SYLLABUS

PART- A

UNIT – 1: ANTENNA BASICS

Introduction, basic antenna parameters, patterns, beam area, radiation intensity, beam efficiency, directivity and gain, antenna apertures, effective height, bandwidth, radiation, efficiency, antenna temperature and antenna field zones.

7 Hours

UNIT – 2: POINT SOURCES AND ARRAYS

Introduction, point sources, power patterns, power theorem, radiation intensity,field patterns, phase patterns. Array of two isotropic point sources, Endfire Array and Broadside Array

6 Hours

UNIT – 3: ELECTRIC DIPOLES AND THIN LINEAR ANTENNAS

Introduction, short electric dipole, fields of a short dipole(no derivation of field components), radiation resistance of short dipole, radiation resistances of lambda/2 Antenna, thin linear antenna, micro strip arrays, low side lobe arrays, long wire antenna, folded dipole antenna

7 Hours

UNIT – 4: LOOP, SLOT, PATCH AND HORN ANTENNA

Introduction, small loop, comparison of far fields of small loop and short dipole, loop antenna general case, far field patterns of circular loop, radiation resistance, directivity, slot antenna, Babinet's principle and complementary antennas, impedance of complementary and slot antennas, patch antennas.

8 Hours

PART – B

UNIT – 5 & 6: ANTENNA TYPES

Horn antennas, rectangular horn antennas, helical Antenna, Yagi-Uda array, corner reflectors, parabolic reflectors, log periodic antenna, lens antenna, antenna for special applications – sleeve antenna, turnstile antenna, omni- directional antennas, antennas for satellite antennas for ground penetrating radars, embedded antennas, ultra wide band antennas, plasma antenna, high-resolution data, intelligent antennas, antenna for remote sensing.

12 Hours

UNIT - 7 & 8:

RADIO WAVE PROPAGATION: Introduction, Ground wave propagation, free space propagation, ground reflection, surface wave, diffraction.

TROPOSPHERE WAVE PROPAGATION: Tropospheric scatter, Ionosphere propagation, electrical properties of the ionosphere, effects of earth's magnetic field.

10 Hours

TEXT BOOKS:

1. **Antennas and Wave Propagation**, John D. Krauss, 4th edition, McGraw-Hill International edition, 2010
2. **Antennas and Wave Proapagation** – Harish and Sachidananda: Oxford Press 2007.

REFERENCE BOOKS:

1. **Antenna Theory Analysis and Design** - C A Balanis, 2nd ED, John Wiley, 1997
2. **Antennas and Propagation for Wireless Communication Systems** - Sineon R Saunders, John Wiley, 2003.
3. **Antennas and wave propagation -** G S N Raju: Pearson Education 2005

INDEX SHEET

UNIT – 1

ANTENNA BASICS

Syllabus:

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Introduction:

Antenna is a source or radiator of Electromagnetic waves or a sensor of Electromagnetic waves. It is a transition device or transducer between a guided wave and a free space wave or vice versa. It is also an electrical conductor or system of conductors that radiates EM energy into or collects EM energy from free space. Antennas function by transmitting or receiving electromagnetic (EM) waves. Examples of these electromagnetic waves include the light from the sun and the waves received by your cell phone or radio. Your eyes are basically "receiving antennas" that pick up electromagnetic waves that are of a particular frequency. The colors that you see (red, green, blue) are each waves of different frequencies that your eyes can detect. All electromagnetic waves propagate at the same speed in air or in space. This speed (the speed of light) is roughly 671 million miles per hour (1 billion kilometers per hour). This is roughly a million times faster than the speed of sound (which is about 761 miles per hour at sea level). The speed of light will be denoted as c in the equations that follow. We like to use "SI" units in science (length measured in meters, time in seconds, mass in kilograms):

$$c = 3 \times 10^8 \text{ meter/second}$$

Some Antenna Types:

Wire Antennas- dipoles, loops and Helical
Aperture Antennas-Horns and reflectors Array
Antennas-Yagi, Log periodic Patch Antennas-
Microstrips, PIFAs

Basic Antenna Parameters:

A radio antenna may be defined as the structure associated with the region of transition between a guided wave and a free space wave or vice versa.

Principle: Under time varying conditions, Maxwell's equations predict the radiation of EM energy from current source (or accelerated charge). This happens at all frequencies, but is insignificant as long as the size of the source region is not comparable to the wavelength. While transmission lines are designed to minimize this radiation loss, radiation into free space becomes main purpose in case of Antennas. The basic principle of radiation is produced by accelerated charge. The basic equation of radiation is

$$I\,L = Q\,V \quad (\text{Ams}^{-1})$$

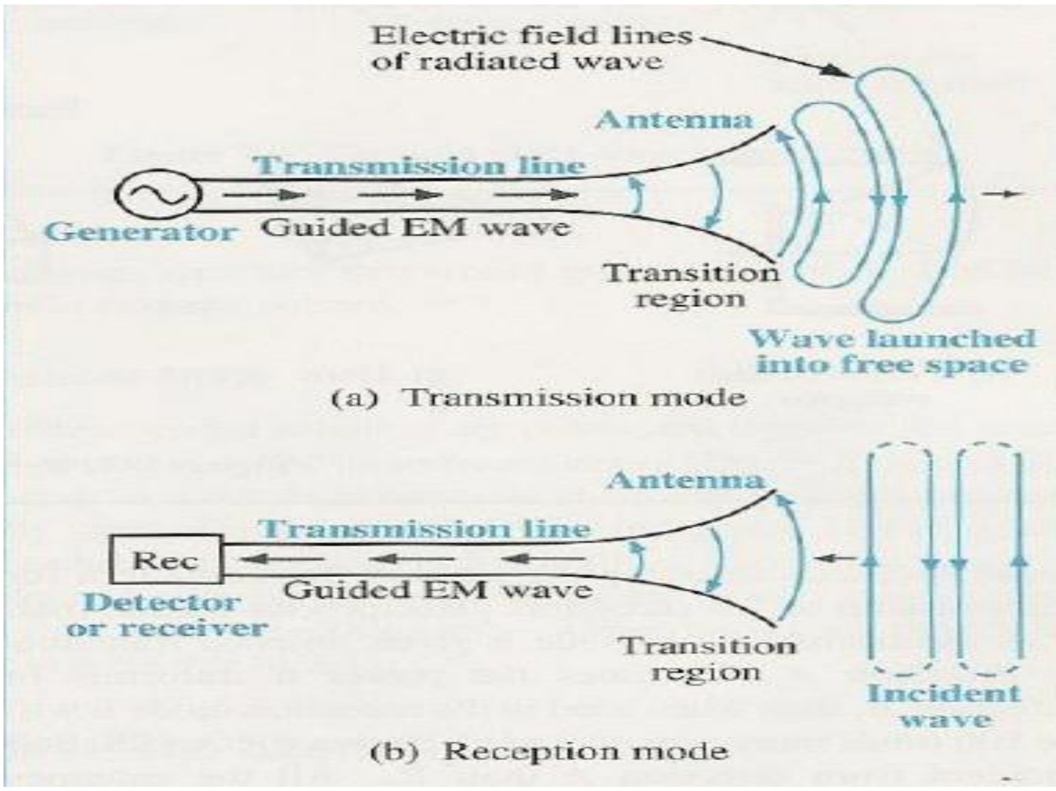
where, I = Time changing current in Amps/sec
L = Length of the current element in meters
Q = Charge in Coulombs
V = Time changing velocity

Thus time changing current radiates and accelerated charge radiates. For steady state harmonic variation, usually we focus on time changing current. For transients or pulses, we focus on accelerated charge. The radiation is perpendicular to the acceleration and the radiated power is proportional to the square of IL or QV.

Transmission line opened out in a Tapered fashion as Antenna:

a). As Transmitting Antenna: Here the Transmission Line is connected to source or generator at one end. Along the uniform part of the line energy is guided as Plane TEM wave with little loss. Spacing between line is a small fraction of λ. As the line is opened out and the separation between the two lines becomes comparable to λ, it acts like an antenna and launches a free space wave since currents on the transmission line flow out on the antenna but fields associated with them keep on going. From the circuit point of view the antennas appear to the transmission lines as a resistance R_r, called Radiation resistance.

b) As Receiving Antenna: Active radiation by other Antenna or Passive radiation from distant objects raises the apparent temperature of R_r .This has nothing to do with the physical temperature of the antenna itself but is related to the temperature of distant objects that the antenna is looking at. R_r may be thought of as virtual resistance that does not exist physically but is a quantity coupling the antenna to distant regions of space via a virtual transmission line.



(a) Transmission mode

(b) Reception mode

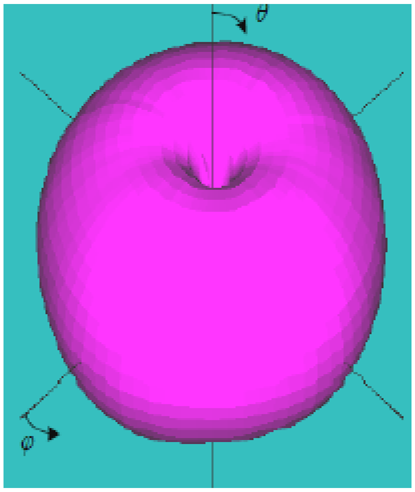
Thus, an antenna is a transition device, or transducer, between a guided wave and a free space wave or vice versa. The antenna is a device which interfaces a circuit and space.

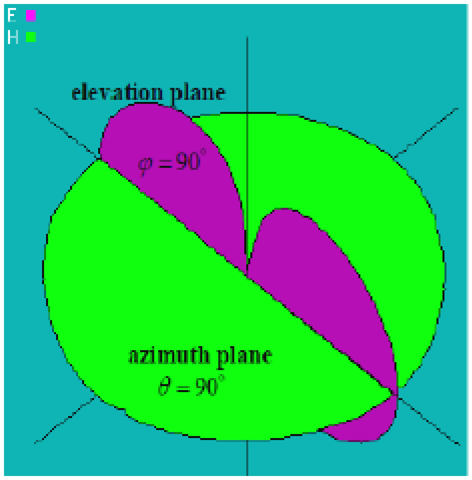
Reciprocity: An antenna exhibits identical impedance during Transmission or Reception, same directional patterns during Transmission or Reception, same effective height while transmitting or receiving**.** Transmission and reception antennas can be used interchangeably. Medium must be linear, passive and isotropic (physical properties are the same in different directions). Antennas are usually optimized for reception or transmission, not both.

Patterns:

The radiation pattern or antenna pattern is the graphical representation of the radiation properties of the antenna as a function of space. That is, the antenna's pattern describes how the antenna radiates energy out into space (or how it receives energy). It is important to state that an antenna can radiate energy in all directions, so the antenna pattern is actually three-dimensional. It is common, however, to describe this 3D pattern with two planar patterns, called the principal plane patterns. These principal plane patterns can be obtained by making two slices through the 3D pattern, through the maximum value of the pattern. It is these principal plane patterns that are commonly referred to as the antenna patterns.

Radiation pattern or Antenna pattern is defined as the spatial distribution of a 'quantity' that characterizes the EM field generated by an antenna. The 'quantity' may be Power, Radiation Intensity, Field amplitude, Relative Phase etc.





Always the radiation has Main lobe through which radiation is maximum in the z direction and Minor lobe (side and back lobes) in the x and y direction. Any field pattern is presented by 3D spherical coordinates or by plane cuts through main lobe axis. Two plane cuts as right angles are called as principal plane pattern. To specify the radiation pattern with respect to field intensity and polarization requires three patterns:

(i). The θ component of the electric field as a function of the angles θ and Φ or $E_\theta(\theta,\Phi)$ in Vm^{-1}.

(ii).The Φ component of the electric field as a function of the angles θ and Φ or $E_\Phi(\theta,\Phi)$ in Vm^{-1}.

(iii). The phases of these fields as a function of the angles θ and Φ or $\delta_\theta(\theta,\Phi)$ and $\delta_\Phi(\theta,\Phi)$ in radian or degree.

Normalized field pattern: It is obtained by dividing a field component by its maximum value. The normalized field pattern is a dimensionless number with maximum value of unity.

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

Half power level occurs at those angles (θ,Φ)for which $E_\theta(\theta,\Phi)_n$ =0.707. At distance d>>λ and d>> size of the antenna, the shape of the field pattern is independent of the distance.

Normalized power pattern: Pattern expressed in terms of power per unit area is called power pattern. Normalizing the power with respect to maximum value yields normalized power patterns as a function of angle which is dimensionless and maximum value is unity.

$$Pn(\theta,\phi)n = \frac{S(\theta,\phi)}{S(\theta,\phi)max}$$

Where, $S(\theta,\Phi)$ is the Poynting vector = [$E_\theta^2(\theta,\Phi) + E_\Phi^2(\theta,\Phi)$] / Z_0 Wm^{-2}

$S(\theta,\Phi)_{max}$ is the maximum value of $S(\theta,\Phi)$, Wm^{-2}

Z_0 is the intrinsic impedance of free space = 376.7Ω.

