UNIT 1

1. Explain the radiation from two-wire.

Ans:

**Radiation from Two – wire**

Figure 1.1.1 shows a voltage source connected two-wire transmission line which is further connected to an antenna. An electric field is created between the conductors, when a voltage is applied across the two-wire transmission line. The produced electric lines of force are tangent to the electric field at each point and whose strength is proportional to the electric field intensity. The free electrons associated with conductor are acted upon by the electric line of force. A magnetic field intensity is created by a current, due to the movement of charges. Similarly, the magnetic lines of force are tangent to the magnetic field.

Since the electric field lines, start on positive charges and end on negative charges. These lines can also start at infinity and end on a negative charge or start on a positive charge and end at infinity or form closed loops neither starting nor ending on any charge. Due to the absence of magnetic charges, the magnetic field lines always form closed loops encircling current carrying conductors.
The distribution of charge property is exhibited by the electric field lines drawn between the two conductors. When a sinusoidal signal is applied at the source, the electric field between the conductors may be sinusoidal with a period of applied source. Electromagnetic waves are formed by the time-varying electric and magnetic fields between the conductors and which will travel along the transmission line shown in figure 1.1.1.

![Diagram showing electromagnetic waves](image)

**Fig 1.1.2 Radiation from Two-wire**

The electromagnetic waves enter into the antenna with associated electric charges and corresponding currents. When a part of antenna structure is removed (as shown in figure (1.1.2)), by connecting the open ends of the electric lines, free space waves are formed. The free space waves are also periodic but a constant phase point ‘$x_0$’ moves outwardly with the speed of light and travels a distance $\lambda/2$ (to ‘$x_1$’) in the time of one-half a period. The constant phase point ‘$x_0$’ moves faster than the speed of light but approaches the speed of light at points far away from the antenna.
2. Define and account for the presence of,
(i) Radial power flow
(ii) Radiation resistance for a short dipole
(iii) Uniform current distribution.

Ans:
(i) **Radial power flow**
   Radial power flow represents the amount of power moving in radial direction, which corresponds to the power density associated with the electromagnetic fields of an antenna.

   The total power radiated can be calculated with the help of pointing vector \( P \) as,

   \[ P = E \times H \]

   Where,
   - \( E \) = Electric field
   - \( H \) = Magnetic field.

   Therefore Total radiated power,

   \[ P_r = \oint P r^2 \sin \theta \, d\theta \, d\Phi \]

   Therefore, the integration involves combination of imaginary part and real part. The combination of imaginary and real power is known as "Complex Power". Radial power is the part of complex power moving in radial direction. It corresponds to the real radiated power.

(ii) **Radiation Resistance for a short dipole**
   The resistance observed, (or) experienced by transmission line when it is terminated by a short dipole is known as radiation resistance of short dipole.

   General expression is,

   \[ (R_r)_{\text{short dipole}} = 80\pi^2 \left( \frac{dl}{\lambda} \right)^2 \]

   Where,
   - \( dl \) = Length of the dipole
   - \( \lambda \) = Operating wavelength.
(iii) **Uniform Current Distribution**

Uniform current distribution signifies that the current flowing through antenna is constant. Uniform current distribution is possible, when the size of the antenna is very small. If the size of antenna is finite, uniform current distribution is not possible. This is valid for only small length antennas.

3. **What are principle planes? How the antenna beam width is defined in such planes?**

**Ans:**

**Principle planes**

These planes are used to describe the performance of antennas. Principle planes are classified into two types. They are,

1. E-plane pattern
2. H-plane pattern.

**1. E-plane pattern**

E-plane pattern is defined as the plane containing electric field vector in the direction of maximum radiation. The E-plane pattern is shown in the figure 1.3.1

**2. H-plane pattern**

H-plane pattern is defined as the plane containing magnetic field vector in the direction of maximum radiation. The H-plane pattern is shown in the figure 1.3.1

![Fig 1.3.1 E-plane and H-plane Principle Patterns](image1)

![Fig 1.3.2 Radiation Lobes and Beam Width of an Antenna](image2)
4. Explain the following terms,

(i) **Beam width**

It is used to measure the directivity of an antenna. In general antenna beam width is defined as "the angular width of the major lobe between the two directions at which maximum power is twice the radiated or received power.

\[
\text{Beam width} = (\text{HPBW})_{\text{Vertical}} \times (\text{HPBW})_{\text{Horizontal}}
\]

There are two factors effecting the beam width. They are,

1. Wavelength
2. Radiation pattern shape.

(ii) **Omnidirectional pattern**

The radiation pattern which is distributed equally well in all directions is called as omnidirectional patterns. The antenna which exhibits such a property is known as omnidirectional antenna or nondirectional antenna (since it does not favour any particular direction). Figure 1.4.1 shows omnidirectional pattern with and without minor lobes. The omnidirectional pattern can be approximated by,

\[
U = |\sin^n \theta| ; \quad 0 \leq \theta \leq \pi, \quad 0 \leq \Phi \leq 2\pi
\]

Where,

\[
n = \text{Either integer or non integer value.}
\]

This type of pattern is commonly associated with verticals, ground planes and other antenna types in which the radiator element is vertical with respect to the earth's surface. The approximated formula for directivity of an omnidirectional antenna with minor lobes can be calculated as,

\[
D_0 = 101/\text{HPBW}(\text{degrees}) - 0.0027[\text{HPBW}(\text{degrees})]^2
\]

and, the directivity of an omnidirectional antenna without minor lobes can be calculated using,

\[
D_0 = -172.4 + 191\sqrt{0.818 + 1/\text{HPBW}(\text{degrees})}
\]
(iii) **Side Lobe Level**

The ratio (in dB) of the amplitude at the peak of the main lobe to the amplitude at the peak of a side lobe is known as side lobe level. Where the side lobe is a radiation lobe in any direction other than the intended lobe. Normally a side lobe is adjacent to the main lobe and occupies the hemisphere in direction of main lobe. Usually, the side lobes are the largest of the minor lobes, figure 1.4.2 shows the linear plot of power patterns.

![Side Lobe Level](image)

The side lobe level can be reduced by tapering the edges of the aperture distribution at the expense of reduced directivity. The null between side lobes occur when the radiation pattern passes through the origin in the complex plane. Hence, adjacent side lobes are generally 180° out of phase to each other.

(iv) **Field Pattern of Antenna**

There are two different types of field patterns of antenna namely. Far-field and near-field patterns. The near-field pattern is most commonly defined over a plane placed in front of the source or over a cylindrical or spherical surface enclosing it. The far-field pattern of an antenna may be determined experimentally at an antenna range. The near-field pattern may be found using a near-field scanner and the radiation pattern deduced from it by computation.
The far-field pattern may be represented graphically as a plot of one of a number of related variables including, the field strength at a constant radius, the power per unit solid angle and the directive gain. The plotted quantity may be taken on a linear scale or in dB.

5. Define the terms, 
(i) Bandwidth
(ii) Polarization
(iii) Effective aperture area.

Ans:
(i) **Bandwidth**

There is the range of frequencies for which the antenna maintains certain specific characteristics. It is given as,

\[ \Delta \omega = \frac{\omega_r}{Q} \]

Where,

\[ \omega_r = \text{Angular resonating frequency} \]

\[ Q = \text{Quality factor} \]

(ii) **Polarization**

The time varying behavior of the electric field strength vector at a fixed point in space is known as polarization of a uniform plane wave. Consider a plane wave is travelling in the z-direction with ‘E’ and ‘H’ components lying in the xy plane. The wave is said to be polarized in x-direction, if \( E_x \neq 0 \) and \( E_y = 0 \). Similarly, the wave is said to be polarized in y-direction, if \( E_x = 0 \) and \( E_y \neq 0 \).

The resultant electric field has a direction dependent on the relative magnitudes of \( E_x \) and \( E_y \), if both the fields are present and are in phase. The direction with the x-axis is given by,

\[ \theta = \tan^{-1}\left(\frac{E_y}{E_x}\right) \]

An linearly polarized wave in which the direction of the resultant vector is constant with time. An elliptically polarized wave in which the two field components are not equal and are in out of phase (i.e., if they are reached maximum values at different instances) and the resultant vector direction is varied with time. A circularly polarized wave in which the two field components are having equal magnitudes and a 90° phase difference.
Effective Aperture Area

Effective area is defined as the ratio of power received at the antenna load terminal to the poynting vector (P), of the incident wave. Effective area is also known as effective aperture (or) capture area.

Effective Area,

\[ (A_e) = \frac{\text{Power Received}}{\text{Poynting Vector}} \]

\[ A_e = \frac{W}{P} \]

Where,

W = Power received (watts)

P = Poynting vector (watts/m²)

6. Distinguish between directive gain and power gain.

Ans:

Differences between Directive Gain and Power Gain

<table>
<thead>
<tr>
<th>Directive Gain (G_d)</th>
<th>Power Gain (G_p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Directive gain in a given direction is defined as the ratio of the radiation intensity in that direction to the average radiated power.</td>
<td>1. Power gain is defined as the ratio of radiation intensity in given direction to the total input power.</td>
</tr>
<tr>
<td>2. In the calculation of directivity, the radiated power is considered for the directive antenna.</td>
<td>2. In the calculation of power gain, the power fed to the antenna is considered.</td>
</tr>
<tr>
<td>3. The concept of directive gain is most convenient to antenna theorist because, it depends only up on the antenna pattern.</td>
<td>3. The concept of power gain is most important to a radio system designer.</td>
</tr>
<tr>
<td>4. The directive gain is solely depends on the distribution of radiated power in space.</td>
<td>4. The power gain is depends on the power input to the antenna, antenna losses or the power consumed in a terminating resistance.</td>
</tr>
<tr>
<td>5. It is basically measured in dB</td>
<td>5. It is also basically measured in dB</td>
</tr>
<tr>
<td>[ G_d (\text{dB}) = 10 \log_{10}(G_d) ]</td>
<td>[ G_p (\text{dB}) = 10 \log_{10}(G_p) ]</td>
</tr>
</tbody>
</table>
7. Draw the dual characteristics of an antenna.

Ans:
Dual Characteristics of an Antenna

The duality of an antenna specifies a circuit device on one band and a space device on the other hand. Figure 1.7.1 shows the schematic diagram of basic antenna parameters, illustrating dual characteristics of an antenna.

![Schematic Diagram of Basic Antenna Parameters](image1.png)

8. Explain briefly radiation mechanism in single wire antenna?

Ans:
Radiation Mechanism in Single Wire Antenna

Let us consider a single wire and a circular cross sectional cylinder with volume charge density, \( q_v \).

![Charge Uniformly Distributed in a Circular Cross Section Cylinder](image2.png)
The field is distributed in a wire of cross-sectional area, \(A\) and volume, \(V\) as shown in figure 1.8.1. The current density, \(J_z\) over the cross-section of the wire is,

\[
J_z = q_v V_z ....(1)
\]

Where,
- \(q_v\) = Volume charge density (coulombs/m\(^3\))
- \(V_z\) = Velocity in z-direction.

The radius of the wire is zero, and then the current in the wire is given by,

\[
I_z = q_v V_z ....(2)
\]

If the current is time varying then the equation (2),

\[
dI_z/dt = q_v dV_z/dt = q_v a_z
\]

Where, \(a_z\) is the acceleration.

Hence,
(i) There is no radiation for a stationary charge
(ii) If a charge has uniform velocity and the wire is straight and infinite in extent, there is no radiation unless the wire is curried, bent, discontinued, terminated or truncated.
(iii) If the charge is oscillating in a time-motion, it develops radiation at the surrounding even for straight wire.

9. Write short note on Normalized field pattern.

Ans:

Normalized Field Pattern

Normalized field pattern is the field pattern, which is obtained by dividing a field component by its maximum value. It is a dimensionless number and whose maximum value is one. Normalized field pattern for an electric field is expressed as,

\[
\text{Normalized Field Pattern, } E_{d}(\theta,\Phi) = E_{d}(\theta,\Phi)/E_{d}(\theta,\Phi)_{\text{max}}
\]

Where,
- \(E_{d}(\theta,\Phi)\) = Electric field component
- \(E_{d}(\theta,\Phi)_{\text{max}}\) = Maximum value of electric field component.

Figure 1.9.1 shows the normalized field pattern for the electric field ‘\(E\)’. For \(E_{d}(\theta,\Phi)_{\text{max}} = 1/\sqrt{2} = 0.707\), the half power levels occurs at those angles \(\theta\) and \(\Phi\). The shape normalized field pattern is independent of distance for,

1. The distance that are large compared to the size of the an antenna.
2. The distance that are large compared to the wavelength.

10. Explain the following,
   i. Beam area
   ii. Radiation intensity
   iii. Beam efficiency
   iv. Directivity.
   Ans:
   i. Beam Area

   In polar two-dimensional coordinates an incremental area \( dA \) on the surface of sphere is the product of the length \( r \, d\theta \) in the \( \theta \) direction and \( r \sin \theta \, d\Phi \) in the \( \Phi \) direction as shown in figure 1.10.1.

   Thus,
   \[
   dA = (r \, d\theta) (r \sin \theta \, d\Phi) = r^2 \, d\Omega
   \]

   Where,
   \( d\Omega = \) solid angle expressed in steradians.
The area of the strip of width \( r \, d\theta \) extending around the sphere at a constant angle \( \theta \) is given by \((2\pi r \sin \theta) \, (r \, d\theta)\). Integrating this for \( \theta \) values from 0 to \( \pi \) yields the area of the sphere. Thus,

\[
\text{Area of sphere} = 2\pi r^2 \, \int_0^\pi \sin \theta \, d\theta = 2\pi r^2 [-\cos \theta]_0^\pi = 4\pi r^2
\]

Where,

\(4\pi = \text{Solid angle subtended by a sphere}\)

The beam area or beam solid angle or \( \Omega_A \) of an antenna is given by the integral of the normalized power pattern over a sphere

\[
\text{Beam area, } \Omega_A = \iint P(\theta, \phi) \, d\Omega \quad (\text{sr})
\]

Where,

\(d\Omega = \sin \theta \, d\theta \, d\phi\)

**ii. Radiation Intensity**

The power radiated from an antenna per unit solid angle is called the radiation intensity \( U \) (watts per steradian or per square degree). The normalized power pattern of the previous section can also be expressed in terms of this parameter as the ratio of the radiation intensity \( U(\theta, \phi) \), as a function of angle, to its maximum value. Thus,

\[
P_d(\theta, \phi) = \frac{U(\theta, \phi)}{U(\theta, \phi)_{\text{max}}} = \frac{S(\theta, \phi)}{S(\theta, \phi)_{\text{max}}}
\]

Whereas the Poynting vector \( S \) depends on the distance from the antenna (varying inversely as the square of the distance), the radiation intensity \( U \) is independent of the distance, assuming in both cases that we are in the far field of the antenna.
iii. **Beam Efficiency**

The beam area $Q_A$ (or beam solid angle) consists of the main beam area (or solid angle) $\Omega_M$ plus the minor-lobe area (or solid angle) $\Omega_m$. Thus,

$$\Omega_A = \Omega_M + \Omega_m$$

The ratio of the main beam area to the (total) beam area is called the (main) beam efficiency $\varepsilon_M$. Thus,

$$\text{Beam Efficiency} = \varepsilon_M = \frac{\Omega_M}{\Omega_A} \quad \text{(dimensionless)}$$

The ratio of the minor-lobe area ($\Omega_m$) to the (total) beam area is called the stray factor. Thus,

$$\varepsilon_m = \frac{\Omega_m}{\Omega_A} = \text{stray factor}.$$  

iv. **Directivity**

It is defined as the ratio of maximum radiation intensity of subject or test antenna to the radiation intensity of an isotropic antenna.

(or)

Directivity is defined as the ratio of maximum radiation intensity to the average radiation intensity.

$$\text{Directivity, } D = \frac{U_{\text{max}}}{U_{\text{avg}}} = \frac{\text{Maximum radiation intensity}}{\text{Average radiation intensity}}$$

Directivity ($D$) in terms of total power radiated is,

$$D = 4\pi \times \frac{\text{Maximum radiation intensity}}{\text{Total power radiated}}$$
1. What is retarded potential? Explain different approaches to solve radiation problems?

Ans:
Retarded Potential
The potential functions are defined as,

\[ A(r,t) = \frac{\mu}{4\pi} \int \frac{l(r^+ t-R/v)}{R} \, dv^1 \]

\[ V(r,t) = \frac{1}{4\pi} \int \frac{\rho(r^+ t-R/v)}{R} \, dv^1 \]

The above potential functions are called as Retarded potentials. Since a time delay of \( R/v \) has been introduced. So that now the potentials have been delayed or retarded by \( R/v \).

Approaches to Solve Radiation Problems
A difficulty in the subject of electromagnetic is, it is hard to visualize electromagnetic wave propagation and interaction. With today's advanced numerical and computational methods, and computational and visualization software and hardware, this dilemma can, to a large extent, be minimized. To address this problem, computer programs have been developed to animate and visualize three radiation problems. Each problem is solved using the Finite-Difference Time-Domain (FD-TD) method, a method which solves Maxwell's equations as a function of time in discrete time steps at discrete points in space. A picture of the fields can then be taken at each time step to create a movie which can be viewed as a function of time.

The three radiation problems that are animated and can be visualized using the computer program are,

(a) Infinite length line source (two dimensional) excited by a single Gaussian Pulse and radiating in an unbounded medium.

(b) Infinite length line source excited by a single Gaussian Pulse and radiating inside a Perfectly Electric Conducting (PEC) square cylinder

(c) E-plane sectoral horn excited by a continuous co-sinusoidal voltage source and radiating in an unbounded medium.

In order to animate and then visualize each of the three radiation problems, the user needs the professional edition of MATLAB[11] and the MATLAB-File, to produce the corresponding FD-TD solution of each radiation problem. For each radiation problem, the M-File executed in MATLAB produces a movie by taking a picture of the computational domain every third time step. The movie is viewed as a function of time as the wave travels in the computational space.
(i) Infinite Line Source in an Unbounded Medium:

The first FD-TD solution is that of an infinite length line source excited by a single time derivative Gaussian pulse, with a duration of approximately 0.4 nano seconds, in a two dimensional $TM_z$ - computational domain. The unbounded medium is simulated using a six layer Berenger Perfectly Matched Layer (PML) Absorbing Boundary Condition (ABC) to truncate the computational space at finite distance without, in principle creating any reflections. Thus the pulse travels radically outward creating a traveling type of a wave front. The outward moving wave fronts are easily for the sily identified using the coloring scheme for the intensity when viewing the movie. The movie is created by the MATLAB M-File which produces the FD-TD solution by taking a picture of the computational domain every third time step. The movie is 37 frames long covering 185 picoseconds of elapsed time. The entire computational space is 15.3 cm by 15.3 cm and is modeled by 2500 square FD-TD cells (50x50), including 6 cells to implement the PML ABC.

