. **Derive the relation for field strength for space wave propagation.**

Answer

1. When the distance (d) between transmitting and receiving antenna is sufficiently large in comparison to antenna height (h_t, h_r), the angle of incidence ψ of the ray on earth is small.
2. Consider the Fig. 5.5.1 shows propagation of waves from transmitter to receiver in which energy is received at the receiving point by the two ways *i.e.*, one is direct ray and other is indirect ray after reflection from the ground.
3. The field strength at the receiving end is vector sum of field of two rays.
4. The direct ray has negligible attenuation but in reflected ray the magnitude remains same but phase changes.
5. Let E_0 be the field strength at R as distance travelled by both ray are approximately equal. If K is the reflection coefficient of the ground, then the magnitude of ground reflected wave is KE_0.

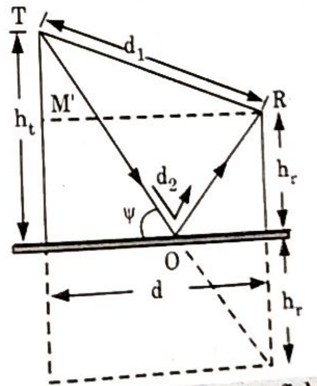


Fig. 5.5.1. Space wave propagation field strength determination at receiving point R.

6. The two rays at the receiving end combine vectorially. From Fig. 5.5.1, we get

$$d_1^2 = (h_t - h_r)^2 + d^2$$

$$d_1 = [d^2 + (h_t - h_r)^2]^{1/2}$$

$$= d\left[1+\left(\frac{h_t-h_r}{d}\right)^2\right]^{1/2}$$

$$= d\left[1+\frac{1}{2}\left(\frac{h_t-h_r}{d}\right)^2+\ldots\ldots\right]$$

$$d_1 = d\left[1+\frac{(h_t-h_r)^2}{2d^2}\right] = d+\frac{(h_t-h_r)^2}{2d}$$

Similarly, $d_2 = d+\dfrac{(h_t+h_r)^2}{2d}$

7. Then, the path difference between direct ray and indirect ray is given by

Path difference $= d_2 - d_1$

$$= d+\frac{(h_t+h_r)^2}{2d} - d - \frac{(h_t-h_r)^2}{2d} = \frac{4h_th_r}{2d}$$

Path difference $= \dfrac{2h_th_r}{d}$

8. $\therefore$ Phase difference $\alpha = \dfrac{2\pi}{\lambda}$ (Path difference)

$$= \frac{2\pi}{\lambda}\left(\frac{2h_th_r}{d}\right)$$

$$\alpha = \frac{4\pi h_th_r}{d\lambda} \text{ radian}$$

9. This is phase difference due to path difference. Along this there is another phase difference of 180° due to reflection from the ground.

10. Hence the total phase difference

$\theta = \alpha + \beta$

where, α = Phase difference due to path difference.

β = Phase difference due to reflection from ground.

11. Now at point R the resultant field strength is given by

$$E_R = E_0\,(1 + Ke^{-j\theta})$$

$$E_R = E_0\,[1 + K(\cos\theta - j\sin\theta)]$$

$$|E_R| = E_o\sqrt{(1+K\cos\theta)^2+(K\sin\theta)^2}$$

$$= E_0\sqrt{1+K^2+2K\cos\theta}$$

12. Since earth is assumed perfect,

$\therefore$ $K = 1$, and $\beta = 180°$ or π radian

$\therefore$ $$|E_R| = E_o\sqrt{1+1^2+2\times1(2\cos^2\frac{\theta}{2}-1)} = 2E_0\cos\theta/2$$

$$|E_R| = 2E_0\cos\left(\frac{\alpha+\pi}{2}\right) = 2E_0\sin\frac{\alpha}{2}$$

$(\because\ \theta = \alpha+\beta = \alpha+\pi)$

$$|E_R| = 2E_0\sin\left(\frac{4\pi h_th_r}{2d\lambda}\right)$$

13. Since, $d >> h_t$

$$\sin\frac{4\pi h_th_r}{2d\lambda} = \frac{4\pi h_th_r}{2d\lambda}$$

$\therefore$ $$\boxed{|E_R| = \frac{E_0 4\pi h_th_r}{d\lambda}}$$

Que 5.6. **Derive the expression for maximum distance covered by space wave propagation.**

Answer

1. Let us consider the distance between transmitter and receiver is d and height of receiving and transmitting antenna be h_r and h_t respectively above ground. Then from Fig. 5.6.1, line of sight distance is given by

$$d = d_1 + d_2 \qquad \ldots(5.6.1)$$

2. If r be the radius of earth then from ΔABO and ΔCBO

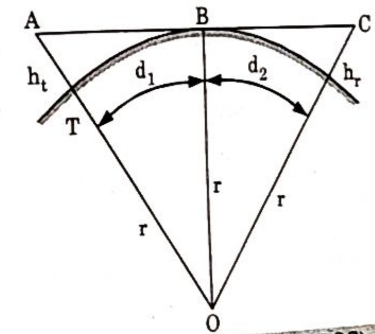


Fig. 5.6.1. Optical range of line of sight (LOS) propagation.

$$d_1 = \sqrt{(h_t+r)^2-r^2}$$

$$= \sqrt{2rh_t+h_t^2} = \sqrt{2rh_t} \qquad (h_t^2 << 2rh_t)$$

3. Similarly, $$d_2 = \sqrt{(h_r+r)^2-r^2}$$

$$= \sqrt{h_r^2+2h_rr} = \sqrt{2rh_r} \qquad (h_r^2 << 2rh_r)$$

4. Putting the value of d_1 and d_2 in eq. (5.6.1) we get

$$d = \sqrt{2rh_t} + \sqrt{2rh_r}$$

$$= \sqrt{2r}\left[\sqrt{h_t} + \sqrt{h_r}\right]$$

5. Since radius of earth is equal to 6370 km

$$r = 6370 \text{ km} = 6370 \times 10^3 \text{ m}$$

$$d = \sqrt{2 \times 6370 \times 10^3}\left[\sqrt{h_t} + \sqrt{h_r}\right] \text{meter}$$

$$= 3.570 \times 10^3 \left[\sqrt{h_t} + \sqrt{h_r}\right]$$

$$d = 3.57\left[\sqrt{h_t} + \sqrt{h_r}\right] \text{km}$$

6. This expression gives maximum line of sight distance covered by space wave propagation.

Que 5.7. **What are the effects of imperfect earth ?**

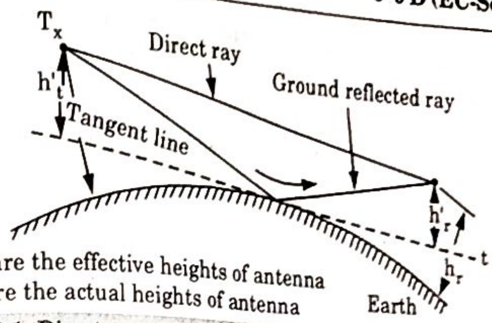
Answer

1. If E_0/d is the field strength for direct wave (DW) then it will also correspond to reflected wave for perfectly conducting earth.
2. The field strength at distance d is always less than E_0/d for the predominant condition $|R_h|$ and $|R_v|$ both are less than 1 for $\sigma \neq \infty$.
3. Beside $\phi \neq 180°$ *i.e.*, there is no phase reversal of reflected wave (RW). Thus, $RW < DW$ and total field is less than at $\sigma = \infty$
4. The effect is less on HPW than in case of VPW. For VPW, $|R_v| << |R_h|$ at small angles.
5. When $\sigma = \infty$ the horizontal components of incident electric field E_i and reflected electric field E_r get cancelled at reflected surface and vertical components add together.
6. When $\sigma < \infty$, $|R_v| < 1$, there is neither complete cancellation nor complete addition.

Que 5.8. **What are the effects of earth curvature on space wave propagation ?**

Answer

1. There is a difference in actual height and effective height of the antenna as shown in Fig. 5.8.1. This difference in height will depend on 'separation distance' between transmitter and receiver.
2. There is reduction in distance d at which free space field and oscillating field for a perfectly conducting earth become equal.
3. The reflected wave at the receiving antenna is weak as the wave is reflected by the ground diverges.
4. This effect is less when the incident angle is large or moderate near the grazing angle, the field effect of reflected wave reduces significantly by the receiver.



h'_t and h'_r are the effective heights of antenna
h_t and h_r are the actual heights of antenna

Fig. 5.8.1. Direct ray and reflected ray over curved earth.

5. At large distance for small incidence angles the directed wave and reflected waves are in phase opposition. The resultant field strength at the receiver is appreciably greater than that if earth were flat.
6. There is a reduction in d, beyond which the two waves tend to be out of phase.

Que 5.9. **Calculate the maximum distance at which signal from transmitting antenna with 144 m height would be received by the receiving antenna of 25 m height.**

Answer

Given : $h_t = 144$ m, $h_r = 25$ m

To Find : Maximum distance.

$$\text{LOS} = 3.57\left[\sqrt{h_t} + \sqrt{h_r}\right] \text{km}$$

$$= 3.57\left(\sqrt{144} + \sqrt{25}\right)$$

$$= 60.69 \text{ km}$$

Que 5.10. **What is troposphere ? Explain the mechanism of wave propagation in this region.**

Answer

1. Troposphere is that portion of earth atmosphere which extends from earth surface up to a height of 8 to 10 km at polar latitude, 10 to 12 km at moderate latitude and up to 16 to 18 km at the equator.
2. The entire belt is called as troposphere or region of change. The percentage of gas content remains almost constant with increase of height, but water vapour component sharply decreases with height.
3. The other important property of the troposphere is that temperature decreases with increase of height and falls to a minimum temperature of – 55 °C.

4. Refractive index of the troposphere at the surface of the earth is 0.0003% greater than unity. *i.e.*,

$$N = (\mu - 1) \times 10^{-6}$$

N = excess refractive index over unity

5. The gradient of N within the troposphere is constant.

$$\therefore \quad \frac{dN}{dh} = 4.45 \times 10^{-2} \text{ per meter}$$

6. Tropospheric Propagation or Forward Scatter Propagation is at UHF and Microwaves *i.e.*, above 300 MHz.

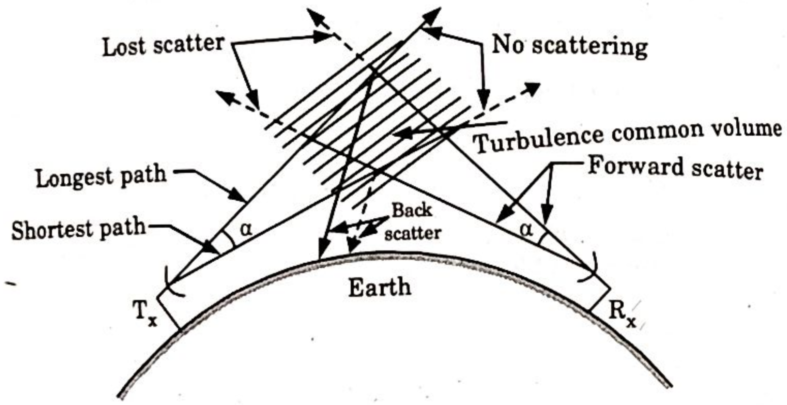


Fig. 5.10.1. Tropospheric scatter propagation.

7. Forward scatter propagation or simply scatter propagation is of practical importance at VHF, UHF and microwaves. UHF and microwave signals were found to be propagated much beyond the line of the sight propagation through the forward scattering in the tropospheric irregularities.

8. It uses certain properties of troposphere and is known as Troposcatter. This has also led to the discovery of ionosphere scatter propagation for signal frequencies in the lower end of VHF band.

9. There are two different theories involved in forward scatter propagation. The first mode is ionospheric and is believed to be resulted from scattering of radio waves from the lower E layer of the ionosphere.

10. The second mode is tropospheric and is thought to be result of scattering from fine layers in the troposphere.

11. Due to greater attenuation of signals along the path, forward scatter propagation is mainly useful for point to point communication, radio or television relay links; where it is possible to use extremely high gain antennas and high power transmitters.

PART-2

Sky Wave Propagation : Introduction, Structural Details of the Ionosphere, Wave Propagation Mechanism, Refraction and Reflection of Sky Waves by Ionosphere, Ray Path, Critical frequency, MUF, LUF, OF, Virtual Height and Skip Distance, Relation Between MUF and the Skip Distance, Multi-Hop Propagation Wave Characteristics

CONCEPT OUTLINE : PART-2

- Sky wave propagation takes place at frequencies between 2 MHz to 30 MHz.
- The ionosphere is a region above the earth and is composed of ionized layers.
- The refraction phenomenon is governed by the following relation in the ionosphere :

$$n = \sqrt{1 - \frac{81N}{f^2}}$$

where, n = Refractive index of ionosphere.
N = Number of electrons per cubic cm.
f = Frequency in kHz.

Critical frequency,

$$\boxed{f_c = 9\sqrt{N_{max}}}$$

N_{max} = Maximum electron density

- **Relation between MUF and skip distance :**

$$d = (2h)\sqrt{\left(\frac{f_{MUF}^2}{f_c^2} - 1\right)}$$

where, d = Skip distance.
h = Height of ionospheric layer.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.11. What are two modes of radio propagation ? Discuss the space wave propagation. **AKTU 2017-18, Marks 05**

Answer

A. Two modes of radio propagation are :

i. Ground wave : Refer Q. 5.1, Page 5–2D, Unit-5.

ii. Sky wave :

1. The sky waves are of practical importance at medium and high frequencies for very long distance radio communications.
2. In this mode of propagation, EM waves reach the receiving point after reflection from the ionized region in the upper atmosphere called ionosphere which is situated between 50 km to 400 km above earth surface.
3. The ionosphere acts like a reflecting surface and is able to reflect back the EM waves of frequencies between 2 to 30 MHz.
4. Electromagnetic waves of frequencies more than 30 MHz are not reflected back from the ionosphere rather they penetrate it. This mode of propagation is also called as Short Wave Propagation.
5. Sky wave propagation takes place after reflection from the ionosphere, so it is also called as ionospheric propagation.

B. Space wave : Refer Q. 5.4, Page 5–4D, Unit-5.

Que 5.12. Explain how ground wave and space-wave propagates the signal via troposphere. Distinguish clearly between surface wave, space wave and sky wave. **AKTU 2015-16, Marks 10**

Answer

A. Ground Wave : Refer Q. 5.1, Page 5–2D, Unit-5.

B. Space Wave : Refer Q. 5.4, Page 5–4D, Unit-5.

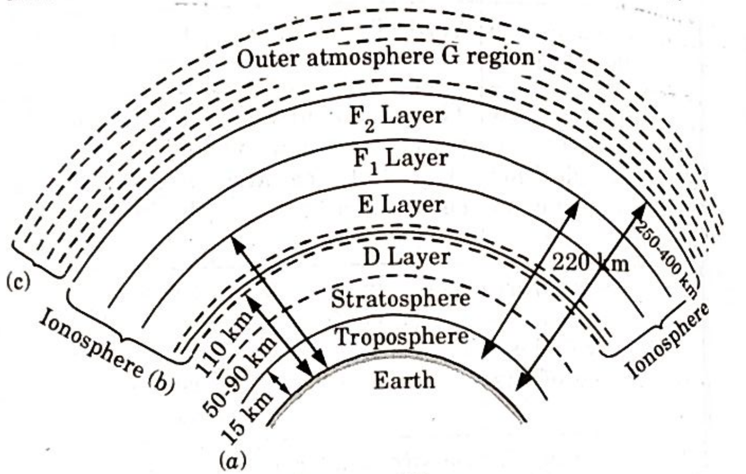
S. No.	Ground wave propagation	Sky wave propagation	Space wave propagation
1.	It exists in the frequency range of 30 kHz to 3 MHz.	Exists in the range of 3 MHz to 30 MHz.	Used for frequencies above 30 MHz.
2.	Used for radio broadcasting.	Used for radio broadcast.	Used for TV and FM broadcasting.
3.	Ground waves are vertically polarized.	Vertically polarized.	Horizontally polarized.
4.	Ground waves tilt progressively and eventually die. This limits the range of communication.	The transmission path is limited by the skip distance and curvature of earth.	The transmission path is limited by the line of sight and radio horizon.
5	Ground waves are surface waves which travel along the surface of the earth.	Sky waves are reflected from the ionosphere.	Space waves travel in a straight line from transmitter to receiver through space.
6	The service range is a few hundred km.	Service range can be few thousand km.	Service range is not more than 100 km.
7	Power loss takes place due to absorption by ground and due to tilting of waves.	Power loss due to absorption of energy by the layers of ionosphere.	Power loss due to the absorption and scattering by the tall and massive objects.
8	Problem of fading is not very severe.	Problem of fading is severe. Diversity reception is used.	Fading is not severe but shadow zones due to tall objects and ghost interference are serious problems.