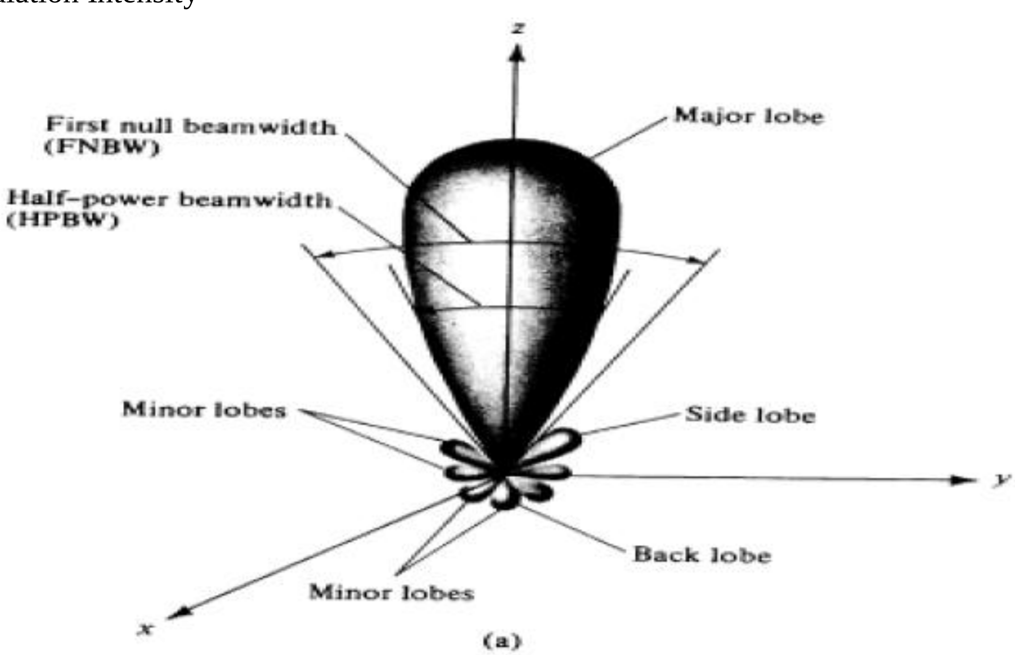
Decibel level is given by $dB = 10 \log_{10} P_n(\theta,\Phi)$

Half power levels occurs at those angles (θ,Φ) for which $P(\theta,\Phi)_n = 0.5$.

Pattern Lobes and Beamwidths:

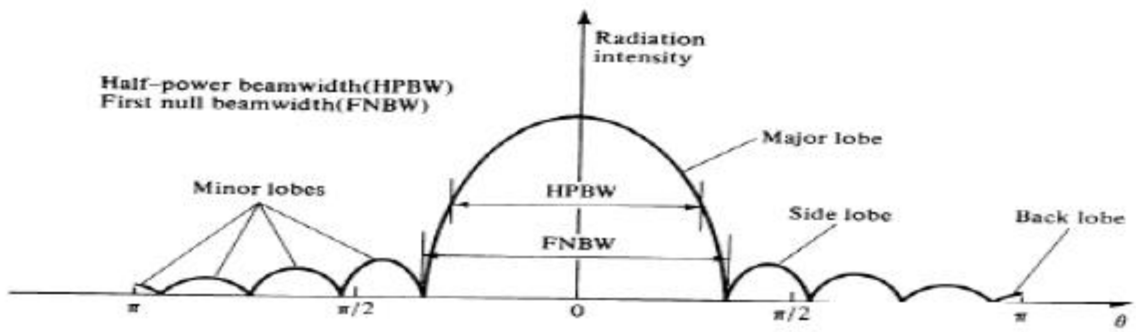
The radiation pattern characteristics involve three dimensional vector fields for full representation, but the scalar quantities can be used. They are:

1. Half power beam-width HPBW
2. Beam Area, Ω_A
3. Bema Efficiency, ε_M
4. Directivity D, Gain G
5. Effective Aperture, A_e
6. Radiation Intensity



Pattern in spherical co-ordinate system

Beamwidth is associated with the lobes in the antenna pattern. It is defined as the angular separation between two identical points on the opposite sides of the main lobe. The most common type of beamwidth is the half-power (3 dB) beamwidth (HPBW). To find HPBW, in the equation, defining the radiation pattern, we set power equal to 0.5 and solve it for angles. Another frequently used measure of beamwidth is the first-null beamwidth (FNBW), which is the angular separation between the first nulls on either sides of the main lobe.



Pattern in Cartesian co-ordinate system

Beamwidth:

Antenna Beam-width is the measure of directivity of an antenna. The antenna beamwidth is the angular width expressed in degrees which is measured on the major lobe of the radiation pattern of an antenna.

HPBW:

The angular width on the major lobe of radiation pattern between two points where the power is half of the maximum radiated power is called Half Power Beam-width. Here the power decreases to half of its maximum value.

FNBW:

When the angular width is measured between the first nulls or first side lobes it is called First Null Beam Width.

The factors affecting beam width are:

1. Shape of the radiation pattern.
2. Dimensions of antenna.
3. Wavelength.

Beam width defines the resolution capability of the antenna, i.e., the ability of the system to separate two adjacent targets.

Beam Area (or Beam Solid Angle) Ω_A :

The beam solid angle of an antenna is given by the integral of the normalized power pattern over a sphere (4π steradians).

$$\Omega A = \int_{\phi=0}^{\phi=2\pi} \int_{\theta=0}^{\theta=2\pi} Pn\,(\theta, \Phi)\, \sin\theta\, d\theta\, d\Phi$$

Beam area Ω_A is the solid angle through which all of the power radiated by antenna would stream if $P(\theta, \Phi)$ maintained its maximum value over Ω_A and was zero.

Total power radiated = $P(\theta, \Phi)\, \Omega_A$ watts

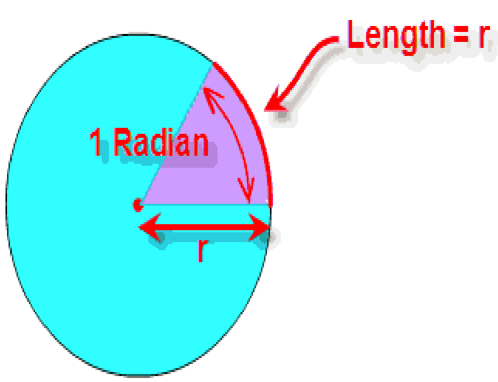
Beam area is the solid angle Ω_A is often approximated in terms of the angles subtended by the Half Power points of the main lobe in the two principal planes(Minor lobes are neglected)

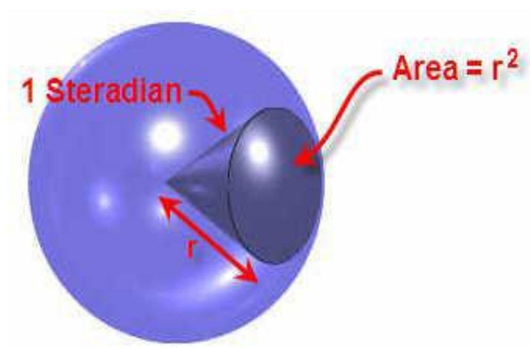
$$\Omega A = \theta_{HP}\, \Phi_{HP}\ (S_r)$$

Radian and Steradian: Radian is plane angle with its vertex a the centre of a circle of radius r and is subtended by an arc whose length is equal to r. Circumference of the circle is 2πr Therefore total angle of the circle is 2π radians.

Steradian is solid angle with its vertex at the centre of a sphere of radius r, which is subtended by a spherical surface area equal to the area of a square with side length r

Area of the sphere is $4\pi r^2$. Therefore the total solid angle of the sphere is 4πsteradians





1steradian = $(1\text{radian})^2$

= $(180 / \pi)^2$

= 3282.8064 square degrees

4π steradians = 3282.8064 x 4π

= 41,253 square degrees

The infinitesimal area ds on a surface of a sphere of radius r in spherical co-ordinates(with θ as vertical angle and Φ as azimuth angle) is

$$ds = r^2 \sin\theta \, d\theta \, d\Phi$$

By definition of solid angle: $ds = r^2 \, d\Omega$

Hence, $$d\Omega = \sin\theta \, d\theta \, d\Phi$$

Radiation Intensity :

Definition: The power radiated from an Antenna per unit solid angle is called the Radiation Intensity. "**U**" Units: Watts/steradians or Watts/ square degree

Poynting vector or power density is dependent on distance from the antenna while Radiation intensity is independent of the distance from the antenna.

The normalized power pattern can also be expressed as the ratio of radiation intensity as a function of angle to its maximum value.

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

Beam Efficiency :

The total beam area Ω_A consists of the main beam area Ω_M plus the minor lobe area Ω_m .

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

The ratio of main beam area to the total beam area is called the beam efficiency ε_M

$$\varepsilon_M = \Omega_M / \Omega_A$$

The ratio of minor lobe area to the total beam area is called stray factor ε_m

$$\varepsilon_m = \Omega_m / \Omega_A$$

Directivity D and Gain G :

From the field point of view, the most important quantitative information on the antenna is the directivity, which is a measure of the concentration of radiated power in a particular direction. It is defined as the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total radiated power divided by 4π. If the direction is not specified, the direction of maximum radiation is implied. Mathematically, the directivity (dimensionless) can be written as

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

The directivity is a dimensionless quantity. The maximum directivity is always ≥ 1

Directivity and Beam area

$$P(\theta,\phi)_{Av} = \frac{1}{4\Pi}\int_0^{2\Pi}\int_0^{\Pi} P(\theta,\phi) Sin\theta d\theta d\phi$$

$$= \frac{1}{4\Pi}\int_0^{2\Pi}\int_0^{\Pi} P(\theta,\phi) d\Omega$$

$$\therefore D = \frac{P(\theta,\phi)_{max}}{\frac{1}{4\Pi}\int_0^{2\Pi}\int_0^{\Pi} P(\theta,\phi) d\Omega}$$

$$D = \frac{1}{\frac{1}{4\Pi}\int_0^{2\Pi}\int_0^{\Pi} P_n(\theta,\phi) d\Omega}$$

$$i.e., D = \frac{4\Pi}{\Omega_A}$$

Directivity is the ratio of total solid angle of the sphere to beam solid angle. For antennas with rotationally symmetric lobes, the directivity D can be approximated as:

$D = 4\pi / \theta\, \Phi$

Directivity of isotropic antenna is equal to unity , for an isotropic antenna Beam area $\Omega A = 4\pi$

- Directivity indicates how well an antenna radiates in a particular direction in comparison with an isotropic antenna radiating same amount of power
- Smaller the beam area, larger is the directivity

Gain: Any physical Antenna has losses associated with it. Depending on structure both ohmic and dielectric losses can be present. Input power P_{in} is the sum of the Radiated power P_{rad} and losses P_{loss}

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

The Gain G of an Antenna is an actual or realized quantity which is less than Directivity D due to ohmic losses in the antenna. Mismatch in feeding the antenna also reduces gain.
The ratio of Gain to Directivity is the Antenna efficiency factor k (dimensionless)

$$\therefore G = kD$$

$$0 \leq k \leq 1$$

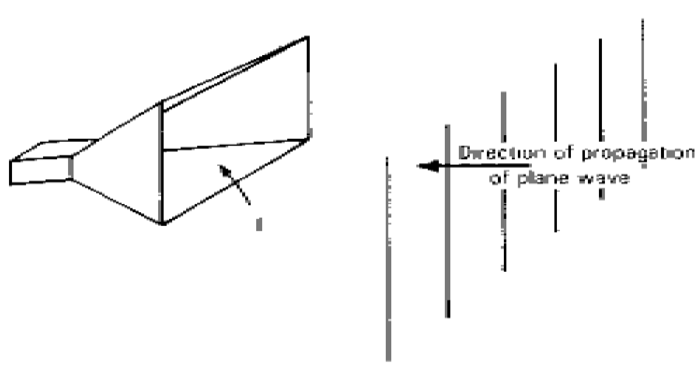
In practice, the total input power to an antenna can be obtained easily, but the total radiated power by an antenna is actually hard to get. The gain of an antenna is introduced *to solve* this problem. This is defined as the ratio of the radiation intensity in a given direction from the antenna to the total input power accepted by the antenna divided by 4π. *If the direction* is not specified, the direction of maximum radiation is implied. Mathematically, the gain (dimensionless) can be written as

$$G = \frac{4\pi U}{Pin}$$

Directivity and Gain: Directivity and Gain of an antenna represent the ability to focus it's beam in a particular direction. Directivity is a parameter dependant only on the shape of radiation pattern while gain takes ohmic and other losses into account.