(ii) Infinite Line Source in a PEC Square Cylinder

This problem is simulated similarly as that of the line source in an unbounded medium, including the characteristics of the pulse. The major difference is that the computational domain of this problem is truncated by PEC walls, therefore there is no need for PML ABC. For this problem pulse travels in an outward direction and is reflected when it reaches the walls of the cylinder. The reflected pulses along with the radially outward traveling pulse interface constructively and destructively with each other and create a standing type wavefront. The peaks and valleys of the modified wavefront can be easily identified when viewing the movie, using colored or gray scale intensity schemes. Sufficient time is allowed in the movie to permit the pulse to travel-form the source to the walls of the cylinder. Each time step is 5 picoseconds and each FD-TD cell is 3 mm on, a side. The movie is 70 frames long covering 350 picoseconds of elapsed time. The square cylinder and thus the computational space, has a cross section of 15.3 cm by 15.3 cm and is modeled using an area 50 by FD-TD cells.

(iii) E-plane Sectoral Horn in an Unfounded Medium

The E-plane sectoral horn is excited by a co sinusoidal voltage (CW) of 9.84 GHz in a $TE_2$ computational domain, instead of Gaussian pulse excitation of the previous two problems. The unbounded medium is implemented using an eight-layer Berenger PMLABC. The computational space is 25.4 cm by 25.4 cm and is modeled using 100 by 100 FD-TD cells (each square cell being 2.54 mm on a side). The movie is 70 frames long covering 296 picoseconds of elapsed time and is created by taking a picture every third frame. Each time step is 4.23 picoseconds in duration. The horn has total fare angle of 52° and its fared section is 2.62 cm long, is fed by a parallel plate 1cm wide and 4.06 cm long, and has a aperture of 3.56 cm.

2. What is polarization? How many types of polarizations are used in antenna? Explain?

Ans: Electromagnetic Polarization

Electromagnetic polarization refers to the orientation of the electric field vector with respect to earth's surface. In this concept, the electric field whose orientation is varied in regular intervals to retain its strength along all directions. A polarization vector is a vector whose direction is along the path of the polarization (i.e., electric field orientation direction).
Antenna and Wave Propagation

There are three kinds of polarization namely,
1. Linear-polarization
2. Circular polarization
3. Elliptical polarization.

1. Linear Polarization
It is also known as plane polarization. In this electric field is confined to only one particular direction.

There are two forms of linear polarization. They are,
(i) Horizontal polarization
(ii) Vertical polarization.

In horizontal polarization, the electric field propagates parallel to the earth's surface, whereas in vertical polarization, the electric field propagates perpendicular to the earth's surface.

2. Circular Polarization
The polarization in which polarization vector rotates 360° over one period of the wave is referred as circular polarization. In the circular polarization, the strength of the field vector has a constant Value in all directions of polarization.

3. Elliptical Polarization
The elliptical polarization in which also, the polarization vector rotates 360° over one period of the wave. In elliptical polarization, the strength of the field varies with the changes in polarization.
This polarization is further classified into left handed and right handed elliptical polarization based on the rotating direction of the wave. If the vector rotates in clockwise direction, it is referred to as right handed and if the vector rotates in anticlockwise direction, it is referred to as left handed.

3. State reciprocity theorem for antennas. Prove that he self –impedance of an antenna in transmitting and receiving antenna are same?

Ans:
Reciprocity Theorem
Statement
Reciprocity theorem states that when current I is applied at the terminals of antenna 1, an e.m.f E_{21} induces at terminals of antenna 2 and when current I applied at the terminals of antenna 2, an e.m.f E_{12} induces at terminals of antenna 1, then E_{12} = E_{21} provided I_1 = I_2.

![Fig 3.1 General Antenna System](image-url)
Equality of Antenna Impedance

Consider, the two antennas separated with wide separation as shown below figure 3.2.

![Figure 3.2 Two antennas 1 and 2 with a wide separation](mywbut.com)

The current distribution is same in case of transmitting and receiving antenna. Let antenna no. 1 is the transmitting antenna and antenna no.2 is the receiving antenna. The self impedance ($Z_{11}$) of transmitting antenna is given by,

$$E_1 = Z_{11}I_1 + Z_{12}I_2$$

Here,
- $Z_{11}$ = Self impedance of antenna 1
- $Z_{12}$ = Mutual impedance between the two antennas.

Since the separation is more, mutual impedance ($Z_{12}$) is neglected,

$$Z_{12} = 0$$
$$E_1 = Z_{11}I_1 + 0I_2$$
$$E_1 = Z_{11}I_1$$

The receiving antenna under open circuit and short circuit conditions are shown below.

(a) Receiving Antenna under Open Circuit Condition

![Figure 3.3 Receiving antenna under open circuit condition](mywbut.com)

Here,
Antenna and Wave Propagation

Question and Answers

\[ E_1 = Z_{11}I_1 + Z_{12}I_2 \]
When the receiving antenna is open circuited, current \( I_1 \) is zero

\[ E_1 = Z_{11}(0) + Z_{12}I_2 \]

\[ E_{OC} = Z_{12}I_2 \]

(b) Receiving Antenna under Short Circuit Condition
When the receiving antenna is short circuited, the voltage (E) will be zero.

\[ E_1 = Z_{11}I_1 + Z_{12}I_2 \]
\[ 0 = Z_{11}I_{SC} + Z_{12}I_2 \]

\[ I_{SC} = \frac{-Z_{12}I_2}{Z_{11}} \]

From above, the term \( Z_{12}I_2 \) acts as a voltage source and \( Z_{11} \) as the self impedance. Hence, impedance of the antenna is same whether it is used for transmission or reception.

4. State the Maximum power transfer theorem and bring out their importance in antenna measurements?

Ans:

**Maximum Power Transfer Theorem**

Statement

Maximum power transfer theorem states that, an antenna can radiated maximum power, when the terminal resistance, \( R_L \) of the antenna is same as that of finite source resistance, \( R_S \).

![Fig 2.4.1 Maximum Power Transfer Theorem](image)

This theorem applies to the maximum power, but not for maximum efficiency. If the antenna terminal resistance is made large than the resistance of the source, then the efficiency is more, since most of the power is generated at the terminals, but the overall power is lowered. If the internal source resistance is made larger than the terminal resistance then most of the power ends up being dissipated in the source.

Thus, the main use of maximum power transfer theorem for antennas is impedance matching i.e., maximum power transfer to and from an antenna occurs when the source or receiver impedance is same as that of antenna. But, when an antenna is not correctly matched internal reflections will occur.
5. Find the effective length of a half-wave dipole?

Ans:

Effective Length of a Half-wave Dipole

The effective length of an antenna is defined as the ratio of induced voltage at the terminal of the receiving antenna under open circuited condition to the incident electric field intensity i.e.,

Effective length, \( l_e = \frac{V}{E} \)

However, the included voltage ‘V’ also depends on the effective aperture as,

\[
A_e = \frac{(V^2 R_L) / \{(R_A + R_L)^2 + (X_A + X_L)^2\} P)}{R_L}
\]

Where,
- \( R_L \) = Load resistance
- \( R_A \) = Antenna resistance
- \( X_L \) = Load reactance
- \( X_A \) = Antenna reactance
- \( P \) = Poynting vector.

\[
V^2 = \{A_e \{(R_A + R_L)^2 + (X_A + X_L)^2\} E^2\} / R_L
\]

Since,
- \( P = E^2/Z \), Where \( Z \) – Intrinsic impedance
  - \( Z = 120\pi \)

Then,

\[
V = \sqrt{A_e \{(R_A + R_L)^2 + (X_A + X_L)^2\} E^2\} / R_L
\]

Effective length, \( l_e = \frac{V}{E} = \sqrt{\{A_e \{(R_A + R_L)^2 + (X_A + X_L)^2\} E^2\} / R_L Z}
\]

For obtaining maximum effective aperture,

\[
X_A = -X_L
\]

\( R_A = R_L = R_r = \text{Radiation resistance} \)

Thus,

\[
l_e = \sqrt{Ae(2Rr)^2/ZRr} = 2 \sqrt{AeRr/Z}
\]

But, the effective aperture of a half wave dipole is given by, \( A_e = 0.13\lambda^2 \) and the radiation resistance of a half wave dipole is, \( R_r = 73\Omega \).

\[
(l_e)_{\lambda/2 \text{ dipole}} = 2 \sqrt{(0.13\lambda^2 \times 73)} / 120\pi = 0.318\lambda.
\]
6. Write short note on small loops.

Ans:

The field pattern of a small circular loop of radius $a$ may be determined very simple by considering a square loop of the same area, that is.

$$d^2 = \pi a^2 \quad \ldots (1)$$

where $d =$ side length of square loop

It is assumed that the loop dimensions are small compared to the wavelength. It will be shown that the far-field patterns of circular and square loops of the same area are the same when the loops are small but different when they are large in terms of the wavelength.

If loop is oriented as in fig.2.6.2, its far electric field has only an $E_{\phi}$ component. To find the far-field pattern in the $yz$ plane, it is only necessary to consider two of the four small linear dipoles (2 and 4). A cross section through the loop in the $yz$ plane is presented in Fig.2.6.3. Since the individual small dipoles 2 and 4 are nondirectional in the $yz$ plane, the field pattern of the loop in this plane is the same as that for two isotropic point sources. Thus,

$$E_{\phi} = -E_{\phi0} e^{j\psi/2} + E_{\phi0} e^{-j\psi/2} \quad \ldots (2)$$

Where $E_{\phi0} =$ electric field from individual dipole and

$$\psi = (2\pi d/\lambda) \sin \theta = d_r \sin \theta \quad \ldots (3)$$

It follows that

$$E_{\phi} = -2j E_{\phi0} \sin(d_r \sin \theta/2) \quad \ldots (4)$$

The factor $j$ in (4) indicates that the total field $E_{\phi}$ is in phase quadrature with the field $E_{\phi0}$ be individual dipole.
Antenna and Wave Propagation  Question and Answers

However, the length L of the short dipole is the same as $d$, that is, $L = d$.

<table>
<thead>
<tr>
<th>Field</th>
<th>Electric Dipole</th>
<th>Loop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric</td>
<td>$E_\theta = (j \ 60 \ \pi [\ I ] \sin \theta \ L)/(r \ \lambda)$</td>
<td>$E_\Phi = (120 \ \pi^2 [\ I ] \sin \theta \ A)/(r \ \lambda^2)$</td>
</tr>
<tr>
<td>Magnetic</td>
<td>$H_\Phi = (j [\ I ] \sin \theta \ L)/(2r \ \lambda)$</td>
<td>$H_\theta = (\pi [\ I ] \sin \theta \ A)/(r \ \lambda^2)$</td>
</tr>
</tbody>
</table>

This is the instantaneous value of the $E_\Phi$, component of the far field of a small loop of area $A$. The peak value of the field is obtained by replacing $[I]$ by $I_0$, where $I_0$ is the peak current in time on the loop.

7. Compare far fields of small loop and short dipole?
Ans:

Comparison of far fields of Small Loop and Short Dipole

It is of interest to compare the far-field expressions for a small loop with those for a short electric dipole. The comparison is made in table. The presence of the operator $j$ in the dipole expressions and its absence in the loop equations indicate that the fields of the electric dipole and of the loop are in time-phase quadrature, the current $I$ being in the same phase in both the dipole and loop. This quadrature relationship is a fundamental difference between fields of loops and dipoles.

8. What are the different advantages and disadvantages of loop antennas?
Ans:

Advantages
1. A small loop is generally used as magnetic dipole.
2. A loop antenna has directional properties whereas a simple vertical antenna not has the same.
3. The induced e.m.f around the loop must be equal to the difference between the two vertical sides only.
4. No e.m.f is produced in case of horizontal arms of a loop antenna.
5. The radiation pattern of the loop antenna does not depend upon the shape of the loop (for small loops).
6. The currents are at same magnitude and phase, throughout the loop.

Disadvantages
1. Transmission efficiency of the loop is very poor.
2. It is suitable for low and medium frequencies and not for high frequencies.
3. In loop antenna, the two nulls of the pattern result in 180° ambiguity.
4. Loop antennas used as direction finders are unable to distinguish between bearing of a distant transmitter and its reciprocal bearing.
9. Sketch the far field patterns of loops of $0.1\lambda$, $\lambda$, and $3\lambda/2$ diameter. What is the effect of the shape of the small loop on its far field pattern?

**Ans:**

The far field of loop antenna is,

$$E_\phi = (\mu \omega |I_a| I_1(\beta a \sin \theta))/2r$$

$$H_\theta = (\beta a |I| J_1(\beta a \sin \theta))/2r$$

The above expression shows the far field pattern for loop of any size. The far field expressions $E_\phi$ and $H_\theta$ as a function of $\theta$ is given by $J_1(C_\lambda \sin \theta)$

Here,

$$C_\lambda = \text{Circumference of the loop}$$

$$C_\lambda = a\beta$$

$$\beta = (2\pi/\lambda)$$

$$C_\lambda = (2\pi/\lambda) a$$

Far Field Patterns of Loops of $0.1\lambda$, $\lambda$, and $3\lambda/4$ diameters

(i) Field patterns of $0.1\lambda$.

![Fig 9.1 Field pattern of $0.1\lambda$](image)

(ii) Field pattern of $\lambda$.

![Fig 9.2 Field Pattern of $\lambda$](image)
10. Define and explain directivity and power gain for an antenna. What is the relation between the two?

Ans:

Directivity

It is defined as the ratio of maximum radiation intensity of subject or test antenna to the radiation intensity of an isotropic antenna.

(or)

Directivity is defined as the ratio of maximum radiation intensity to the average radiation intensity.

| Directivity, \( D = \frac{U_{\text{max}}}{U_{\text{avg}}} = \frac{\text{Maximum radiation intensity}}{\text{Average radiation intensity}} \) |

Directivity (D) in terms of total power radiated is,

\[ D = \frac{4\pi \times \text{Maximum radiation intensity}}{\text{Total power radiated}} \]

\[ D = \frac{4\pi \times U_{\text{max}}}{W_T} \]

Therefore

\[ U_{\text{av}} = \frac{W_T}{4\pi} \]
Power Gain ($G_P$)

It is defined as the ratio of radiation intensity in given direction to the total input power.

$$G_P = \text{Radiation intensity in given direction} / \text{Total input power}$$

$$G_P = U(\theta, \Phi) /[W_T / 4\pi]$$

Therefore,

Total input power, $P_i = W_T / 4\pi$

$$G_P = (4\pi U(\theta, \Phi) / W_T)$$

Therefore, thus the power gain ($G_P$) depends upon volume of the radiation pattern.

Relation between Directivity and Power Gain

The expression for power gain of an antenna is given by,

$$G_P = (4\pi U(\theta, \Phi)) / P_{in} \quad \text{...(1)}$$

However, the relation between total radiated power, $P_{rad}$ and the total input power, $P_{in}$ is given by,

$$P_{rad} = C P_{in} \quad \text{.... (2)}$$

Where,

$\eta_{rad} = \text{Antenna radiation efficiency}$

Then, equation (1) can be written as,

$$G_P = (4\pi U(\theta, \Phi)) / (P_{rad} / \eta_{rad})$$

$$G_P = \eta_{rad} (4\pi U(\theta, \Phi)) / (P_{rad})$$

$$G_P = \eta_{rad} D \quad \text{[D = (4\pi U(\theta, \Phi)) / (P_{rad})]}$$

Therefore, $G_P = \eta_{rad} D$
UNIT-3

1. Derive the field components and draw the field pattern for two point source with spacing of \( \lambda/2 \) and fed with current of equal magnitude but out of phase by \( 180^\circ \)?

**Ans:** Arrays of two point sources with equal amplitude and opposite phase:

In this, point source 1 is out of phase or opposite phase (180°) to source 2 i.e. when there is maximum in source 1 at one particular instant, and then there is minimum in source 2 at that instant and vice-versa.

Referring to Fig.1, the total far field at distant point \( P \), is given by

\[
E = (-E_1e^{-j\phi/2}) + (+E_2e^{+j\phi/2})
\]

But

\[
E_1 = E_2 = E_0 \text{(say)}
\]

Then

\[
E = 2jE_0\left(\frac{e^{j\phi} - e^{-j\phi}}{2j}\right) \sin \frac{\phi}{2} \quad \text{…………… (1.1a)}
\]

\[
E = 2jE_0\sin \frac{\phi}{2} \cos \theta \quad \text{…………… (1.1b)}
\]

Let \( d = \lambda/2 \) and \( 2E_0j = 1 \)

\[
E = \sin \left(\frac{\pi}{2}\cos \theta\right) \quad \text{……………… (1.2)}
\]

**Maximum directions:** Maximum value of sine function is \( \pm 1 \)

\[
\sin \left(\frac{\pi}{2}\cos \theta\right) = \pm 1
\]

\[
\sin(\frac{\pi}{2}\cos \theta_{\text{max}}) = \pm (2n + 1) \frac{n}{2} \quad \text{where } n = 0, 1, 2
\]

\[
\cos \theta_{\text{max}} = \pm 1 \quad \text{if } n = 0
\]

\[
\theta_{\text{max}} = 0^\circ \text{ and } 180^\circ \quad \text{…………….. (1.3 a)}
\]

**Minima directions:** Minimum value of a sine function is 0

\[
\sin \left(\frac{\pi}{2}\cos \theta\right) = 0
\]

\[
\cos \theta_{\text{min}} = -\pm \pi \quad \text{where } n = 0, 1, 2………
\]

\[
\cos \theta_{\text{min}} = 0
\]

Therefore \( \theta_{\text{min}} = 90^\circ \text{ and } -90^\circ \quad \text{……………. (1.3b)}

**Half power point directions:**

\[
\sin \left(\frac{\pi}{2}\cos \theta\right) = \pm \frac{1}{\sqrt{2}}
\]

\[
\sin(\frac{\pi}{2}\cos \theta_{\text{HPPD}}) = \pm (2n + 1) \frac{x}{4}
\]

\[
\cos \theta_{\text{HPPD}} = \pm \frac{1}{2} \quad \text{if } n = 0
\]

\[
\theta_{\text{HPPD}} = 60^\circ, 120^\circ \quad \text{………………… (1.3c)}
\]
From these, it is possible to draw the field pattern which is as shown in Fig.1.2

![Fig 1.2 Two Point source with equal amplitude and opposite phase spacing λ/2](image)

It is seen that maxima have shifted 90° along X-axis in comparison to in-phase field pattern. The figure is horizontal figure of 8 and 3-dimensional space pattern is obtained by rotating it along X-axis. Once the arrangement gives maxima along line joining the two sources and hence this is one of the simplest type of "End fire" "Array."

2. What is the necessity of an array? Explain the three different types of array with regard to beam pointing direction

Ans: Antenna Array

This is one of the common methods of combining the radiations from a group of similar antennas in which the wave-interference phenomenon is involved. The field strength can be increased in preferred directions by properly exciting group or array of antennas simultaneously, such as arrangement is known as antenna array. Array of antenna is an arrangement, of several individual antennas so spaced and phased that their individual contributions coming in one preferred direction and cancel in all other directions, which will be going to increase the directivity of the system.

The different types of arrays with regard to beam pointing direction are as follows,

1. Broadside array
2. End fire array
3. Collinear array.

1. Broadside Array

Broadside array is one of the most commonly used antenna array in practice. The array in which a number of identical parallel antennas are arranged along a line perpendicular to the line of array axis is known as broadside array, which is shown in figure (2.1). In this, the individual antennas are equally spaced along a line and each element is fed with current of equal magnitude, all in the same phase.