Que 5.13. Describe the structure of ionosphere.

Answer

1. The upper part of the atmosphere where the ionization is appreciable is known as ionosphere. The upper part of the earth's atmosphere absorbs large quantities of radiant energy from the sun.

2. This not only heats the atmosphere but also produces ionizations. The ionized region consists of free electron, positive ions and negative ions.
3. The ions, electrons and atoms in a gas are constantly in motion; so frequent collisions occur between them and consequently the process of recombination continues all the time.
4. The time of recombination depends on many factors and one such is the average distance between the particles of the gas.
5. In the lower part of the atmosphere, collisions are very frequent and hence air molecules do not remain ionized for a longer time.



(a) Troposphere up to 15 km
(b) Ionosphere 50-400 km
(c) Outer atmosphere above 400 km

Fig. 5.13.1. Medium above earth surface.

Que 5.14. **Explain the structure of ionosphere with its region.**

Answer

A. Structure of ionosphere : Refer Q. 5.13, Page 5–13D, Unit-5.

B. Different region of ionosphere :

i. *D*-region :

1. *D* region is the lower most region of the ionosphere and is located at the height range of 50 to 90 km. This layer is present only during the day light hours and disappears at night because the recombination rate is highest.
2. Its electron density is ranging from 10^{14} to 10^{16} per cubic centimeter. *D* layer is also known as absorbing layer for short wave signals (*i.e.*, *HF*).
3. Since the density of electrons in this region is not sufficient to effect appreciable bending of radio waves and hence they suffer attenuation while passing.

Normal *E*-region :

E-region (normal) lies as narrow layer of ionization just above the *D*-region in the height range of 90 to 140 km.

During night hours *E*-region remains weekly ionized and during day light hours its height remains practically constant.

Critical frequency of *E*-layer lies in the range of 3 MHz to 5 MHz. *E*-layer is the most useful layer for long distance radio propagation during day light hours.

The main function of *E*-layer is to reflect some *HF* waves in day hours.

Sporadic *E*-region (E_s) :

This region usually occurs in the form of clouds, varying in size from about one km to several hundred km.

Its presence is purely regional and its occurrence and intensity of ionization has no connection with sun radiation. It ranges from 90 km to 130 km.

It is not important in long distance propagation but sometimes it allows unexpectedly good reception.

It helps long distance scatter propagation of *VHF* signals.

F_1, F_2 and *F* Regions or Appleton Regions :

The region of the ionosphere lying between 140 km to 400 km from earth surface is called as *F*-region or layer. Its average height is around 270 km.

F-region facilitates long distance sky wave propagation of radio signals during night hours. It is highly ionized and hence some ionization remain even after sun set.

Although ionization density is high, the actual air density is not much and hence most of the molecules of this layer are ionized.

Its critical frequency at noon time is of the order of 5 MHz to 7 MHz. F_1 layer is formed by ionization of oxygen atoms. The main effect of F_1 layer is to provide more absorption for *HF* waves.

F_2 layer is uppermost region situated at a height range of about 250 km to 400 km in day.

Its critical frequency is 10 MHz or still more at low altitude stations. It ranges from 5 MHz to 12 MHz. The ionization in the F_2 layer is effected largely by earth's magnetic field, atmospheric, ionospheric storms and other geomagnetic disturbances.

Its ionization density shows large changes with solar activity and the change from sun spot minimum to sun spot maximum is highest for this layer. F_2 layer is the most important reflecting medium for high frequency radio waves.

Que 5.15. What is the role of ionosphere in propagation ? How do reflection and refraction occur ?

AKTU 2017-18, Marks 05

Answer

A. Role of ionosphere in propagation :

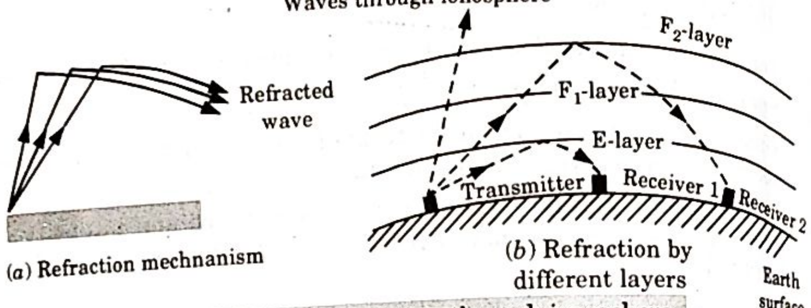


Fig. 5.15.1 Propagation through ionosphere.

1. Ionospheric wave propagation is important as it assists global short wave communication. Due to the existence of the different ionized layers in the ionosphere, the long distance communication is possible.
2. The layers of ionosphere are mainly useful in long distance communication. The *D*-layer exists during day time. It cannot reflect high frequency waves back to the earth.
3. Instead the intensity of the waves reflected back from the *E* or *F*-layer decreases during day time due to the presence of the *D*-layers.
4. The layers which exist permanently act as a radio mirror to bounce back the sky waves to the earth. The waves which return back to the earth appear to be the waves reflected by the layers of the ionosphere.
5. But practically the ionized layers refract or bend the waves back towards the earth in much the same way as the refraction of the light waves travelling through media of different densities.
6. The propagation of radio wave through ionosphere is as shown in Fig. 5.15.1.

B. Reflection and refraction :

1. The incident signal (signal transmitted towards the ionosphere) approaches the ionosphere, where the ionization density increases.
2. The increases in the ionization density will reduce the refractive index of the layer progressively. Due to this the incident wave is bent farther and farther away from the normal.
3. Due to this mechanism the incident wave is "reflected" back to the earth. The angle of incidence and the angle of reflection are equal.
4. The refracted wave penetrates to the second layer where it is partially refracted. The resultant reflected signal is the sum of reflections of various parts of the ionized layers.
5. The signals get attenuated in between frequencies and hence reflection at low and high frequencies is considered.

Que 5.16. What do you understand by plane earth reflection ? Derive the formulas of reflection coefficient for horizontal polarization and reflection coefficient for vertical polarization.

AKTU 2017-18, Marks 05

Answer

A. Plane earth reflection : Refer Q. 5.3, Page 5–3D, Unit-5.

B. Reflection coefficient for horizontal polarization :

1. It is also called perpendicular polarization because the electric field vector is perpendicular to the plane of incidence and parallel to the reflecting surface. The reflection coefficient is,

$$R_H = \frac{E_r}{E_i} = \frac{\sqrt{\epsilon_1}\cos\theta_1 - \sqrt{\epsilon_2 - \epsilon_1 \sin^2\theta_1}}{\sqrt{\epsilon_1}\cos\theta_1 + \sqrt{\epsilon_2 - \epsilon_1 \sin^2\theta_1}}$$

2. For oblique incidence of a radiated wave the reflection factor is,

$$R_H = \frac{E_r}{E_i} = \frac{\sqrt{\epsilon_0}\cos\theta - \sqrt{\left(\epsilon + \frac{\sigma}{j\omega}\right) - \epsilon_0 \sin^2\theta}}{\sqrt{\epsilon_0}\cos\theta + \sqrt{\left(\epsilon + \frac{\sigma}{j\omega}\right) - \epsilon_0 \sin^2\theta}}$$

where ϵ_0 = Dielectric constant of free space

$\left(\epsilon + \frac{\sigma}{j\omega}\right)$ = Dielectric constant of earth

3. The direction of incident wave is expressed in terms of ψ such that,

$$\psi = 90° - \theta°$$

$$\theta = 90° - \psi$$

$$\therefore \quad R_H = \frac{\sqrt{\epsilon_0}\left[\sin\psi - \sqrt{\left(\frac{\epsilon}{\epsilon_0} - \frac{j\sigma}{\omega\,\epsilon_0}\right) - \cos^2\psi}\right]}{\sqrt{\epsilon_0}\left[\sin\psi + \sqrt{\left(\frac{\epsilon}{\epsilon_0} - \frac{j\sigma}{\omega\,\epsilon_0}\right) - \cos^2\psi}\right]}$$

4. As, $\epsilon = \epsilon_r \epsilon_0$

$$\therefore \quad R_H = \frac{\sin\psi - \sqrt{\left(\epsilon_r - \dfrac{j\sigma}{\omega\,\epsilon_0}\right) - \cos^2\psi}}{\sin\psi + \sqrt{\left(\epsilon_r - \dfrac{j\sigma}{\omega\,\epsilon_0}\right) - \cos^2\psi}}$$

5. Let $X = \dfrac{\sigma}{\omega\,\epsilon_0}$

$$\therefore \quad R_H = \frac{\sin\psi - \sqrt{(\epsilon_r - jX) - \cos^2\psi}}{\sin\psi + \sqrt{(\epsilon_r - jX) - \cos^2\psi}}$$

C. Reflection coefficient for vertical polarization :

1. The electric field vector is parallel to the plane of incidence and magnetic field vector is parallel to the reflecting surface for vertical polarization.

The reflection coefficient R_V is,

$$R_V = \frac{E_r}{E_i} = \frac{\left(\dfrac{\epsilon_2}{\epsilon_1}\right)\cos\theta_1 - \sqrt{\left(\dfrac{\epsilon_2}{\epsilon_1}\right) - \sin^2\theta_1}}{\left(\dfrac{\epsilon_2}{\epsilon_1}\right)\cos\theta_1 + \sqrt{\left(\dfrac{\epsilon_2}{\epsilon_1}\right) - \sin^2\theta_1}}$$

2. For oblique incidence,

$$R_V = \frac{E_r}{E_i} = \frac{\dfrac{\left(\epsilon + \dfrac{\sigma}{j\omega}\right)}{\epsilon_0}\cos\theta - \sqrt{\dfrac{\left(\epsilon + \dfrac{\sigma}{j\omega}\right)}{\epsilon_0} - \sin^2\theta}}{\dfrac{\left(\epsilon + \dfrac{\sigma}{j\omega}\right)}{\epsilon_0}\cos\theta + \sqrt{\dfrac{\left(\epsilon + \dfrac{\sigma}{j\omega}\right)}{\epsilon_0} - \sin^2\theta}}$$

$$R_V = \frac{\left(\dfrac{\epsilon}{\epsilon_0} - \dfrac{j\sigma}{\epsilon_0\,\omega}\right)\cos\theta - \sqrt{\left(\dfrac{\epsilon}{\epsilon_0} - \dfrac{j\sigma}{\epsilon_0\,\omega}\right) - \sin^2\theta}}{\left(\dfrac{\epsilon}{\epsilon_0} - \dfrac{j\sigma}{\epsilon_0\,\omega}\right)\cos\theta + \sqrt{\left(\dfrac{\epsilon}{\epsilon_0} - \dfrac{j\sigma}{\epsilon_0\,\omega}\right) - \sin^2\theta}}$$

3. Here $\psi = 90° - \theta°$

and $\cos\psi = \sin\theta$

$\sin\psi = \cos\theta$

$$\therefore \quad R_V = \frac{\left(\dfrac{\epsilon}{\epsilon_0} - \dfrac{j\sigma}{\epsilon_0\,\omega}\right)\sin\psi - \sqrt{\left(\dfrac{\epsilon}{\epsilon_0} - \dfrac{j\sigma}{\epsilon_0\,\omega}\right) - \cos^2\psi}}{\left(\dfrac{\epsilon}{\epsilon_0} - \dfrac{j\sigma}{\epsilon_0\,\omega}\right)\sin\psi + \sqrt{\left(\dfrac{\epsilon}{\epsilon_0} - \dfrac{j\sigma}{\epsilon_0\,\omega}\right) - \cos^2\psi}}$$

4. As, $\epsilon = \epsilon_r \epsilon_0$

Let $X = \dfrac{\sigma}{\epsilon_0\,\omega}$

$$\therefore \quad R_V = \frac{(\epsilon_r - jX)\sin\psi - \sqrt{(\epsilon_r - jX) - \cos^2\psi}}{(\epsilon_r - jX)\sin\psi + \sqrt{(\epsilon_r - jX) - \cos^2\psi}}$$

Que 5.17. **Explain how earth's magnetic field affects the propagation of radio waves in ionosphere ?**

AKTU 2015-16, Marks 10

Answer

1. In the ionized medium *i.e.*, ionosphere, the electrons are set in motion by the electric field of the radio wave and the earth's magnetic field, then exerts a force on the vibrating electrons producing twisting effect on their paths. This reacts on the incident radio waves.
2. Thus, the earth's magnetic field splits up the incident radio waves in two components : ordinary and extra ordinary waves.
3. The two waves bend by different amounts in the ionosphere and hence they travel through the ionosphere in a slightly different path *i.e.*, elliptical path. The rate of absorption of energy and velocity is also different for both the waves.
4. The two waves have elliptical polarization and rotate in opposite directions. The phenomenon of splitting of waves into different components by earth's magnetic field is called as magneto ionic splitting.
5. The effect of earth's magnetic field is frequency dependent. At lower frequencies the effect is greater as the average velocity of electrons is inversely proportional to the frequency. Hence paths of electrons changes with frequency.
6. At high frequencies, the path of vibration follows a narrow elliptical shape. The variation in path of electrons continues till frequency is reduced to a value at which cyclotron resonance occurs and electrons follow a spiral path.
7. There is a direct correlation between the earth's magnetic field lines and electron gyro-frequencies.
8. Basically, the electron gyro-frequency is a measure of the interaction between electron in the earth's atmosphere and the earth's magnetic field.
9. Gyro-frequency (f_g) is defined as the frequency whose period is equal to the period of revolution of a electron in its circular orbit under the influence of the earth's magnetic field of flux B.

$$\omega_g = \frac{Be}{m}$$

where, B = earth's magnetic field = 0.5×10^{-4} Wb/m

e = charge of electron = 1.6×10^{-19} C

and m = mass of electron = 9.1×10^{-31} kg

$$2\pi f_g = \frac{Be}{m}$$

$$f_g = \frac{1}{2\pi}\frac{Be}{m} = 1.4 \text{ MHz}$$

(i) $f < f_g$ (ii) $f = f_g$ (iii) $f > f_g$

Fig. 5.17.1. Effect of earth's magnetic field at different frequencies.

10. If the frequency (f) of the incident radio wave is equal or nearly equal to f_g, then there is resonance phenomenon and the oscillating electron receives more and more energy from the incident wave. Hence attenuation is maximum at gyro-frequency.
11. If the frequency $f > f_g$, then the electron motion follows an elliptical path and the ellipse gets narrowed as the frequency increases. Consequently, a high frequency plane polarized wave gets elliptically polarized after reflection from the ionosphere.
12. If the frequency $f < f_g$, then the electrons vibrate in small loops, usually making several loops like a stretched spiral and the polarization is not much affected.

Que 5.18. **Explain the mechanism of reflection and refraction of sky wave by ionosphere and derive the relevant relationship for same.**

AKTU 2014-15, Marks 05

OR

Discuss in detail about the mechanism of refraction in sky wave propagation.

AKTU 2016-17, Marks 03

OR

Obtain the expression for refractive index and critical frequency.

AKTU 2016-17, Marks 12

Answer

A. Mechanism of reflection and refraction of sky wave :

1. The incident signal (signal transmitted towards the ionosphere) approaches the ionosphere, where the ionization density increases.
2. The increase in the ionization density will reduce the refractive index of the layer progressively. Due to this the incident wave is bent farther and farther away from the normal.