Effective Aperture

Aperture Concept: Aperture of an Antenna is the area through which the power is radiated or received. Concept of Apertures is most simply introduced by considering a Receiving Antenna. Let receiving antenna be a rectangular Horn immersed in the field of uniform plane wave as shown,



Let the poynting vector or power density of the plane wave be S watts/sq –m and let the area or physical aperture be A_p sq-m.If the Horn extracts all the power from the Wave over it's entire physical Aperture A_p, Power absorbed is given by $P=SA_p=(E^2/Z)A_p$ Watts, S is poynting vector ,
Z is intrinsic impedance of medium, E is rms value of electric field

But the Field response of Horn is not uniform across A_p because E at sidewalls must equal zero. Thus effective Aperture Ae of the Horn is less than Ap.

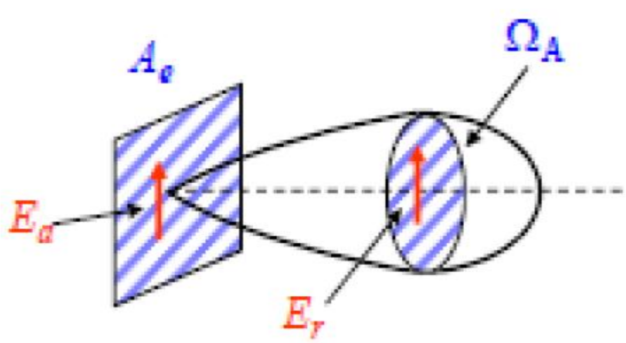
Aperture Efficiency is as follows:

$$\varepsilon_{ap} = \frac{A_e}{A_p}$$

The effective antenna aperture is the ratio of the available power at the terminals of the antenna to the power flux density of a plane wave incident upon the antenna, which is matched to the antenna in terms of polarization. If no direction is specified, the direction of maximum radiation is implied**.** Effective Aperture (Ae) describes the effectiveness of an Antenna in receiving mode, It is the ratio of power delivered to receiver to incident power density

It is the area that captures energy from a passing EM wave
An Antenna with large aperture (Ae) has more gain than one with smaller aperture(Ae) since it captures more energy from a passing radio wave and can radiate more in that direction while transmitting

Effective Aperture and Beam area: Consider an Antenna with an effective Aperture A_e which radiates all of it's power in a conical pattern of beam area Ω_A, assuming uniform field E_a over the aperture, power radiated is



$$P = \frac{E_a^2}{z_0} A_e$$

Assuming a uniform field E_r in far field at a distance r, Power Radiated is also given by $P = \frac{E_r^2}{z_0} r^2 \Omega_A$

Equating the two and noting that $E_r = E_a A_e / r\lambda$ we get Aperture –Beam area relation $\lambda^2 = A_e \Omega_A$

At a given wavelength if Effective Aperture is known, Beam area can be determined or vice- versa

Directivity in terms of beam area is given by $D = \frac{4\Pi}{\Omega_A}$

Aperture and beam area are related by $\lambda^2 = A_e \Omega_A$

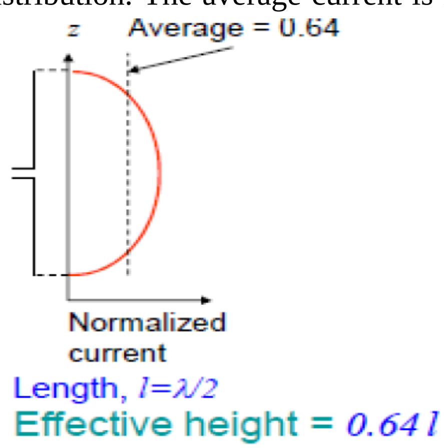
Directivity can be written as $D = \frac{4\Pi}{\lambda^2} A_e$

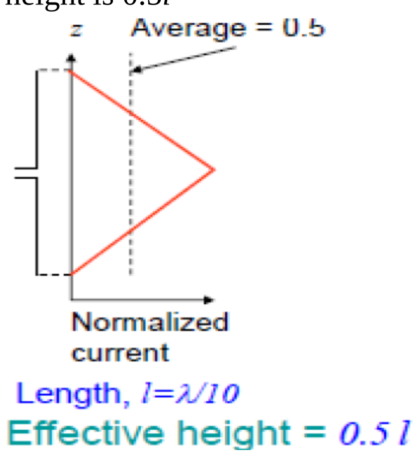
Effective height

The effective height is another parameer related to the apertures. Multiplying the effective height, h_e(meters), times the magnitudeof the incident electric field E (V/m) yields the voltage V induced. Thus $V = h_e E$ or $h_e = V/E$ (m). Effective height provides an indication as to how much of the antenna is involved in radiating (or receiving. To demonstrate this, consider the current distributions a dipole antenna for two different lengths.

If the current distribution of the dipole were uniform, it's effective height would be *l* Here the current distribution is nearly sinusoidal with average value $2/\pi = 0.64$(of the maximum) so that it's effective height is $0.64l$ .It is assumed that antenna is oriented for maximum response.

If the same dipole is used at longer wavelength so that it is only 0.1λ long, the current tapers almost linearly from the central feed point to zero at the ends in a triangular distribution. The average current is now 0.5 & effective height is $0.5l$





For an antenna of radiation resistance R_r matched to it'd load , power delivered to load is $P=V^2/(4R_r)$, voltage is given by $V=h_e\,E$.

Therefore $P=(h_e\,E)^2/(4R_r)$

In terms of Effective aperture the same power is given by

$P=SA_e=(E^2/Z_0)A_e$

Equating the two,

$$P=\frac{h_e^2\cancel{E^2}}{4R_r}=\frac{\cancel{E^2}}{Z_0}A_e \Rightarrow h_e=\sqrt{\frac{4R_rA_e}{Z_0}}\ (\text{m})\ \text{ and }\ A_e=\frac{h_e^2Z_0}{4R_r}\ (\text{m}^2)$$

Bandwidth or frequency bandwidth:

This is the range of frequencies, within which the antenna characteristics (input impedance, pattern) conform to certain specifications . Antenna characteristics, which should conform to certain requirements, might be: input impedance, radiation pattern, beamwidth, polarization, side-lobe level, gain, beam direction and width, radiation efficiency. Separate bandwidths may be introduced: impedance bandwidth, pattern bandwidth, etc.

The FBW of broadband antennas is expressed as the ratio of the upper to the lower frequencies, where the antenna performance is acceptable.

Based on Bandwidth antennas can be classified as

1. Broad band antennas-BW expressed as ratio of upper to lower frequencies of acceptable operation eg: 10:1 BW means f_H is 10 times greater than f_L
2. Narrow band antennas-BW is expressed as percentage of frequency difference over centre frequency eg:5% means $(f_H - f_L)/f_0$ is .05. Bandwidth can be considered to be the range of frequencies on either sides of a centre frequency(usually resonant freq. for a dipole)

The FBW of broadband antennas is expressed as the ratio of the upper to the lower frequencies, where the antenna performance is acceptable

$$\text{FBW} = f_{max} / f_{min}.$$

Broadband antennas with FBW as large as 40:1 have been designed. Such antennas are referred to as frequency independent antennas.

For narrowband antennas, the FBW is expressed as a percentage of the frequency difference over the center frequency

$$\text{FBW} = \frac{f_{max} - f_{min}}{f_0} \cdot 100\ \%.$$

Usually, $f_0 = (f_{max} + f_{min})/2$ or $f_0 = \sqrt{f_{max} f_{min}}$.

The characteristics such as Zi, G, Polarization etc of antenna does not necessarily vary in the same manner. Some times they are critically affected by frequency Usually there is a distinction made between pattern and input impedance variations. Accordingly pattern bandwidth or impedance bandwidth are used .pattern bandwidth is associated with characteristics such as Gain, Side lobe level, Polarization, Beam area. (large antennas)

Impedance bandwidth is associated with characteristics such as input impedance, radiation efficiency(Short dipole)

Intermediate length antennas BW may be limited either by pattern or impedance variations depending on application

If BW is Very large (like 40:1 or greater), Antenna can be considered frequency independent.

Radiation Efficiency

Total antenna resistance is the sum of 5 components

Rr+Rg+Ri+Rc+Rw

Rr is Radiation resistance

Rg is ground resistance

Ri is equivalent insulation loss

Rc is resistance of tuning inductance

Rw is resistance equivalent of conductor loss

Radiation efficiency=Rr/(Rr+Rg+Ri+Rc+Rw). It is the ratio of power radiated from the antenna to the total power supplied to the antenna

Antenna temperature

The antenna noise can be divided into two types according to its physical source:

- noise due to the loss resistance of the antenna itself; and
- noise, which the antenna picks up from the surrounding environment The noise power per unit bandwidth is proportional to the object's temperature and is given by Nyquist's relation

$$p_h = kT_P,\ \text{W/Hz}$$

where

T_P is the physical temperature of the object in K (Kelvin degrees); and k is Boltzmann's constant (1.38×10^{-23} J/K

A resistor is a thermal noise source. The noise voltage(rms value) generated by a resistor R, kept at a temperature T, is given by

$$V_n = \sqrt{4kTBR}$$

Where,

k is Boltzmann's constant ($1.38\text{x}10^{-23}$ J/K). And

B is the bandwidth in Hz

Often, we assume that heat energy is evenly distributed in the frequency band Δf .

Then, the associated heat power in Δf is

$$P_h = kT_P \Delta f \text{ , W.}$$

For a temperature distribution T(θ,Φ) and radiation pattern R(θ,Φ) of the antenna ,

Then noise temperature T_A is given by

$$T_A = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} R(\theta,\phi).T(\theta,\phi)\sin\theta d\theta d\phi$$

The noise power P_{TA} received from an antenna at temperature T_A can be expressed in terms of Bandwidth B over which the antenna(and it's Receiver) is operating as $P_{TA} = kT_A B$

The receiver also has a temperature T_R associated with it and the total system noise temperature (i.e., Antenna + Receiver) has combined temperature given b

$$T_{sys} = T_A + T_R$$

And total noise power in the system is

$$P_{Total} = kT_{sys} B$$

Antenna Field Zones:

The space surrounding the antenna is divided into three regions according to the predominant field behaviour. The boundaries between the regions are not distinct and the field behaviour changes gradually as these boundaries are crossed. In this course, we are mostly concerned with the far-field characteristics of the antennas.

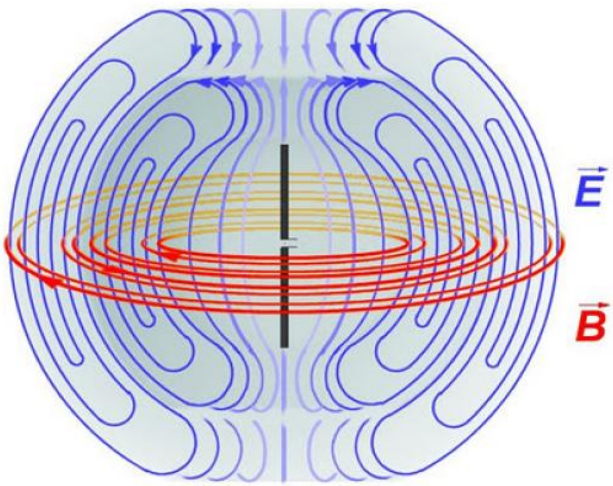


Fig: Radiation from a dipole

1.Reactive near-field region: This is the region immediately surrounding the antenna, where the reactive field dominates. For most antennas, it is assumed that this region is a sphere with the antenna at its centre

2. Radiating near-field (Fresnel) region : This is an intermediate region between the reactive near-field region and the far-field region, where the radiation field is more significant but the angular field distribution is still dependent on the distance from the antenna.

3. Far-field (Fraunhofer) region : Here r >> D and r >> λ

The angular field distribution does not depend on the distance from the source any more, i.e., the far-field pattern is already well established.

RECOMMENDED QUESTIONS

1. Define the following parameters with respect to antenna:
    i. Radiation resistance.
    ii. Beam area.
    iii. Radiation intensity.
    iv. Directivity.
    v. Gain.
    vi. Isotropic radiator.
    vii. Directive gain.
    viii. Hertzian dipole.
    ix. Power gain.
    x. Efficiency.
    xi. Power density.
    xii. Steradians & radians.
2. With the help of neat diagrams explain the principle of radiation in antennas.
3. Explain the antenna as a transmitting device and as a receiving device.
4. Write a note on radiation pattern and radiation lobes.
5. Draw the radiation pattern of: (i) Directional antenna. (ii) Isotropic antenna.
6. Explain different types of aperture.
7. Define aperture of an antenna and find its relation with directivity.
8. Explain effective height of an antenna.
9. Derive FRIIS transmission formula and explain its significance.
10. Derive an expression for power radiated by an isotropic antenna.
11. Derive the relation between directivity and beam solid angle.
12. Derive the relationship between radiation resistance and efficiency.
13. Derive an expression for field intensity at a distant point.
14. Write short notes on: (a) Fields of an oscillating dipole
    (b) Antenna field zones.
15. Show that an isotropic radiator radiating 1 KW power gives a field of 173mv/m at a distance of 1 Km.
16. Find the directivity of an antenna having radiation resistance of 72 Ω and loss resistance of 12 Ω and a gain of 20.
17. What is the maximum effective aperture of a microwave antenna which has a directivity of 900?
18. Using FRISS transmission formula find the maximum power received at a distance of 0.75 Km over a free space. A 100 MHz circuit consisting of a transmitting antenna of 30dB gain and a receiving antenna with a 25dB gain is used. The power input to the transmitting antenna is 120W.
19. A radio station radiates a total power of 10KW and a gain of 30. Find the field intensity at a distance of 100Km from the antenna. Assume free space propagation.