![Fig 2.1 Broad side array](image)
The radiation pattern of broadside array is bidirectional, which radiates equally well in either direction of maximum radiation.

2. **End Fire Array**

The array in which a number of identical antennas are spaced equally along a line and individual elements are fed with currents of unequal phases (i.e., with a phase shift of 180°) is known as end fire array. This array is similar to that of broadside array except that individual elements are fed in with a phase shift of 180°. In this, the direction of radiation coincides with the direction of the array axis, which is shown in figure (2.2).

![Fig. 2.2 End fire array](image)

The radiation pattern of end fire array is unidirectional. But, the end fire array may be bidirectional also. One such example is a two element array, fed with equal current, 180° out of phase.

3. **Collinear Array**

The array in which antennas are arranged end to end in a single line is known as collinear array. Figure (2.3), shows the arrangement of collinear array, in which one antenna is stacked over another antenna. Similar to that of broadside array, the individual elements of the collinear array are fed with equal in phase currents. A collinear array is a broadside radiator, in which the direction of maximum radiation is perpendicular to the line of antenna. The collinear array is sometimes called as broadcast or Omni directional arrays because its radiation pattern has circular symmetry with its main to be everywhere perpendicular to the principal axis.

![Fig. 2.3 Collinear array](image)

3. Explain the principal of pattern multiplication. What is the effect of earth of radiation pattern of antennas?

**Ans:** Multiplication of Patterns

The total field pattern of an array of non-isotropic but similar sources is the multiplication of the individual source pattern and the pattern of an array of isotropic point sources each located at the phase centre of individual source and having the relative amplitude and phase, where as the total phase patterns is the addition of the phase pattern of the individual sources and the array of isotropic point sources. Total field by an array is defined as

\[
E = \{ E_d(\theta, \phi) \times E_i(\theta, \phi) \} \times \{ E_{pi}(\theta, \phi) + E_{pa}(\theta, \phi) \}
\]

= (Multiplication of field patterns) (Addition of phase patterns)
Antenna and Wave Propagation  

Where

\[ E \] - Total field

\[ E_0(\theta, \phi) = \text{Field pattern of individual source} \]

\[ E_i(\theta, \phi) = \text{Field pattern of array of isotropic point source} \]

\[ E_{pi}(\theta, \phi) = \text{Phase pattern of individual source} \]

\[ E_{pa}(\theta, \phi) = \text{Phase pattern of array of isotropic point sources}. \]

Hence, \( \theta \) and \( \phi \) are polar and azimuth angles respectively.

The principle of multiplication of pattern is best suited for any number of similar sources. Considering a two dimensional case, the resulting pattern is given by the equation,

\[ E = 2 E_0 \cos \phi /2 \]

\[ E = 2 E_1 \sin \theta \cos \phi /2. \]

\[ E = E (\theta) \cos \phi /2 \]

It can be seen that \( E_0 \) is a function of \( E (\theta) \). In the above equation the total field pattern is equal to the product of primary pattern \( E (\theta) \) and a secondary pattern \( \cos \phi/2 \).

**Effect of Pattern**

The effect of can be obtained
In image as an image current as

**Earth on the Radiation**

earth on the radiation pattern by using an image principle. principle, earth is considered antenna of same length and shown in the figure (3.1).

For vertical antenna, currents in actual and image antennas are equal and have same direction, whereas opposite direction for horizontal antenna. The resultant field is obtained by the addition of field of an image antenna to that of an actual antenna. The shape of the vertical pattern is affected more than the horizontal pattern.
Effect of Earth on the Radiation Pattern of Vertical Antenna

The ground-effect factor of a perfectly conducting earth is given as,

$$2\cos\left[\frac{2\pi h}{\lambda} \sin \varphi_0\right]$$

Where,

- $h =$ Height of the center of antenna above earth
- $\varphi =$ Elevation angle above horizontal.

But, for the case of finite conducting of earth, the above given expression is valid for large angles of $\varphi_0$. Whereas, for low angles of $\varphi_0$, less than 15° known as "Pseudo-Brewster angle", the phase of the reflection factor is nearer to 180° than it is to 0° and the use of above equation would lead to erroneous result.

The effect of earth on radiation pattern can be explained by taking different cases of conductivities ($\sigma$). The function ‘$n$’ is defined as,

$$n = \frac{x}{\varepsilon_r}$$

Where, $x = \sigma / \omega \varepsilon_r$

$\sigma =$ conductivity of the earth in mho/meter

$\varepsilon_r = 15$, Relative dielectric of the earth.

The vertical radiation pattern of a vertical dipole is shown in the fig 3.2
Effect of Earth on the Radiation Pattern of Horizontal Antenna

The effect of ground is obtained by multiplying free-space pattern and ground factor, i.e.

\[ 2 \cos \left( \frac{2\pi n h}{\lambda} \sin \phi_0 \right) \]

The first maxima in this pattern occurs at,

\[ \sin \phi_0 = \frac{\lambda}{4h} \quad (h > \frac{\lambda}{4}) \]

The effect of earth on the vertical pattern perpendicular to the axis of dipole is as shown in figure 3.4.
4. Explain about radiation pattern of 4-isotropic and 8-isotropic elements fed in phase, spaced $\lambda/2$ apart?

**Ans:** Radiation Pattern of 4-isotropic elements fed in phase, spaced $\lambda/2$ apart:

Let the 4-elements of isotropic (or non-directive) radiators are in a linear arrays (Fig. 4.1) in elements are placed at a distance of $\lambda/2$ and are fed in phase, i.e. $\alpha = 0$. One of the method to get the radiation pattern of the array is to add the fields of individual four elements at a distance point P vectorially but instead an alternative method, using the principle of multiplicity of pattern, will be shown to get the same.

The radiation pattern of two isotropic radiation spaced $\lambda$ apart, fed in phase is known to be as shown in Fig. 4.2. Now elements (1) and (2) are considered as one unit and is considered to be placed between the midway of the elements and so also the elements (3) and (4) as another unit assumed to be placed between the two elements as shown in fig 4.2.

Thus 4 elements spaced $\lambda/2$ have been replaced by two units spaced $\lambda$ and by doing so, the problem of determining radiation of 4 elements has reduced to find out the radiation pattern of two antennas spaced $\lambda$ apart.
Then according to multiplicity of pattern. The resultant radiation pattern of 4 elements is obtained by multiplying the radiation pattern of individual element Fig. 4.3 (b) and array of two units spaced $\lambda$.

In place of isotropic (non-directional) if the array is replaced by an non-isotropic (i.e. directional) antennas, then the radiation pattern Fig. 4.2 must be accordingly modified.

**Radiation pattern of 8-isotropic elements fed in phase, spaced $\lambda/2$ apart.** As above the principle can be applied to broad-side linear array of 8-isotropic elements also as shown in Fig. 4.5 In this case 4-isotropic elements are assumed to be one unit and then to find the radiation pattern of two such units paced a distance $2\lambda$ apart. The radiation pattern of isotropic element is just seen in Fig. 4.4

![Fig. 4.4 Resultant radiation pattern of 4-isotropic elements by pattern multiplication](image-url)

**Fig. 4.4 Resultant radiation pattern of 4-isotropic elements by pattern multiplication**

**Fig. 4.5 (a) Linear array of 8 isotropic elements spaced $\lambda/2$.**
**Fig. 4.5 (b) Equivalent two units array spaced $2\lambda$.**

**Fig. 4.6 Radiation Pattern of isotropic radiators spaced $2\lambda$.**
Thus the radiation pattern of 8 isotropic elements is obtained by multiplying the unit pattern of 4 individual elements as already obtained in Fig. 4.4 and Group pattern of two isotropic radiators spaced 2λ is as shown in Fig. 4.6 and hence the resultant (Fig. 4.7).

5. What is uniform linear array? Discuss the application of linear array? and also explain the advantages and disadvantage of linear array?

**Ans:** In general single element antennas having non-uniform radiation pattern are used in several broadcast services. But this type of radiation pattern is not useful in point-to-point communication and services that require to radiate most of the energy in one particular direction i.e., there are applications where we need high directive antennas. This type of radiation pattern is achieved by a mechanism called antenna array. An antenna array consists of identical antenna elements with identical orientation distributed in space. The individual antennas radiate and their radiation is coherently added in space to form the antenna beam.

In a linear array, the individual antennas of the array are equally spaced along a straight line. This individual antennas of an array are also known as elements. A linear array is said to be uniform linear array, if each element in the array is fed with a current of equal magnitude with progressive phase shift (phase shift between adjacent antenna elements).

**Application of Linear Array**

1. Adaptive linear arrays are used extensively in wireless communication to reduce interference between desired users and interfering signals.

2. Many linear arrays spaced parallel on the common plane create a planar array antenna. These are used in mobile radar equipment.

3. The linear array is most often used to generate a fan beam and is useful where broad coverage in one plane and narrow beam width in the orthogonal plane are desired.

4. Linear arrays can be made extremely compact and are therefore very attractive for shipboard applications.

The advantages and disadvantages of linear arrays are as follows.

**Advantages**

1. Increases the overall gain.

2. Provide diversity receptions.
3. Cancel out interference from a particular set of directions.
4. "Steer" the array so that it is more sensitive in a particular direction.
5. Determines the direction of arrival of the incoming signals.
6. It maximize the Signal to Interference plus Noise ratio

Disadvantages

1. Ray deflection only in a single plane possible.
2. Complicated arrangement and more electronically controlled phase shifter needed.
3. Field view is restricted.
4. Considerable minor lobes are formed.
5. Large power loss due to current flowing in all elements.
6. Overall efficiency decreases.
7. Costly to implement.

6. What is the optimum spacing in parasitic array? why?

**Ans:** The simplest case of a parasitic array is one driven element and one parasitic element and this may be considered as two element array. A parasitic array consists of one or more driven element and a number of parasitic elements. Hence in parasitic arrays there are one or more parasitic elements and at least one driven element to introduce power in the array.
A parasitic array with linear half-wave dipole as elements is normally called as "Yagi-Uda" or simply "Yagi" antenna after the name of inventor S.Uda (Japanese) and H. Yagi (English).

The amplitude and phase of the current introduced in a parasitic element depends on its tuning and the spacing between parasitic element and driven element to which it is coupled. A variation in the distance between driven element and parasitic element changes the relative phases and this proves to be very convenient. It helps in making the radiation pattern unidirectional. A distance of $\lambda/4$ and phase difference of $\pi/2$ radian (or 90°), for example, provides a unidirectional pattern.

7. What is linear array? Compare Broad side array and End fire array?

Ans:

**Linear arrays:** The arrays in which the individual antennas (called as elements) are equally spaced along a straight line are called as linear arrays. Thus, linear antenna array is a system of equally spaced elements.
1. The array is said to be broad side array, if the direction of maximum radiation is perpendicular to the array axis.

2. In broad side, phase difference $\alpha = 0$

3. General equation for pattern maxima is

$$\phi_{\text{max}} = \cos^{-1} \left( \frac{1}{\beta d} \left[ \frac{2N+1}{n} \right] \right)$$

4. General expression for pattern minima is

$$\phi_{\text{min}} = \cos^{-1} \left( \frac{N \lambda}{\pi d} \right)$$

5. Half power beam width is given by,

$$\text{HPBW} = \frac{57.3}{\lambda} \text{ degree}$$

6. Directivity of broad side array is,

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

$L$ = Length of array

7. Beam width between first nulls is,

$$\text{BWFN} = \frac{114.6}{\lambda} \text{ degree}$$

8. In broad side array, all elements are equally spaced along the array axis and fed with current of equal magnitude and same phase.

9. Radiation pattern of broad side array is bidirectional

10. In broad side array,

$$\phi = \beta \cos \theta + \alpha \quad \text{(since } \alpha = 0\text{)}$$

Therefore

$$\phi = \beta \cos \theta$$

1. The array is said to be end fire array, if maximum radiation is along the array axis.

2. In end fire, phase difference between adjacent element is $\alpha = -\beta d$

3. General expression for pattern maxima is

$$\phi_{\text{max}} = \cos^{-1} \left( \frac{1}{\beta d} \left[ \frac{2N+1}{n} + 1 \right] \right)$$

4. General expression for pattern minima is

$$\phi_{\text{min}} = 2 \sin^{-1} \left( \frac{\lambda}{2 \pi d} \right)$$

5. Half power beam width is given by,

$$\text{HPBW} = 57.3 \left( \frac{\pi}{\lambda} \right) \text{ degree}$$

6. Directivity of end fire array is,

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

$L$ = Length of array

7. Beam width between first nulls is

$$\text{BWFN} = \frac{114.6}{\lambda} \text{ degree}$$

8. In end fire array, all elements are equally spaced along the array axis and fed with current of equal magnitude but their phases are different.

9. Radiation pattern of broad side array is Unidirectional

10. In end fire array,

$$\phi = \beta \cos \theta + \alpha \quad \text{(since } \alpha = -\beta d\text{)}$$

Therefore

$$\phi = \beta d (\cos \theta - 1)$$
8. What are the various difference between binomial and linear arrays?

**Ans:**

<table>
<thead>
<tr>
<th>Binomial Array</th>
<th>Linear Array</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The binomial array is one in which all the elements are fed with currents of non-uniform amplitude.</td>
<td>1. In antenna array if the individual antennas are equal spaced in a straight line, then it is said to be linear array.</td>
</tr>
<tr>
<td>2. Elements are fed with unequal amplitude.</td>
<td>2. If elements are fed with equal amplitude, it is called as uniform linear array.</td>
</tr>
<tr>
<td>3. We use Pascal triangle to select the coefficient or amplitudes of elements.</td>
<td>3. We do not use Pascal triangle,</td>
</tr>
<tr>
<td>4. Principle of multiplication of pattern is used for derivation of pattern.</td>
<td>4. Principle of multiplication of pattern is used for derivation of pattern.</td>
</tr>
<tr>
<td>5. Secondary lobes does not appear in the radiation pattern.</td>
<td>5. Secondary lobes appear in the radiation pattern</td>
</tr>
<tr>
<td>6. HPBW increases and directivity decreases.</td>
<td>6. HPBW is less compared to binomial array.</td>
</tr>
<tr>
<td><strong>For Example:</strong> For 5 element array with $\frac{\lambda}{2}$ spacing HPBW $= 31^\circ$</td>
<td><strong>For Example:</strong> For 5 $\degree$ element array with $\frac{\lambda}{2}$ spacing HPBW $= 23^\circ$.</td>
</tr>
<tr>
<td>7. Design is complex for large array due to large amplitude ratio.</td>
<td>7. Design is simple for large array due to uniform amplitude</td>
</tr>
</tbody>
</table>

9. Explain the concept of scanning arrays and What the requirement of tapering of arrays is

**Ans:** In broad side (or) end fire array, the maximum radiation occurs in a specific direction. In broad side array, the direction of radiation pattern is perpendicular to the array axis whereas in end fire array radiation pattern is normal, to the array axis.

It is possible to change the orientation of maximum radiation in any direction with the help of scanning (or) phased arrays

Let,

$\theta_0=$Orientation angle

Therefore Phase difference ($\alpha$) can be calculated by,
\[ y = (\beta \cos \theta + \alpha)_{\theta=0} \]

\[ 0 = \beta \cos \theta + \alpha \]

\[ \alpha = -\beta \cos \theta_0 \]

From above equation, the phase difference is directly proportional to the orientation angle. By maintaining the proper phase difference between the elements, desired radiation can be obtained in any direction.

The basic principle of scanning and phased array is to get the maximum radiation in any direction.

**Tapering of Arrays:**

The bidirectional patterns of antennas contain minor lobes in addition to major lobes. These minor lobes not only waste the amount of power but cause interference thus they are undesirable. The interference is severe in case of radar applications where it may cause improper detection of the target object.

Tapering is a technique in which currents or amplitudes are fed non-uniformly in the sources of a linear array. If the centre source is made to radiate more strongly than the end sources, the level of minor lobes are reduced.

Minor lobes are the lobes other than major lobes in the radiation pattern and the minor lobes adjacent to major lobes are called side lobes. By tapering of arrays from centre to end according to some prescription reduces the side lobe level. If the tapering amplitudes follow coefficients of binomial series or Tchebyscheff polynomial, then accordingly the arrays are known as binomial arrays or dolph Tchebyscheff arrays respectively.

**NOTE:**

This technique is primarily intended for broadside arrays and also applicable to end fire arrays because the side lobe ratio in case of broadside arrays is approximately 20 or 13 dB.

**10. Explain the advantages and disadvantages of binomial array? and also Explain the procedure for measuring the radiation pattern of half wave dipole?**

**Ans:**

**Advantages of Binomial Array**

1. The binomial array is one in which all the elements are fed with current of non uniform amplitude such that it reduces minor lobes.

2. Hence, we use Pascal triangle to select the coefficient or amplitudes of elements.

3. Hence, we use Pascal triangle to select the coefficient or amplitudes of elements.


**Disadvantages of Binomial Array.**

1. HPBW increases and hence the directivity decreases.

2. Large amplitude ratio is required for a design of a large array

**Procedure for Measuring the Radiation Pattern of a Half Wave Dipole**

1. Initially, the primary half wave dipole i.e., dipole antenna under test must be kept stationary where as the secondary half wave dipole i.e., dipole antenna with known radiation pattern is transported around along a circular path at a constant distance.

2. If the secondary half wave dipole antenna is directional, then it is kept aimed at primary half wave dipole antenna so that only primary half wave dipole antenna pattern will affect the result.

3. Basically, primary half wave dipole antenna may be a transmitting antenna (not a compulsion).
4. The field strength readings and direction of the secondary half wave dipole antenna with respect to primary half wave dipole antenna are recorded along the circle at different points.

5. Finally, using the readings of field strengths at a number of points the plot of radiation pattern of primary half wave dipole antenna is made either in rectangular form or in polar form.
UNIT 4

1. Write short notes on travelling wave antenna?

Ans:

**Travelling Wave Antenna**

Travelling wave or non-resonant or aperiodic antennas are those antennas in which there is no reflected wave i.e., standing wave does not travel over such antennas. As against this, there are resonant or tuned or standing waves or periodic antennas in which standing waves exist due to improper termination. Such antenna operates properly on limited band for which they are tuned. Since in radio communications which employ ionosphere for reflection, frequently require to operate on a widely spaced frequencies and thus there is a need for an antenna having greater band width. This need of larger bandwidth is met by these travelling wave antennas. In order to avoid reflected waves from the radiator so that only incident travelling wave travel on the antenna, the antennas are terminated at one end other than the feed end. Although this dissipates some powers but because of its simplicity it has its own attraction. Now to have a thorough understanding of travelling wave radiators we have to consider the radiation from a single wire carrying travelling waves.

![Direction of Travelling Wave](image)

(a) A travelling wave radiator. (b) Radiation pattern.