3. Due to this mechanism the incident wave is "reflected" back to the earth. The angle of incidence and the angle of reflection are equal.
4. The refracted wave penetrates to the second layer where it is partially refracted. The resultant reflected signal is the sum of reflections of various parts of the ionized layer.
5. The signals get attenuated in the between frequencies and hence reflection at low and high frequencies is considered.

B. Reflection or Refraction at High Frequencies :

1. The phase velocity of a wave in medium having negligible loss is given by,

$$V_p = \frac{1}{\sqrt{\mu\epsilon}} = \frac{c}{\sqrt{\mu_r \epsilon_r}} \quad ...(5.18.1)$$

where $c = \frac{1}{\sqrt{\mu_V \epsilon_V}}$ is the velocity of light in vacuum

2. If the permeability of ionosphere remains unchanged by the presence of electrons, so that $\mu_r = 1$, the phase velocity is,

$$V_p = \frac{c}{\sqrt{\epsilon_r}} \quad ...(5.18.2)$$

ϵ_r depends on electron density

3. If the electron density change in the distance of a wavelength is small, the change in phase velocity will be also small.
4. The signal penetrates the lower edge of ionosphere without reflection.

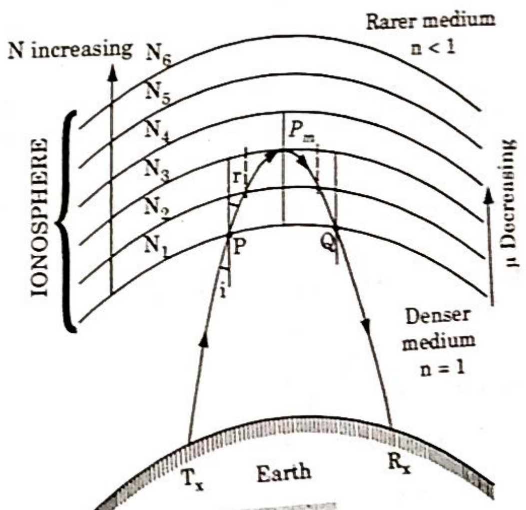


Fig. 5.18.1

5. In the ionosphere the signal travels in a curved path as shown in Fig. 5.18.1. At any point along the path, the angle ϕ between the path and normal is given by Snell's law of refraction.

$$n = \frac{\sin \phi_i}{\sin \phi_r} \quad ...(5.18.3)$$

where n is refractive index

6. The refractive index for any medium is given as,

$$n = \frac{\text{Velocity of light in vacuum}}{\text{Phase velocity of the medium}}$$

$$\therefore \quad n = \frac{c}{v_p} \quad ...(5.18.4)$$

Substituting eq. (5.18.2) in eq. (5.18.4) we get

$$n = \sqrt{\epsilon_r}$$

$$\epsilon_r = 1 - \frac{Ne^2}{\epsilon_v\, m\, \omega^2}$$

For an electron, $e = 1.59 \times 10^{-19}$ C,

$\boxed{m = 9 \times 10^{-31} \text{ kg}}$ $\boxed{1.6 \times 10^{-19}\ C}$

$$\therefore \quad \epsilon_r = \left(1 - \frac{81\,N}{f^2}\right) \quad ...(5.18.5)$$

where M = number of electrons per cubic meter.

f = frequency in hertz.

Substituting in eq. (5.18.4) we get

$$n = \sqrt{1 - \frac{81\,N}{f^2}} \quad ...(5.18.6)$$

7. As the wave penetrates into region of higher electron density the angle of refraction ϕ_r increase. This will cause a decrease in the refractive index.

8. If $\phi_r = 90°$, $\sin \phi_r = 1$. In such a case the refractive index $n = \sin \phi_i$ and the wave travels horizontally.

$$n = \sin \phi_i \quad ...(5.18.7)$$

Substituting eq. (5.18.6) in eq. (5.18.7) we get,

$$\sin \phi_i = \sqrt{1 - \frac{81\,N}{f^2}}$$

Squaring both the sides we get,

$$\sin^2 \phi_i = 1 - \frac{81\,N}{f^2}$$

$$\frac{81\,N}{f^2} = 1 - \sin^2 \phi_i = \cos^2 \phi_i \quad (\because \ \sin^2\theta + \cos^2\theta = 1)$$

$$N = \frac{f^2 \cos^2 \phi_i}{81} \quad ...(5.18.8)$$

9. As the angle of incidence goes on decreasing, the electron density goes on increasing and reaches to a maximum density (N_m) at $\phi_i = 0$.

10. The highest frequency that can be reflected by the ionosphere is one for which refractive index n becomes 0.

$$\therefore \quad n = \frac{\sin \phi_i}{\sin \phi_r} = \sqrt{1 - \frac{81\,N_m}{f_c^2}}$$

where N_m = maximum ionization density,

f_c = critical frequency.

Que 5.19. **Define virtual height.**

Answer

1. Virtual height of an ionospheric layer may be defined as the height to which a short pulse of energy sent vertically upward and traveling with the speed of light would reach taking the same two ways travel time as does the actual pulse reflected from the ionospheric layer.

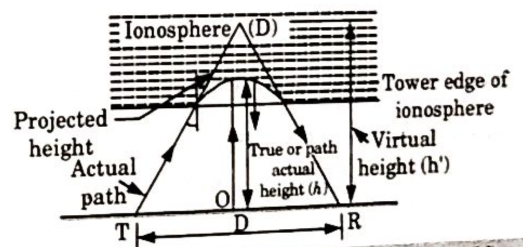


Fig. 5.19.1. Virtual and actual heights of an ionized layer.

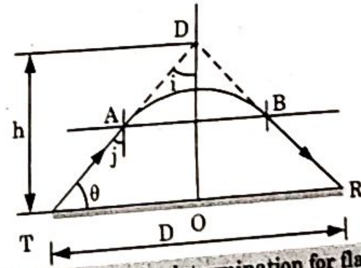


Fig. 5.19.2. Virtual height determination for flat earth.

2. For flat earth Fig. 5.19.3, assuming that the ionosphere conditions are symmetrical for the incident and reflected waves, the distance TR is obtained :

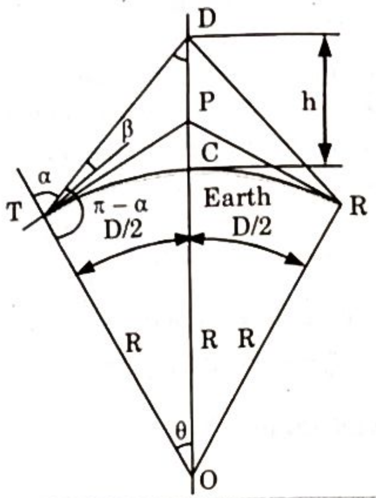


Fig. 5.19.3. Virtual height determination for flat earth.

$$\tan\beta = \frac{DO}{TO} = \frac{h}{TR/2}$$

$$\frac{TR}{2} = \frac{h}{\tan\beta}$$

$$\Rightarrow \quad TR = \frac{2h}{\tan\beta} = D$$

3. When curvature of earth is accounted for, then

$$\frac{\sin i}{R} = \frac{\sin(\pi-\alpha)}{(R+h)} = \frac{\sin\alpha}{R+h}$$

But $\quad i = \alpha - \theta$

$$\Rightarrow \quad \frac{\sin(\alpha-\theta)}{R} = \frac{\sin\alpha}{R+h}$$

$$\theta = \alpha - \sin^{-1}\left(\frac{R\sin\alpha}{R+h}\right)$$

Again; $\quad \alpha = 90 - \beta$

So, $\quad \theta = 90 - \beta - \sin^{-1}\left(\frac{R\cos\beta}{R+h}\right)$

4. Now, $\quad \text{Angle} = \frac{\text{Arc}}{\text{Radius}}$

and $\quad \theta = \frac{\text{Arc } TC}{R} = \frac{D/2}{R} = \frac{D}{2R}$

$$D = 2R\theta$$

$$= 2R\left[(90-\beta) - \sin^{-1}\left(\frac{R\cos\beta}{R+h}\right)\right]$$

5. Measurement of virtual height is normally carried out by means of an instrument known as an ionosonde.
6. The reflected signal is received close to the transmission point, and the time T required for the round trip is measured. Then the virtual height is given by

$$h = \frac{cT}{2} = \text{virtual height}$$

Que 5.20. **Define maximum usable frequency and derive an expression for the same in the case of a thin ionospheric layer over a plane earth.** **AKTU 2013-14, Marks 05**

Answer

1. Maximum usable frequency (MUF) is a limiting frequency which can be reflected back to earth but at some specific angle of incidence rather than the vertical incidence.
2. The maximum possible value of frequency for which reflection takes place for a given distance of propagation, is called the maximum usable frequency for that distance and for the given ionospheric layer.
3. For a sky wave to return to earth, the sky wave requires angle of reflection, $\phi_r = 90°$, $N = N_{max}$ and $f = f_{MUF}$.
4. Thus, if ϕ_i is the incident angle and ϕ_r is the reflection angle, the refractive index n can be written as

$$n = \frac{\sin\phi_i}{\sin\phi_r} = \frac{\sin\phi_i}{\sin 90} = \sin\phi_i = \sqrt{1 - \frac{81\,N_{max}}{f_{MUF}^2}}$$

$$\sin^2\phi_i = 1 - \frac{81\,N_{max}}{f_{MUF}^2}$$

But $\quad f_c^2 = 81\,N_{max}$

5. Thus, $\sin^2\phi_i = 1 - \frac{f_c^2}{f_{MUF}^2}$ or $\frac{f_c^2}{f_{MUF}^2} = 1 - \sin^2\phi_i = \cos^2\phi_i \quad$ ...(5.20.1)

$$f_{MUF}^2 = \frac{f_c^2}{\cos^2\phi_i} = f_c^2\sec^2\phi_i \quad \text{...(5.20.2)}$$

$$\therefore \quad f_{MUF} = f_c\sec\phi_i \quad \text{...(5.20.3)}$$

6. Eq. (5.20.1) is known as secant law. It indicates that f_{MUF} is greater than f_c by a factor $\sec\phi_i$.

Que 5.21. **With a neat sketch explain about skip distance.** **AKTU 2016-17, Marks 10**

Answer

1. Radio wave radiated horizontally from a transmitter near the earth's surface is quickly absorbed due to large ground losses and hence only short distance communication is carried out by this horizontal radiation of ground or surface wave.
2. Radio wave radiated at high angle may not be bent sufficiently at the ionospheric layers to return to earth at all and hence escapes rather penetrates the layer.
3. Thus radio wave radiated at shallow angle (*i.e.*, angle between horizontal and high angle) just great enough to escape absorption by the earth, will enter the lower layer, suffer attenuation, be bent at the upper layer and return to earth.
4. In other words, between the distance at which surface wave becomes negligible and the distance at which the first wave returns to earth from the ionospheric layer, there is a zone which is not covered by any wave (*i.e.*, neither ground nor sky).
5. This is called skip zone or area and the distance across it is the 'skip distance'.
6. Hence, skip distance may be defined as :

i. The minimum distance from the transmitter at which a sky wave of given frequency is returned to earth by the ionosphere. It is represented by D as in the Fig. 5.21.1.

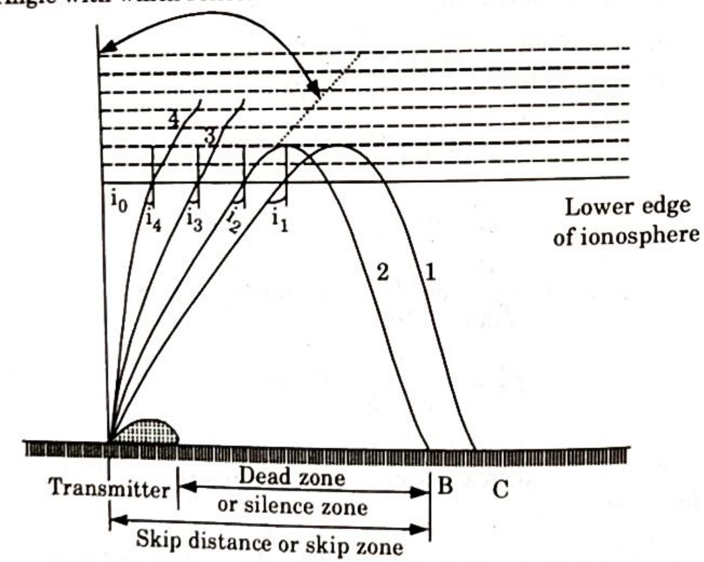


Fig. 5.21.1.

ii. The minimum distance from the transmitter to a point where sky wave of a given frequency is first received.

iii. The minimum distance within which a sky wave of given frequency fails to be reflected back.

iv. The minimum distance for which sky wave propagation just takes place and no sky wave propagation is possible for points nearer than this distance.

6. The higher the frequency, the higher the skip distance and for a frequency less than critical frequency of a layer, skip distance is zero.
7. As the angle of incidence at the ionosphere decreases, the distance from the transmitter, at which the ray returns to ground first decreases. This behaviour continues until eventually an angle of incidence is reached at which the distance becomes minimum.
8. The minimum distance is called skip distance D, and is given as :

$$D = 2h\sqrt{\left(\frac{f_{muf}}{f_c}\right)^2 - 1}$$

Que 5.22. **Derive the skip distance for region between transmitter and receiver using sky wave propagation when curvature of earth is taken into consideration.** **AKTU 2014-15, Marks 05**

Answer

1. Fig. 5.22.1 shows the ionized layer and curved earth surface.
2. Let 2θ be the angle subtended by skip distance D at the centre of earth O.

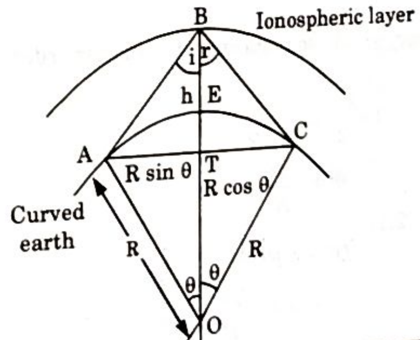


Fig. 5.22.1. Reflection from a thin inospheric layer but on curved earth accouting its curvature.

3. From Fig. 5.22.1,

$$\text{Angle} = \frac{\text{arc}}{\text{radius}} \qquad \therefore 2\theta = \frac{D}{R} \qquad ...(5.22.1)$$

$$D = 2R\theta$$

4. Now,

$$AT = R\sin\theta \,;\; OT = R\cos\theta$$

$$BT = OE + EB - OT$$

$\therefore$

$$= R + h - R\cos\theta$$

$\therefore$

$$AB = \sqrt{AT^2 + BT^2}$$

$$= \sqrt{(R\sin\theta)^2 + (h + R - R\cos\theta)^2}$$

5. Hence,

$$\cos i = \frac{BT}{AB} = \frac{h + R - R\cos\theta}{\sqrt{(R\sin\theta)^2 + (h + R - R\cos\theta)^2}}$$

$$\cos^2 i = \frac{(h + R - R\cos\theta)^2}{(R\sin\theta)^2 + (h + R - R\cos\theta)^2} \quad \text{...(5.22.2)}$$

$$\cos^2 i = \frac{f_c^2}{f_{MUF}^2} = \frac{(h + R - R\cos\theta)^2}{(R\sin\theta)^2 + (h + R - R\cos\theta)^2} \quad \text{...(5.22.3)}$$

6. The curvature of earth limits both MUF and skip distance D and limit is obtained when wave leaves the transmitter at grazing angle *i.e.*, $\angle OAB = 90°$.