20. Find the number of square degrees in the solid angle on a spherical surface that is between ?=20^{o} and 40^{o} and ?=30^{o} and 70^{o}.
21. Calculate the length of half wave dipole antenna meant to have wavelength at 60MHz.
22. Calculate the gain of an antenna with a circular aperture of diameter 3m at a frequency of 5 GHz.
23. An antenna radiates a total power of 100W in the direction of maximum radiation, the field strength at a distance of 10Km was found to be 12mV/m. What is the gain of the antenna? Assume free space propagation. If ?=90% find directivity.
24. An antenna has a radiation resistance of 72 Ω loss resistance of 8 Ω power gain of 12dB. Determine the antenna efficiency and directivity.
25. An antenna has a loss resistance of 10 Ω power gain of 20 and directivity gain of 22. Calculate the radiation resistance.
26. Calculate the effective length of a ƒÉ/2 antenna gives Rr=73 Ω effective aperture 0.13 ƒÉ^{2}.
27. An antenna radiates power equally in all directions. The total power delivered to the radiator is 100 KW. Calculate the power density at distance of (i) 100m (ii) 1000m.

UNIT – 2

POINT SOURCES AND ARRAYS

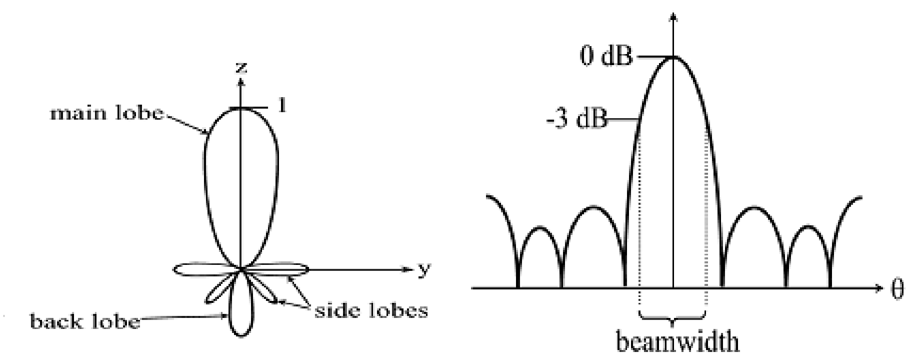
Syllabus:

Introduction, point sources, power patterns, power theorem, radiation intensity, field patterns, phase patterns. Array of two isotropic point sources, Endfire Array and Broadside Array

Radiation Pattern:

The radiation pattern of antenna is a representation (pictorial or mathematical) of the distribution of the power out-flowing (radiated) from the antenna (in the case of transmitting antenna), or inflowing (received) to the antenna (in the case of receiving antenna) as a function of direction angles from the antenna.

Antenna radiation pattern (antenna pattern): It is defined for large distances from the antenna, where the spatial (angular) distribution of the radiated power does not depend on the distance from the radiation source is independent on the power flow direction



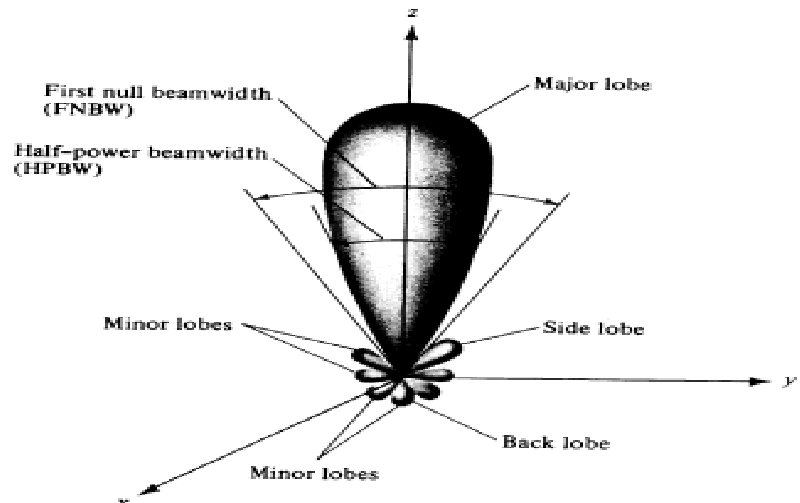
(a) (b)

It is clear in Figures a and b that in some very specific directions there are zeros, or nulls, in the pattern indicating no radiation.

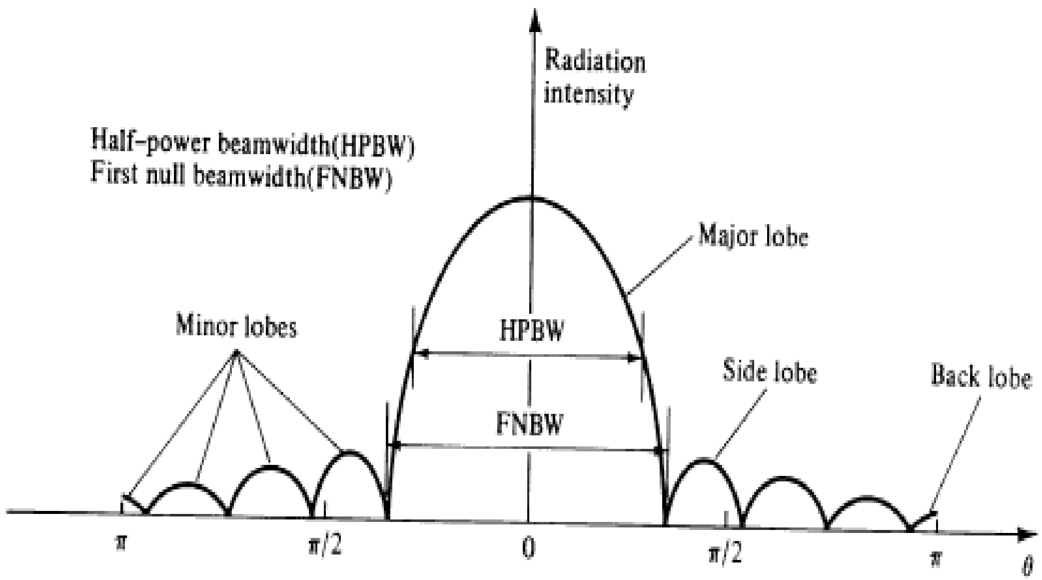
The protuberances between the nulls are referred to as lobes, and the main, or major, lobe is in the direction of maximum radiation.

There are also side lobes and back lobes. These other lobes divert power away from the main beam and are desired as small as possible.

Pattern lobe is a portion of the radiation pattern with a local maximum. Lobes are classified as: major, minor, side lobes, back lobes



(a)

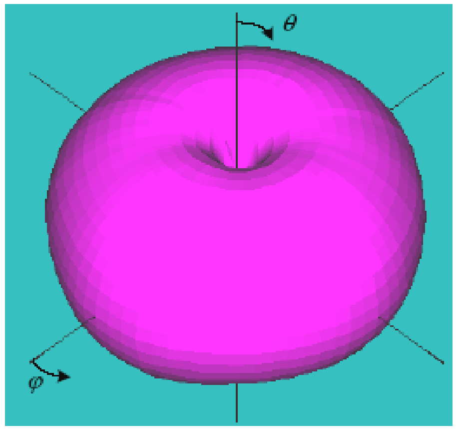


(b)

Normalized pattern:

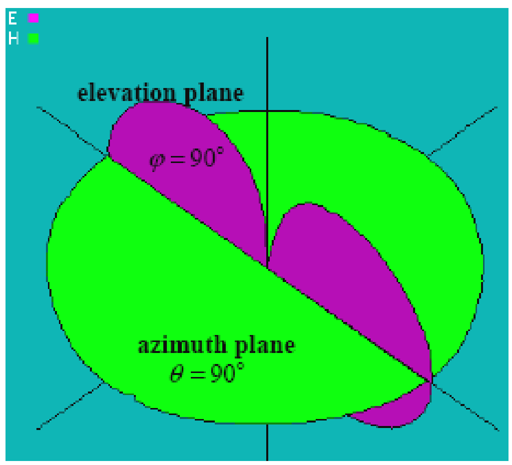
Usually, the pattern describes the normalized field (power) values with respect to the maximum value.

Note**:** The power pattern and the amplitude field pattern are the same when computed and when plotted in dB.



3-Dimensional pattern

Antenna radiation pattern is 3-dimensional. The 3-D plot of antenna pattern assumes both angles θ and φ varying.

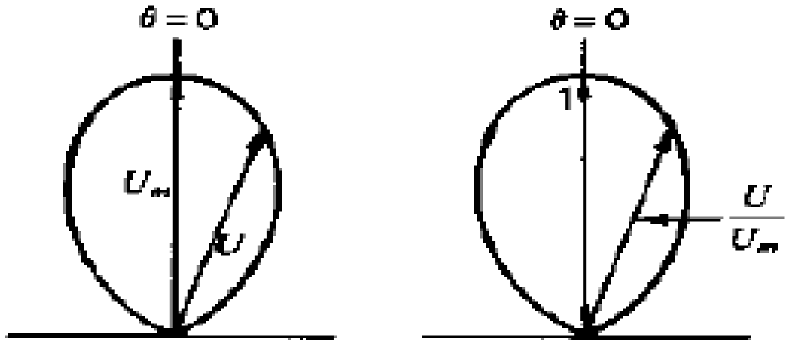


2-Dimensional pattern

Usually the antenna pattern is presented as a 2-D plot, with only one of the direction angles, θ or φ varies.
It is an intersection of the 3-D one with a given plane .Usually it is a θ = const plane or a φ = const plane that contains the pattern's maximum.

RADIATION INTENSITY

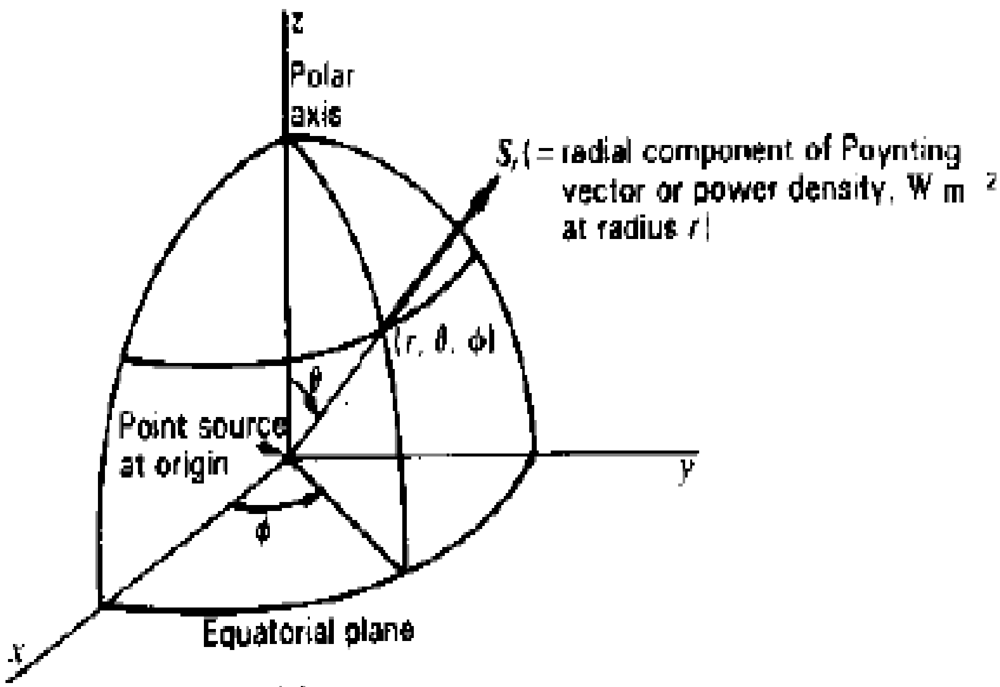
The radiation intensity is total power radiated per unit solid angle and is denoted by **U** and it is expressed as $U = P/4\pi$.