**Fig 4.1.1 Travelling Wave Radiator and its Radiation Pattern**

Now consider a two wire transmission line terminated at its far end by its characteristics impedance so that there is no reflected wave and travelling waves travel along the line. The spacing between two wires transmission line and the other line (i.e. return conductor of the line) can be disregarded for the moment, as radiation from a current element can be applied for a single wire. Further uniform current throughout the single wire is assumed. Thus a single long wire may be thought as number of Hertzian dipoles joined end to end (Fig.4.1.1) with current with phase lagging according to distance i.e. it is similar to an end fire array of collinear Hertzian dipoles, if velocity of light is assumed to be same in the wire and the free space. Thus travelling wave antenna is essentially an end fire antenna with a sharp null in the forward direction Fig.4.1.1 (b). The field strength at a distance r from the wire at an angle θ can be shown to be

\[
E = (60 I_{rms}/ r). (\sin \theta /1-cos \theta ). \sin ( \pi L/ \lambda \{1-cos \theta \})
\]

Where,
L = Length of the wire, \(I_{\text{rms}}\) = rms value of travelling wave current.

If radiation pattern for various lengths are plotted as in Fig.4.1.2, it would be seen that as the length of wire increases, the major lobes get closer and narrower to the wire axis.

It is further seen that for a variation of length of travelling wave radiator from 2\(\lambda\) to 8\(\lambda\), the angle of major lobe varies from 17° to 68°. Besides the amplitude of the lobe also increases. The travelling wave radiators can be excited without the second line or return conductor. Since an end fed antenna possesses standing wave so it can be made a travelling wave radiator if its other end is terminated with a suitable value resistor. Thus a single wire radiator, if terminated with impedance of value equal to characteristic impedance, will work as travelling wave radiator.

2. Write short notes on Long wire or Harmonic antenna?

Ans:

An antenna will be resonant so long as its length is integral multiple of half wave length. When an antenna is more than a half-wave long it is called as a long-wire or a harmonic antenna. Thus the long wire antenna is a single long wire, generally two or more wave length (i.e. 4\(\lambda/2\) or more \(\lambda/2\)) long at the operating frequency. The higher the number of \(\lambda/2\) the better its directivity. Since the wire is made longer in terms of the number of half wave lengths (\(\lambda/2\)), the directional effect changes. The directional characteristics split up into various lobes at different angles from wire axis as against "doughnut shape" of a single \(\lambda/2\) antenna. It radiates a horizontally polarized wave at low angles from about 17° to 24° relative to the earth surface. In
long wire antenna, the currents in adjacent half wave section must be out of phase and hence any feeder system can be used that does that disturb this condition. This condition can be satisfied if long wire antenna is fed at either end or at any current loop. A long wire antenna is generally made a half wave length at the lowest frequency of operation and fed at the end. Long wire antennas are shown in Fig. 4.2.1 in which n is the number of half wavelength.

The long wire may assume two forms e.g. resonant (unterminated) and non-resonant (terminated at characteristics impedance). In resonant long wire antenna standing wave exists along its length and the pattern is bidirectional corresponding to incident waves and reflected waves. However, in case of non-resonant long wire antenna all the incident waves are absorbed in terminating impedance and there is no reflected wave. This is why the pattern is only due to incident wave’s i.e. unidirectional only and uniform current and voltage exist along the axis of the wire.

The directional patterns of resonant and non-resonant types of antennas are shown in Fig. 4.2.2. The angle of radiation with reference to wire axis depends on number of wavelength i.e. even or odd. For n = 3 and n = 4 directional pattern is shown in figure. For example maximum radiation from a long wire antenna of 8 \( \lambda \) long w.r.t. wire axis is at 17.5° with many small minor lobes.

The physical length of a long wire antenna can be extended from the physical length of \( \lambda/2 \) antenna as follow from equation

\[
\lambda/2 = (492 \times 0.95)/f(\text{MHz}) \text{ feet} \quad \text{if one half wavelength in wavelength}
\]

Hence for n half wavelength long wire antenna

\[
(\text{length}) = \frac{492(n - 0.05)}{f(\text{MHz})} \text{ feet}
\]
Where $n$ is the number half wave length in the wire length.

Resonant and non resonant long wire antennas are used for transmission and reception i.e. from 500 kHz to 30 MHz. They provide a simple and effective method of obtaining directional pattern and power gain. These properties are utilized when long wire antennas are used as in an array antennas. They are practical of its simplicity and low cost, irrespective of theoretical complications.

3. What is a V-antenna? Explain its characteristics?

**Ans:**

V–antenna

The V antenna is an extension of long wire antennas. Two long wire antennas (called legs) are arranged in the form of a horizontal V, fed at the apex as shown in Fig. 4.3.1.

If the angle between the two sides of the V, is equal to twice the angle 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 the line bisecting the apex angle of V, and there produce a maximum lobe of radiation. The two wires are fed 180° out of phase with each other. This provides gain and directivity. The higher the length of legs, the greater the directivity and gain. These are achieved by cancelling oppositely directed corresponding radiation lobes in each leg and by adding the
similarly directed corresponding lobes in each leg. The resultant is bi-directional patterns which are sharper than the same length single long wire. The gain achieved with the V antenna is nearly twice in comparison to the single long wire antenna, which has a length equal to that of the legs of the V antenna. For example, nearly 12 db gain is achieved over a \( \lambda/2 \) dipole if the each leg is 16 \( \times \lambda/2 \) i.e. 8 \( \lambda \) long. The apex angle for a particular V antenna structure is also important. This apex angle varies according to length of the leg. It varies between 36° to 72° for a V antenna structure of 8 \( \lambda \) to 2 \( \lambda \) long. If the V antenna is to be operated over a wide range, the apex angle is made the average between the optimum for the highest and lowest frequencies in terms of the number of \( \lambda/2 \) in each leg.

V antenna provides multiband operation so it can conveniently be fed by tuned feeders. If non resonant lines are to be used, probably a better matching system is to use a \( \lambda/4 \) matching section or stub. The resonant V antenna is perhaps the one of the cheapest forms of receiving or transmitting antenna for providing a low angle beam for fixed frequency operation in HF band. One of the serious drawback of V antenna is that it provides strong minor lobes too.

4. **Write a short note on the inverted V antenna?**

**Ans:**

**Inverted V antenna**

Antennas are to be operated on a number of allotted frequencies, travelling wave antennas are employed for the purpose. Travelling wave antennas are those antennas in which there are no standing waves and waves travel in only one direction. Travelling wave distribution is obtained simply by terminating one end of antennas by a non-inductive resistance of value equal to its characteristic impedance. Such antennas are also called as aperiodic or non-resonant antennas. By doing so, the band width is increased. Inverted V antenna used in high frequency band, is one of the travelling wave antenna. A travelling wave antenna for low frequency reception is antenna already discussed.

As shown in Fig 4.4.1 the inverted V installed on a mast. Unlike flat V, inverted V antenna is easily non-conducting
requires only one mast as against 3 in the former. The direction of maximum radiation is towards terminated end as shown. The input from transmitter is fed at point C through a transmission line. The other end is connected to a number of radial earth wires. The next end of the Antenna wire D is terminated with a resistor which itself is connected to the radial earth wide.

The value of resistor is generally of $400\, \Omega$ and is adjusted to set substantially travelling waves in the antenna wire CBD. The length of legs of V antenna is $8\, \lambda/2$ at the highest frequency and $4\, \lambda/2$ at the lowest frequency. Although legs of length $2\, \lambda/2$ is also employed.

The angle $\theta$ is known as tilt angle and for a given number of wave length $L/\lambda$ in leg CB is a compromise between two factors e.g.

(i) Angle of major lobe corresponding to $L/\lambda$
(ii) Angle of tilt for which the fields from BC and BD will combine to give maximum gain.

From the Fig. 4.4.1 the lobes A and B' will be cancelled out but B and A' should be made to combine at a distance. But since these lobes are on opposites of the wire, a phase reversal is needed. This can be achieved either by reversal of current fed at a point B or by spacing towards the $R_c$. Ultimately a optimum value of $\theta$ is determined by taking a average value. This angle ranges from 36° to 71°.

The disadvantages in the inverted V antenna are that it has considerable undesired minor lobes due to the other portion of the radiating lobes. These minor lobes emits horizontally polarized wave in some directions and hence this inverted V antenna may also receive some horizontally polarized waves from these waves.

5. Explain the constructional features and characteristics of a rhombic antenna?

Ans: Rhombic antenna which is over the ground figure 4.5.1.

![Fig. 4.1 Inverted V antenna](image-url)
It consists of two wires arranged in the form of diamond or rhombus. The basic principle of rhombic antenna depends upon the travelling wave radiator. Rhombic antenna is used for both transmission and reception. In case of transmission, the input is applied through a feed line and receiving end is terminated by characteristic impedance. The rhombic antenna is similar to the two V-antennas connected in series and is suitable for point-to-point communication. The each arm of the rhombic antenna produces a pattern as shown in figure 4.5.2. The lobes BCEG are producing the resultant field pattern at the receiving end which is terminated by characteristic impedance. The remaining lobes such as ADFG are also participating in the radiation pattern process and which are going to increase the directivity of the resulting signal further. Radiation pattern of rhombic antenna as shown in figure 4.5.2. The gain of rhombic antenna is increased by adding four lobes BDEK and tilt angle is equal to the angle of major lobe minus 98.

![Fig 4.5.1 Rhombic Antenna](image1)

**Construction of Rhombic Antenna**

Construction of rhombic antenna depends upon three major factors. They are,

1. Tilt angle(θ)
2. Leg length(L)
3. Height above ground (h).

Basically, there are two types of design. They are,

1. Alignment design
2. Maximum output design.

This classification is based upon the elevation angle(β).

1. **Alignment design**

In alignment design, the height h above ground is selected such that, angle of main beam is equal to the elevation angle (β). General expression for height is,
Leg length, \( L = \frac{0.37\lambda}{\sin^2\beta} \) and

Tilt angle, \( \theta = 90^\circ - \beta \)

**2. Maximum output design**

In maximum output design, the height \( h \) above ground is selected such that, the maximum field strength is obtained from desired elevation angle \( \beta \). The values of tilt angle \( \theta \), leg length \( L \) and height above ground \( h \) is calculated below. In vertical plane, the relative field intensity of rhombic antenna is,

\[
E = \frac{2\cos\theta \cdot \sin(2\pi h \sin\beta / \lambda) \cdot \sin(\pi L / \lambda) \cdot (1 - \cos\beta \cdot \sin\theta)^2}{(1 - \cos\beta \cdot \sin\theta)}
\]

Where,

- \( E \) = Electric field strength (V/m)
- \( \beta \) = Elevation angle
- \( L \) = Leg length
- \( \lambda \) = Operating wavelength
- \( h \) = Height above ground.

From above field strength equation, we calculate the values of leg length \( L \), height \( h \) and tilt angle \( \theta \).

**Advantages of Rhombic Antenna**

1. Rhombic antennas are very much useful for radio communication.
2. It is useful for long distance propagation because of low vertical angle of radiation.
3. The input impedance of single wire antenna is half of the impedance of rhombic antenna.
4. The performance of rhombic antenna is measured in terms of leg length, height and tilt angle.
5. Single wire antennas have less receiving power along main axis whereas, rhombic antennas have more receiving power. So, rhombic antennas are highly directional broadband antennas.
6. The input impedance and radiation pattern does not depend upon frequency so, rhombic antennas are used in broadside arrays.
7. Rhombic antennas are untuned and easily convert from one frequency to another frequency.

**Disadvantages of Rhombic Antenna**

1. Transmission efficiency of rhombic antenna is very less.
2. It requires more space.
6. Sketch and explain the constructional features of a helical antenna?

Ans:

Helical Antenna

Helical antenna is useful at very high frequency and ultra high frequencies to provide circular polarization. Consider a helical antenna as shown in figure 4.6.1.

Here helical antenna is connected between the coaxial cable and ground plane. Ground plane is made of radial and concentric conductors. The radiation characteristics of helical antenna depend upon the diameter (D) and spacing S.

![Fig 4.6.1 Helical antenna and its radiation pattern](image)

In the above figure,

- \( L \) = length of one turn = \( \sqrt{S^2 + (\pi D)^2} \)
- \( N \) = Number of turns
- \( D \) = Diameter of helix = \( \pi D \)
- \( \alpha \) = Pitch angle = \( \tan^{-1}(S/\pi D) \)
- \( l \) = Distance between helix and ground plane.

Helical antenna is operated in two modes. They are,

1. Normal mode of radiation
1. **Normal mode of radiation**

Normal mode of radiation characteristics is obtained when dimensions of helical antenna are very small compared to the operating wavelength. Here, the radiation field is maximum in the direction normal to the helical axis. In normal mode, bandwidth and efficiency are very low. The above factors can be increased, by increasing the antenna size. The radiation fields of helical antenna are similar to the loops and short dipoles. So, helical antenna is equivalent to the small loops and short dipoles connected in series.

We know that, general expression for far field in small loop is,

\[ E_\Phi = \{120 \pi^2[I] \sin\theta/r\}[A/\lambda^2] \]

Where,
- \( r = \) Distance
- \( I = I_0 \sin(\omega(t-r/C)) = \) Retarded current
- \( A = \) Area of loop = \( \pi D^2/4 \)
- \( D = \) Diameter
- \( \lambda = \) Operating wavelength.

The performance of helical antenna is measured in terms of Axial Ratio (AR). Axial ratio is defined as the ratio of far fields of short dipole to the small loop.

Axial Ratio, \( AR = |E\theta|/|E\Phi| \)

2. **Axial mode of radiation**

Helical antenna is operated in axial mode when circumference \( C \) and spacing \( S \) are in the order of one wavelength. Here, maximum radiation field is along the helical axis and polarization is circular. In axial mode, pitch angle lies between 12° to 18° and beam width and antenna gain depends upon helix length \( NS \).

General expression for terminal impedance is,

\[ R = 140C/\lambda \text{ ohms} \]

Where,
- \( R = \) Terminal impedance
- \( C = \) Circumference.

In normal mode, beam width and radiation efficiency is very small. The above factors increased by using axial mode of radiation. Half power beam width in axial mode is,

\[ \text{HPBW} = 52/C\sqrt{\lambda^3/NS} \text{ degrees.} \]

Where,
- \( \lambda = \) Wavelength
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C = Circumference
N = Number of turns
S = Spacing.
Axial Ratio, AR = 1 + 1/2N

7. Distinguish between Resonant and non-resonant antennas.

Ans:

Difference between Resonant and Non-resonant Antennas

<table>
<thead>
<tr>
<th>Resonant Antenna</th>
<th>Non-resonant Antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. These correspond to a resonant transmission line that is an exact number of half wave length long and is open at both ends.</td>
<td>1. These correspond to a transmission line that is exited at one end and terminated with characteristic impedance at the other end.</td>
</tr>
<tr>
<td>2. Because of incident and reflected waves, standing waves exist.</td>
<td>2. Due to the absence of reflected waves, standing waves do not exist.</td>
</tr>
<tr>
<td>3. The radiation pattern of this antenna is bi-directional.</td>
<td>3. The radiation pattern of this antenna is uni-directional.</td>
</tr>
<tr>
<td>4. These antennas are used for fixed frequency operations.</td>
<td>4. These antennas are used for variable and wide frequency operations.</td>
</tr>
<tr>
<td>5. Resonant antenna</td>
<td>5. Non-resonant antenna</td>
</tr>
<tr>
<td><img src="image1" alt="Long wire resonant antenna." /></td>
<td><img src="image2" alt="Long wire non-resonant antenna." /></td>
</tr>
<tr>
<td>6. Radiation pattern</td>
<td>6. Radiation pattern</td>
</tr>
<tr>
<td>Bi-directional radiation pattern.</td>
<td>Uni-directional radiation pattern.</td>
</tr>
</tbody>
</table>

8. Distinguish between travelling wave and standing wave antennas.

Ans:

<table>
<thead>
<tr>
<th>Travelling Wave Antennas</th>
<th>Standing Wave Antennas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Question and Answers

| 1. Travelling wave antenna is one, in which standing waves does not exist.          | 1. In standing wave antenna, standing wave exists.          |
| 2. Travelling wave antennas are also known as aperiodic or non-resonant antenna.   | 2. Standing wave antennas are also known as periodic or resonant antennas.   |
| 3. Reflected wave does not appear in travelling wave antennas.                     | 3. Reflected wave appears in standing wave antenna.                     |
| 4. Radiation pattern of travelling wave antenna is uni-directional.                | 4. Radiation pattern of standing wave antenna is bi-directional.          |
| 5. Uni-directional pattern for $n = 4$ is shown in figure. Here, $n =$ Number of wave lengths. | 5. Bi-directional pattern for $n = 3$ is shown in figure.          |
| 6. Directivity is more.                                                           | 6. Directivity is less.                                                   |
| 7. The length of wire increases, major lobes get closer and narrower to the wire axis. | 7. Length of wire does not depend upon the lobes.                       |

#### 9. Draw the radiation pattern for travelling wave antenna for $L = \lambda/2, \lambda, 2\lambda, 4\lambda, \text{ and } 8\lambda$.  

**Ans:**  
For $L = \lambda/2$

![Radiation Pattern for L = \lambda/2](image1)

Directivity = 1.25

For $L = \lambda$

![Radiation Pattern for L = \lambda](image2)
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Directivity = 2

For \( L = 2\lambda \).

Directivity = 2.9

For \( L = 4\lambda \).

Directivity = 4.2

For \( L = 8\lambda \).
10. **Distinguish between Narrow band and Wide band antennas.**

**Ans:**

<table>
<thead>
<tr>
<th>Narrow Band Antennas</th>
<th>Wide Band Antennas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Since, the bandwidth of receiving antenna is narrow, it is difficult for high-speed data communication.</td>
<td>1. Since, the bandwidth of receiving antenna is very high, it is very easy for high-speed data communication.</td>
</tr>
<tr>
<td>2. These are bigger in size.</td>
<td>2. These are small in size.</td>
</tr>
<tr>
<td>3. Because of the constitution of narrow band radio module, these are more expensive.</td>
<td>3. These are less expensive than narrow band antennas.</td>
</tr>
<tr>
<td>4. These antennas can realize stable long range communication.</td>
<td>4. Because of large bandwidth, these are not suitable for long range communication.</td>
</tr>
<tr>
<td>5. These antennas lead to the high efficiency of radio wave use within same frequency band.</td>
<td>5. These antennas lead to the less efficiency of radio wave use within same frequency band.</td>
</tr>
</tbody>
</table>
UNIT 5

1. What is parasitic element? Describe the use of different types of parasites in TV receiving antennas?

Ans:

Parasitic Element
A radio antenna element which does not have any wired input is known as parasitic element. It absorbs radio waves radiated from another active antenna element in proximity and reradiates it in phase with the active element, so that it adds to the total transmitted signal. This will change the antenna pattern and beam width.

Usage of Different Types of Parasites in TV Receiving Antennas

Basically, there are two different types of parasites used in TV receiving antennas. They are,

1. Reflector
2. Director.

The above parasitic elements (i.e., passive elements which are not connected directly to the transmission line but electrically coupled) are able to receive their induced voltage by the current flow in the driven element. The phases of the currents are determined by the spacing between elements and the lengths of the parasitic elements. Using the parasitic elements, we can either reflect or direct the radiated energy, so that a compact directional antenna system can be obtained. A parasitic element of length less than $\frac{\lambda}{2}$, will be capacitive while the elements of length equal to or greater than $\frac{\lambda}{2}$, will be inductive. Thus, the phases of currents in the former case will lead the induced voltage and in the later case will lag the induced voltage.