7. Thus when D is maximum, θ is maximum that is given by

$$\cos\theta = \frac{OA}{OB} = \frac{R}{R + h} \quad \text{...(5.22.4)}$$

8. Since, the actual value of θ is very small thus expanding the eq. (5.22.4)

$$\cos\theta = \frac{R}{R\left(1 + \frac{h}{R}\right)} = \left(1 + \frac{h}{R}\right)^{-1}$$

$$\cos\theta = \left(1 - \frac{h}{R} + \frac{h^2}{R^2} - \ldots\ldots\right) \quad \text{...(5.22.5)}$$

9. Since $\frac{h}{R}$ is very small, so neglecting the higher order terms, we get

$$1 - \frac{\theta^2}{2} = 1 - \frac{h}{R}$$

$$\theta^2 = \frac{2h}{R} \quad \text{...(5.22.6)}$$

10. From eq. (5.22.1)

$$D^2 = 4R^2\theta^2$$

$$= 4R^2 \cdot \frac{2h}{R} = 8hR$$

$$h = \frac{D^2}{8R}$$

$\therefore$

$$\cos\theta = \left(1 - \frac{h}{R}\right) = \left(1 - \frac{D^2}{8R^2}\right) \quad \text{...(5.22.7)}$$

$$\sin\theta = \theta = \frac{D}{2R} \quad \text{(since } \theta \text{ is very small)} \quad \text{...(5.22.8)}$$

11. From eq. (5.22.3), (5.22.5) and (5.22.8), we get

$$\frac{f_c^2}{(f_{MUF}^2)_{max}} = \frac{\left\{h + R - R\left(1 - \frac{D^2}{8R^2}\right)\right\}^2}{R^2 \cdot \frac{D^2}{4R^2} + \left[h + R - R\left(1 - \frac{D^2}{8R^2}\right)\right]^2}$$

$$= \frac{\left(h + \frac{D^2}{8R}\right)^2}{\frac{D^2}{4} + \left(h + \frac{D^2}{8R}\right)^2}$$

$$\frac{(f_{MUF})_{max}}{f_c} = \frac{\sqrt{\frac{D^2}{4} + \left(h + \frac{D^2}{8R}\right)^2}}{\sqrt{\left(h + \frac{D^2}{8R}\right)^2}}$$

$$(f_{MUF})_{max} = \frac{f_c\sqrt{\frac{D^2}{4} + \left(h + \frac{D^2}{8R}\right)^2}}{\sqrt{\left(h + \frac{D^2}{8R}\right)^2}}$$

$$D = 2\left(h + \frac{D^2}{8R}\right)\sqrt{\frac{f_{MUF}^2}{f_c^2} - 1}$$

This is the expression for skip distance.

Que 5.23. **Find the skip distance for waves of frequency 4.6 × 10⁶ Hz at a time when the maximum ionization in the *E*-region has a value of 1 × 10¹¹ e/m³ at a height of 110 km.**

AKTU 2013-14, Marks 05

Answer

Given : $f_{MUF} = 4.6 \times 10^6$ Hz, $h = 110$ km, $N_{max} = 1 \times 10^{11}$ e/m³

To Find : Skip distance.

1. Since,

$$f_c = 9\sqrt{N_{max}} = 9\sqrt{1 \times 10^{11}}$$

$$f_c = 2.84 \times 10^6 \text{ Hz}$$

2.

$$f_{MUF} = f_c\sqrt{1 + \left(\frac{d}{2h}\right)^2}$$

3. $\therefore$ $4.6 \times 10^6 = 2.84 \times 10^6 \sqrt{1+\left(\frac{d}{2h}\right)^2}$

$$1+\left(\frac{d}{2h}\right)^2 = 2.62$$

$$\frac{d}{2h} = 1.62$$

d = skip distance

$$= 2 \times 1.62 \times 110 = 356.65 \text{ km}$$

Que 5.24. **Define duct propagation.**

Answer

1. At VHF, UHF and microwaves, the waves are neither reflected by ionosphere nor propagate along the earth's surface.
2. But, in the troposphere region, the high frequency waves are refracted and transmission takes far beyond line of sight (LOS) distance.
3. An atmosphere where the dielectric constant is assumed to decrease uniformly with height to value equal to unity at which air density is supposed to be zero is commonly called normal atmosphere or standard atmosphere.
4. There are different air region or layers one above other with different temperatures and water vapour contents. In one of the regions, there is a region where $\frac{dM}{dh}$ is negative.
5. The energy originating in this region propagates around curved surfaces in the form of series of hops with successive reflections from the earth as shown in the Fig. 5.24.1. This phenomenon is called super refraction or duct propagation.
6. Two boundaries of surfaces between two air layers form a duct which guide the radio waves between walls *i.e.*, boundaries.

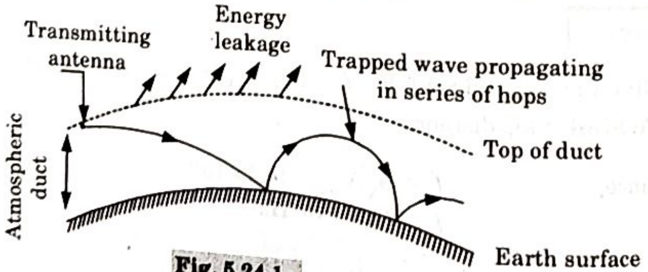


Fig. 5.24.1.

7. If ΔM is the total decrease in M from bottom to top of the duct the wavelength $\lambda = \lambda_{max}$ at which the duct propagation ceases is given by :

$$\lambda_{max} = 2.5\, h_d \sqrt{\Delta M \times 10^{-6}}$$

where, h_d = Height of duct

Que 5.25. **Why we use the term modified refractive index in propagation of radio waves ? Explain duct propagation.**

AKTU 2015-16, Marks 15

Answer

1. **Modified Refractive Index :**
1. A standard atmosphere is one where the dielectric constant is assumed to be decrease uniformly with height to a value of unity at height where air density is zero.
2. Where the refracting conditions are sufficiently different from standard to cause trapping of the wave, the concept of effective earth radius does not hold good.
3. In order to give the necessary curvature, the actual refractive index (μ) is expressed in terms of a modified refractive index (μ_m) which is given by,

$$\mu_m = \mu + \frac{h}{R_E} \quad ...(5.25.1)$$

where, h = Height above earth surface or ground

R_E = Radius of earth = 3.37×10^6 m

μ_m is approximately unity.

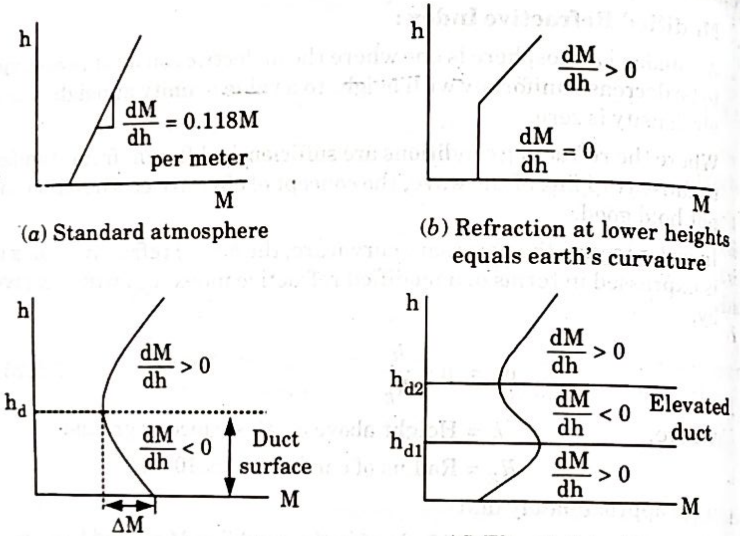
4. Hence the excessive modified refractive modulus M related to μ_m is

$$M = (\mu_m - 1) \times 10^6 = \left(\mu - 1 + \frac{h}{R_E}\right) \times 10^6$$

As the height increases, the refractive index decreases.

5. In standard atmosphere, $\frac{dM}{dh}$ is positive.
6. Fig. 5.25.1(*c*) shows the variation of M occurs when the moisture content of the air at the surface of ground is very high, but rapidly decreases with increasing height. In the region where slope $\frac{dM}{dh}$ is negative, the curvature of the rays passing through the atmosphere is greater than that of the earth.
7. As a result a wave originated approximately parallel to earth's surface tends to be trapped and propagates around the curved surface of the earth in a series of hops which is termed as duct propagation.

8. When the duct propagation exists, the line of sight and diffraction zone concept no longer apply and energy will travel distances around the curvature of earth with relatively low attenuation.
9. Duct propagation will occur only if the height of the transmitting antenna is less than the height of the duct.
10. Fig. 5.25.1(*d*) shows an elevated duct. When the height of the transmitting antenna is sufficient to feed power to the elevated duct, the energy will propagate in the duct points below the normal horizon with low attenuations.



(*a*) Standard atmosphere

(*b*) Refraction at lower heights equals earth's curvature

(c) Surface duct formed over sea

(*d*) Elevated duct formed over land

Fig. 5.25.1.

B. Duct propagation : Refer Q. 5.24, Page 5–30D, Unit-5.

Que 5.26. **Explain the following terms :**
Ray path, Optimum frequency, and lowest usable frequency.

Answer

A. Ray path : The path followed by wave is termed as ray path.

B. Optimum frequency :

1. The frequency utilized for ionospheric propagation is called optimum working frequency.
2. Generally for transmission between any two points the optimum frequency lies between 50 % and 85 % of the predicted maximum usable frequency between the two points.

C. Lowest usable frequency :

1. It is defined as the lowest frequency that gives satisfactory reception for required distance and power. The reflection of waves takes place from *F*-layer in case of high frequency.
2. Due to these some part of waves are absorbed. The frequencies that are near MUF undergo retardation.
3. For these frequencies strength of received signal is weak because of considerable absorption. Hence there is a limit on the highest frequency used as a optimum frequency. It is called as lowest useful high frequency.
4. For ionospheric propagation frequency selected should be lies between MUF and LUF.

Que 5.27. **Explain MUF, critical frequency and virtual height as applied to sky wave propagation.** **AKTU 2014-15, Marks 05**

OR

Explain the following :
i. Atmospheric noise
ii. Maximum usable frequency
iii. Critical frequency
iv. Skip distance in a short wave communication.

AKTU 2017-18, Marks 10

Answer

i. Atmospheric noise :

1. Atmospheric noise is the radio noise caused by natural atmospheric process, primarily lightning discharges in thunderstorms.
2. It is the most erratic noise. It is also called precipitation noise.

ii. MUF : Refer Q. 5.20, Page 5–25D, Unit-5.

iii. Critical frequency :

1. Critical frequency f_c is the highest frequency that returns from an ionospheric layer at vertical incidence.
2. Refractive index, $\mu = \dfrac{\sin i}{\sin r} = \sqrt{1 - \dfrac{81N}{f^2}}$
3. Refractive index becomes zero for the highest frequency that is reflected back by the ionosphere.

$$\mu = \frac{\sin i}{\sin r} = \sqrt{1 - \frac{81N}{f_c^2}} = 0$$

$$\Rightarrow \quad f_c = 9\sqrt{N_m}$$

4. This is the expression for critical frequency for which wave is reflected back to the ionosphere.

iv. **Skip distance :** Refer Q. 5.21, Page 5–25D, Unit-5.

v. **Virtual height :** Refer Q. 5.19, Page 5–23D, Unit-5.

Que 5.28. **Derive the relation between MUF and skip distance. Also explain critical frequency, MUF, virtual height, skip distance.**

AKTU 2015-16, Marks 15

Answer

A. Relation between MUF and skip distance :

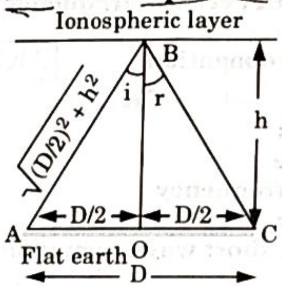


Fig. 5.28.1. Reflection from thin layer on flat earth.

1. From Fig. 5.28.1.

$$\cos i = \frac{BO}{AB} = \frac{h}{\sqrt{h^2 + \frac{D^2}{4}}} = \frac{2h}{\sqrt{4h^2 + D^2}}$$

where, h = height of layer
and D = skip distance

2. The maximum usable frequency for which the wave is to be reflected from the layer for returning to earth $f = f_m$, $\angle r = 90°$ and $N = N_m$.

$$\mu = \sin i = \sqrt{1 - \frac{81 N_m}{f_{\text{MUF}}^2}} = \sqrt{1 - \frac{f_c^2}{f_{\text{MUF}}^2}}$$

$$\cos^2 i = \frac{f_c^2}{f_{\text{MUF}}^2} = \frac{4h^2}{4h^2 + D^2}$$

$$\frac{f_{\text{MUF}}}{f_c} = \sqrt{1 + \frac{D^2}{4h^2}}$$

$$f_{\text{MUF}} = f_c \sqrt{1 + \left(\frac{D}{2h}\right)^2}$$

$$D = 2h \sqrt{\frac{f_{\text{MUF}}^2}{f_c^2} - 1}$$

3. This is the expression for skip distance in terms of maximum usable frequency and height h of the layer.

B. **Critical frequency :** Refer Q. 5.27, Page 5–33D, Unit-5.

C. **MUF :** Refer Q. 5.20, Page 5–25D, Unit-5.

D. **Virtual height :** Refer Q. 5.19, Page 5–23D, Unit-5.

E. **Skip distance :** Refer Q. 5.21, Page 5–25D, Unit-5.

Que 5.29. **What do you understand by multi-hop propagation ?**

Answer

1. Since the transmission path is limited by the skip distance and the curvature of earth.
2. The maximum range of the single hop transmission is restricted to 4000 km due to skip distance and curvature of earth. However, semi circumference of earth is about 20,000 km.
3. The single hop transmission is not useful to cover this long distance range. Hence, multi-hop transmission is preferred.

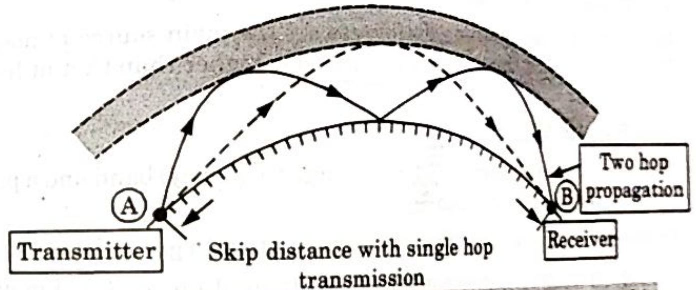


Fig. 5.29.1. Multiple hop sky wave propagation (north-south).

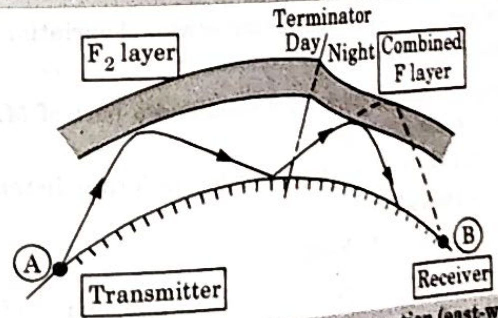


Fig. 5.29.2. Multiple hop sky wave propagation (east-west).

4. There is no problem in the multiple hop transmission in the north-south direction. But care is to be taken while planning it for east-west direction if the transmitter and receiver are present on either side of terminator.

5. As shown in Fig. 5.29.2, if there is day on one side of terminator and night on other side. The height of the combined *F* layers at night is lower than that of F_2 layer.
6. Because of this, ray will return earlier than expected and will miss the receiver.

Que 5.30. **Write a note on wave characteristics.**

Answer

Wave propagation characteristics :

1. (3 kHz – 30 kHz) :

i. This is low frequency wave having limited carrier frequency, thus limits the bandwidth and hence the information contents, so it can't be used for communication.

ii. Since these waves can penetrate deep into the sea as well as earth, hence it is used in submarine and mine communication.

iii. These waves have attenuation of about 3 dB/1000 km for propagation of over the sea water and 6 dB/1000 km over the land.

iv. In this range the lightning discharges are the main source of noise. The noise level at this range is considerably higher than that at high frequencies.

2. (20 kHz – 100 kHz) :

i. This range includes part of VLF (very large frequency) band and a part of LF (Large frequency) band.

ii. In this range, there is relatively low attenuation in ground waves.

iii. In this range ground wave mode is mostly used up to 1000 km and above it sky wave mode is used.

iv. Received signal shows during day and seasonal variation.