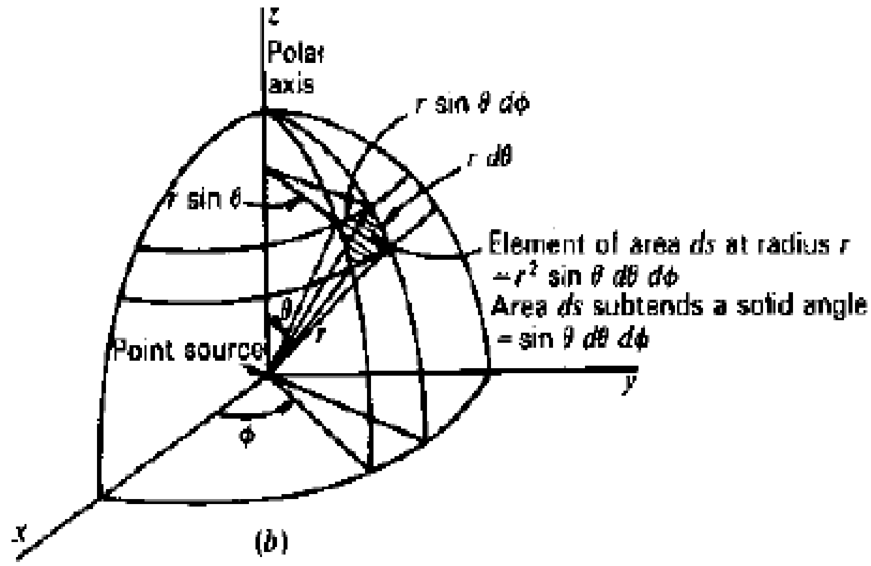
First figure shows radiation intensity of a source and second figure is relative radiation intensity of that source.

POINT SOURCE

A point source is a radiator that has dimensions of a point in space.



(a)



POWER PATTERN

The directional property of the antenna is often described in the form of a **power pattern**. The power pattern is simply the effective area normalized to be unity at the maximum.

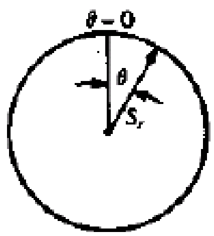


Fig: Power pattern for isotropic source

Power pattern and relative power patterns of a source

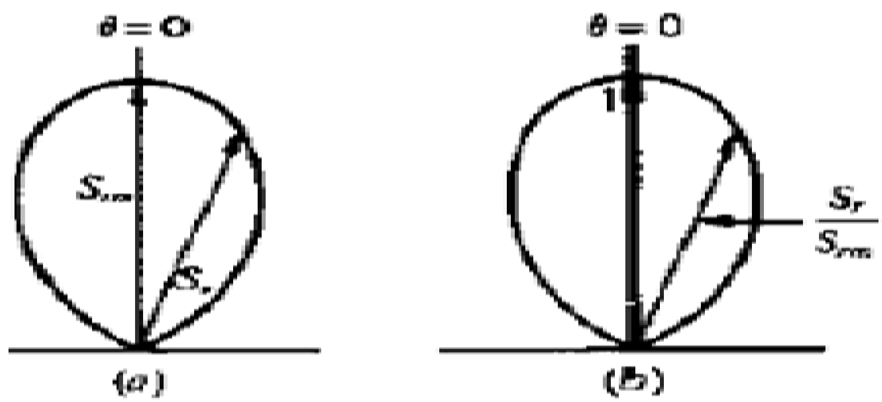


Figure (a) shows power pattern of a source. Figure(b) shows relative power pattern of a same source. Both Patterns have the same shape. The relative power pattern is normalized to a maximum of unity

The radiated energy streams from the source in radial lines.

Time rate of Energy flow/unit area is called as Poynting vector (PowerDensity)

It is expressed as ……….watts / square meters.
For a Point source Poynting vector has only radial component Sr
S component in Θ and φ directions are zero. Magnitude of S = Sr
Source radiating uniformly in all directions – Isotropic Source. It is independent of Θ and φ
.
Graph of Sr at a constant radius as a function of angle is POWER PATTERN

Field pattern

A pattern showing variation of the electric field intensity at a constant radius r as a function of angle(θ , φ) is called **"field pattern"**

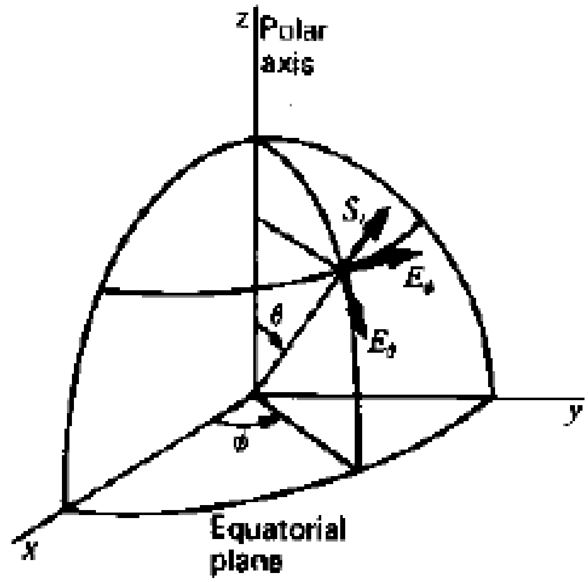


Fig: Relation of poynting vector s and 2 electric field components of a far field

The power pattern and the field patterns are inter-related:

$$P(\theta, \varphi) = (1/\eta)*|E(\theta, \varphi)|2 = \eta*|H(\theta, \varphi)|2$$

P = power
E = electrical field component vector
H = magnetic field component vector
η = 377 ohm (free-space impedance)

The power pattern is the measured (calculated) and plotted received power: |P(θ, φ)| at a constant (large) distance from the antenna
The amplitude field pattern is the measured (calculated) and plotted electric (magnetic)

field intensity, |E(θ, φ)| or |H(θ, φ)| at a constant (large) distance from the antennas

Antenna Arrays

Antennas with a given radiation pattern may be arranged in a pattern line, circle, plane, etc.) to yield a different radiation pattern.
Antenna array - a configuration of multiple antennas (elements) arranged to achieve a given radiation pattern.
Simple antennas can be combined to achieve desired directional effects. Individual antennas are called elements and the combination is an array

Types of Arrays

1. Linear array - antenna elements arranged along a straight line.
2. Circular array - antenna elements arranged around a circular ring.
3. Planar array - antenna elements arranged over some planar surface (example - rectangular array).
4. Conformal array - antenna elements arranged to conform two some non-planar surface (such as an aircraft skin).

Design Principles of Arrays

There are several array design variables which can be changed to achieve the overall array pattern design. Array Design Variables
1. General array shape (linear, circular,planar)
2. Element spacing.
3. Element excitation amplitude.
4. Element excitation phase.
5. Patterns of array elements.

Types of Arrays:

•Broadside: maximum radiation at right angles to main axis of antenna
•End-fire: maximum radiation along the main axis of antenna
•Phased: all elements connected to source
• Parasitic: some elements not connected to source: They re-radiate power from other elements.

Yagi-Uda Array

•Often called Yagi array
•Parasitic, end-fire, unidirectional
•One driven element: dipole or folded dipole
•One reflector behind driven element and slightly longer
•One or more directors in front of driven element and slightly shorter

Log-Periodic Dipole Array

•Multiple driven elements (dipoles) of varying lengths
•Phased array
•Unidirectional end-fire
•Noted for wide bandwidth
•Often used for TV antennas

Monopole Array

•Vertical monopoles can be combined to achieve a variety of horizontal patterns
• Patterns can be changed by adjusting amplitude and phase of signal applied to each element
•Not necessary to move elements
– Useful for AM broadcasting

Collinear Array

•All elements along same axis
•Used to provide an omnidirectional horizontal pattern from a vertical antenna
•Concentrates radiation in horizontal plane

Broadside Array

•Bidirectional Array
•Uses Dipoles fed in phase and separated by 1/2 wavelength

End-Fire Array

•Similar to broadside array except dipoles are fed 180 degrees out of phase
•Radiation max. off the ends

<u>Application of Arrays</u>

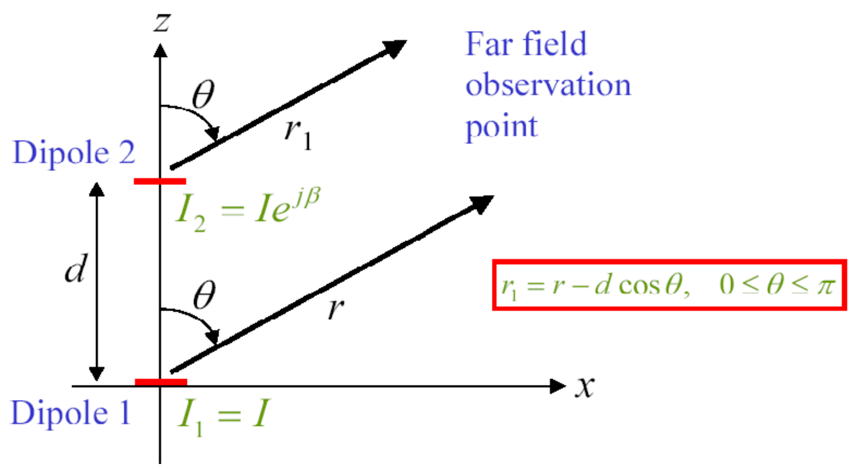
An array of antennas may be used in a variety of ways to improve the performance of a communications system. Perhaps most important is its capability to cancel co channel interferences. An array works on the premise that the desired signal and unwanted co channel interferences arrive from different directions. The beam pattern of the array is adjusted to suit the requirements by combining signals from different antennas with appropriate weighting. An array of antennas mounted on vehicles, ships, aircraft, satellites, and base stations is expected to play an important role in fulfilling the increased demand of channel requirement for these services

ARRAY OF POINT SOURCES

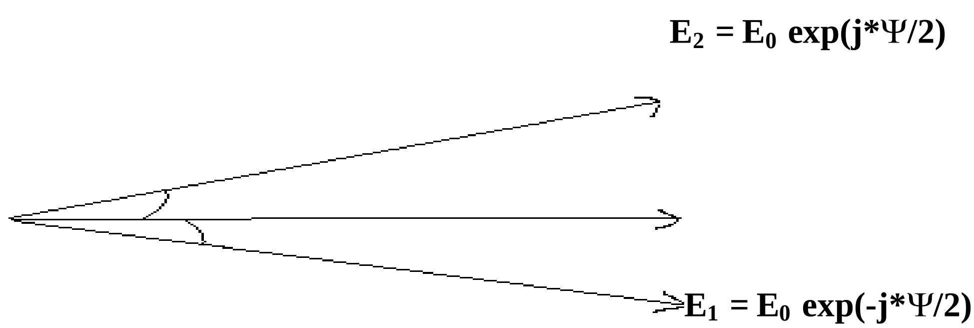
ARRAY is an assembly of antennas in an electrical and geometrical of such a nature that the radiation from each element add up to give a maximum field intensity in a particular direction& cancels in other directions. An important characteristic of an array is the change of its radiation pattern in response to different excitations of its antenna elements.