The director which is shorter than driven element used to add the fields of driven element in the direction away from the driven element. In case of more than one directors, each one is used to excite the next director. The reflector which is equal to or greater than driven element, used to add up the fields of driven element in the direction from reflector to driven element. Further, the use of parasitic elements in conjunction with driven element causes the dipole impedance to fall below $73\Omega$.

Gain up to 12 dB is also achieved by using additional directors at an interval of 0.15 $\lambda$ in the beam direction. When the distance between driven and director elements is increased, the capacitive reactance needed to provide correct phasing of parasitic current is also more. The variations in the distance between driven element and parasitic element allow us to make the radiation pattern as unidirectional by changing the relative phases. Practically, a parasitic element shortened by 5% with respect to driven element acts as director and lengthened by 5% acts as reflector. The parasitic antennas which are properly designed with a large front to back ratio are having special use at higher frequencies between 100-1000 MH.
2. Explain the working of Yagi antenna?

Ans:

Yagi-Uda Antenna

It consists of a reflector, a driven element and one or more directors. Consider the arrangement of Yagi-Uda antenna shown in figure 5.2.1 below. Here resonant half-wave dipole acts as a driven element and parasitic elements are arranged parallel to the driven element.

Fig 5.2.1 (a) Yagi-Uda Antenna  (b) Its Radiation Pattern

Here,
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D - Director or Parasitic element
R - Reflector or Parasitic element
Dr - Driven element.

The current flowing through the director depends upon the voltage induced in the parasitic elements. The spacing between the driven element and parasitic element is approximately 0.1 \( \lambda \) (or) 0.15 \( \lambda \).

The driven element is placed between two parasitic elements. The parasitic element in the back of the driven element is known as reflector and in front of the driven element is known as director. The length of director is approximately 0.45 \( \lambda \) and reflector is 0.55 \( \lambda \). The length of director, reflector and parasitic element depends upon the frequency. The general expressions for 3-element Yagi-Uda antenna is,

- Reflector length = \( \frac{500}{f(MHz)} \) feet
- Director length = \( \frac{455}{f(MHz)} \) feet
- Driven element length = \( \frac{475}{f(MHz)} \) feet

The length of parasitic element determines its reactance. If the length is equal or greater than \( \frac{\lambda}{2} \), it will be inductive and less than \( \frac{\lambda}{2} \), it will be capacitive.

(i) If the less than \( \frac{\lambda}{2} \), the current lags the induced voltage.
(ii) If the length is greater than \( \frac{\lambda}{2} \), the current leads the induced voltage.

Hence there is 180° phase difference between the parasitic elements, and therefore which can be analyzed as an end fire-array. Yagi-Uda antenna is also known as super gain antenna because the gain can be increased by adding a number of directors after the driven element. The distance between any two elements range from 0.1 \( \lambda \) to 0.3 \( \lambda \). As the distance between the driven element and parasitic element reduces, the input impedance of driven element reduces.

3. List out the differences between the active and passive corner reflectors. What are retro reflectors?

Ans: Backward radiations from an antenna can be eliminated by using plane conducting sheets as reflectors. When two flat sheets intersecting at an angle \( \alpha \) are used as reflectors, then such an arrangement is called corner reflector. Corner reflectors are of two types. They are,

(i) Active corner reflector
(ii) Passive corner reflector.

(i) Active Corner Reflector
When two flat sheets intersecting at an angle \( \alpha < 180^\circ \) with a driven element producing a sharp radiation pattern, then such an arrangement is called active corner reflector. The opening of the corner or aperture should be in the range of 1\( \lambda \) to 2\( \lambda \).
(ii) Passive corner reflector

When two metal sheets intersecting at an angle $\alpha = 90^\circ$ without any driven element used, it reflects back the entire incident wave towards its source. Such an arrangement is called passive corner reflector. The main characteristic differences between an active and passive corner reflector are,

(a) Absence of driven element
(b) Angle of corner ($\alpha$)
(c) Aperture length.

(a) Absence of driven element

There is no driven element present in passive corner reflector, hence spacing of the antenna from corner and corner with antenna is not a concern.

(b) Angle of corner

The angle of corner in passive corner reflector should always be equal to $90^\circ$ ($\alpha = 90^\circ$) whereas in active corner reflector it can have any value satisfying $\alpha < 180^\circ$, practically it can be $\alpha = 180^\circ / n$ where $n$ is any positive integer.

(c) Aperture Length

The passive corner reflector should have the aperture length equal to several wavelengths whereas in active corner reflector the aperture length should be limited up to $\lambda$ or $2\lambda$.

Passive reflectors are used in radar applications and active corner reflectors are used in wide band applications.

Retro reflectors
A passive corner reflector is also called as retro corner reflector. It consists of 3 mutually perpendicular reflecting sheets intersecting each other at the centre producing eight 3-dimensional square-corner reflectors. Each square corner occupies one octant (5157 square degree) and 8 square corners occupy a full sphere solid angle of 41, 253 square degree. The cluster of 8 square corners together is called a Retro reflector. The maximum value of reflecting area is \( \sqrt{3}d^2 \) from any direction out of total area of \( 4d^2 \). The retro reflector is used in radar applications. The metal sheets can be replaced with mesh having lengths equal to several \( \lambda \) and mesh holes \( \lambda/2 \) and surface should be flat in the vicinity of \( \lambda/16 \).

To improve the aperture area to \( 3/4 d^2 \), the reflector is truncated along the diagonal lines, hence a uniform echo area is obtained.

4. With reference to paraboloids, explain the following,
   (i) Aperture efficiency
   (ii) Front to back ratio of feeds.
   (iii) Types of feeds.

Ans:

- **Aperture efficiency**
  
- **Front to back ratio of feeds.**

- **Types of feeds**

  ![Fig 5.3.2 Retro Reflector](image)

  Where,
  
  \( A_e = \text{Effective aperture area} \)
  
  \( A_p = \text{Physical area of reflector} \)
  
  \( \eta = \frac{A_e}{A_p} \)
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Physical area, \( A_p = \frac{\pi D^2}{4} = \pi r^2 \)

Where, \( D \) – Diameter

(ii) **Front to Back Ratio**

Radiation pattern of paraboloids is a combination of front side radiation and back side radiation. Front to back ratio is defined as the ratio of power radiated in desired direction to the power radiated in opposite direction. Back radiation is a function of spill over and edges of diffraction.

(iii) **Types of Feed**

Feed systems are used to improve aperture efficiency and effective area. Paraboloid feed systems are classified into,

- (a) Cassegrain feed
- (b) Gregorian feed
- (c) Offset feed.

(a) **Cassegrain Feed**

Cassegrain principle is an optical technique widely used in telescope construction. The same principle is used to build cassegrain antenna used in microwave region. Cassegrain feed is a dual reflector system with the larger primary reflector having a parabolic surface and a secondary sub-reflector with a hyperbolic contour in order to achieve uniform illumination of the primary reflector. This arrangement is shown in the figure 5.4.1.

(b) **Gregorian Feed**

These forms are the variations from Cassegrain form which employ a different form of main reflectors and sub-reflectors. The convex, concave or even flat shapes may be used. A classical Gregorian reflector form is shown in figure 5.4.2.
Here the focal point of the main dish is moved to the region between the two dishes, a concave elliptical sub-reflector is used.

(c) Offset Feed
To overcome the disadvantage of Cassegrain feed we go for offset feed as shown in figure 5.4.3.

Fig 5.5.1 Folded Dipole Antenna Arrangement

5. Write short notes on folded dipole?
Ans: A very important variation of conventional half-wave dipole is the folded dipole. One of the application of the folded dipole is impedance matching. A folded dipole is made of two half-wave dipoles, one continuous and the other split at the centre. Both have been folded and joined together in parallel at the ends, as shown in Fig. 5.5.1. The split dipole is fed at the centre by a transmission line, which is balanced.
The radiation pattern of a folded dipole is same as the conventional half-wave dipole, but the input impedance of the former is higher. A folded dipole differs from the conventional dipole mainly in two aspects viz, directivity and broadness in bandwidth. The directivity of a folded dipole is bidirectional, but because of the distribution of currents in the parts of the folded dipole, the input impedance becomes higher. As the radii of the 2 conductors are equal, the current flow in the two dipoles are equal in magnitude and phase. As the total power developed in folded dipole is equal to that developed in a conventional dipole, the input terminal impedance of the folded dipole, is therefore greater than that of the conventional dipole. The input impedance at the terminals of the folded dipole antenna is equal to the square of the number of conductors comprising the antenna times the impedance at the terminals of a conventional dipole.

Advantages of Folded Dipole

Other than impedance matching or transformation, folded dipoles can be used in wide band operation such as televisions. The folded dipole has the following advantages,

a. High input impedance
b. Wide band in frequency

6. Write short notes on Corner Reflector Antenna?

Ans:

Corner reflector antenna

Corner reflector antenna is an arrangement with a corner reflector i.e., flat reflecting sheets meeting at an angle or corner, and a driven antenna, generally a half wave dipole as shown in Fig.5.6.1. If corner angle $\beta = 90^\circ$ then the two flat sheets meeting at right angles form a square corner reflector shown in Fig.5.6.2.
When the driven antenna is used in conjunction with the corner reflector, the arrangement is an effective or active directional antenna for a wider range or corner, i.e. $0 < \beta < \pi$. The square corner reflector without the driven antenna is an effective passive reflector over a wide range of angles of incidence ($0 < \theta < \pm \pi/4$).

**Applications**

Corner reflectors are extensively used in applications like

(a) Television

(b) Point to point communication

(c) Radio Astronomy.

The advantage of using corner reflector for these applications lies in the increased power gain of 10 to 13 db (10 to 20 times that of an isolated half wave dipole antenna with reasonable radiation resistance).
7. Distinguish between spherical and cylindrical paraboloids. Comment on their efficiency and applications.

**Ans:**

<table>
<thead>
<tr>
<th><strong>Cylindrical</strong></th>
<th><strong>Spherical</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A cylindrical paraboloid is shown in the following figure.</td>
<td>1. A spherical paraboloid is shown in the following figure.</td>
</tr>
<tr>
<td><img src="image1" alt="Cylindrical" /></td>
<td><img src="image2" alt="Spherical" /></td>
</tr>
<tr>
<td>2. The most widely used feed for this paraboloid is a linear dipole, a linear array or a slotted waveguide.</td>
<td>2. The most widely used for this paraboloid is a pyramidal or conical horn.</td>
</tr>
<tr>
<td>3. The amplitude taper, is proportional to $1/p$.</td>
<td>3. The amplitude taper, is proportional to $1/r^2$.</td>
</tr>
<tr>
<td>4. The focal region, where incident plane wave.</td>
<td>4. The focal region where incident plane wave converge is a point source (focal point).</td>
</tr>
<tr>
<td>5. No cross-polarized components are produced.</td>
<td>5. Cross-polarized components are produced.</td>
</tr>
<tr>
<td>6. Simpler to build.</td>
<td>6. Compared to cylindrical paraboloids, complex to build.</td>
</tr>
<tr>
<td>7. Provide larger aperture blockage.</td>
<td>7. Provide lesser aperture blockage.</td>
</tr>
</tbody>
</table>
| 8. Aperture efficiency,  
\[ \eta_a = (D\lambda^2/4\pi A) \] | 8. Aperture efficiency,  
\[ \eta_a = (D\lambda^2/4\pi A) \] |
| 9. This is used in,  
(i) Low – noise application as radio astronomy.  
(ii) Satellite ground based systems. | 9. This is used in,  
(i) Radio astronomy.  
(ii) Small- earth station applications. |
8. Compare corner reflector and parabolic reflector.

**Ans:**

<table>
<thead>
<tr>
<th><strong>Corner Reflector</strong></th>
<th><strong>Parabolic Reflector</strong></th>
</tr>
</thead>
</table>
| 1. The corner reflector consists of two flat conducting plates that meet at $\beta'$ angle forming a corner as shown in the following figure.  
*Fig 5.8.1 Corner Reflector* | 1. The parabolic reflector is formed by the revolution of parabola along its axis as shown in the following figure.  
*Fig 5.8.2 Parabolic Reflector* |
| 2. The corner reflector does not need a directional feed as the direct and reflected rays are combined as per image theory. | 2. This reflector should have a directional feed to avoid spill over, so that feed should be radiated maximum into parabolic surface. |
| 3. There is no need to place feed at focal point perhaps, no focal point exists in this reflector. | 3. Feed should be placed at focal point only, so that maximum radiation occurs on to the surface of reflector. |
| 4. Corner reflectors are used for small apertures only. | 4. Parabolic reflectors are used for both small and very large apertures. |
| 5. The gain of corner reflectors depends on length of plates and ‘d’ at a particular ‘$\beta$’. | 5. The gain of parabolic reflector depends on aperture ratio $(D/\lambda)$ i.e., on focal points position. |
| 6. Corner reflector antennas are simple and easy to build. | 6. They are complex and costlier. |
| 7. Corner reflector provides applications in radar field, stealth mode for military, and TV reception in homes. | 7. These are widely used in radio astronomy. |
9. With reference to paraboloids. Explain,
   (i) Aperture blocking (ii) F/D ratio (iii) Spill over.
   Ans:
   (i) **Aperture blocking**

   Aperture blocking is the undesirable phenomenon associated with a Cassegrain feed reflector where the primary reflector is obstructed by the sub-reflector.

   ![Aperture Blocking Diagram]

   If the dimensions of paraboloid are small, the effect of aperture blocking is significant. To minimize this, the sub-reflector should be small compared to the parabola. Aperture blocking can be eliminated by employing offset feed.

   (ii) **F/D Ratio**

   In the case of paraboloids, the ratio of focal length to dish diameter is referred as the F/D ratio. The F/D ratio exhibited by a paraboloid reflector with a diameter of 3 m and a focal length of 1.26 m is 0.42. The F/D ratio considered by the antenna designer also calculates the depth of the dish i.e., the amount of contour of the paraboloid within its fixed diameter. A high F/D (long focus) paraboloid reflector will have a shallow contour and where as a low F/D (short focus) paraboloid reflector represents a deep bowl. The minimum value of F/D ratio is 0.25, which places the focal point directly in the plane of the aperture antenna.

   In antenna design, a small value of F/D ratio requires a feed horn that has a wider beam width and a large value of F/D ratio requires a feed horn that has a narrower beam width.

   (iii) **Spill Over**

   The waves originating from focus will be reflected parallel to the axis of parabola. Some of the waves originating from focus may not fall on the parabola. This phenomenon is called spill over.
10. Explain the cassegrain mechanism in transmission mode. List out the advantages and disadvantages of cassegrain feed?

Ans:

Cassegrain feed

Cassegrain principle is an optical technique widely used in telescope construction. The same principle is used to build cassegrain antenna used in microwave region.

Advantages of Cassegrain Feed Arrangement

1. The paraboloid surface is more uniformly illuminated.
2. There is less spill over reducing interface.
3. Shorter wave guide feed of the horn results in lower feed losses.
4. There is a greater reduction in side-lobe power.
5. The noise level is lower due to small cross-section.
6. There are lesser polarization errors.

Disadvantages

1. Design of the entire antenna system is with critical mechanical alignment and is complex.

Uses

1. Cassegrain feed arrangement is extensively used in Monopulse Radar.
2. Low noise temperature makes this antenna very important for radio astronomy, microwave communication and satellite tracking.
UNIT 6

1. What is meant by zoning? What are their advantages?

**Ans:** Lens, antennas are suitable for frequencies above 3000 MHz. If the frequency is less than 3000 MHz, lens antennas have more thickness. The thickness of lens antennas can be reduced with the help of zoning. Thickness \( t \) is given by,

\[
  t = \frac{\lambda}{\mu - 1}
\]

Where,

- \( t \) = Thickness
- \( \lambda \) = Free space wavelength
- \( \mu \) = Refractive index \( = \frac{c}{v} \)

Zoning is classified into two types

(i) Curved surface zoning

(ii) Plane surface zoning.

(a) Curved Surface Zoning

1. In curved, surface zoning stepping or zoning is done to the curved surface of lens antenna.

2. Thickness of curved surface zoned lens is \( t = \frac{\lambda}{\mu - 1} \)

3. Curved surface zoned lens is mechanically stronger than the plane surface zoned lens,

4. Curved surface zoning lens antennas have less weight and less power dissipation

5. Example

(b) Plane Surface Zoning

1. In plane surface zoning stepping or zoning is done to the plane surface.

2. Thickness of plane surface zoned lens is, \( t = \frac{\lambda}{\mu - 1} \)

3. Plane surface zoned lens is less strong

4. Here the power dissipation is more.
Curved surface zoning is preferable compared to the plane surface zoning.

Advantages of Zoning
1. This process reduces the weight of lens considerably.
2. The zoned dielectric lens antenna ensures that signals are in phase after emergence, despite difference in appearance.
3. The zoned lens is having less power dissipation.

Disadvantage
The zoned lens antennas are frequency sensitive i.e., they are dependent on wavelength, $\lambda$.

2. Explain the basic principal of operation of lens antenna and also distinguish between natural dielectric and artificial dielectric lenses.

Ans:
Lens antennas work on the principle of refraction. Lens antennas are made of a dielectric material. Figure 2.1(a) illustrates the principle of operation of such an antenna. A point source of radiation is placed at the focus of the km. The rays arriving at the lens closer to the edges of the lens encounter a larger curvature as compared to those arriving at the center portion of the lens. The rays closer to the edges are refracted more than the rays closer to the center.

On reception the rays arriving parallel to the lens axis are focused on to the focal point where the feed antenna is placed. Figure 2.1(b) shows that spherical waves emitted by the point source are transformed into plane waves during transmission. The reason for this is that those portions of the wave front closer to the center are slowed down relatively more than those portions that are closer to the edges, with result that outgoing waves are planar. The same way plane waves incident on the lens antenna during reception emerge as spherical waves travelling towards the feed.

The precision with which these transformations take place depends upon the thickness of the lens in terms of operating wavelength. This makes the lens antennas less attractive at lower microwave frequencies.
Differences between Natural Dielectric Lenses and Artificial Dielectric Lenses

1. Artificial dielectric lenses have less weight compared to natural dielectric lenses.

2. Artificial dielectric lenses are made up of discrete metal particles whereas natural dielectric lenses consist of molecular particles.

3. Natural dielectric lenses, does not have any resonant effect

Characteristics

1. Both type of lens can be used to speed up (or) delay the travelling wave front.

2. Artificial and natural dielectric lenses are not much dependent on the wavelength.

3. The variation in thickness front ideal contour and variations in refractive index causes change in path length.

4. Lenses may be turned frequency sensitive with the help of zoning.

5. The thickness of lens antenna depends upon the refractive index \((n)\). Thickness can be increased by reducing the refractive index.

6. The design conditions of artificial and natural dielectric lens antennas are same for same refractive index.

Merits and Demerits

1. Artificial dielectric lenses have less weight compared to the natural dielectric lenses.

2. Disadvantage of artificial dielectric lens is that they may have resonance effects.

3. Power dissipation is more in natural dielectric lenses.

3. Distinguish between sartorial, pyramidal and conical horns. Explain their utility?

Ans: Horn Antenna:

A Horn Antenna is similar to the opened out waveguide. It is excited at one end and kept opened at the other to get the energy radiated out of it.