3. (100 kHz – 535 kHz) :

i. This range includes a part of *LF* band and a part of *MF* (Moderate frequency) band.

ii. In this range sky wave are preferred for moderate distance.

4. (535 kHz – 1600 kHz) :

i. This is a segment of MF band.

ii. This range includes frequencies that are primarily used for broadcast purpose.

iii. In this range sky waves are completely absorbed in day and broadcast entirely depends on ground wave propagation.

iv. In day time ground waves signal strength decreases more rapidly with distance.

5. (1600 kHz – 30 MHz) :

i. This range includes part of *MF* band along with entire *HF* band.

ii. In this range except for short distance communication ground waves mode is of no use as these waves attenuate more rapidly.

iii. For long distance communication ionospheric reflection is used.

6. Frequencies above 30 MHz :

i. Rarely reflected back to the earth except occasionally from sporadic *E*-region in the 30 to 60 MHz range.

ii. Usefulness above 30 MHz depends mainly upon space-wave propagation.

iii. Communication even with reasonable transmitted power is not possible beyond line of sight distance.

iv. Height of transmitting and receiving antenna determine the distance.

7. VHF waves :

i. These waves supports all modes of propagation *i.e.*, ground waves and tropospheric waves etc.

ii. These waves are capable of passing through ionosphere as direct wave.

8. UHF (decimetric) and SHF (centimetric waves) :

i. These waves can propagate as ground waves over short (LOS) distance.

ii. For long distance communication is done through tropospheric waves.

iii. Diffraction is negligible in this range.

9. EHF (millimetric waves) :

i. No effect of ionosphere, troposphere causes bending due to atmospheric refraction.

ii. Heavy rain and dense fog will completely stop propagation.

10. Sub millimetric and optical waves :

i. These waves can propagate only as direct wave and ground wave.

ii. Atmospheric refraction causes bending of path.

iv. These waves are well suited for space communication outside the troposphere.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Discuss the phenomenon of ground wave propagation at long and medium waves.

Ans. Refer Q. 5.1.

Q. 2. Derive the relation for field strength for space wave propagation.

Ans. Refer Q. 5.5.

Q. 3. Explain how ground wave and space-wave propagates the signal via troposphere. Distinguish clearly between surface wave, space wave and sky wave.

Ans. Refer Q. 5.12.

Q. 4. Obtain the expression for refractive index and critical frequency.

Ans. Refer Q. 5.18.

Q. 5. Why we use the term modified refractive index in propagation of radio waves ? Explain duct propagation.

Ans. Refer Q. 5.25.

Q. 6. Explain MUF, critical frequency and virtual height as applied to sky wave propagation.

Ans. Refer Q. 5.27.

☺☺☺

1 UNIT

Antennas Basics (2 Marks Questions)

1.1. What do you mean by "Antenna" ?

Ans. In radio sense, antenna is a device used for sending and receiving the radio waves. Antenna radiates/couple/concentrate electromagnetic energy in the desired/assigned direction.

1.2. List out which parameters to consider for receiving antenna design. AKTU 2016-17, Marks 02

Ans.

i. Radiation pattern.
ii. Directivity.
iii. Power density.
iv. Gain.

1.3. Define radiation pattern.

Ans. Radiation patterns are diagrammatical representations of the distribution of radiated energy into space, as a function of direction.

1.4. Define gain of antenna.

Ans. Gain of antenna is defined as the ratio of maximum radiation intensity in a given direction to the maximum radiation intensity produced in the same direction from a reference antenna.

1.5. Define radiation intensity $U(\theta,\phi)$.

Ans. The power radiated from an antenna per unit solid angle is called radiation intensity.

$$P_n(\theta,\phi) = \frac{U(\theta,\phi)}{U(\theta,\phi)_{max}}$$

1.6. What do you understand by beam efficiency ?

Ans. The ratio of main beam area to the total beam area is called beam efficiency.

$$\text{Beam efficiency} = \frac{\Omega_M}{\Omega_m}$$

where Ω_M = Main beam area.
Ω_m = Minor lobe area.

1.7. Define beamwidth of an antenna.

Ans. Antenna beamwidth is an angular width in degrees measured on the radiation pattern between points where the radiated power falls to half of its maximum value.

1.8. Explain half power beamwidth and first null beam width.

AKTU 2017-18, Marks 02

Ans.

A. **Half power beamwidth :** The angular width measured between the two points on the major lobe of a radiation pattern where the radiated power decreases to half of its maximum value is called half power beam width (HPBW).

B. **First null beamwidth :** The angular width between first null or first side lobes is called first null beamwidth (FNBW).

1.9. Define effective height of an antenna.

AKTU 2015-16, Marks 02

Ans.

1. Effective length or height of an antenna represents the effectiveness of an antenna as radiator or collector of the electromagnetic wave energy.
2. Effective length indicates how far an antenna is effective in transmitting or receiving the electromagnetic energy.
3. It is the ratio of induced voltage at the terminal of the receiving antenna under open circuit condition to the incident electric field intensity or strength.

$$h_e = l_e = \frac{V}{E} \text{ in m}$$

1.10. Write down the Friis transmission formula.

Ans.

$$\frac{P_r}{P_t} = \frac{A_{er}\,A_{et}}{r^2\,\lambda^2}$$

where P_r = Radiated power in watts.
P_t = Transmitted power in watts.
A_{et} = Effective aperture of transmitting antenna.
A_{er} = Effective aperture of receiving antenna.
r = Distance between antenna.
λ = Wavelength.

1.11. Define signal to noise ratio (SNR).

Ans. The signal to noise ratio is defined as the ratio of signal power to the noise power. It is most important parameter used to measure the detection capability of the system.

1.12. Explain antenna temperature in brief.

AKTU 2017-18, Marks 02

Ans. Antenna temperature (T_A) is a parameter that depends on the temperature of the region the antenna is looking at. In this sense, a receiving antenna may be regarded as a remote sensing, temperature measuring device.

$$T_A = \frac{SA_e}{k}$$

where A_e = Effective aperture.
k = Boltzmann's constant.
S = Power density per unit bandwidth.

1.13. Why the resolution of an antenna is equals to the directivity of the antenna ?

Ans. The directivity is equal to the number of point source in the sky that the antenna can resolve under the ideal condition of a uniform source distribution.

1.14. The radiation resistance of an antenna is 72 Ω and loss resistance is 8 Ω. What is the directivity in dB if the power gain 16 ?

AKTU 2017-18, Marks 02

Ans.

Given : Radiation resistance = 72 Ω, Loss resistance = 8Ω, G = 16
To Find : D (in dB).

1. Antenna efficiency,

$$\eta = \frac{72}{72+8} = 0.9 \text{ or } 90\,\%$$

and

2. Directivity, $D = \dfrac{G}{\eta} = \dfrac{160}{9} = 17.77$

$$(D)_{\text{dB}} = 10 \log_{10} D = 10 \log_{10} 17.77 = 10 \times 1.2497$$

$$D = 12.497 \text{ dB}$$

1.15. A 12-turn axial helix antenna of circumference λ has turn spacing of λ/4. Determine HPBW, BWFN, directivity and also examine polarization characteristic of the antenna.

AKTU 2015-16, Marks 02

Ans.

Given : $N = 12, S = \lambda/4, C = \lambda$
To Find : HPBW, BWFN and D.

1. $$\text{HPBW} = \frac{52}{C}\sqrt{\frac{\lambda^3}{N.S}} \text{ degrees}$$
$$= \frac{52}{\lambda}\sqrt{\frac{\lambda^3}{12.(\lambda/4)}} = \frac{52}{\lambda}\sqrt{\frac{\lambda^2 4}{12}} = 52\sqrt{\frac{1}{3}} = 30.02^\circ$$

2. $$\text{BWFN} = \frac{115}{C}\sqrt{\frac{\lambda^3}{NS}} = \frac{115}{\lambda}\sqrt{\frac{\lambda^3}{12.(\lambda/4)}} = 115\sqrt{\frac{1}{3}}$$
$$= 66.39^\circ$$

3. Directivity, $$D = \frac{15\, NSC^2}{\lambda^3} = \frac{15 \times 12 \times \lambda \times \lambda^2}{\lambda^3 . 4} = 45$$

B. Polarization characteristics : The helix may have right handed pitch or left handed pitch. So accordingly the circular polarization may be right handed or left handed.

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2 UNIT

Point Sources and Array (2 Marks Questions)

2.1. Explain the concept of point sources.

AKTU 2017-18, Marks 02

Ans.
1. The idea of point source used for describing antenna is based on looking upon the antenna as a volumeless emitter located at a point from a large distance where only the far field exists. However, the isotropic radiator can be a point source.
2. The ratio of the distance between the antenna and the point of observation of the field to the physical size of an antenna is the deciding factor for considering an antenna to be point source.
3. If the ratio is much greater than unity, an antenna may be considered to be point source.

2.2. State the power theorem.

Ans. In a lossless medium, if the Poynting vectors are known at all points on the sphere of radius r from a point source, then the total power radiated by the source is given by,

$$P = \oiint S_r \, ds$$

where $$S_r = \frac{P}{4\pi r^2}$$

2.3. What do you understand by radiation intensity ?

Ans. Radiation intensity is defined as power per unit solid angle.

$$U = \frac{P}{4\pi} = r^2 S_r$$

2.4. What is an antenna array ?

Ans. An antenna array is a system of similar antennas oriented similarly to get greater directivity in a desired direction.

2.5. Classify various types of antenna arrays.

AKTU 2015-16, Marks 02

Ans.
i. Broadside array
ii. Endfire array
iii. Collinear array
iv. Parasitic array

2.6. What do you mean by broadside array antenna ?

Ans. Broadside array antenna is the array of identical parallel antennas. Antennas are setup along a line perpendicular to their respective axis.

2.7. What is endfire array antenna ?

Ans. The endfire array is the array of identical antennas and is spaced equally along a line and individual elements are feed with currents of equal magnitude but their phase varies progressively along the line of array.

2.8. Define parasitic arrays antenna.

Ans. Multi-element array having number of parasitic elements are called parasitic arrays. A parasitic element lengthened by 5 % with respect to driven element acts as a reflector and shortened by 5 % acts as director.

2.9. State the principle of pattern multiplications.

AKTU 2016-17, Marks 02

Ans. The field pattern of an array of non-isotropic but similar point source is the product of the pattern of individual source and pattern of an array of isotropic point source having the same locations, relative amplitude and phase as the non-isotropic point source.

2.10. What do you understand by uniform linear array ?

Ans. An array is said to be linear if the individual elements of the array are spaced equally along a line uniform and they are fed with currents of equal amplitude and having a uniform progressive phase shift along the line.

2.11. What is binomial array ?

Ans. In this array, the amplitude of the radiating source arranged according to the coefficient of successive terms of the binomial series.

2.12. Write down the necessary condition for an array to be binomial array.

Ans.
1. Spacing between two consecutive radiating sources does not exceed $\lambda/2$.

2. The current amplitude in radiating source is proportional to the coefficient of the successive terms of binomial series.

2.13. What are the disadvantages of binomial array ?

Ans.
1. HPBW increases and hence the directivity decreases.
2. For design of larger array, large amplitude ratio of source is required.

2.14. What is tapering ? Explain it with suitable example.

AKTU 2017-18, Marks 02

Ans.
1. The techniques used in reduction of side lobe level are called as tapering which means that the current or amplitudes in the sources of a linear array is non-uniform.

Example :

1. To reduce the Side-Lobe-Level (SLL) of linear in-phase broadside arrays, the sources have amplitudes proportional to the coefficients of a binomial series of the form

$$(a + b)^{n-1} = a^{n-1} + (n-1)a^{n-2}b + \frac{(n-1)(n-2)}{2!}a^{(n-3)}b^2 + \ldots \quad \ldots(2.14.1)$$

where n is the number of sources.

2. Thus, for arrays of three to six sources the relative amplitudes are given in such a way that the amplitudes are arranged as in Pascal's triangle.
3. Applying the binomial distribution to the array of five sources spaced $\lambda/2$ apart, the resulting pattern, designated as binomial.
4. The pattern has no minor lobes, but this has been achieved at the expense of an increased beamwidth.

2.15. Draw the unidirectional and bidirectional pattern for $U = U_m \cos\theta$ and $U_m \sin\theta$.

AKTU 2016-17, Marks 02

Ans. The pattern for $U = U_m \cos\theta$ is shown in Fig. 2.15.1.

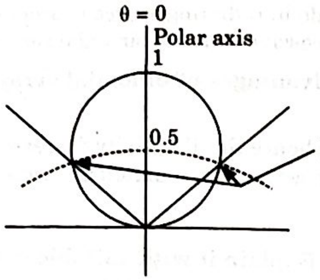

Fig. 2.15.1.

The pattern for $U = U_m \sin\theta$ is shown in Fig. 2.15.2.

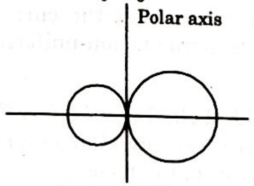

Fig. 2.15.2.

2.16. A uniform linear array consists of 20 isotropic point sources with a spacing of λ/4 if the phase difference is – 90°. Calculate its HPBW and directivity.

AKTU 2017-18, Marks 02

Ans.

Given : $d = \lambda/4$, $n = 20$
To Find : HPBW, D.

1. The given array of 20 isotropic point sources is of end fire type because of the phase shift so, HPBW for an end fire radiation is given by

$$\text{HPBW} = \frac{57.3°}{\sqrt{L/2\lambda}}$$

here, L = length of array = $(n-1)\,d$

$$L = (20-1)\,\frac{\lambda}{4}$$

so, $$L = 19 \times \frac{\lambda}{4}$$

2. $$\text{HPBW} = \frac{57.3°}{\sqrt{\dfrac{19\times\lambda/4}{2\lambda}}} = \frac{57.3°}{1.541} = 37.181°$$

3. Directivity, $$D = \frac{4L}{\lambda} = \frac{4\times19\times\lambda}{4\times\lambda} = 19.$$

2.17. A linear broadside array consists of four equal isotropic in-phase point sources with λ / 3 spacing. Find the beamwidth.

AKTU 2016-17, Marks 02

Ans.

Given : $n = 4$, $d = \lambda/3$.
To Find : Beamwidth.

The beamwidth of major lobe is given by

$$\text{BWFN} = \frac{2\lambda}{nd} = \frac{2\lambda}{4\times\lambda/3}$$
$$\text{BWFN} = 1.5 \text{ rad} = 85.94°$$

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3 UNIT

Thin Linear Antennas and Arrays of Dipoles (2 Marks Questions)

3.1. What is electric dipole ?

Ans. A short linear conductor is so short that current may be assumed to be constant throughout its length, such short conductor is called as electric dipole.

3.2. Define radiation resistance of dipole.

Ans. The Poynting vector of the far field is integrated over a large sphere to obtain the total power radiated. This power is then equated to I^2R, where I = rms current on the dipole and R = resistance.

$$R_r = 80\pi^2\left(\frac{L}{\lambda}\right)^2$$

where L = Length of dipole.
λ = Wavelength.

3.3. Relate radian and steradian. **AKTU 2016-17, Marks 02**

Ans. Radian is the measure of a plane angle while the steradian is the measure of a solid angle.

$$1\text{ Sr} = 1\text{ rad}^2 = \left(\frac{180}{\pi}\right)^2 (\text{deg})^2 = 3282.81 \text{ square degrees.}$$

3.4. Write down the expression for the electric field components of a short dipole. **AKTU 2015-16, Marks 02**

Ans. Electric field components of a short dipole is given as

$$E_r = \frac{I_m L \cos\theta\, e^{j\omega(t-r/c)}}{2\pi\varepsilon_0}\left(\frac{1}{cr^2} + \frac{1}{j\omega r^3}\right)$$

$$E_\theta = \frac{I_m L \sin\theta\, e^{j\omega(t-r/c)}}{4\pi\varepsilon_0}\left(\frac{j\omega}{c^2 r} + \frac{1}{cr^2} + \frac{1}{j\omega r^3}\right)$$

where, L = Length of dipole

3.5. What is grounded antenna ?

Ans. When an antenna is close to the ground, then regardless of whether the antenna is grounded or not, the earth acts as a mirror and becomes radiating system.