CASE1:

2 isotropic point sources of same amplitude and phase



- **Phase difference** $=\beta d/2*\cos\theta=2\pi/\lambda*d/2*\cos\theta$
- β = propagation constant
- $d_r= \beta d=2\pi/\lambda*d$ = **Path difference**



The total field strength at a large distance r in the direction θ is :

$E = E_1 + E_2 = E_0[\exp(j*\Psi/2 + \exp(-j*\Psi/2)]$

Therefore: $E = 2E_0\cos\Psi/2$ .... (1)

Ψ=phase difference between E1 & E2 & $\Psi/2= dr/2*\cos\theta$

E_0 =amplitude of the field at a distance by single isotropic antenna

Substituting for Ψ in (1) & normalizing

$E=2E_0\ COS(2\pi/\lambda*d/2*\cos\theta)$ $E_{nor}=COS(dr/2*\cos\theta)$

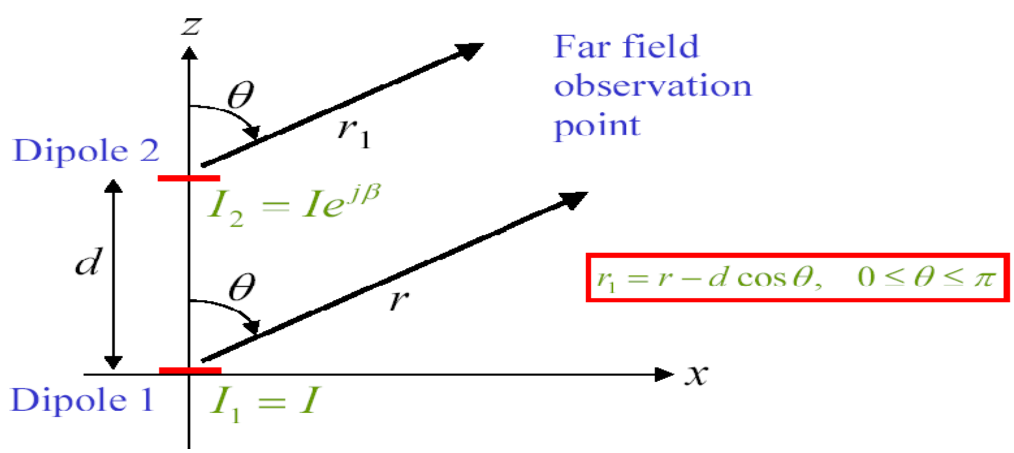
for $d=\lambda/2$

$E=COS(\pi/2*\cos\theta)$

At $\theta=\pi/2$	E=1...	Point of maxima= $\pi/2$(or) $3\pi/2$
At $\theta=0$	E=0...	Point of minima= 0 (or) π
At $\theta=\pm\pi/3$	$E=1/\sqrt{2}$	3db bandwidth point= $\pm\pi/3$

CASE2:

<u>2 isotropic point sources of same amplitude but opposite phase</u>



The total field strength at a large distance r in the direction θ is :

$$E = E_1 + E_2 = E_0[\exp(j*\Psi/2 - \exp(-j*\Psi/2)]$$

Therefore: $E = 2jE_0SIN(\Psi/2)$ ....(2)

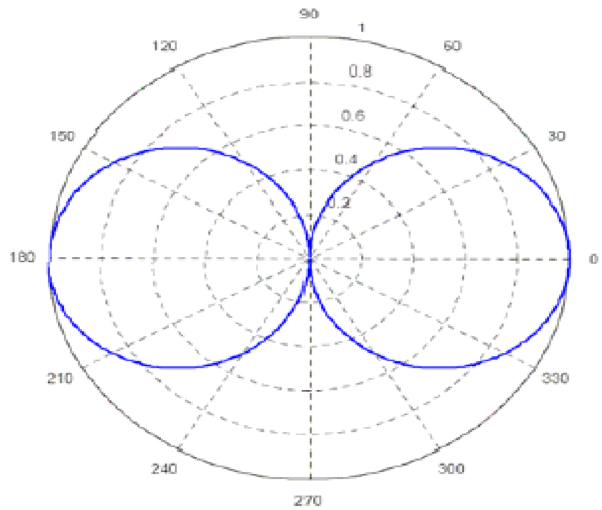
Ψ= phase difference between E_1&E_2

$\Psi/2=dr/2*\cos\theta$

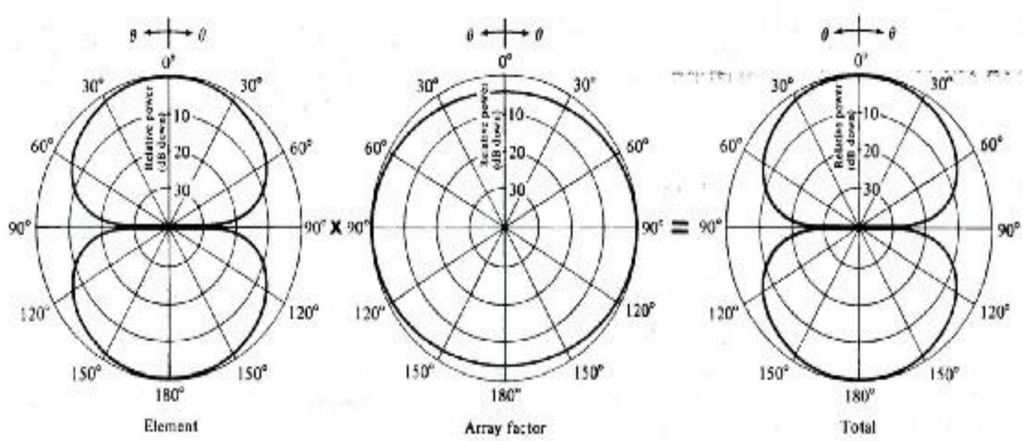
E_0 =amplitude of the field at a distance by single isotropic antenna

At k=0	E=1	Point of maxima= 0(or) π
At $k=0,\theta=\pi/2$	E=0	Point of minima= $\pi/2$(or)-$\pi/2$
At $\theta=\pm\pi/3$	$E=1/\sqrt{2}$	3db bandwidth point= $\pm\pi/3$

END FIRE ARRAY PATTERN



Examples of array patterns using pattern multiplication:



Array pattern of a two-element array of Hertzian dipoles ($\beta = 0°$, and $d = \lambda/4$)

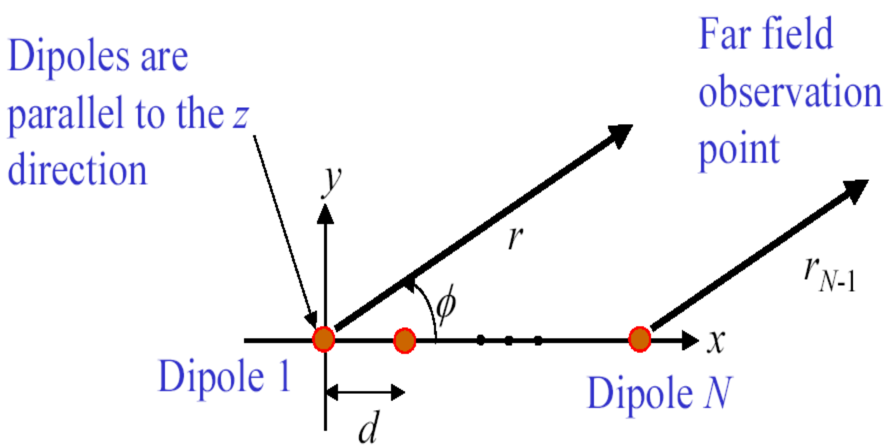
Pattern multiplication:

The total far-field radiation pattern |E| of array (array pattern) consists of the original radiation pattern of a single array element multiplying with the magnitude of the array factor |AF|. This is a general property of antenna arrays and is called the principle of pattern multiplication.

Uniformly excited equally spaced linear arrays

Linear arrays of N-isotropic point sources of equal amplitude and spacing:

An array is said to be linear if the individual elements of the array are spaced equally along a line and uniform if the same are fed with currents of equal amplitude and having a uniform phase shift along the line



The total field E at distance point in the direction of is given by

$$E=1+e^{j\Psi}+e^{j2\psi}+e^{j2\psi}+\ldots\ldots+e^{j(n-1)\psi} \quad (1)$$

Where Ψ= total phase difference between adjacent source Ψ =dr*cos +δ =$2\pi/\lambda$*d*cosφ +δ

δ = phase difference of adjacent source

multipliying equation (1) by $e^{j\varphi}$

$$E\, e^{j\psi}=e^{j\psi}+e^{j2\psi}+e^{j3\psi}+\ldots\ldots+e^{jn\psi} \quad (3)$$

(1)-(3)

$E(1-e^{j\Psi})=(1-e^{jn\psi})$ $E=1e^{jn\Psi}/1-e^{j\psi}$

$E=e^{j(n-1)\psi/2}$ $\{\sin(n\Psi/2))/\sin(\Psi/2)\}$

If the phase is referred to the centre point of the array, then E reduces to

$E=(\sin(n\Psi/2))/\sin(\Psi/2)$

when $\Psi=0$ $E=\lim_{\psi \to 0}(\sin(n\Psi/2))/\sin(\Psi/2)$, $E=n=E_{max}$

$\Psi=0$ $E=E_{max}=n$ ……….normalizing

$E_{norm}=E/E_{max}=(1/n)(\sin(n\Psi/2))/\sin(\Psi/2)$

<u>CASE 1:</u> LINEAR BROAD SIDE ARRAY

An array is said to be **broadside** if the phase angle is such that it makes maximum radiation perpendicular to the line of array i.e. 90^0&270^0

For broad side array $\Psi=0$ & $\delta=0$

Therefore Ψ =dr*cos Φ +δ=βdcos Φ +0=0 $\Phi=\pm 90^0$

therefore $\Phi_{max}=90^0$&270^0

Broadside array example for n=4 and d=λ/2

By previous results we have Φ max = 90^0&270^0

Direction of pattern maxima:

$E=(1/n)(\sin(n\Psi/2))/\sin(\Psi/2)$

This is maximum when numerator is maximum i.e. $\sin(n\Psi/2)=1$ $n\Psi/2=\pm(2k+1)\pi/2$ where k=0,1,2.........

K=0 major lobe maxima

K=1 $n\Psi/2=\pm 3\pi/2$ $\Psi=\pm 3\pi/4$

Therefore $dr*\cos\Phi = 2\pi/\lambda*d*\cos\Phi = \pm 3\pi/4$ $\cos\Phi = \pm 3/4$

$\Phi = (\Phi_{max})_{minor\ lobe} = \cos^{-1}(\pm 3/4) = \pm 41.4^0$ or $\pm 138.6^0$

At K=2, $\phi=\cos^{-1}(\pm 5/4)$ which is not possible

Direction of pattern minima or nulls

It occurs when numerator=0 i.e. $\sin(n\Psi/2)=0$ $n\Psi/2=\pm k\pi$

where k=1,2,3................................. now using condition $\delta=0$

$\Psi=\pm 2k\pi/n=\pm k\pi/2$ $dr*\cos\Phi = 2\pi/\lambda*d/2*\cos\Phi$

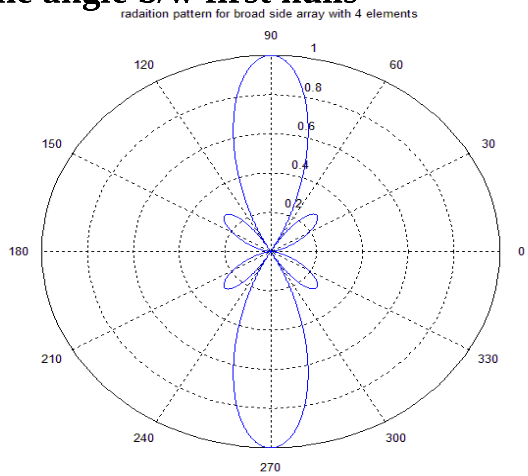
Substituting for d and rearranging the above term $\pi\cos\Phi=\pm k\pi/2$ $\cos\Phi=\pm k/2$

therefore Φ_{min} =cos-1($\pm$k/2)

K=1 $\Phi_{min}=\cos^{-1}(\pm 1/2)=\pm 60^0$ or $\pm 120^0$

K=2 $\Phi_{min}=\cos^{-1}(\pm 1) = 0^0$ or $\pm 180^0$

Beam width is the angle b/w first nulls



From the pattern we see that

Beamwidth between first pair of nulls =BWFN=60^0

Half power beam width =BWFN/ 2=30^0

CASE2: END FIRE ARRAY

An array is said to be end fire if the phase angle is such that it makes maximum radiation in the line of array i.e. 0^0&180^0

For end fire array $\Psi=0$ & $\Phi=0^0$ &180^0

Therefore $\Psi = dr*\cos\Phi + \delta$ $\delta= -dr$

The above result indicates that for an end fire array the phase difference b/w sources is retarded progressively by the same amount as spacing b/w the sources in radians.
If $d= \lambda/2$ $\delta= -dr = -2\pi/\lambda \times \lambda/2= -\pi$
The above result indicates that source 2 lags behind source1 by π radians.

End fire array example for n=4 and d=λ/2
Direction of maxima

Maxima occurs when $\sin(n\Psi/2)=1$
i.e. $\Psi/2= \pm(2k+1)\pi/2$ where k=0,1,2.........
$\Psi = \pm(2k+1)\pi/n$ $dr*\cos\Phi + \delta= \pm(2k+1)\pi/n$
$\cos\Phi = [\pm(2k+1)\pi/n - \delta]/dr$

Therefore $\Phi_{max} = \cos^{-1} \{[\pm(2k+1)\pi/n - \delta]/dr\}$
By definition For end fire array : $\delta= -dr = -2\pi/\lambda*d$
Therefore $\Phi_{max} = \cos^{-1} \{[\pm(2k+1)\pi/n - \delta]/ (-2\pi/\lambda*d)\}$
For n=4, $d=\lambda/2$ $dr=\pi$ after substituting these values in above equation & solving we get
$\Phi_{max}=\cos^{-1} \{[\pm(2k+1)/4 +1\}$ Where k=0,1,2......