The radiation is more from a waveguide compared to two wire transmission lines.

The amount of energy radiated from (out of) the waveguide is very less compared to the reflected energy due to impedance mismatch. In order to overcome the non-directive radiation pattern and poor radiation, we use horn antenna. The horn antenna is similar to the opened waveguide only difference is abrupt discontinuity is replaced by a gradual transformation.

Horn antennas are classified as,

1. Sectoral horn antenna
2. Pyramidal horn antenna
3. Conical horn antenna.

Depending upon the flaring, all the above horn antennas are classified.

Sectoral Horn Antenna

When the flaring is done at only one particular direction, it is known as sectoral horn antenna, depending upon the direction of flaring, sectoral horn antenna is classified as,

(i) H-plane sectoral horn antenna
(ii) E-plane sectoral horn antenna.
If the flaring is done to the walls of circular waveguide it is known as **Conical Horn** as shown below.

The main function of electromagnetic horn antenna is the impedance matching and to produce uniform phase front with a larger aperture to provide greater directivity. The general equation for flare angle ($2\theta$) in horn antenna is given as,

$$\theta = \tan^{-1}(h/2L) = \cos^{-1}(L/L + \delta)$$

and $L = h^2/8\delta$

Here,
- $h$ = Height of horn antenna
- $L$ = Axial length
δ = Permissible phase angle variations expressed as a fraction of 360° and 1
θ = (1/2) of flare angle.

The above equations are design conditions of horn antenna. If the value of flare angle (26) is very large, the wave front on the mouth of the horn antenna will be curved rather than plane.

General expressions for Half Power Beam Width (HPBW) of optimum flare horn in E and H directions, is given approximately as,

\[ \theta_E = \left( \frac{56 \lambda}{h} \right) \text{ and } \theta_H = \left( \frac{67 \lambda}{\omega} \right) \]

Uses:
1. Horn antennas are generally used at microwave frequencies for moderate power gain.
2. Horn antennas are also used as a universal standard for calibration and gain measurement of other high gain antennas.
3. They are also used as primary radiators for reflector antennas.

4. What is the principal of equality of path length? How is it applicable to horn antenna and also explain the Frii’s transmission formula and its applicability for gain measurements?

Ans:

All the rays from the source to the plane surface of a lens will have equal path lengths as shown in the figure below.

Principal of equality of path Lengths
All the rays from the source to the plane surface of a lens will have equal path lengths as shown in the figure below.

This principle is also applicable if we consider the source of electromagnetic radiations at 'O'.

Hence, if the waves coming out of 'O' are made to reach the aperture 'xy' at the same time, by properly designing the lens, they will all be in phase producing a uniform beam of radiation.

The same principle is applicable to the horn antennas. The horn antennas are designed so that the waves coming out of the plane of horn mouth is in phase with a slight deviation (not more than a specified amount).

This can be achieved by properly selecting the flare angle '2θ'. If the flare angle is greater than the optimum value, the waveform on the mouth of the horn will be curved which results in poor directivity. If the flare angle is less than optimum, the directivity again decreases due to decrease in aperture area (resulting from small flare angle).

Hence, by keeping the optimum flare angle of
2θ = 2 tan⁻¹(h/2L)
Maximum directivity can be achieved.

**First transmission formula:**

Frii’s transmission formula is used to evaluate the power received by one antenna under idealized condition given another antenna some distance away transmitting a known amount of power,

**Derivation**

Consider two antennas in free space separated by distance R.

Assume that PT watts of total power are delivered to transmit antenna. For the moment, assume that the transmit antenna is Omni directional, lossless, and the receive antenna is in the far field of the transmit antenna. Then the power ‘P’ of the plane wave incident on the receive antenna a distance ‘R’ from the transmit antenna is given by,

\[ P = \frac{P_T}{4 \pi R^2} \]  \hspace{1cm} \text{(1)}

If the transmitting antenna has a gain ‘Gr’ in the direction of the receiving antenna, then the above power equation becomes,

\[ P = \left(\frac{P_T}{4 \pi R^2}\right) G_T \]  \hspace{1cm} \text{(2)}

The gain term factors in the directionality and losses a real antenna. Assume now that the receive antenna an effective aperture given by Ae. Then the power received by this antenna Pr is given by,

\[ P_r = \left(\frac{P_T}{4 \pi R^2}\right) G_T A_e \]  \hspace{1cm} \text{(3)}

This is known as frii’s transmission formula. It relates the free space path loss, antenna gains and wavelength to the received and transmits powers.

**Measurement of Antenna Gain Using above Formula**
Assume that transmitting and receiving antennas are identical and separated by a distance ‘R’ such that

\[ R \geq \frac{2d^2}{\lambda} \]

Where, \( d \) = Depth of antenna

Since Antennas are identical, \( G_T = G_r = G_0 \).

Equation (1) can be written as

Equation (1) can be written as,

Gain of antenna using first transmission formula is,

\[
P_R = \frac{P_T G_0^2 \lambda^2}{(4\pi R)^2}
\]

\[
G_0^2 = \left( \frac{4\pi R \lambda}{P_T} \right)^2 \frac{P_R}{P_T}
\]

\[
G_0 = \frac{4\pi R \lambda}{P_T} \sqrt{\frac{P_R}{P_T}}
\]

Therefore the gain of the antenna using first transmission formula is,

\[
G_0 = \frac{4\pi R \lambda}{2} \sqrt{\frac{P_R}{P_T}}
\]

5. Write a short note on “Antenna Pattern Measurements”? 
Ans:
The antenna pattern is also termed as radiation pattern of an antenna. The radiation pattern is nothing but the plot of the intensity of radiation taken at different points that are at equal distance from the antenna. It is also defined as plot of power density with respect to the direction. The radiation pattern of an antenna is a 3-D figure. Hence, it needs intensity of radiation measurement over all spatial angles.

Let us assume a 3-coordinate Cartesian system in which the antenna, whose pattern is to be measured, is placed at the origin as shown in figure 5.1

The plane $XY$ is horizontal plane. For horizontal plane antenna, the two patterns exhibited are,

(a) The $\theta$ component of E-field (horizontal) is measured as a function of (j) in $XY$ plane $(\theta = 90^\circ)$. This is indicated as $E_\theta (\theta = 90^\circ, (j>)$ and called as $E$-plane pattern.

(b) The $\Phi$ component of E-field is measured as a function of c in $XZ$ plane $(\Phi = 0^\circ)$. This is represented as $E_\Phi = (\theta, \Phi = 0^\circ)$ and called as H-plane pattern.

These $E$-plane and H-plane patterns are mutually perpendicular to the major lobe.

The plane $XZ$ is called vertical plane and the two patterns to be measured in this plane are,

(a) The $\theta$ component of E-field is measured as a function of $\Phi$ in $XY$ plane $(\theta = 90^\circ)$. This is represented by $E_\theta (\theta = 90^\circ, \Phi)$ and called as H-plane pattern.

(b) The $\theta$ component of E-field is measured as a function of $\theta$ in $XZ$ plane $(\Phi = 0^\circ)$. This is represented as $E_\theta (\theta, \Phi = 90^\circ)$ and called as E-plane pattern.

For circularly or elliptically polarized antennas, these four patterns should be measured. The two types of techniques for measuring antenna pattern in any one of the plane are,

1. The primary antenna is fixed, and the secondary antenna is equipped for free rotation around the primary antenna in circular fashion. The field strength and direction of secondary antenna with respect to primary is noted at different points on the circular path of secondary antenna. Then, the required antenna pattern plot is made.

2. In this procedure, the primary antenna is rotated along vertical axis with respect to secondary antenna. The field strength at primary receiving antenna with respect to transmitting secondary antenna is recorded at different point on the vertical rotation path of primary antenna. Then, with recorded values, plot is made.

6. Describe the method of measuring the gain and radiation pattern of an antenna?

Ans:
Absolute Method of Gain Measurement:
To measure the absolute gain of an antenna another identical antenna is used. They are arranged at a distance V from each other as shown in the figure.

The directions of both the antennas are adjusted for maximum signal. Then the input to the transmitting antenna is adjusted to a specified level and the corresponding receiver reading is recorded, i.e., the attenuator dial setting and power bridge readings are recorded as \( W_r \) and \( P_{t1} \) respectively.

Then the transmitter is connected to the receiver directly (through pads). The attenuator dial is adjusted until the receiver shows the same previous level. Now the attenuator dial setting and the power bridge readings are recorded as \( W_r \) and \( P_{t2} \)

Since the two antennas are identical \( P_{t1} = P_{t2} \) and the gain \( G \) is calculated as,

Measurement of Field Pattern

The energy radiated by an antenna is not same in all directions it is more in one direction and less in another direction. The energy radiated by an antenna is measured in terms of field strength. Consider the general arrangement shown below.

Here primary antenna (transmitting antenna) and receiving antenna are separated by a distance of

\[
R \geq 2d^2/\lambda
\]

Depending upon the direction of rotation, the antenna support shaft is rotated.

(i) \( E_\phi (\theta = 90^\circ) \)

In this measurement, the antenna support shaft is rotated and both primary and secondary antennas are horizontal.

(ii) \( E_\phi (\theta, \Phi = 0^\circ) \)

![fig 6.1 Measurement of field pattern](image-url)
In this pattern measurement, the antenna support shaft is rotated both primary and secondary antennas are vertical. Radiation pattern of an antenna is generally expressed in terms of horizontal and vertical plane,

(a) Radiation Pattern (Horizontal and Vertical) of Horizontal Antenna

![Image of radiation pattern](image-url)
(i) $E_{\phi}(\theta=90^\circ, \Phi)$ is known as E-plane pattern because the electric field is function of $\Phi$
(ii) $E_{\phi}(\theta, \Phi=90^\circ)$ is known as H-plane pattern because the electric field is function of $\phi$.
From reciprocity theorem the pattern of an antenna is same for receiving mode and transmitting mode. Hence figure (a) and figure (b) are valid under receiving mode also.

(b) Radiation Pattern (Horizontal and Vertical) of Vertical Antenna

(i) $E_{\theta}(\theta=90^\circ, \phi = 0^\circ)$ is known as H-plane pattern because the electric field component $E_{\theta}$ as a function of $\Phi$
(ii) $E_{\theta}(\theta, \Phi = 0^\circ)$ is known as E-plane pattern because the electric field $E_{\theta}$ as a function of $\phi$

After calculation of radiation pattern directivity can be calculated as follows. Directivity is defined as the ratio of maximum radiation intensity to the average radiation intensity.
7. Explain the impedance measurement of a horn antenna by using slotted line method with necessary relations?

**Ans:**

**Slotted Line Method for Impedance Measurement**

Measurement of antenna impedance depends upon the frequency. Impedance measurement can be done by two methods,

1. Bridge method
2. Slotted line method,

The slotted line method is of practical importance at frequencies 30 MHz - 1000 MHz. The block diagram of slotted line method is shown below.
In this method, impedance of antenna is determined from the voltage and current standing wave ratio. So that, this method is also known as "Standing wave ratio method".

The load impedance (or antenna input impedance) \(Z_L\) is given by,

\[
Z_L = \frac{Z_0 (1+K)}{(1+K)}
\]

Where,
- \(Z_L\) = Load impedance
- \(Z_0\) = Characteristic impedance
- \(K\) = Reflection coefficient

Voltage standing wave ratio is defined as the ratio of maximum voltage to the minimum voltage.

\[
V_{SWR} = \left| \frac{V_{max}}{V_{min}} \right|
\]

\[
V_{SWR} = \frac{|Vi|+|Vr|}{|Vi|-|Vr|}
\]

\[
V_{SWR} = \frac{1+|Vr|/|Vi|}{1-|Vr|/|Vi|}
\]

Where,
- \(Vr\) = Reflected voltage
- \(Vi\) = Incident voltage

The ratio of reflected voltage to the incident voltage is known as reflection coefficient

\[
K = \frac{|Vr|}{|Vi|}
\]

Therefore

\[
V_{SWR} = \frac{1+|K|}{1+|K|}
\]

i.e. \(|K| = \frac{V_{SWR} - 1}{V_{SWR} + 1}\)
and phase angle, \( \theta = 180 \left( 1 - \frac{4d}{\lambda} \right) \)

8. Explain the method of measurement of HPBV of a horn antenna in H-plane with a neat sketch and also explain the method to find the directivity of the horn antenna?

**Ans:** Measurement of HPBW

Measurement of Half power beam width depends upon the radiation patterns. We know that half power beam width is defined as the product of beam angle in electric and magnetic field direction.

\[ \text{HPBW} = \theta_e \cdot \theta_h \]

The graph of various values of \( \theta \) corresponding to the field is shown below.

Beam width is defined as angular width in degrees (or) maximum width of beam pattern. From figure, beam width is 3 dB (or) - 3 dB.
Without knowing the radiation pattern, we can measure the half power beam width by rotating the primary antenna instead of secondary. The meter is adjusted until the voltage level of primary antenna becomes = (or) 0.707.

The same process applied to the secondary antenna and the meter is adjusted to the voltage level of $1/\sqrt{2}$ (or) 0.707. The difference between the two maximum angle readings gives the beam width.

General setup for measurement of half power beam-width of horn antenna is shown below.

![Diagram of horn antenna measurement setup](image)

**Fig 8.2 Measurement of Beam width**

The above setup is similar to the gain measurement. Here primary and secondary antenna are separated by a distance $r = 2d^2/\lambda$. The primary antenna is rotated with respect to the secondary antenna, the meter reading adjusted to 0.707 of voltage level.

**Directivity of Horn Antenna**

The general expressions for half power beam width in $E$ and $H$-plane is,

$$\theta_E = \frac{56\lambda}{h} \text{ degree}$$

$$\theta_H = \frac{63\lambda}{h} \text{ degree} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots
We know that directivity is defined as the product of HPBW in E and H-plane direction.

\[ D = \frac{41,257}{\theta_E \theta_H} \]  

Substitute equation (1) in equation (2), then

\[ D = \frac{10.9hw}{\lambda^2} \]

The product of \( h \) and \( \omega \) is the area of horn mouth,

\[ A = h \times w \]

\[ D = 10.9A/\lambda^2 \]

9. Calculate the minimum distance required to measure the field pattern of an antenna of diameter 2 m at a frequency of 3 GHz. Derive the necessary equation?

**Ans:** Given that,

For the measurement of field pattern,
- Diameter of the antenna, \( d = 2 \) m
- Operating frequency, \( f = 3 \) GHz
- Minimum distance required to measure the field pattern, \( r = ? \)

Then,
- Operating wavelength,
  \[ \lambda = \frac{C}{f} \]

Thus, the minimum distance required to measure the field pattern of an antenna is given by,

\[ r = \frac{2d^2}{\lambda} \]

Therefore \( r = 80 \) m

**Derivation**

The distance between transmitting and receiving antennas should be very large in order to obtain the Fraunhofer (or) far field region. Hence distance requirement is one of the important parameters for measuring radiation pattern of an antenna. If this distance is very small, then near field (or) Fresnel pattern is obtained. So the antenna under test should be illuminated by a plane wave front which is available only at infinite distances.
But the upper limit is that the phase difference between centre and end of the receiving antenna aperture should not exceed $\frac{\lambda}{16}$

Hence for the measurement of radiation pattern the distance between transmitting and receiving antennas should be greater than $\frac{2d^2}{\lambda}$

In general the value of $r$ is expressed in terms of $d$ and phase difference error ($\delta$) as,

\[
(r + \delta)^2 = \left(\frac{d}{2} + r^2\right)
\]

\[
r^2 + \delta^2 + 2\delta r = \left(\frac{d}{2} + r^2\right)
\]

\[
\delta^2 + 2\delta r = \left(\frac{d}{2}\right)^2
\]

Since $\delta^2$ is very small, then

\[2\delta r = \left(\frac{d}{2}\right)^2\]

Therefore

\[2\delta r = \frac{d^2}{4}\]

\[r = \frac{d^2}{8\delta}\]

From above equation, we can say that the minimum distance required for transmitting and receiving antenna are $\frac{d^2}{8\delta}$

10. Explain the principal of operation of dielectric lens antenna?

Ans:

Lens antennas are useful at higher frequencies above 3000 MHz.
Dielectric Lens

Dielectric lens are also known as "H-plane Metal Plate Lens".

Here the travelling wave fronts are delayed or retorted by the lens medium.
Again dielectric lens antennas are classified into two types,

(a) Non-metallic dielectric lens antennas
(b) Metallic dielectric lens antennas.

Non-Metallic Dielectric Lens Antennas

Consider, the general arrangement of non-metallic dielectric lens antenna is shown in fig 10.1

Here source is located at point O, the rays are incident on the plane surface PQ of the lens. The rays emerging from source have equal distance and constant phase. According to the geometry,

\[ OA + AA' = OC + CE = OC + CB + BB' \]

\[ OA + AA' = OC + CB + BB' = OA = OC + CB \]

Here, \( c \) = Velocity of wave in air
\( v \) = Velocity of wave in lens medium

Multiplying \( "c"\) on both side

\[ c \left( \frac{r}{c} \right) = c \cdot \frac{L}{c} + c \cdot \frac{x}{v} \]
\[ r = L + \frac{x \cdot c}{v} \]

Since \( \mu = \left( \frac{c}{v} \right) \)

Therefore

\[ r = L + \mu (xcos\theta - L) \]

\[ r = L + \mu rcos\theta - \mu L \]

The above expression represents the contour of lens in polar coordinates.

b) **Metallic Dielectric Lens Antennas**

The metallic dielectric lenses are made with discrete metal particles of microscopic size.

The particles should be so small compared to the design wave length that the maximum particle dimension (parallel to the E-field) is less than \( \lambda \) and the spacing to avoid diffraction effects.
UNIT-7

1. Briefly describe the terms related to the sky wave propagation: virtual heights, critical frequency, maximum usable frequency, skip distance and fading?

Ans:

Sky wave propagation:
It is also called as Ionosphere wave propagation. The ionosphere acts like a reflecting surface and is able to reflect back the electromagnetic waves of frequencies between 2 MHz to 30MHz. Since, long distance point to point communication is possible with sky propagation, it is also called as point to point propagation. This mode of propagation is also known as short wave propagation.

Virtual heights:
The virtual height \( h \) has the great advantage of being easily measured, and it is very useful in transmission path calculations.

For flat earth approximation and assuming that ionosphere conditions are symmetrical for incident and refracted waves,

\[ TR = \frac{2h}{\tan \beta} \]

Where \( \beta \) = Angle of elevation
\( h \) = Virtual height

Critical frequency:
When the refractive index, \( n \) has decreased to the point where \( n = \sin \varphi \), the angle of refraction \( \varphi \) will be 90° and wave will be travelling horizontally. The higher point reached by the wave is free. The electron density \( N \) at the that point satisfies the relation

\[ \sqrt{1 - \frac{81N'}{f^2}} = \sin \varphi_i \]

(or)

\[ N' = \frac{f^2 \cos^2 \varphi_i}{81} \]

If the electron density at some level in a layer is sufficient great to satisfy the above condition, then the wave will be returned to earth from that level.

If maximum electron density in a layer is less than \( n' \), the wave will penetrate the layer

(Though it may be reflected back from a higher layer for which \( n \) is greater).