3.6. Define ungrounded antenna.

Ans. Ungrounded antenna (ground assumed to be a perfect conductor) has source of radiation near the reflecting surface, the radiation received at any distant point is the vector sum of the direct and indirect radiations.

3.7. Write down the advantage of Marconi antenna over ungrounded antenna.

Ans. Marconi antenna has one important advantage over ungrounded antenna that only half height of antenna is required in comparison to ungrounded antenna for producing same radiation pattern.

3.8. What is Yagi-Uda antenna ?

Ans. Yagi-Uda or simply Yagi antenna is the most high gain antenna. It consists of a driven element, a reflector and one or more directors. Yagi-Uda antenna is an array of a driven element and one or more parasitic elements.

3.9. What are the properties of Yagi-Uda antenna ?

Ans.

i. It provides gain of the order of 8 dB.
ii. If greater directivity is desired, further element may be used.
iii. With spacing 0.1λ to 0.15λ, a frequency bandwidth of order of 2 % is obtained.

3.10. What do you mean by rhombic antenna ?

Ans. Rhombic antenna is based on the principle of travelling wave radiator. By the application of return conductor, two wires are pulled apart at one point so that diamond or rhombus shape is formed, hence it named as rhombic antenna.

3.11. Explain V-antenna.

Ans. The V-antenna is an extension of long wire antenna. In this antenna the two long wire antennas are arranged in the form of horizontal V, fed at the apex.

3.12. Define magneto-ionic splitting. **AKTU 2016-17, Marks 02**

Ans.

1. Because earth's magnetic field, there are two possible values of refractive index of the ionosphere. Due to this the radio wave is split into two components that travel over different paths with different group velocities.
2. After reflection they reach the receiver at different times so that the received signal is said to be 'split'. This phenomenon is termed as the magneto-ionic splitting of radio wave.

3.13. Define folded dipole antenna.

Ans. This antenna consists of two closely spaced $\lambda/2$ element connected together at the outer ends. In folded dipole two half wave dipoles are folded and joined together in parallel at the ends. Hence it is fed at the center by a balanced transmission line.

3.14. What is the radiation resistance of a current element whose overall length is $\lambda / 50$? **AKTU 2016-17, Marks 02**

Ans. The radiation resistance is given by

$$R_r = 80\pi^2\left(\frac{dl}{\lambda}\right)^2$$

Here, $dl = \lambda/50$

$$R_r = 80\pi^2\left(\frac{\lambda}{50\lambda}\right)^2 = 0.315\ \Omega$$

3.15. A thin dipole antenna is $\left(\frac{\lambda}{10}\right)$ long. If loss resistance is 1.5 Ω, find radiation resistance and efficiency. **AKTU 2015-16, Marks 02**

Ans.

Given : $l = \lambda/10$, Loss resistance (R_{loss}) = 1.5 Ω
To Find : Radiation resistance, efficiency.

Radiation resistance, $R_r = 80\,\pi^2\left(\frac{l}{\lambda}\right)^2 = 80 \times \pi^2\left(\frac{\lambda}{10 \times \lambda}\right)^2$

$$R_r = 7.89\ \Omega$$

Antenna efficiency, $\eta = \dfrac{R_r}{R_{Loss} + R_r} = \dfrac{7.89}{1.5 + 7.89} = 0.84$ or 84 %

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4 UNIT

Loop Antenna and Reflector Antenna (2 Marks Questions)

4.1. Define a loop antenna and frame.

Ans. Loop antenna is a radiating coil of any shape with one or more turns carrying RF current. The loop may consist turns on a ferrite or air core. If loop consists more than one turn then it is commonly called as frame.

4.2. Mention the applications of loop antenna. **AKTU 2016-17, Marks 02**

Ans.
i. Large loop antenna can be used as direction finder.
ii. A small loop antenna is used as a source for paraboloid in many applications.

4.3. What do you mean by frequency independent antenna ? **AKTU 2015-16, Marks 02**

OR

What are frequency independent antennas ? Give example. **AKTU 2016-17, Marks 02**

Ans. **Frequency independent antenna :** A frequency independent antenna is physically fixed in size and operates on an instantaneous basis over a wide bandwidth with relatively constant impedance, pattern, polarization and gain.
Example : Log periodic antenna, conical-spiral antenna.

4.4. What do you understand by horn antenna ?

Ans. A horn antenna may be regarded as flared out (or opened-out) waveguide. The function of the horn is to produce a uniform phase front with a larger aperture than that of the waveguide and hence greater directivity.

4.5. Write the types of horn antenna.

Ans.
i. Rectangular horn antenna.
ii. Circular horn antenna.

4.6. What is helical antenna ?

Ans. This is a type of radiator and simplest antenna that provides circularly polarized wave and are used in extraterrestrial communication in satellite relay etc. It consists of conducting wire wound in the form of helix.

4.7. What are the applications of helical antenna ?

Ans.
i. Helical antennas are must extensively used in satellite communication.
ii. A single helical antenna or an array of helical antenna is useful in transmitting or receiving VHF signal through the ionosphere.

4.8. List the applications of microstrip antenna.

Ans.
i. Military applications.
ii. Space applications.
iii. Commercial applications.

4.9. Write advantages and disadvantages of microstrip antennas.

Ans.
A. Advantages :
i. The microstrip antenna is low profile antenna. They are smaller in size, light weight antenna.
ii. They are easily conformable to non-planer surface.

B. Disadvantages :
i. The microstrip antenna are low gain and low efficiency antennas.
ii. The microstrip antenna have narrow bandwidth of operation moreover they have low power handling capacity.

4.10. What do you understand by reflectors ?

Ans.
1. Reflectors are secondary antennas. They are used to modify the radiation pattern of radiating antenna.
2. By using large metallic plane sheet as a reflector the backward radiation from the antenna can be eliminated thus improving radiation pattern of the radiating antenna.

4.11. Named the types of reflectors.

Ans.
i. Parabolic cylinder reflector.
ii. Parabolic reflector.
iii. Truncated paraboloid reflector.
iv. Pill box antenna.
v. Cheese antenna.

4.12. What are the differences between parabolic reflectors and corner reflectors ?

Ans.

S. No.	Parabolic reflectors	Corner reflectors
1.	Parabolic reflectors have a specific focal point.	Corner reflector does not have a specific focal point.
2.	A parabolic reflector has a directional feed, which radiates all or most of the energy into the parabola.	Corner reflector does not require a directional feed since the direct reflected waves are properly combined.

4.13. What do you understand by feed system of reflector ?

Ans. A parabolic reflector antenna as a system consists of two basic parts namely a source of radiation located at the focus is called primary radiator, while reflector is called secondary radiator. The primary radiator *i.e.*, the source is commonly called feed radiator or simply feed.

4.14. A pyramidal horn antenna of mouth length 10 λ cm is fed by a rectangular waveguide in TE_{10} mode. Determine the design parameters of the antenna at operating frequency 2.5 Hz.

AKTU 2015-16, Marks 02

Ans.

Given : $h = 10\lambda, f = 2.5$ Hz
To Find : Design parameter.

1. Consider typical value of δ in E and H-plane

i.e.,
$$\delta = 0.20\lambda \text{ ; in } E\text{-plane}$$
$$\delta = 0.375\lambda \text{ ; in } H\text{-plane}$$
$$L = \frac{h^2}{8\delta} = \frac{(10\lambda)^2}{8 \times 0.2\lambda} = \frac{100\lambda}{1.6}$$
$$L = 62.5\lambda$$
$$\theta_E = 2\tan^{-1}\left(\frac{h}{2L}\right) = 2\tan^{-1}\left(\frac{10\lambda}{2 \times 62.5\lambda}\right) = 9.14°$$

$$\theta_H = 2\cos^{-1}\left(\frac{L}{L+\delta}\right) = 2\cos^{-1}\left(\frac{62.5}{62.5+0.375}\right)$$

$$\theta_H = 12.52°$$

$$\tan\frac{\theta_H}{2} = \frac{W}{2L}$$

$$W = 2L\tan\theta_{H/2} = 2 \times 62.5\lambda \tan(6.26)$$

$$= 125\lambda \times 0.1104$$

$$W = 13.7\lambda$$

4.15. Find the power gain and directivity of a horn whose dimensions are 10 cm × 5 cm and operating at a frequency of 6 GHz.

AKTU 2017-18, Marks 02

Ans.

Given : Dimensions = 10 cm × 5 cm, f = 6 GHz
To Find : G, D.

1. Area, A = 10 cm × 5 cm = 50 cm^2

$$\lambda = \frac{3\times10^8}{6\times10^9} = 0.5\times10^{-1}\ \text{m} = 5\ \text{cm}$$

2. Power gain, $G_p = \dfrac{4.5\,A}{\lambda^2} = \dfrac{4.5\times50}{(5)^2} = 9$

3. Directivity, $D = \dfrac{7.5A}{\lambda^2} = \dfrac{7.5\times50}{(5)^2} = 15$

4.16. For a parabolic reflector having directivity of 30 dB and an aperture efficiency of 55 % operating at 15 MHz. Calculate the area of parabolic reflector and HPBW.

AKTU 2017-18, Marks 02

Ans.

Given : D = 30 dB, f = 15 MHz, η = 55 % = 0.55
To Find : Area of parabolic reflector, HPBW.

1. $$\lambda = c/f = \frac{3\times10^8}{15\times10^6} = 20$$

and $10\log D = 30$ dB

$$D = \text{antilog}(3)$$

$$= 1000$$

2. Area of parabolic reflector,

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

$$A = \frac{D\lambda^2}{4\pi} = \frac{1000\times(20)^2}{4\pi} = 31830.98\ \text{m}^2$$

3. HPBW : $\dfrac{58\,\lambda}{D} = \dfrac{58\times20}{1000} = 1.16°$

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5 UNIT

Wave Propagation (2 Marks Questions)

5.1. What do you mean by ground wave ?

Ans. The ground wave is a wave that is guided along the surface of the earth. An EM wave is guided by a waveguide or transmission line.

5.2. List of advantages and disadvantages of ground wave.

Ans.

A. Advantages :

i. The atmospheric conditions do not affect the ground wave propagation too much.

ii. If transmitted power is large it can be used to communicate between any two points of the world.

B. Disadvantages :

i. Limited range for higher operating frequencies.

ii. High transmission power is required for adequate range.

iii. At low frequencies, very tall antennas are required.

5.3. Define space wave.

Ans. Space wave consists of direct and indirect components. In direct component, wave reaches directly from the transmitting antenna to receiving antenna and in indirect component, the wave reaches to the receiving antenna after reflection from the ground.

5.4. What is radio horizon ?

Ans. It is the maximum distance over which a direct radio wave link can be established. The radio horizon is slightly greater than the optical horizon for space wave.

5.5. Define LOS (line of sight).

Ans. The maximum possible distance at which direct wave transmission is possible between a transmitting and receiving antennas with heights h_t and h_r is often referred to as line of sight (LOS).

5.6. What are the effects of imperfect earth on space wave propagation ?

Ans.

i. The field strength at distance d is always less than E_o/d for the predominant condition $|R_h|$ and $|R_v|$ both are less than 1 for $\sigma \neq \infty$.

ii. When $\sigma < \infty$, $|R_v| < 1$, there is neither complete cancellation nor complete addition.

5.7. Write the effects of earth curvature on space wave propagation.

Ans.

i. There is reduction in distance d at which free space field and oscillating field for a perfectly conducting earth become equal.

ii. There is reduction in d beyond which the two waves tend to be out of phase.

5.8. What is troposphere ?

Ans. Troposphere is that portion of earth atmosphere which extends from earth surface up to a height of 8 to 10 km at polar latitude, 10 to 12 km at moderate latitude and up to 16 to 18 km at the equator.

5.9. Define gyro frequency.

Ans. It is defined as the frequency whose period is equal to the period of revolution of an electron in its circular orbit under the influence of earth's magnetic field.

$$f_g = \frac{1}{2\pi} B\left(\frac{e}{m}\right)$$

5.10. What do you mean by critical frequency ?

Ans. Critical frequency is the highest frequency which can be reflected by the particular layer at vertical incidence. This highest frequency is different for different layer.

$$\mu = \frac{\sin i}{\sin r}$$

$$= \sqrt{\frac{1 - 81N_{max}}{f_c^2}}; \quad Li = 0$$

$$f_c = 9\sqrt{N_{max}}$$

5.11. What is maximum usable frequency ?

AKTU 2016-17, Marks 02

Ans. The maximum usable frequency is a limiting frequency which can be reflected back to earth but at some specific angle of incidence rather than the vertical incidence.

$$f_{MUF} = f_c\sqrt{1 + \left(\frac{D}{2h}\right)^2}$$

5.12. What do you understand by lowest usable frequency ?

Ans. It is defined as the lowest frequency that gives satisfactory reception for required distance and power. For ionospheric propagation frequency selected should be lies between MUF and LUF.

5.13. Define skip distance and virtual height.

AKTU 2017-18, Marks 02

Ans. Skip distance : Skip distance may be defined as :

i. The minimum distance from the transmitter at which a sky wave of given frequency is returned to the earth by the ionosphere.

ii. The minimum distance from the transmitter to a point where sky wave of a given frequency is first received. Skip distance is calculated as

$$D_{skip} = 2h\sqrt{\left(\frac{f_{MUF}}{f_c}\right)^2 - 1}$$

Virtual height :

Virtual height of an ionospheric layer may be defined as the height to which a short pulse of energy sent vertically upward and traveling with the speed of light would reach taking the same two ways travel time as does the actual pulse reflected from the ionospheric layer.

5.14. Relate MUF with skip distance for flat earth.

AKTU 2015-16, Marks 02

Ans. The relation between MUF and skip distance for flat earth surface can be given as :

$$f_{MUF} = f_c\sqrt{1+\left(\frac{D}{2h}\right)^2}$$

or

$$D = 2h\sqrt{\frac{f^2_{MUF}}{f_c^2} - 1}$$

where, D = skip distance

h = height of layer

f_{MUF} = maximum usable frequency.

5.15. Define ionospheric storms.

Ans. Ionospheric storms are caused by disturbances in the earth's magnetic field and are related to solar eruptions and the 27 day cycle of the sun. The effect of these storms may lead to a turbulent ionospheres and erratic sky wave propagation

5.16. At what frequency a wave must propagate for the D region to have a refractive index of 0.7 ? Given N = 400 electrons/cm^3.

AKTU 2015-16, Marks 02

Ans.

Given : Refractive index, $n = 0.7$, $N = 400$ electrons/cm^3.

To Find : f.

We know, $n = \sqrt{1 - \frac{81N}{f^2}}$, where f in kHz

$$0.7 = \sqrt{1 - \frac{81\times400}{f^2}}$$

$$0.49 = 1 - \frac{81\times400}{f^2}$$

$$f^2 = \frac{81\times400}{0.51}$$

$$f = 252.05 \text{ kHz}$$

5.17. A 10 MHz satellite communication is taking place through ionosphere layer with refractive index 0.975 and height 500 km. Calculate the ground range of this propagation assuming 10 GHz as MUF and 2.24 GHz as critical frequency.

AKTU 2015-16, Marks 02

Ans.

Given : f_{MUF} = 10 GHz, h = 50 km, refractive index = 0.975, f_c = 2.24 GHz.

To Find : Ground range.

$$d = (2h)\sqrt{\frac{f^2_{MUF}}{f_c^2} - 1} = 2\times500\sqrt{\frac{(10\text{ GHz})^2}{(2.24\text{ GHz})^2} - 1}$$

$$= 1000\sqrt{18.92} = 4350.04 \text{ km}$$

5.18. A microwave signal of 1.9 GHz arrives at an antenna via two paths differing in length by 19 m. Calculate (i) the difference in arrival time for two paths (ii) phase difference between the two signals.

AKTU 2017-18, Marks 02

Ans.