For major lobe maxima,

$\Psi = 0=dr*\cos\Phi + \delta$
$=dr*\cos\Phi - dr$
$=dr(\cos\Phi - 1)$ $\cos\Phi_m=1$ there fore $\Phi_m=0^0$ or 180^0
Minor lobe maxima occurs when k=1,2,3......
K=1 $(\Phi_{max})_{minor1}=\cos^{-1} \{[\pm(3)/4 +1\}$
$=\cos^{-1} (7/4 \text{ or } 1/4)$ Since $\cos^{-1} (7/4)$ is not possible
Therefore $(\Phi_{max})_{minor1}=\cos^{-1} (1/4)=75.5$

K=2 $(\Phi_{max})_{minor2}=\cos^{-1} \{[\pm(5)/4 +1\}$
$=\cos^{-1} (9/4 \text{ or } -1/4)$
Since $\cos^{-1} (9/4)$ is not possible
Therefore
$(\Phi_{max})_{minor1}=\cos^{-1} (-1/4)=104.4$

Direction of nulls:

it occurs when numerator=0

i.e. $\sin(n\Psi/2) = 0$ $n\Psi/2 = \pm k\pi$

where k=1,2,3................................. Here $\Psi = dr*\cos\Phi + \delta = dr(\cos\Phi - 1)$ $dr = 2\pi/\lambda*\lambda/2 = \pi$

Substituting for d and n

$dr(\cos\Phi - 1) = \pm 2k\pi/n$ $\cos\Phi = \pm k/2+1$ therefore

Φ null $= \cos-1(\pm k/2+1)$

k=1 , Φ null1 $= \cos-1(\pm 1/2+1) = \cos-1(3/2 \text{ or } 1/2)$

since cos-1(3/2) not exist , Φ null1 $= \cos-1(1/2) = \pm 60$ there fore

Φ null1 $= \pm 60$

k= 2,

Φ null2 $= \cos-1(\pm 2/2+1)$

$= \cos-1(2 \text{ or } 0)$

since cos-1(2) not exist ,

Φ null2 $= \cos-1(0) = \pm 90$ there fore Φ null2 $= \pm 900$

k=3, Φ null3 $= \cos-1(\pm 3/2+1) = \cos-1(5/2 \text{ or} -1/2)$

since cos-1(5/2) not exist , Φ null3 $= \cos-1(-1/2) = \pm 120$ 0 there fore, Φ null3 $= \pm 1200$

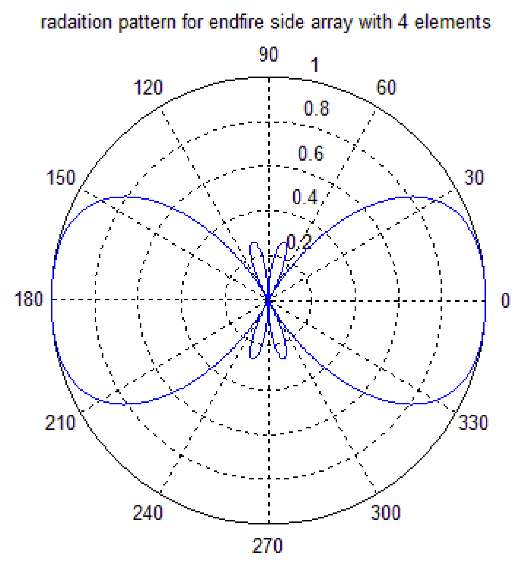
k=4 , $\Phi_{\text{null4}} = \cos^{-1}(\pm 4/2+1) = \cos^{-1}(3 \text{ or} -1)$

since $\cos^{-1}(3)$ not exist , $\Phi_{\text{null4}} = \cos^{-1}(-1) = \pm 180^0$

there fore $\Phi_{\text{null14}} = \pm 180^0$

k=5 , $\Phi_{\text{null5}} = \cos^{-1}(\pm 5/2+1) = \cos^{-1}(7/2 \text{ or} -3/2)$

both values doesn't exists



BWFN=60+60=120^0

END FIRE ARRAY WITH INCREASED DIRECTIVITY HANSEN&WOODYARD CONDITION:

It states that a large directivity is obtained by increasing phase change b/w sources so that,
$\delta = -(d_r + \pi/n)$
now, $\Psi = d_r \cos\Phi + \delta$
$= d_r \cos\Phi - (d_r + \pi/n)$

$= d_r(\cos\Phi - 1) - \pi/n$

End fire array with Increased directivity

Example with n= 4 &d= $\lambda/2$
$d_r = 2\pi/\lambda * \lambda/2$ $\Psi = \pi(\cos\Phi - 1) - \pi/4$
W.K.T major lobe occurs in the direction $\Phi = 0^0$ or 180^0
at 0^0 $E = (1/n)(\sin(n\Psi/2))/\sin(\Psi/2)$
where $\Psi = \pi(\cos\Phi - 1) - \pi/4$
$= \pi(\cos 0 - 1) - \pi/4$
$= -\pi/4$
therefore
$E = (1/4)\sin(-\pi/2)/\sin(-\pi/8) = 0.653$

At 180^0
$E = (1/n)(\sin(n\Psi/2))/\sin(\Psi/2)$
where $\Psi = \pi(\cos\Phi - 1) - \pi/4$
$= \pi(\cos 180 - 1) - \pi/4$
$= -9\pi/4$
therefore
$E = (1/4)\sin(-9\pi/2)/\sin(-9\pi/8)$
$= -0.653$

MAXIMA DIRECTIONS:

by definition $\sin(n\Psi/2) = 1$ $n\Psi/2 = \pm(2k+1)\pi/2$
Where k =1,2,3..............
now, $\Psi = \pm(2k+1)\pi/n$ $\pi(\cos\Phi - 1) - \pi/4 = \pm(2k+1)\pi/4$ there fore
$\cos\Phi = \pm(2k+1)/4 + 5/4$
K=1 $\cos\Phi = \pm(3)/4 + 5/4 = 1/2$
which implies $\Phi = \cos^{-1}(1/2) = \pm 60^0$
there fore $(\phi_{max})_{minor1} = \pm 60^{0}$

Now $E = (1/n)(\sin(n\Psi/2))/\sin(\Psi/2)$
where $\Psi = \pi(\cos\Phi - 1) - \pi/4$
$= \pi(\cos 60 - 1) - \pi/4$
$= -3\pi/4$

Now,
E =(1/4) sin(- 3π/2)/sin(- 3π/8) =-0.27
therefore E = -0.27 at ± 60^0

K=2, cos Φ = ±(5)/4+5/4=0 &10/4 which is not possible which implies Φ =cos-1(0)= ± 90^0
there fore (Φ max)minor2 = ± 90^0

Now E=(1/n)(sin(nΨ/2)) /sin(Ψ/2)

where Ψ = π (cos Φ -1)- π/4
= π (cos90-1)- π/4
=- 5π/4
Now, E =(1/4) sin(-5π/2)/sin(-5π/8)=0.27 therefore E = 0.27 at ± 90^0

K=3,cos Φ = ±(7)/4+5/4=-1/2 &12/4 which is not possible which implies
Φ =cos-1(-1/2)= ± 120^0
there fore (Φ max)minor3 = ± 120^0

Now E=(1/n)(sin(nΨ/2)) /sin(Ψ/2)
where Ψ = π (cosϕ-1)- π/4
= π (cos120-1)- π/4
=- 7π/4
Now, E =(1/4) sin(-7π/2)/sin(-7π/8)= ± 0.653 therefore E = ±0.653 at ± 120^0

K=4, cos Φ = ±(9)/4+5/4=-1 &14/4 which is not possible which implies
Φ =cos-1(-1)= ± 180 ^{0}
there fore (Φ max)minor4 = ± 180^0

Direction of nulls
(sin(nΨ/2)=0 nΨ/2= ±kπ
Where k=1,2,3,4.....
now, Ψ= ±2kπ/n π(cos Φ -1)- π/4 there fore cos Φ = ±(2k/4)-5/4
K=1 cos Φ = ±(1)/2+5/4=3/4 &7/4 which is not possible which implies
Φ =cos-1(3/4)= ± 41.4^0
there fore Φ null1 = ± 41.4^0
K=2 cos Φ = ±(1)+5/4=1/4 &9/4 which is not possible which implies
Φ =cos-1(1/4)= ± 75.5 ^{0}
there fore Φ null2 = ± 75.5^0

K=3, cos Φ = ±(6/4)+5/4=-1/4 &11/4 which is not possible which implies

$\Phi = \cos^{-1}(-1/4) = \pm\ 104.4^0$

there fore $\Phi_{null3} = \pm 104.4^0$

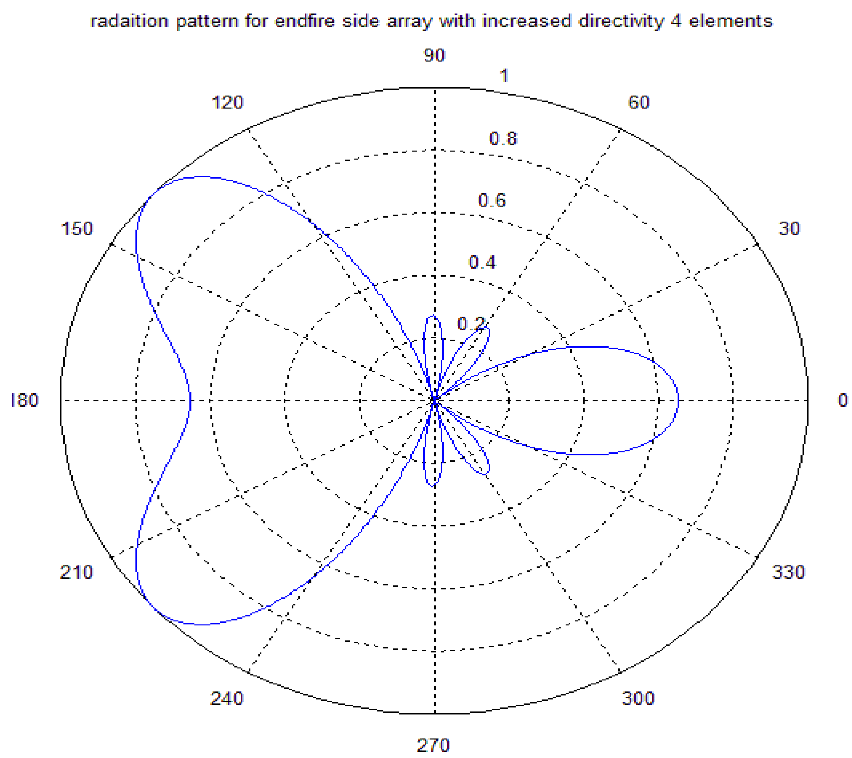
K=4, cos ϕ= ±(8/4)+5/4=-3/4 &13/4 which is not possible which implies

$\Phi = \cos^{-1}(-3/4) = \pm 75.5\ ^0$

there fore $\Phi_{null4} = \pm 75.50^0$

K=5, cosϕ= ±(10/4)+5/4=-5/4 &15/4

Both values are not possible



RECOMMENDED QUESTIONS

1. Explain different types of power pattern.
2. Explain power theorem.
3. Find the directivity for the following intensity patterns:
4. Hemispheric power pattern of a uni directional antenna.
5. Unidirectional cosine power pattern.
6. Bi directional sine power pattern.
7. Bi directional $\sin^2$ power pattern.
8. Unidirectional $\cos^2$ power pattern.
9. Show that directivity for unidirectional operation is 2(n+1) for an intensity variation of $U=UmCos^n$?.
10. Write a note on antenna arrays. Mention the factors on which the resultant pattern
11. depends.
12. Differentiate between BSA and EFA.
13. Draw the radiation pattern of
14. 2 isotropic point sources of same amplitude and phase that are ?/2 apart along X axis symmetric w.r.t origin & ƒÂ=0
15. 2 isotropic point sources of same amplitude and phase that are ?/2 apart along X axis symmetric w.r.t origin & ƒÂ=ƒÎ
16. 2 isotropic point sources of same amplitude and opposite phase that are ?/2 apart along X axis symmetric w.r.t origin & ƒÂ=0
17. 2 isotropic point sources of same amplitude and phase that are ?/2 apart along X axis with 1 source at origin & ƒÂ=0
18. 2 isotropic point sources of same amplitude and in phase quadrature.
19. Derive an expression for electric field intensity of array of n isotropic sources of equal amplitude and spacing and having a phase difference of ƒÕ.
20. Explain the principle of pattern multiplication.
21. Obtain the electric field intensity of non isotropic but similar point sources.
22. obtain the radiation pattern of 4 sources forming a uniform BSA with a spacing of ?/2.
23. Obtain BWFN & HPBW for BSA.
24. Obtain BWFN & HPBW for EFA.
25. Explain Hansen Woodyard condition for increased directivity.
26. 4 sources have equal magnitude & are spaced ?/2 apart. Maximum field is to be in line with sources. Plot the field pattern of the array given ƒÕ=0.
27. Find BWFN for uniform EFA & extended EFA. Given (i) n=4 (ii) d= ?/2.
28. The principle lobe width of uniform 10 elements of BSA was observed to be 30^o at a frequency of 30MHz. Estimate the distance between the individual elements of the array.