The largest electron density required for reflection occurs when the angle of incident \( \varphi_i \) is zero, i.e., for vertical incidence. For any given layer the highest frequency that will be reflected back for vertical incidence will be..
\[ f_{cr} = \sqrt{81N_{\text{max}}} \]

Where

- \( f_{cr} \) = Critical frequency for the layer
- \( N_{\text{max}} \) = Maximum ionization density (electrons per cubic meter).

The characteristics of the ionospheric layers are usually described in terms of their virtual heights and critical frequencies, as these quantities can be readily measured. The virtual height is the height that would be reached by a short pulse of energy showing the same time delay as the actual pulse reflected from the layer travelling with the speed of light. The virtual height is always greater than the true height of reflection, because the interchange of energy taking place between the wave and electrons of the ionosphere causes the velocity of propagation to be reduced. The extent of this difference is influenced, by the electron distributions in the regions below the level of reflection. It is usually very small, but on occasions may be as large as 100 Kms or so.

The critical frequency is the highest frequency that is returned by a layer at vertical incidence. For regular layers,

\[ f_c = \sqrt{\text{max electron density in the layer}} \]

i.e.

\[ f_c = \sqrt{Ne} \]

The critical frequencies of the E and F\(_1\) layers primarily depend on the zenith angle of the sun. It, therefore, follows a regular diurnal cycle, being maximum at noon and tapering off on either side. The \( f_c \) of the F\(_2\) layer, shows much larger seasonal variation and also changes more from day to day. It can be seen that the critical frequencies of the regular layers decrease greatly during night as a result of recombination in the absence of solar radiation. But the \( f_c \) of sporadic E shows regular variation throughout the day and night suggesting that sporadic E is affected strongly by factors other than solar radiation.

There is a long term variation in all ionospheric characteristics closely associated with the 11 year sunspot cycle. From the minimum to maximum of the cycle, \( f_c \) of F\(_2\) layer varies from about 6 to 11 MHz (ratio of 1:1.8), \( f_c \) of E layer varies from 3.1 to 3.8 MHz (a ratio of mere 1 to 1.2). Long term predictions of ionospheric characteristics are based on predictions of the sunspot number. Reliable estimates can be made, for as much as a year, in advance.

**Maximum usable Frequency**

Although the critical frequency for any layer represents the highest frequency that will be reflected back from that layer at vertical incidence, it is not the highest frequency that can be reflected from the layer. The highest frequency that can be reflected depends also upon the angle of incidence, and hence, for a given layer height, upon the distance between the transmitting and receiving points.

The maximum, frequency that can be reflected back for a given distance of transmission is called the maximum usable frequency (MUF) for that distance.

It is seen that the MUF is related to the critical frequency and the angle of incidence by the simple expression

\[ \text{MUF} = f_{cr} \sec \phi_i \]

The MUF for a layer is greater than the critical frequency by the factor \( \sec \phi_i \), the largest angle of incidence \( \phi_i \), that can be obtained in F-layer reflection is of the order of 74°. This occurs for a ray that leaves the earth at the grazing angle. The geometry for this case is shown by Fig. 1.2

\[ \phi_{i \text{max}} = \sin^{-1}\left(\frac{r}{r+h}\right) \]
The MUF at this limiting angle is related to the critical frequency of the layer by

\[ MUF_{\text{max}} = \frac{f_{\text{cr}}}{\cos 74^\circ} = 3.6 f_{\text{cr}} \]

2. Explain the structure of ionosphere on the surface of the earth?

**Ans: Structure of the ionosphere**

As the medium between the transmitting and receiving antennas plays a significant role, it is essential to study the medium above the earth, through which the radio waves propagate. The various regions above the earth’s surface are illustrated in Fig. 2.1.

The portion of the atmosphere, extending up to a height (average of 15 Km) of about 16 to 18 Kms from the earth’s surface, at the equator is termed as troposphere or region of change.

Tropopause starts at the top of the troposphere and ends at the beginning of or region of calm.

Above the stratosphere, the upper stratosphere parts of the earth’s atmosphere absorb large quantities of radiant energy from the sun. This not only heats up the atmosphere, but also produces some ionization in the form of free electrons, positive and negative ions. This part of the atmosphere where the ionization is appreciable, is known as the ionosphere. The most important ionizing agents are ultraviolet UV radiation, a, \( \beta \) and cosmic rays and meteors. The ionization tends to be stratified due to the differences in the physical properties of the atmosphere at different heights and also because various kinds of radiation are involved.
The levels, at which the electron density reaches maximum, are called as layers. The three principal day time maxima are called E, F1, and F2 layers. In addition to these three regular layers, there is a region (below E) responsible for much of the day time attenuations of HF radio waves, called D region (ref. Fig. 4a). It lies between the heights of 50 and 90 Km (ref. Fig. 3). The heights of maximum density of regular layers E and F1 are relatively constant at about 110 Km and 220Km respectively. These have little or no diurnal variation, whereas the F2 layer is more variable, with heights in the range of 250 to 350 Km.

At night F1 and F2 layers combine to form a single night time F2 layer (Fig. 4b). The E layer is governed closely by the amount of UV light from the sun and at night tends to decay uniformly with time. The D layer ionization is largely absent during night.

A sporadic E layer is not a thick layer. It is formed without any cause. The ionization is often present in the region, in addition to the regular E ionization. Sporadic E exhibits the characteristics of a very thin layer appearing at a height of about 90 to 130 Kms. Often, it occurs in the form of clouds, varying in size from 1 Km to several 100 Kms across and its occurrence is quite unpredictable. It may be observed both day and night and its cause is still uncertain.
3 Explain the mechanism of refraction, under what circumstances does it occur, and what causes it?

**Ans:**

We have mentioned earlier, that the path of the radio wave is bent by the ionosphere. Neglecting the effect of the earth's magnetic field and the effect of energy loss, the refractive index of the ionosphere is given by

$$n = \sqrt{\mu_r \varepsilon_r}$$

$$\mu_r = 1$$

$$n = \sqrt{\varepsilon_r} = \sqrt{1 - \left(\frac{81N}{f^2}\right)}$$  \[1a\]

This will always show the values of $n < 1$. Lower the frequency and higher the electron density, greater is the deviation of the Refractive Index from unity. When $f^2 < 81N$, $n$ is imaginary, i.e. the ionized region is not able to transmit a wave freely at such a frequency. Instead, attenuation takes place, analogous to the action of a waveguide operating beyond cut off.

The phase velocity of a wave travelling through the ionosphere behaves in the same way as the phase velocity of a wave on a transmission line, i.e. the velocity is inversely proportional to the square root of the dielectric constant.

$$\text{i.e. Phase velocity} = \frac{\text{Velocity of light}}{n} = \frac{c}{n}$$  \[1b\]

since $n < 1$ for an ionized medium, the phase velocity in the ionosphere, is always greater than $V$ by an amount that is greater, larger the quantity $\frac{N}{f^2}$.

As a result, when a wave enters the ionosphere, the edge of the wave front in the region of the highest electron density will advance faster than the part of the waveforms encountering regions of lower electron density. Accordingly, the path of the wave is bent in the ionosphere as illustrated in Fig. 6. This bending of the wave follows ordinary optical laws. The direction, in which a wave travels at $P$, in the ionosphere, is given by Snell's Law.
Where \( \varphi_0 \) = angle of incidence
\( n \) = Refractive index of 1st medium

Here, it is assumed that below the ionosphere, where the direction of travel is given by \( \varphi_0 \), \( n = 1 \)

\[
\frac{\sin \theta_1}{\sin \theta_2} = \sqrt{\frac{\epsilon r_1}{\epsilon r_2}}
\]

The top \( P_m \) of the path corresponds to \( \varphi = 90^\circ \) and occurs at a point in the ionosphere where
\[
n = \sin \varphi_0 \quad \text{.........(3)}
\]

\( P_m \) is commonly referred to as the point of reflection, though, actually, it is the point of refraction. Eq. (3) shows that smaller the \( \varphi_0 \), smaller is the ‘n’ required to return the wave to the earth.

With vertical incidence, i.e. \( \varphi_0 = 0 \), \( n \) must be reduced to 0 for reflection to take place. The wave then penetrates the ionized region until it reaches a point, where the electron density \( N \) and the frequency \( f_v \) of the vertically incident wave are so related that
\[
f_v^2 = 81N \quad \text{.........(4)}
\]
4. Explain briefly about ground wave propagation with neat sketch?

**Ans:** Ground Wave Propagation

The ground wave is a wave that is guided along the surface of the earth just as an electromagnetic wave is guided by a wave guide or transmission line. This ground wave propagation takes place around the curvature of the earth in the frequency bands up to 2 MHz. This is also called as surface wave propagation.

![Ground Wave Propagation](image)

The ground wave is vertically polarized, as any horizontal component of the E field in contact with the earth is short-circuited by it. In this mode, the wave glides over the surface of the earth and induces charges in the earth which travel with the wave, thus constituting a current, (see Fig. 4.1). While carrying this current, the earth acts as a leaky capacitor. Hence it can be represented by a resistance or conductance shunted by a capacitive reactance. Thus, the characteristics of the earth as a conductor can be described in terms of conductivity (a) and dielectric constant (ε).

As the ground wave passes over the surface of the earth, it is weakened due to the absorption of its energy by the earth. The energy loss is due to the induced current flowing through the earth's resistance and is replenished partly, by the downward diffraction of additional energy, from the portions of the wave in the immediate vicinity of the earth's surface.

5. Discuss the characteristics of F₁ and F₂ layers?

**Ans:**

*Characteristics of F₁ Layer:*

1. F₁ layer is the lower end region of F-layer and which will be situated at an average height of 220 km. (generally, 140 km to 250 km).
2. The behavior of F₁ layer is similar to that of E-region (normal) and obeys the Chapman's law of variations.
3. Its critical frequency ranges from 5 MHz to 7 MHz at noon time.
4. The value of electron density varies from 2 x 10⁵ to 4.5 x 10⁵.
5. F1 layer is formed by the ionization of oxygen atoms, due to an accepted view.

6. Maximum HF waves are penetrated through the F1 layer, even though some of them are reflected back.

7. The main function of F1 layer is to provide more absorption for HF waves.

8. The density of F1 layer is lower in winter than summer, even though no great variations in height.

**Characteristics of F2 Layer**

F2 layer is the upper end region of F-layer and which will be situated at a height range of 250 km to 400 km.

Its critical frequency ranges from 5 MHz to 12 MHz (basically 10 MHz) and may be even more at low altitude stations.

The electron density of F2 layer may varies from 3 x 10⁵ to 2 x 10⁶.

Being the upper most regions, the air density is very low due to which ionization disappears very slowly.

F2 layer is formed by ionization of UV, X-rays and corpuscular radiations.

The earth's magnetic field, atmospheric, ionosphere storms and other geomagnetic disturbances have large effect on the ionization in F2 layer.

This layer does not follow Chapman's law of variations.

This is the most important reflecting medium for high frequency radio waves.

**6. Write a short note on,**

(a) **Selective fading and interference fading**

(b) **Lowest usable high frequency**

(c) **Field strength calculation for radio AM Broadcast waves**.

**Ans:**

(a) **Selective Fading**

This type of fading produces serious distortion in modulated signal. Selective fading is important at higher frequencies. Selective fading generally occurs in amplitude modulated signals. SSB signals become less distorted compared to the AM signals due to selective fading.

**Interference Fading**

Interference fading occurs due to the variation in different layers of ionospheric region. This type of fading is very serious and produces interference between the upper and lower rays of sky wave propagation. Interference fading can be reduced with the help of frequency and space diversity reception.

(b) **Lowest Usable High Frequency (LUHF)**

The lowest usable frequency can be defined as the maximum value of frequency necessary to establish (or maintain) point to point communication. As the frequency decreases, the sensitivity and external noise increases. The lowest usable frequency (LUF) depends on the transmitted power.

Lowest usable frequency is higher in day time compared to night time depending upon the noise level at the receiving side, lowest usable frequency is measured.

Where,

Lowest usable frequency for sky wave propagation is limited due to:
1. Sky wave absorption and
2. Atmospheric noise.

(c) Field strength calculation for radio AM Broadcast waves:

Ground wave propagation is very useful at lower frequencies between 1 -2 MHz this mode of propagation exists when the transmitting and receiving antennas are very close to the surface of the earth. The general expression for field strength of ground wave propagation is given as,

\[ E = \frac{(120\pi h_t h_r I_s)}{\lambda d} \]

Where

- \( E \) = Field strength due to ground wave propagation
- \( h_t \) = Height of transmitting antenna
- \( h_r \) = Height of receiving antenna
- \( \lambda \) = Wavelength (meters)
- \( d \) = Distance between the transmitting and receiving antenna
- \( I_s \) = Current in antenna

The above expression is valid when distance \( d \) is very small. As the distance increases, ground attenuation and absorption increase. Field strength of ground wave propagation according to Sommerfield is,

\[ E_g = \frac{(E_0 A)}{d} \]

Where,

- \( A \) = Attenuation factor
- \( d \) = Distance between the transmitting and receiving antenna
- \( E_0 \) = Ground field strength at the surface of earth
- \( E_g \) = Ground field strength.

The value of ground field strength at the surface of earth \( (E_g) \) depends upon,

(i) Directivity of planes which are vertical and horizontal.
(ii) Power radiation of transmitting antenna.

The field at unit distance (1Km) for a radiated power of 1 kW, can be calculated as,

\[ E_0 = \frac{(300\sqrt{P})}{d} \text{ (V/m)} \]

Where,

- \( d \) = Distance in kilometers (km)
- \( P \) = Radiated power (1 kW)

In case of vertical uni-pole antenna, the field strength \( E_0 \) at a distance of \( d \) is,

\[ E_0 = \frac{\sqrt{90P}}{d} \text{ volts/meter} \]

From above, field strength is directly proportional to the square root of the power radiated.

- \( E_0 = 300 \text{ mV/m. at } P = 1 \text{ kW, } d = 1 \text{ km} \)
  \[ = 186.45 \text{ mV/m at } J = 1 \text{ mile} \]
7. Discuss the following

(i) Ionospheric storms

(ii) Sudden ionospheric disturbances.

And also discuss the reason for reduction of field strength in sky wave propagation?

Ans:

(i) Ionospheric Storms

Ionospheric storms are the disturbances which occur with the rapid and excessive fluctuations associated with magnetic storms in ionosphere. These disturbances are dependent on the magnetic storms that occur in earth's magnetic field. Ionospheric storm disturbance causes absorption of sky waves and change in critical frequency of \( F_2 \) and \( E \) layers.

These ionospheric storms occur throughout the day and night and may extend up to two or more days. During ionospheric storms, the ionosphere loses its layered structure. In order to establish communication in this situation, we have to lower the working frequency. The virtual height of \( F_2 \) layer increases because of sudden decrease in critical frequency due to ionospheric storm.

Ionospheric storm is caused by \( \alpha \) and \( \beta \) ray particles that are emitted from sun. The ionospheric storm effect decreases as one moves from poles to equator. The ionospheric effect causes narrowing of range of frequencies on radio transmission.

(ii) Sudden Ionosphere Disturbances (SID)

Sudden Ionospheric Disturbances (SIDs) are also called as Mongel-Dellinger effect. SID is caused due to appearance of bright spots on solar disc suddenly. These bright spots are caused due to large emission of hydrogen from the sun. The X-rays along with bright spot causes a tremendous increase in the ionization electron density till the D-layer.

This causes increase in absorption, reflection and atmospheric noise. Hence, the value of LUF increases and exceeds MUF, causing complete blackout of sky wave communication over ionosphere. This blackout effect is known as sudden ionospheric disturbance. SID is high at noon and at equator position SID doesn't occur during nights. SID takes place for a very less duration and it will depend on the sunlit portions of globe. It doesn't affect \( E, F_1 \) and \( F_2 \) layers. SID is caused due to UV radiation intensity from solar flares (bright spot on solar disk), that penetrates through \( E, F_1, F_2 \) layers and cause tremendous increase in ionization density in D-layer.

Reduction of Field Strength in Sky Wave Propagation

The low frequency radio signals lie in the band of 30-300 kHz. The electric field strength of three low frequency broadcasting stations, CLT, MCO and CZE has been monitored by a sampling frequency. The low frequency signals are characterized by the ground wave and the sky wave propagation modes.

The daytime electric field strength is lower than at night because the sky wave is greatly attenuated by the lower ionosphere and the ground wave alone is providing the signal which is faint. At nighttime, the low attenuation of the lower ionosphere permits an increase of 10-15 dB in the sky wave signal such that the received signal is practically all due to the sky wave propagation. The decrease in CLT radio-signal is mainly due to a reduction of electric field strength of the ground wave.

8. Bring out the various problems associated with sky wave mode of propagation. How are these problems overcome?

Ans: Sky wave propagation is also called as ionospheric propagation. Since propagation takes place after reflection from ionosphere. The waves cannot be reflected back to earth if the frequency is above 30 MHz.
Ionospheric Abnormalities

Various problems associated with skyways propagation are due to abnormalities in ionosphere and are of two types.
1. Normal
2. Abnormal

Normal variations include seasonal, height as thickness variation, noise.

Abnormal variation includes tides and winds, sunspot cycle, fading, whistles.

Some of the important variations are as follows.

Tides and Winds

Atmosphere experiences tidal pulls of the sun and moon. As the free period of isolation of the atmosphere coincides with the solve tidal period of 12 hours, it results in resonance phenomenon. This becomes more important and complicated by thermal heating of the atmosphere by the sun rays which have a 24 hours time period, which is twice that of tidal period.

The $F_2$ layer has the highest speed of tidal motion with lowest particle density sighted at the height level.

Hence, $F_2$ layer suffers maximum from effect of tides and result in irregularities in its layer and causes a small peak of maximum ionization density in $F_2$ layer at midnight.

Sudden Ionospheric Disturbances

Sudden appearance of height spot on solar disc increases the ionization density of D-region. This intern causes increased absorption of high frequency signals resulting in a complete blackout of all high frequency. It is known as Sudden Ionospheric Disturbance (SID).

Sunspot Cycle

SID are measured by sunspot cycle. In the graph below, critical frequency of the ionosphere are highest during sunspot maxima and lowest during sunspot minima.

Critical frequency of $F_2$ layer is minimum at 6 MHz and maximum at 10MHz.

![Graph 1](image1.png)  ![Graph 2](image2.png)

fig 8.1 (a) Sun Spot Number

fig 8.2 Critical Frequency of $F_2$ layer
Fading

Sky wave propagation largely suffers from fading variations or a fluctuation in the received signal strength is defined as fading. Wherever the signals that are propagated through sky wave propagation, at the receiver end the signals or wave follow different paths due to variations in the height and density of the ionization layer.

Fading is one of the important parameter in sky wave propagation and occurs due to reflections from the earth. The values of fading are very small when the variation in signal strength is 20 to 30 dB. Fading can be reduced by using diversity reception.

Sudden Ionospheric Disturbances

With the sudden appearance of strong solar flares i.e., bright spot on the solar disc, there occurs an intense increase in D layer ionization. 'An increase in the D-layer, causes increased absorption of high frequency signals resulting in a complete blackout of all high frequencies. It is known as "sudden ionospheric disturbances".