Given : f = 1.9 GHz, d = 19 m

To Find : Difference in arrival time for two paths, phase difference between two signals.

i. Difference in arrival time for the two paths.

$$\Delta s = \frac{2h_t h_r}{d} = \frac{2h_t h_r}{19}$$
$$= 0.105\, h_t\, h_r \text{ metres}$$

ii. Phase difference,

$$\phi_s = \frac{2\pi}{\lambda} \times \frac{2h_t h_r}{d}$$
$$= \frac{2\pi}{\lambda} \times \frac{2h_t h_r}{19}$$
$$= 0.6614\, \frac{h_t h_r}{\lambda}$$

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B. Tech.
(SEM. V) ODD SEMESTER THEORY EXAMINATION, 2013-14
ANTENNA AND WAVE PROPAGATION

Time : 3 Hours **Max. Marks : 50**

Note : Attempt **all** the questions. All questions carry equal marks.

1. Attempt any **two** parts of the following : **(5 × 2 = 10)**

a. **Prove that the radiation resistance of half wave dipole antenna is 73 ohms.**

Ans. Refer Q. 3.5, Page 3–9D, Unit-3.

b. **A transmitting antenna having an effective height of 100 meters has a current at the base 100 A at the frequency of 300 kHz. Calculate :**

i. **The field strength at a distance of 100 km**

ii. **The value of radiation resistance.**

Ans. Refer Q. 1.22, Page 1–24D, Unit-1.

c. **How the directivity of an antenna is defined and what is the relation between directivity and gain of an antenna ?**

Ans. Refer Q. 1.7, Page 1–8D, Unit-1.

2. Attempt any **two** parts of the following : **(5 × 2 = 10)**

a. **Design a four element broadside array of λ/2 spacing between elements. Consider unit element as λ/2 length antenna. Draw its radiation pattern and calculate its HPBW.**

Ans. Refer Q. 2.3, Page 2–5D, Unit-2.

b. **What is end-fire array ? Deduce an expression for the radiation pattern of an end-fire array with *n* vertical dipoles.**

Ans. Refer Q. 2.4, Page 2–6D, Unit-2.

c. **What is meant by Dolph-Chebyshev distribution for a linear array ? Show that such a distribution gives a minimum side lobe level for a given beam-width of major lobe.**

Ans. Refer Q. 2.15, Page 2–22D, Unit-2.

3. Attempt any **two** parts of the following : **(5 × 2 = 10)**

a. **A loop aerial for use at 500 kHz is of height 0.5 meter, width 0.5 meter and 25 turns, when directed to receive a maximum signal. The emf induced in the loop is 150 µV. What is the field strength of the signal picked up ?**

Ans. Refer Q. 4.4, Page 4–6D, Unit-4.

b. **What is a rhombic antenna ? Describe its construction and properties with special reference to directivity and bandwidth.**

Ans. Refer Q. 3.14, Page 3–19D, Unit-3.

c. **Design log-periodic antenna of your own defined parameter. Describe microstrip antenna. What are its advantage and disadvantage ? Describe any one feed method.**

Ans. Refer Q. 4.15, Page 4–21D, Unit-4.

4. Attempt any **two** parts of the following : (5 × 2 = 10)

a. **Explain the important features of the horn antenna and the principle of its working. Describe helical antenna in normal mode of operation.**

Ans. Refer Q. 4.11, Page 4–14D, Unit-4.

b. **Describe the parabolic antenna used at microwave frequencies. Describe the methods of feeding a paraboloid reflector in which the primary antenna is located at the focal point.**

Ans. Refer Q. 4.19, Page 4–26D, Unit-4.

c. **Describe the method of radiation pattern measurement in the lab.**

Ans. Refer Q. 1.3, Page 1–5D, Unit-1.

5. Attempt any **two** parts of the following : (5 × 2 = 10)

a. **Find the skip distance for waves of frequency 4.6×10^6 Hz at a time when the maximum ionization in the *E*-region has a value of 1×10^{11} e/m^3 at a height of 110 km.**

Ans. Refer Q. 5.23, Page 5–29D, Unit-5.

b. **Define maximum usable frequency and derive an expression for the same in the case of a thin ionospheric layer over a plane earth.**

Ans. Refer Q. 5.20, Page 5–25D, Unit-5.

c. **Discuss the phenomenon of ground wave propagation at long and medium waves.**

Ans. Refer Q. 5.1, Page 5–2D, Unit-5.

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B. Tech.

(SEM. V) ODD SEMESTER THEORY EXAMINATION, 2014-15

ANTENNA AND WAVE PROPAGATION

Time : 3 Hours **Max. Marks : 50**

Note : Attempt **all** questions.

1. Attempt any **four** parts of the following : (2.5 × 4 = 10)

a. **Calculate the directivity for a unidirectional source whose pattern is $\phi = \phi_m \sin\theta \sin^3 \phi$, where ϕ_m is maximum radiation intensity.**

Ans. Refer Q. 1.8, Page 1–9D, Unit-1.

b. **Evaluate the radiation resistance of a λ/2 antenna element operating at a frequency of 20 MHz.**

Ans. Refer Q. 3.5, Page 3–9D, Unit-3.

c. **Derive Friis's transmission formula.**

Ans. Refer Q. 1.16, Page 1–17D, Unit-1.

d. **Derive relationship between effective aperture and beam area of an antenna.**

Ans. Refer Q. 1.4, Page 1–6D, Unit-1.

e. **A source has a cosine radiation intensity given by $U = U_m \cos\theta$. The radiation intensity has a value only in upper hemisphere. Find the total power radiated and its directivity.**

Ans. Refer Q. 1.9, Page 1–10D, Unit-1.

f. **Derive the radiation resistance of a short electric dipole.**

Ans. Refer Q. 3.3, Page 3–6D, Unit-3.

2. Answer any **two** of the following : (5 × 2 = 10)

a. **Explain principle angular regions of a flat sheet reflector.**

Ans. Refer Q. 4.17, Page 4–25D, Unit-4.

b. **Derive and hence plot the radiation pattern for two isotropic point sources of same amplitude but opposite phase.**

Ans. Refer Q. 2.7, Page 2–11D, Unit-2.

c. **Derive the expression for power radiated by an alternating current element.**

Ans. Refer Q. 1.20, Page 1–22D, Unit-1.

3. Answer any **two** of the following : **(5 × 2 = 10)**

a. **Discuss about the applications of loop antenna and what is 180° ambiguity ? How it arise and how is it removed ?**

Ans. Refer Q. 4.5, Page 4–6D, Unit-4.

b. **Explain with suitable diagram the working of axial mode of operation of a helical antenna.**

Ans. Refer Q. 4.13, Page 4–18D, Unit-4.

c. **Design log periodic antenna. What are the advantages of microstrip antennas ?**

Ans. Refer Q. 4.15, Page 4–21D, Unit-4.

4. Answer any **two** of the following : **(5 × 2 = 10)**

a. **Make a detailed comparison between corner reflector and parabolic reflector.**

Ans. Refer Q. 4.20, Page 4–27D, Unit-4.

b. **What are the various feeding methods used for reflector antenna ?**

Ans. Refer Q. 4.25, Page 4–35D, Unit-4.

c. **What are antenna measurement ranges ? Explain any two gain measurement techniques.**

Ans. Refer Q. 4.26, Page 4–36D, Unit-4.

5. Answer any **two** of the following : **(5 × 2 = 10)**

a. **Explain MUF, critical frequency and virtual height as applied to sky wave propagation.**

Ans. Refer Q. 5.27, Page 5–33D, Unit-5.

b. **Derive the skip distance for region between transmitter and receiver using sky wave propagation when curvature of earth is taken into consideration.**

Ans. Refer Q. 5.22, Page 5–27D, Unit-5.

c. **Explain the mechanism of reflection and refraction of sky wave by ionosphere and derive the relevant relationship for same.**

Ans. Refer Q. 5.18, Page 5–20D, Unit-5.

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B. Tech.
(SEM. V) ODD SEMESTER THEORY EXAMINATION, 2015-16
ANTENNA AND WAVE PROPAGATION

Time : 3 Hours **Max. Marks : 100**

SECTION - A

1. Attempt **all** parts. All parts carry equal marks. Write answer of each part in short : **(2 × 10 = 20)**

a. **Classify various types of antenna arrays.**

Ans. Refer Q. 2.5, Page SQ–5D, Unit-2, Two Marks Questions.

b. **Define effective height of an antenna.**

Ans. Refer Q. 1.9, Page SQ–2D, Unit-1, Two Marks Questions.

c. **Relate MUF with skip distance for flat earth.**

Ans. Refer Q. 5.14, Page SQ–20D, Unit-5, Two Marks Questions.

d. **At what frequency a wave must propagate for the D region to have a refractive index of 0.7 ? Given N = 400 electrons/cm^3.**

Ans. Refer Q. 5.16, Page SQ–20D, Unit-5, Two Marks Questions.

e. **A 12-turn axial helix antenna of circumference λ has turn spacing of $\lambda/4$. Determine HPBW, BWFN, directivity and also examine polarization characteristic of the antenna.**

Ans. Refer Q. 1.15, Page SQ–3D, Unit-1, Two Marks Questions.

f. **A pyramidal horn antenna of mouth length $10\,\lambda$ cm is fed by a rectangular waveguide in TE10 mode. Determine the design parameters of the antenna at operating frequency 2.5 Hz.**

Ans. Refer Q. 4.14, Page SQ–15D, Unit-4, Two Marks Questions.

g. **What do you mean by frequency independent antenna ?**

Ans. Refer Q. 4.3, Page SQ–13D, Unit-4, Two Marks Questions.

h. **Write down the expression for the electric field components of a short dipole.**

Ans. Refer Q. 3.4, Page SQ–10D, Unit-3, Two Marks Questions.

i. **A 10 MHz satellite communication is taking place through ionosphere layer with refractive index 0.975 and height 500 km. Calculate the ground range of this propagation assuming 10 GHz as MUF and 2.24 GHz as critical frequency.**

Ans. Refer Q. 5.17, Page SQ–21D, Unit-5, Two Marks Questions.

j. **A thin dipole antenna is $\left(\frac{\lambda}{10}\right)$ long. If loss resistance is 1.5 Ω, find radiation resistance and efficiency.**

Ans. Refer Q. 3.15, Page SQ–12D, Unit-3, Two Marks Questions.

SECTION – B

Attempt any **five** questions from this section : **(10 × 5 = 50)**

2. a. **Write a short note on antenna temperature, directivity and antenna impedance.**

Ans. Refer Q. 1.19, Page 1–21D, Unit-1.

b. **A TV transmitter is designed to establish communication at a distance of 50 km from it. The height of Tx antenna is 100 m and transmits a power of 45 W at 90 MHz. Find the height of receiver and field intensity at the Rx antenna.**

Ans. Given, Los distance (d_0) = 50 km, h_t = 100 m, P = 45 W, f = 90MHz

1. Distance,

$$(d_0) = 4.12\left[\sqrt{h_t} + \sqrt{h_r}\right]$$

$$50 = 4.12\left[\sqrt{100} + \sqrt{h_r}\right]$$

$$\sqrt{h_r} = 12.135 - 10 = 2.135$$

$$h_r = 4.56 \text{ m}$$

and

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{90 \times 10^6} = 0.33 \times 10 = 3.33 \text{ m}$$

2. Field intensity,

$$E_r = \frac{88\sqrt{P}\,h_r h_t}{\lambda d^2} = \frac{88 \times \sqrt{45} \times 4.56 \times 100}{3.33 \times (50)^2 \times (10^3)^2}$$

$$E_r = 32.334 \text{ μV/m}$$

3. **Derive the relation between the effective height and effective aperture area. An antenna has a radiation resistance of 100 ohm, a loss resistance of 15 ohm and a power gain of 10 dB. Calculate antenna efficiency and its directivity.**

Ans. Refer Q. 1.14, Page 1–14D, Unit-1.

4. **Explain operation of log periodic antenna in detail.**

Ans. Refer Q. 4.14, Page 4–19D, Unit-4.

5. **Discuss applications of loop antenna as direction finder. What are disadvantages of loop direction finders ? Also explain 180 degree ambiguity and how is it resolved.**

Ans. Refer Q. 4.6, Page 4–7D, Unit-4.

6. **Explain how ground wave and space-wave propagates the signal via troposphere. Distinguish clearly between surface wave, space wave and sky wave.**

Ans. Refer Q. 5.12, Page 5–12D, Unit-5.

7. **Explain Yagi-Uda antenna and design a 5-dipoles Yagi-Uda array for operation at 500 MHz.**

Ans. Refer Q. 3.13, Page 3–19D, Unit-3.

8. **Explain how earth's magnetic field affects the propagation of radio waves in ionosphere ?**

Ans. Refer Q. 5.17, Page 5–19D, Unit-5.

9. **Explain in detail induction field (near-field) and radiation field (far-field) (magnetic field only) applicable to alternating current element.**

Ans. Refer Q. 1.21, Page 1–24D, Unit-1.

SECTION – C

Attempt any **two** questions from this section : **(15 × 2 = 30)**

10. **Why we use the term modified refractive index in propagation of radio waves ? Explain duct propagation.**

Ans. Refer Q. 5.25, Page 5–31D, Unit-5.

11. **Explain parabolic reflector and corner reflector antenna.**

Ans. Refer Q. 4.19, Page 4–26D, Unit-4.

12. **Derive the relation between MUF and skip distance. Also explain critical frequency, MUF, virtual height, skip distance.**

Ans. Refer Q. 5.28, Page 5–34D, Unit-5.

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B. Tech.

(SEM. V) ODD SEMESTER THEORY EXAMINATION, 2016-17

ANTENNA AND WAVE PROPAGATION

Time : 3 Hours **Max. Marks : 100**

SECTION – A

1. Attempt **all** parts. ALL parts carry equal marks. Write answer of each part in short. **(2 × 10 = 20)**

a. **List out which parameters to consider for receiving antenna design.**

Ans. Refer Q. 1.2, Page SQ–1D, Unit-1, Two Marks Questions.

b. **Relate radian and steradian.**

Ans. Refer Q. 3.3, Page SQ–10D, Unit-3, Two Marks Questions.

c. **What is the radiation resistance of a current element whose overall length is $\lambda / 50$?**

Ans. Refer Q. 3.14, Page SQ–12D, Unit-3, Two Marks Questions.

d. **State the principle of pattern multiplications.**

Ans. Refer Q. 2.9, Page SQ–6D, Unit-2, Two Marks Questions.

e. **A linear broadside array consists of four equal isotropic in-phase point sources with $\lambda / 3$ spacing. Find the beamwidth.**

Ans. Refer Q. 2.17, Page SQ–9D, Unit-2, Two Marks Questions.

f. **Draw the unidirectional and bidirectional pattern for $U = U_m \cos\theta$ and $U_m \sin\theta$.**

Ans. Refer Q. 2.15, Page SQ–7D, Unit-2, Two Marks Questions.

g. **Mention the applications of loop antenna.**

Ans. Refer Q. 4.2, Page SQ–13D, Unit-4, Two Marks Questions.

h. **What are frequency independent antennas ? Give example.**

Ans. Refer Q. 4.3, Page SQ–13D, Unit-4, Two Marks Questions.

i. **Define magneto ionic splitting.**

Ans. Refer Q. 3.12, Page SQ–11D, Unit-3, Two Marks Questions.

j. **What is maximum usable frequency ?**

Ans. Refer Q. 5.11, Page SQ–19D, Unit-5, Two Marks Questions.