9. What are the different mechanisms of propagation of electromagnetic waves? Explain?

Ans:

Modes of Propagation

Electromagnetic waves may travel from transmitting antenna to the receiving antenna in a number of ways.

Different propagations of electromagnetic waves are as follows,

(i) Ground wave propagation
(ii) Sky wave propagation
(iii) Space wave propagation
(iv) Tropospheric scatter propagation.

This classification is based upon the frequency range, distance and several other factors.

(i) **Ground Wave Propagation**

Ground wave propagation is also known as surface wave propagation. This propagation is practically important at frequencies up to 2 MHz. Ground wave propagation exists when transmitting and receiving antenna are very close to the earth's curvature.

Ground wave propagation suffers attenuation while propagating along the surface of the earth. This propagation can be subdivided into two types which are space wave and surface wave propagation

Applications

Ground wave propagation is generally used in TV, radio broadcasting etc.

(ii) **Sky Wave Propagation**

Sky wave propagation is practically important at frequencies between 2 to 30 MHz Here the electromagnetic waves reach the receiving point after reflection from an atmospheric layer known as ionosphere. Hence, sky wave propagation is also known as 'ionospheric wave propagation'.

Hence, it is also known as point-to-point propagation or point-to-point communication.

Disadvantage

Sky wave propagation suffers, from fading due to reflections from earth surface, fading can be reduced with the help of diversity reception.

Applications

1. It can provide communication over long distances.
2. Global communication is possible.

(iii) Space Wave Propagation
Space wave propagation is practically important at frequencies above 30 MHz. It is also known as tropospheric wave propagation because the waves reach the receiving point after reflections from tropospheric region.
In space wave propagation, signal at the receiving point is a combination of direct and indirect rays. It provides communication over long distances with VHF, UHF, and microwave frequencies. Space wave propagation is also known as "line of sight propagation".

Applications
1. Space wave propagation is used in satellite communication.
2. It controls radio traffic between a ground station and a satellite.

(iv) Troposcatter Propagation
Troposcatter propagation is also known as forward scatter propagation, it is practically important at frequencies above 300 MHz.
This propagation covers long distances in the range of 160 to 1600 km.

10. Discuss the propagation characteristics of EM wave?
Ans:
Electromagnetic waves carry energy or momentum from one point in space to another by means of their electric and magnetic fields. It consists of electric and magnetic field components which oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation. Depending on the frequency of the EM waves, they are classified into different types, such as radio waves, microwaves, visible light, ultraviolet radiation, x-rays and gamma rays.

Some of the significant characteristics of electromagnetic wave; are as follows.

1. Speed (c)
For most practical purposes the speed is taken as $3 \times 10^8$ m/s although the more exact value is $299792500$ m/s. Although exceedingly fast, they still take a finite time to travel over a given distance.

2. Wavelength ($\lambda$)
This is distance between a given point on one cycle and the same point on the next cycle as shown in figure.

The easiest points to choose are the peaks as these are the easiest to locate.
3. Frequency (f):

It is defined as the inverse of the time period of the wave. Time period of a wave is the time taken by a wave to repeat itself. Figure shows that the time taken by sinusoidal wave to repeat itself is T (seconds).

\[ f = \frac{1}{T} \]

The three characteristics of the wave are related by the equation.

\[ C = f \lambda \]

Or

\[ \lambda = \frac{C}{f} \]
UNIT 8

1. Derive the fundamental equation for free space propagation?

Ans:

Fundamental Equation for Free Space Propagation

Consider the transmitter power ($P_t$) radiated uniformly in all the directions (isotropic), the power received at a distance ($r$) from the isotropic source is given by,

$$P_r = \frac{P_t}{4\pi r^2} \text{ (W/m}^2\text{)}$$

... (1)

Where,

- $P_t = \text{Transmitter power (Watts)}$
- $P_r = \text{Received power (Watts)}$
- $r = \text{Distance between the transmitting (and) receiving antenna.}$

The power density ($P_D$) along the maximum radiation for the directive antenna is given by,

$$P_D = G_t \cdot P_r$$

... (2)

Where,

- $G_t = \text{Gain of the transmitting antenna}$
- $P_r = \text{Received power}$
- $P_D = \text{Power density}$. 

For antenna with an effective aperture area ($A_e$), received power is given by,

$$P_r = P_D \times A_e$$

... (3)

Substitute equations (1) and (2) in equation (3), we get,

$$P_r = P_D \times A_e$$

$$P_r = \left( G_t \cdot P_t / 4\pi r^2 \right) \times A_e$$

$$P_r = \left( G_t \cdot P_t / 4\pi r^2 \right) \times A_e \times (W/m^2)$$

... (4)

We know that, relation between gain and maximum effective aperture is given by,

$$G = \left( 4\pi / \lambda^2 \right) A_e$$

$$G = \left( 4\pi / \lambda^2 \right) A$$

... (5)
Antenna and Wave Propagation

Where,

\[ G_r = \text{Gain of the receiving antenna} \]
\[ A_e = \text{Effective aperture area}. \]

From equation (5),

\[ A_e = \left( \frac{\lambda^2}{4\pi} \right) G_r \]

Substituting equation (6) in equation (4), we get,

\[ P_r = \frac{G_t \cdot P_t}{4\pi r^2} \cdot A_e \]
\[ P_r = \left( \frac{G_t \cdot P_t}{4\pi} \right) \left( \frac{\lambda^2}{4\pi} \right) G_r \]
\[ P_r = P_t G_t G_r \frac{\lambda^2}{(4\pi)^2} \]

The above equation is a general expression for free space propagation.

Here,

\[ P_r = \text{Received power in watts} \]
\[ P_t = \text{Transmitter power in Watts} \]
\[ G_t = \text{Gain of transmitting antenna} \]
\[ G_r = \text{Gain of receiving antenna} \]
\[ \lambda = \text{Wave length (m)} \]
\[ r = \text{Distance between the transmitting (and) receiving antenna}. \]

The above equation written in another form is,

\[ P_r = \frac{P_t G_t G_r}{L_s} \]

Where,

\[ L_s = \left( \frac{4\pi r}{\lambda} \right)^2 \]

Path loss represented in logarithmic form is given as,

\[ 10 \log_{10} \left( \frac{P_r}{P_t} \right) = 10 \log_{10} G_t + 10 \log_{10} G_r + 10 \log_{10} \left( \frac{\lambda}{4\pi r} \right)^2 \]

\[ P_r (\text{dBW}) = P_t (\text{dBW}) + G_t (\text{dB}) + G_r (\text{dB}) - L_s \]
2. What are the different paths used for propagating radio waves from 300 kHz and 300 MHz.

Ans:

The term radio propagation is used to explain how radio waves behave when they are transmitted, or propagated from one point on the earth to another. Like light waves, radio waves are affected by the phenomenon of reflection, refraction, diffraction, absorption and scattering.

Radio waves at different frequencies propagate in different paths. The different modes of propagation for frequencies from 300 KHz to 300 MHz are as follows,

1. **300 KHz to 3000 KHz**

   These frequencies have the property of following the curvature of the earth via ground wave propagation in the majority of occurrences. In this mode the radio wave propagates by interacting with the semi conductive surface of the earth. The wave sticks to the surface of the earth and thus follows the curvature of earth. Vertical polarization is used to reduce short circuiting the electric field through the conductivity of the ground, since the ground is not a perfect electrical conductor, ground waves are attenuated rapidly as they follow the earth's surface. Attenuation is proportional to the frequency making this mode mainly useful for LF and VLF.

2. **3MHz to 30 MHz**

   These range of frequency waves travel from transmitter to receiver through multiple reflections from the ionosphere. This mode of propagation is called as sky-wave or ionospheric wave propagation. The waves cover a maximum of 4000 km in a single reflection. This path of propagation is effective if counter techniques are developed at the receiver to eliminate fading, due to reflection.

3. **30 MHz to 300 MHz**

   These frequencies use direct path propagation. The signals reach receivers directly or after getting reflected from the earths bottom most layer troposphere. This mode of propagation is called as space wave propagation space wave has two components. They are

   (i) Direct component

   (ii) Reflected from ground component.

   In direct component, the wave travel directly from transmitter to receiver. In ground reflected component, the wave reaches the receiver after reflection from ground with a phase change of 180°.

   The transmitter transmits both waves at the same time at the receiver both signals are added. The signal strength is high when direct and reflected components are in phase and low when they are out of phase. This is also called as tropospheric propagation.
3. Distinguish between radio and optical horizons. Give the reasons?

**Ans:**

<table>
<thead>
<tr>
<th>Radio Horizon</th>
<th>Optical Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Micro waves are not bent or refracted beyond the radio horizon.</td>
<td>Micro waves are usually bent or refracted beyond the optical horizon.</td>
</tr>
<tr>
<td>2. This horizon is not visible to our eyes, because generally these are further away from the optical horizon.</td>
<td>This horizon is visible to our eyes.</td>
</tr>
<tr>
<td>3. The distance to radio horizon is varies with the atmospheric refractive changes.</td>
<td>The optical horizon is independent of atmospheric refractive changes.</td>
</tr>
<tr>
<td>4. The distance to the radio horizon is given by,</td>
<td>The distance to the optical horizon is given by,</td>
</tr>
<tr>
<td>[ d_r = 0.49h \text{ km} ]</td>
<td>[ d_r = 0.49\sqrt{h} \text{ km} ]</td>
</tr>
<tr>
<td>where, h = Height of the tower (m).</td>
<td>where, h = Height of the tower (m).</td>
</tr>
<tr>
<td>5. Radio horizon distance can also be calculated as,</td>
<td>Optical horizon distance can also be calculated as,</td>
</tr>
<tr>
<td>[ d_r = \frac{d_0}{k} ]</td>
<td>[ d_0 = kd_r ]</td>
</tr>
<tr>
<td>where, k = Correction factor.</td>
<td>where, k = Correction factor.</td>
</tr>
<tr>
<td>6. If k &lt; 1, the radio horizon is further away from optical horizon</td>
<td>If k &gt; 1 optical horizon is further away from radio horizon</td>
</tr>
</tbody>
</table>
4. What is LOS (Line Of Sight) propagation and explain it?

Ans:

**Line of Sight Propagation (LOS)**

Line of sight propagation is also known as space wave propagation. It is very important at higher frequency such as VHF, UHF and micro wave frequencies, i.e., 30 MHz to 300 MHz. Consider two antennas, height of transmitting antennas is \( h_t \) and receiving antennas is \( h_r \). The energy received at the receiving antenna can take two paths, one is direct from transmitting antenna to the receiving antenna and another is via ground.

Direct and indirect waves leave the transmitting antenna at the same time, but reach the receiving antenna at different times. The signal strength at receiving point is vector sum of direct and indirect waves. The field strength is greater, or less depending upon the two waves which are combining or opposing in phase.

![Fig 8.4.1 Line Of sight Propagation](image)

Here the signal travels from the transmitting antenna to the receiving antenna through earth's tropospheric region, therefore, it is called as “Tropospheric propagation”. At higher frequency, space wave propagation is limited to the line of sight distance and earth curvature, so that line of sight propagation is useful at VHF and UHF. Sky wave and ground wave propagations are failing at these frequencies.

In figure the height of transmitting antenna is \( h_t \) and receiving antenna is \( h_r \), and the distance between the two antennas is \( d \). The signal path directly from transmitter to the receiver is denoted by \( TR \). As the receiving antenna is moved from point \( R \) to \( P \), the line of sight path from \( R \) to \( P \) crosses the surface of the earth.

Here,

\[
TR = \text{Direct path}
\]

\[
TP = \text{Line of sight distance}
\]

The line of sight distance can increased to \( TQ \) by increasing the height of the antenna to \( h_{r3} \).
5. Write short note on tropospheric scatter propagation?

Ans:

Tropospheric Propagation or Tropospheric Scatter Propagation

Tropospheric scatter propagation is also known as forward scatter propagation, it is practically important at ultra high frequencies, VHF and micro wave frequencies. Tropospheric propagation provides communication in the range of 160 km to 1600 km.

Consider tropospheric scatter propagation shown in figure 8.5.1 below. Here the transmitter and receiver very close to each other.

![Tropospheric Scattering](image)

The principle of forward scattering involves,

1. Radio waves scattering from E layer of the ionosphere.
2. Radio waves scattering from either fine layer or blobs in the troposphere.

The attenuation of ionospheric scatter propagation is greater than the tropospheric scattering. So that, at very high frequencies, tropospheric scattering is used. In above figure transmitting and receiving antennas are close, their beams intersect midway between them and above the horizon. The transmitting and receiving antennas are at ultra high frequencies. Here, cone angle (α) depends upon the wave length. The value of α is very small.

Tropospheric scatter propagation suffers from noise and fading which can be reduced by employing diversity reception.

6. Discuss the salient features of space wave propagation?

Ans:

Space Wave Propagation

Space wave propagation is useful in long distance about 30 MHz. The space wave propagation is known as tropospheric propagation, because the electromagnetic waves travelling
from transmitter may reach the receiver either directly or after reflections from tropospheric region. Tropospheric region is just 16 km away from the earth's surface.

Space wave propagation consists of two ray paths. They are,

1. Direct path
2. Indirect path.

The signal from transmitter to the receiver is known as direct path and signal after reflections from ground is known as indirect path. Due to the reflections from ground, the phase 180° is introduced in the received signal. The signal at the receiver is a combination of direct and indirect ray paths. The propagation of electromagnetic waves at higher frequencies is done by space wave propagation, because the ground wave and sky wave propagation are fail at these frequencies.

Space wave propagation is also known as line at sight propagation, because at higher frequencies, electromagnetic wave propagation is limited to the curvature of earth and line of sight distance. The range can be increased with the help of transmitting and receiving antenna heights. Space wave propagation is practically important at frequencies above 30 MHz. it is also known as tropospheric wave propagation, because the waves reach the receiving point after reflections from tropospheric region.

In space wave propagation, signal at the receiving point is a combination of direct and indirect rays. It provides communication over long distances with VHF, UHF and microwave frequencies, space wave propagation is also known as "line of sight propagation".

**Applications**

1. Space wave propagation used in satellite communication.
2. Controls radio traffic between a ground station and a satellite.

**7. Write short notes on “M-curves and their characteristics”?**

**Ans:**

M-curves and their Characteristics
M-curves are known as modified index curves. These curves show the variations of refractive index with height. In order to account for the curvature of earth, the actual index of refraction modified to another refractive index. Due to the change in index of refraction, the straight rays are converted into curved rays above flat earth. The effects of non standard atmospheric conditions can be estimated easily by transforming temperature data, meteorological data into M-curves. M-curves are used to predict the type of transmission path for propagation of electromagnetic waves.

**Characteristics of M-curve**

1. Standard propagation occurs, when the modified index of refraction linearly varies with height. M-curve is a straight line having positive slope.
2. The slope of M-curve decreases near the surface of earth which results in standard propagation.
3. In order to achieve greater coverage, the slope of M-curve increases near the surface of the earth.
4. Greater coverage can be achieved when the rays over flat earth are straight and actual rays have the same curvature as that of the earth.
5. Duct propagation occurs when the rays are curved downward over the flat earth and the wave tends to be guided along the duct.
6. If the inverted portion of M-curve is elevated above the surface of earth then the duct is an "elevated duct".

**8. Write short notes on Duct propagation?**

**Ans:**

**Duct Propagation**

The higher frequencies or microwaves are continuously reflected in the duct and reflected by ground. So that they propagate around the curvature for beyond the line of sight.

This special refraction of electromagnetic waves is called super refraction and the process is called duct propagation. Duct propagation is also known as super refraction. Consider the figure,
Here, two boundary surfaces between layers of air form a duct or a sort of wave guide which guides the electromagnetic waves between the walls. Temperature inversion is one of the important factor for the formation of duct. For proper value of curvature, the refractive index (n) must be replaced by a modified refractive index (N).

\[ N = n + \frac{h}{r} \]

The term modified index of refractive modules (m) is related to N as

\[ N = n + \frac{h}{r} \]

\[ (N-1) = n-1 + \frac{h}{r} \]

\[ (N-1) \times 10^6 = [n-1 + \frac{h}{r}] \times 10^6 \]

\[ m = (N-1) \times 10^6 = [n-1 + \frac{h}{r}] \times 10^6 \]

Where,

- \( n \) = Refractive index
- \( h \) = Height above ground
- \( r \) = Radius of the earth = 6370 km

Duct can be used at VHF, UHF and microwave frequencies. Because, these waves are neither reflected nor propagated along earth surface. So, the only possible way to transmit such signal is to utilize the phenomenon of refraction in the troposphere.

9. Discuss the advantages and disadvantages of communication at ultra high frequencies?

**Ans:**

**Advantages of Ultra High Frequencies (UHF)**

1. Ultra high frequencies range from 30 MHz to 3000 MHz, so that it is useful in space wave or line of sight propagation.
2. UHF is used in radio navigation and detection.
3. Ultra high frequencies are used for television and FM broadcasting stations.
4. Point-to-point communication and moving vehicle communication is possible at UHF.
5. Radio communication in aircraft.
6. Communication between the fixed station and many mobile stations situated in vehicles, ships and aircraft is possible in the frequency band of 30 to 470 MHz.

Disadvantages of UHF
1. Fading of signals, i.e., variation in intensity of signal with time, results due to change in tropospheric conditions and several different mechanisms involved at UHF.
2. The effect of earth imperfections and roughness causes field strength of direct wave to undergo a phase shift, and has a small effect on vertical polarization at ultra high frequency.
3. At UHF, it is not possible to communicate beyond line of sight distance.
4. At ultra high frequencies, radio horizon and heights of antennas are the limiting factors.

10. VHF communication is to be established with a 50 watt transmitter at 100 MHz. Calculate the LOS distance, if the heights of transmitting and receiving antennas are respectively 50 m and 10 m. Assuming the capture area of the transmitting antenna is 25 sqmts, calculate the field strength at the receiving neglecting ground reflected wave.

Ans:

Given that,

For a VHF communication,

Transmitted power, \( P_t = 50 \) watts

Operating frequency, \( f = 100 \) MHz

Height of the transmitting antenna, \( h_t = 50\) m

Height of the receiving antenna, \( h_r = 10\) m

Capture area of the transmitting antenna, \( A = 25\) m\(^2\)

Line of Sight (LOS) distance, \( d = ? \)

Field strength at the receiving end, \( E_R = ? \)

Then,

Operating wavelength,

\[ \lambda = \frac{c}{f} = \frac{3 \times 10^8}{100 \times 10^6} = 3\) m

The Line Of Sight (LOS) distance is given by,

\[ d = 4.12 \left( \sqrt{h_t} + \sqrt{h_r} \right) \]
\[ = 4.12 \left( \sqrt{50} + \sqrt{10} \right) \]
\[ = 4.12 \times (10.233) = 42.16 \) km
Then the field strength at the receiving end is given by,

$$E_R = \frac{(88\sqrt{P_{t} h_{r}})}{(\lambda d^2)}$$

$$E_R = \frac{(88\sqrt{50 \times 50 \times 10})}{(3 \times (42.16 \times 10^3)^2)}$$

$$E_R = 58.347 \mu V/m$$