SECTION-B

Note : Attempt any **five** parts from this section. **(10 × 5 = 50)**

2. a. **Derive Friis transmission formula.**

Ans. Refer Q. 1.16, Page 1–17D, Unit-1.

b. **Show that linear array of N-isotropic point source of equal amplitude and spacing $E_{norm} = 1/\lambda \dfrac{\sin \lambda\phi/2}{\sin \phi/2}$**

Ans. Refer Q. 2.12, Page 2–17D, Unit-2.

c. **A transmitting antenna having effective height of 61.4 m takes a current of 50 A, at a wavelength of 625 m. Find radiation resistance, power radiated by an antenna and antenna efficiency for $R_A = 50$.**

Ans. Refer Q. 1.15, Page 1–15D, Unit-1.

d. **Deduce the relation between effective aperture and gain of an antenna.**

Ans. Refer Q. 1.12, Page 1–12D, Unit-1.

e. **Derive the impedance of a folded dipole antenna.**

Ans. Refer Q. 3.16, Page 3–22D, Unit-3.

f. **Describe in brief about microstrip antennas types and different feeding techniques.**

Ans. Refer Q. 4.15, Page 4–21D, Unit-4.

g. **Narrate in details about Cassegrain feed of a parabolic reflector and explain different reflector types.**

Ans. Refer Q. 4.24, Page 4–33D, Unit-4.

h. **With a neat sketch explain about skip distance.**

Ans. Refer Q. 5.21, Page 5–25D, Unit-5.

SECTION-C

Note : Attempt any **two** questions from this section. **(15 × 2 = 30)**

3. a. **Calculate the directivity of an endfire array of two identical isotropic point source in phase opposition, spaced $\lambda/2$ apart along the polar axis, the relative field pattern being given by $E = \cos (d_r/2 \cos\theta)$.** **(12)**

Ans. Refer Q. 2.8, Page 2–12D, Unit-2.

b. A thin dipole antenna is λ / 15 long. If it's $R_L = 1.5\ \Omega$, find R_r and its efficiency. **(3)**

Ans. Refer Q. 3.7, Page 3–10D, Unit-3.

4. a. With a neat sketch explain the construction and working of Yagi-Uda antenna. **(7)**

Ans. Refer Q. 3.12, Page 3–17D, Unit-3.

b. Illustrate with neat diagram and design equations the working of log periodic antenna **(8)**

Ans. Refer Q. 4.14, Page 4–19D, Unit-4.

5. a. Discuss in detail about the mechanism of refraction in sky wave propagation. **(3)**

Ans. Refer Q. 5.18, Page 5–20D, Unit-5.

b. Obtain the expression for refractive index and critical frequency. **(12)**

Ans. Refer Q. 5.18, Page 5–20D, Unit-5.

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B. Tech.
(SEM. V) ODD SEMESTER THEORY EXAMINATION, 2017-18
ANTENNA AND WAVE PROPAGATION

Time : 3 Hours **Max. Marks : 100**

Note : Attempt **all** questions. If require any missing data; then choose suitably.

SECTION - A

1. Attempt **all** questions in brief. **(2 × 10 = 20)**

a. Explain half power beam width and first null beam width.

Ans. Refer Q. 1.8, Page SQ–2D, Unit-1, Two Marks Questions.

b. Explain the concept of point sources.

Ans. Refer Q. 2.1, Page SQ–5D, Unit-2, Two Marks Questions.

c. Explain antenna temperature in brief.

Ans. Refer Q. 1.12, Page SQ–3D, Unit-1, Two Marks Questions.

d. What is tapering ? Explain it with suitable example.

Ans. Refer Q. 2.14, Page SQ–7D, Unit-2, Two Marks Questions.

e. The radiation resistance of an antenna is 72 Ω and loss resistance is 8 Ω. What is the directivity in dB if the power gain 16 ?

Ans. Refer Q. 1.14, Page SQ–3D, Unit-1, Two Marks Questions.

f. A uniform linear array consists of 20 isotropic point sources with a spacing of λ/4 if the phase difference is – 90°. Calculate its HPBW and directivity.

Ans. Refer Q. 2.16, Page SQ–8D, Unit-2, Two Marks Questions.

g. For a parabolic reflector having directivity of 30 dB and an aperture efficiency of 55 % operating at 15 MHz. Calculate the area of parabolic reflector and HPBW.

Ans. Refer Q. 4.16, Page SQ–16D, Unit-4, Two Marks Questions.

h. Find the power gain and directivity of a horn whose dimensions are 10 cm × 5 cm and operating at a frequency of 6 GHz.

Ans. Refer Q. 4.15, Page SQ–16D, Unit-4, Two Marks Questions.

a. **What are the two modes of radio propagation ? Discuss the space wave propagation.**

Ans. Refer Q. 5.11, Page 5–12D, Unit-5.

b. **What do you understand by plane earth reflection ? Derive the formulas of reflection coefficient for horizontal polarization and reflection coefficient for vertical polarization.**

Ans. Refer Q. 5.16, Page 5–17D, Unit-5.

c. **What is the role of ionosphere in propagation ? How do reflection and refraction occur ?**

Ans. Refer Q. 5.15, Page 5–16D, Unit-5.

7. Attempt any two of the following : **(5 × 2 = 10)**

a. **Explain the principle of pattern multiplication. Synthesize the pattern using this principle for the two case (i) Four isotropic elements spaced λ/2 apart and fed in phase. (ii) Eight isotropic elements spaced λ/2 and fed in phase.**

Ans. Refer Q. 2.11, Page 2–16D, Unit-2.

b. **Define directive gain and power gain in detail and also explain the difference between them.**

Ans. Refer Q. 1.10, Page 1–10D, Unit-1.

c. **How a horn antenna produces a uniform phase front with a large aperture in comparison to waveguide ? Mention one antenna system when a horn is used as a feed system.**

Ans. Refer Q. 4.12, Page 4–17D, Unit-4.

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B. Tech.
(SEM. V) ODD SEMESTER THEORY EXAMINATION, 2018-19
ANTENNA AND WAVE PROPAGATION

Time : 3 Hours **Max. Marks : 70**

Note : Attempt **all** Sections. If require any missing data; then choose suitably.

SECTION – A

1. Attempt **all** questions in brief. **(2 × 7 = 14)**

a. **Give reason why does retardation potential take place.**

Ans. The retarded potentials are the electromagnetic potentials for the electromagnetic field takes place due to time-varying electric current or charge distributions.

b. **A thin dipole antenna is 1/15 long if its loss resistance is 1.5 Ω. Find radiation resistance and efficiency.**

Ans. Refer Q. 3.7, Page 3–10D, Unit-3.

c. **What is endfire array and broad side array ?**

Ans.

i. **Endfire array :** Refer Q. 2.7, Page SQ–6D, Unit-2, 2 Marks Questions.

ii. **Broadside array :** Refer Q. 2.6, Page SQ–6D, Unit-2, 2 Marks Questions.

d. **Define the gain of antenna.**

Ans. Refer Q. 1.4, Page SQ–1D, Unit-1, 2 Marks Questions.

e. **Define virtual height and skip distance.**

Ans. Refer Q. 5.13, Page SQ–20D, Unit-5, 2 Marks Questions.

f. **Estimate the distance and effective aperture of a paraboloid reflector antenna required to produce null beam width of 10^0 at 3 GHz.**

Ans.

Given : BWFN = 1, $f = 3$ GHz
To Find : Distance, Effective aperture.

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{3 \times 10^9} = 0.1 \text{ m}$$

$$\text{BWFN} = \frac{140\,\lambda}{D}$$

$$D = \frac{140 \times 0.1}{1} = 14$$

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

$$= \frac{(0.1)^2 \times 14}{4\pi} = 0.011$$

g. Find the radiation efficiency of a 1 m diameter loop of 10 mm diameter copper wire at 10 MHz.

Ans.

$$\frac{R_e}{R_r} = \frac{3430}{\pi^3 \times 1 \times 10^{-2}} = 11062$$

Radiation efficiency,

$$\eta = \left(\frac{1}{1+11062}\right) = 9 \times 10^{-5}$$

SECTION – B

2. Attempt any **three** of the following : **(7 × 3 = 21)**

a. Calculate the effective aperture for a dipole antenna of length 2 cm at a 1.2 GHz. What will be the power received for an incident power density of 2 mW/m².

Ans.

Given : $D = 2$ cm, $f = 1.2$ GHz, $P_D = 2$ mW/m²
To Find : Effective Aperture (A_e), Power received (P_r).

1. We have, $A_e = \frac{\lambda^2}{4\pi} D$

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{1.2 \times 10^9} = 0.25 \text{ m} = 25 \text{ cm}$$

$$A_e = \frac{(25)^2 \times 2}{4 \times 3.14}$$

$$A_e = 99.41$$

2. Effective Aperture,

$$A_e = \frac{\text{Received power}}{\text{Power density}}$$

$$99.47 = \frac{P_r}{2}$$

$$P_r = 198.94 \text{ W}$$

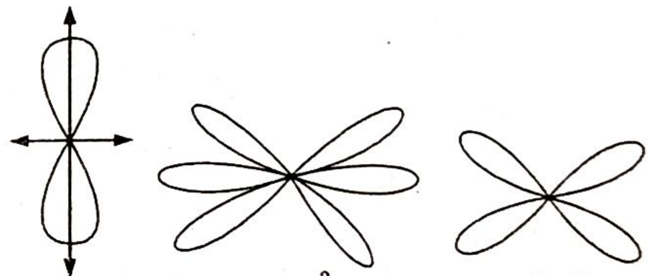
b. Sketch the horizontal and vertical plane radiation pattern of centre-fed vertical dipole for the following length :

i. λ/2 dipole

ii. 3λ/2 dipole

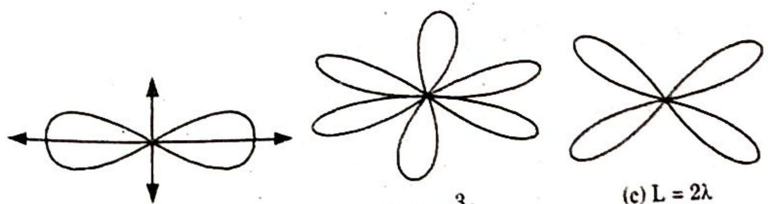
iii. 2λ dipole.

Ans. The radiation pattern of centre-fed vertical and horizontal dipole antenna is shown in Fig. 1 and Fig. 2 respectively.



(a) $L = \lambda/2$ (b) $L = \frac{3}{2}\lambda$ (c) $L = 2\lambda$

Fig. 1. Vertical patterns of centre-fed dipoles.



(a) $L = \lambda/2$ (b) $L = \frac{3}{2}\lambda$ (c) $L = 2\lambda$

Fig. 2. Horizontal patterns of centre-fed dipoles.

c. What is folded dipole antenna ? Describe Yagi-Uda antenna and explain its operation.

Ans.

A. Folded dipole antenna : Refer Q. 3.16, Page 3–22D, Unit-3.

B. Yagi-Uda antenna : Refer Q. 3.12, Page 3–17D, Unit-3.

d. Explain the principle of operation of parabolic dish. Why is the parabolic shape used ?

Ans. Refer Q. 4.19, Page 4–26D, Unit-4.

Parabolic shape is used because :

1. All the waves originating from focus, reflects back to the parabolic axis. Hence, all the waves reaching the aperture are in phase.
2. As the waves are in phase, the beam of radiation along the parabolic axis will be strong and concentrated.

e. Explain the phenomenon of Duct Propagation. What are the ionospheric conditions under which duct propagation can take place ?

Ans. Refer Q. 5.24, Page 5–30D, Unit-5.

Conditions :

1. An increase in temperature by 3 °C or more per 100 ft.
2. A rapid decrease of RH (dew point) with height.

SECTION – C

3. Attempt any **one** part of the following : **(7 × 1 = 7)**

a. Discuss about antenna impedance and antenna temperature.

Ans. Refer Q. 1.18, Page 1–19D, Unit-1.

b. How the directivity of any antenna is defined and what is the relationship between directivity and gain of the antenna ?

Ans. Refer Q. 1.7, Page 1–8D, Unit-1.

4. Attempt any **one** part of the following : **(7 × 1 = 7)**

a. Explain the principle of pattern multiplication. Obtain the radiation pattern of 4 element fed in-phase, spaced λ/2 apart using pattern multiplication.

Ans.

A. Principle of pattern multiplication : Refer Q. 2.9, Page 2–14D, Unit-2.

B. Numerical : Refer Q. 2.10, Page 2–15D, Unit-2.

b. Define the isotropic sources. *N*-isotropic sources are arranged in a uniform linear array. Derive an expression for the array factor.

Ans.

A. Isotropic Source : An isotropic source is a point source of electromagnetic waves which radiates the same intensity of radiation in all directions.

B. Derivation : Refer Q. 2.12, Page 2–17D, Unit-2.

5. Attempt any **one** part of the following : **(7 × 1 = 7)**

a. A linear broadside array consists of four equal isotropic in-phase point source width λ/2 spacing. Find the directivity, BWFN and HPBW of the array.

Ans. Refer Q. 2.3, Page 2–5D, Unit-2.

b. An endfire array consisting of several half wavelength isotropic radiators has a directive gain of 30. Find the array length and width of the major lobe. What will be the value for broadside array ?

Ans. Refer Q. 2.14, Page 2–22D, Unit-2.

6. Attempt any **one** part of the following : **(7 × 1 = 7)**

a. Explain with suitable diagram log periodic antenna. What are practical applications of these antenna ?

Ans. Refer Q. 4.14, Page 4–19D, Unit-4.

Applications :

1. Used for HF communications.
2. Used for particular sort of TV receptions.
3. Used for all round monitoring in higher frequency bands.

b. A loop antenna consists of 10 turns, each having an area of 1 m². A radio wave having a frequency of 1 MHz induces a sinusoidal emf of 100 mV (rms) in this antenna when it is oriented for maximum response. Calculate the peak value of the magnetic field intensity of the RF wave. ($\mu_0 = 4\pi \times 10^{-7}$ H/m).

Ans.

Given : $N = 10$ turns, $A = 1\ \text{m}^2$, $f = 1$ MHz, $V_{rms} = 100$ mV, $\mu_0 = 4\pi \times 10^{-7}$

To Find : H.

1. We have,

$$V_m = \omega BAN$$

$$= \omega\mu_0 HAN \qquad [\because\ B = \mu_0 H]$$

$$V_m = 2\pi f \mu_0 HAN$$

$$H = \frac{V_m}{2\pi f \mu_0 AN}\ \text{A/m} = \frac{\sqrt{2}\,V_{rms}}{2\pi f \mu_0 AN}\ \text{A/m} \qquad \left[\because\ \frac{V_m}{\sqrt{2}} = V_{rms}\right]$$

$$= \frac{1.414 \times 100 \times 10^{-3}}{2\pi \times 1 \times 10^6 \times 4\pi \times 10^{-7} \times 1 \times 10}$$

$$= \frac{141.4 \times 10^{-3}}{8\pi^2}\ \text{A/m}$$

$$= 1.795 \times 10^{-3}\ \text{A/m}$$

$$\therefore \quad H = 1.795\ \text{mA/m}$$

7. Attempt any **one** part of the following : **(7 × 1 = 7)**

a. Assume that reflection take place at a height of 350 km and that the maximum density in the ionosphere corresponds to a 0.8 refractive index at 15 MHz. What will be range for which the MUF is 20 MHz ? Assume flat Earth.

Ans.

Given : $h = 350$ km, $\mu = 0.8$, $f_{muf} = 20$ MHz, $f = 15$ MHz.

To Find : D_{range}.

1. We know that

$$\mu = \sqrt{1 - \frac{81N}{f^2}}$$

$$0.8 = \sqrt{1 - \frac{81N_{max}}{(15 \times 10^6)^2}}$$

$$0.64 = 1 - \frac{81N_{max}}{(15 \times 10^6)^2}$$

$$81N_{max} = (1 - 0.64) \times (15 \times 10^6)^2$$

$$N_{max} = \frac{0.36 \times 225 \times 10^{12}}{81}$$

$$N_{max} = 10^{12}\ \text{m}^{-3}$$

$$f_c = 9\sqrt{N_{max}} = 9 \times 10^6\ \text{Hz}$$

2. When earth is flat,

$$D_{skip} = D_{range} = 2h\sqrt{\left(\frac{f_{muf}}{f_c}\right)^2 - 1}$$

$$= 2 \times 350 \sqrt{\left(\frac{20}{9}\right)^2 - 1}$$

$$= 700 \times 1.9845 = 1389.15 \text{ km}$$

b. Derive expression for refractive index of ionosphere $\mu = \sqrt{1 - \frac{81\,N}{f^2}}$.

Ans. Refer Q. 5.18, Page 5–20D, Unit-5.

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