29. A uniform linear array consists of 16 isotropic sources with a spacing of ?/4 & phase difference ƒÂ= - 90^{o}. Calculate HPBW & effective aperture.
30. The main lobe width of 8 elements of BSA was observed to be 45^{o} at a frequency of 20MHz. Estimate the distance. N=8.
31. An EFA is composed of elements with the axis at right angles to the line of the array is required to have a power gain of 20. Calculate the array length and width of the major lobe between the nulls.
32. Calculate exact & approximate BWFN for BSA given n=4 & d= ?/2..
33. A BSA operating at 200cm wavelength consists of 4 dipoles spaced ?/2 apart & having Rr=73ƒ¶. Each element carries radio frequency in same phase & of magnitude 0.5 A. Calculate (i) radiated power. (ii) HPBW.
34. Complete the field pattern & find BWFN & HPBW for a linear uniform array of 6 isotropic sources spaced ?/2 apart. The power is applied with equal amplitude and in phase.
35. An array of 4 isotropic antennas is placed along a straight line. Distance between the elements is ?/2. The peak is to be obtained in the direction from the axis of the array. What should be the phase difference between the adjacent elements? Compute the pattern and find BWFN & HPBW.

UNIT – 3

ELECTRIC DIPOLES AND THIN LINEAR ANTENNAS

Syllabus:

Introduction, short electric dipole, fields of a short dipole(no derivation of field components), radiation resistance of short dipole, radiation resistances of lambda/2 Antenna, thin linear antenna, micro strip arrays, low side lobe arrays, long wire antenna, folded dipole antenna

Short dipole antenna:

The short dipole antenna is the simplest of all antennas. It is simply an open-circuited wire, fed at its center as shown in Figure 1.

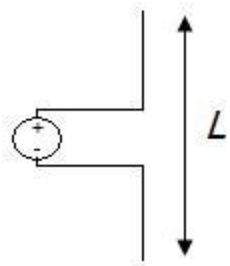


Figure 1. Short dipole antenna of length *L*.

The words "short" or "small" in antenna engineering always imply "relative to a wavelength". So the absolute size of the above dipole does not matter, only the size of the wire relative to the wavelength of the frequency of operation. Typically, a dipole is short if its length is less than a tenth of a wavelength:

$$L < \frac{\lambda}{10}$$

If the antenna is oriented along the z-axis with the center of the dipole at z=0, then the current distribution on a thin, short dipole is given by:

$$I(z) = I_0\left(1 - \frac{2|z|}{L}\right)$$

The current distribution is plotted in Figure 2. Note that this is the amplitude of the current distribution; it is oscillating in time sinusoidally at frequency *f*.

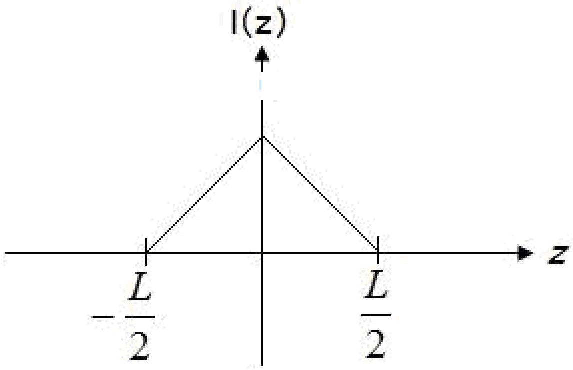


Figure 2. Current distribution along a short dipole.

The fields radiated from this antenna in the far field are given by:

$$E_\theta = \frac{j\eta k I_0 L e^{-jkr}}{8\pi r}\sin\theta$$

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

$$E_r = H_r = E_\phi = H_\theta = 0$$

The above equations can be broken down and understood somewhat intuitively. First, note that in the far-field, only the E_θ and H_ϕ fields are nonzero. Further, these fields are orthogonal and in-phase. Further, the fields are perpendicular to the direction of propagation, which is always in the $\hat{r}$ direction (away from the antenna). Also, the ratio of the E-field to the H-field is given by η (the intrinsic impedance of free space). This indicates that in the far-field region the fields are propagating like a plane-wave.

Second, the fields die off as 1/r, which indicates the power falls of as

$$P(r) \propto \frac{1}{r^2}$$

Third, the fields are proportional to *L*, indicated a longer dipole will radiate more power. This is true as long as increasing the length does not cause the short dipole assumption to become invalid. Also, the fields are proportional to the current amplitude I_0, which should make sense (more current, more power).

The exponential term:

e^{-jkr}

describes the phase-variation of the wave versus distance. Note also that the fields are oscillating in time at a frequency *f* in addition to the above spatial variation.

Finally, the spatial variation of the fields as a function of direction from the antenna are given by $\sin\theta$. For a vertical antenna oriented along the z-axis, the radiation will be maximum in the x-y plane. Theoretically, there is no radiation along the z-axis far from the antenna.

The dipole is similar to the short dipole except it is not required to be small compared to the wavelength (of the frequency the antenna is operating at).

For a dipole antenna of length L oriented along the z-axis and centered at z=0, the current flows in the z-direction with amplitude which closely follows the following function:

$$I(z) = \begin{cases} I_0 \sin\left[k\left(\frac{L}{2} - z\right)\right], & 0 \le z \le \frac{L}{2} \\ I_0 \sin\left[k\left(\frac{L}{2} + z\right)\right], & -\frac{L}{2} \le z \le 0 \end{cases}$$

Note that this current is also oscillating in time sinusoidally at frequency f. The current distributions for a quarter-wavelength (left) and full-wavelength (right) dipoles are given in Figure . Note that the peak value of the current I_0 is not reached along the dipole unless the length is greater than half a wavelength.

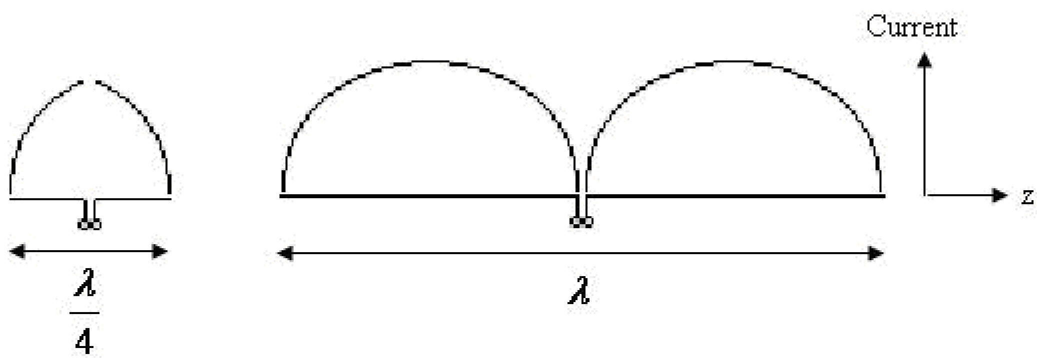


Figure . Current distributions on finite-length dipoles.

Before examining the fields radiated by a dipole, consider the input impedance of a dipole as a function of its length, plotted in Figure below. Note that the input impedance is specified as Z=R + jX, where R is the resistance and X is the reactance.

Note that for very small dipoles, the input impedance is capacitive, which means the impedance is dominated by a negative reactance value (and a relatively small real impedance or resistance). As the dipole gets larger, the input resistance increases, along with the reactance. At slightly less than 0.5 λ the antenna has zero imaginary component to the impedance (reactance X=0), and the antenna is said to be resonant.

If the dipole antenna's length becomes close to one wavelength, the input impedance becomes infinite. This wild change in input impedance can be understood by studying high frequency transmission line theory. As a simpler explanation, consider the one wavelength dipole shown in Figure 1. If a voltage is applied to the terminals on the right antenna in Figure 1, the current distribution will be as shown. Since the current at the terminals is zero, the input impedance (given by Z=V/I) will necessarily be infinite. Consequently, infinite impedance occurs whenever the dipole is an integer multiple of a wavelength.

The far-fields from a dipole antenna of length *L* are given by:

$$E_\theta = \frac{j\eta I_0 e^{-jkr}}{2\pi r}\left[\frac{\cos\left(\frac{kL}{2}\cos\theta\right)-\cos\left(\frac{kL}{2}\right)}{\sin\theta}\right]$$

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

The normalized radiation patterns for dipole antennas of various lengths are shown in Figure

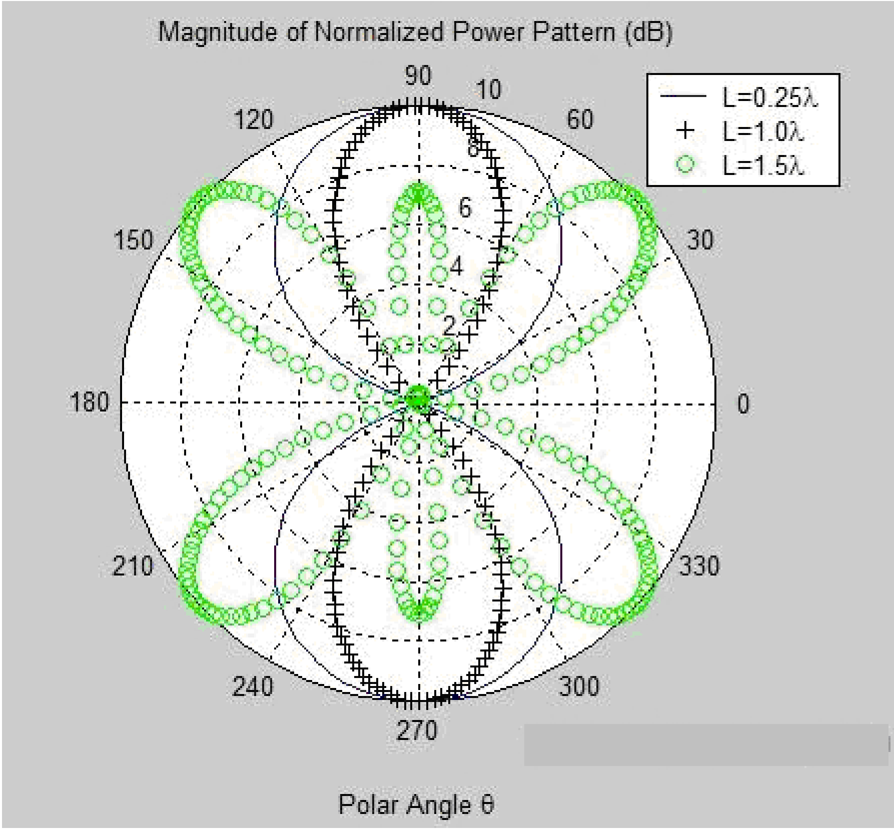


Figure . Normalized radiation patterns for dipoles of specified length.

The full-wavelength dipole is more directional than the shorter quarter-wavelength dipole. This is a typical result in antenna theory: it takes a larger antenna in general to increase directivity. However, the results are not always obvious. The 1.5-wavelength dipole pattern is also plotted in Figure 1. Note that this pattern is maximum at approximately +45 and -45 degrees.

The dipole is symmetric when viewed azimuthally; as a result the radiation pattern is not a function of the azimuthal angle ϕ. Hence, the dipole antenna is an example of an omnidirectional antenna. Further, the E-field only has one vector component and consequently the fields are linearly polarized. When viewed in the x-y plane (for a dipole oriented along the z-axis), the E-field is in the -y direction, and consequently the dipole antenna is vertically polarized.

The 3D pattern for the 1-wavelength dipole is shown in Figure . This pattern is similar to the pattern for the quarter- and half-wave dipole.

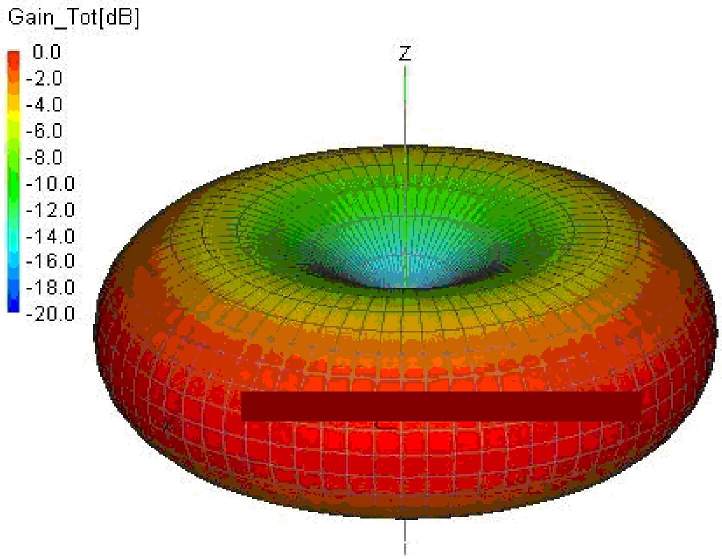


Figure . Normalized 3d radiation pattern for the 1-wavelength dipole.

The 3D radiation pattern for the 1.5-wavelength dipole is significantly different, and is shown in Figure

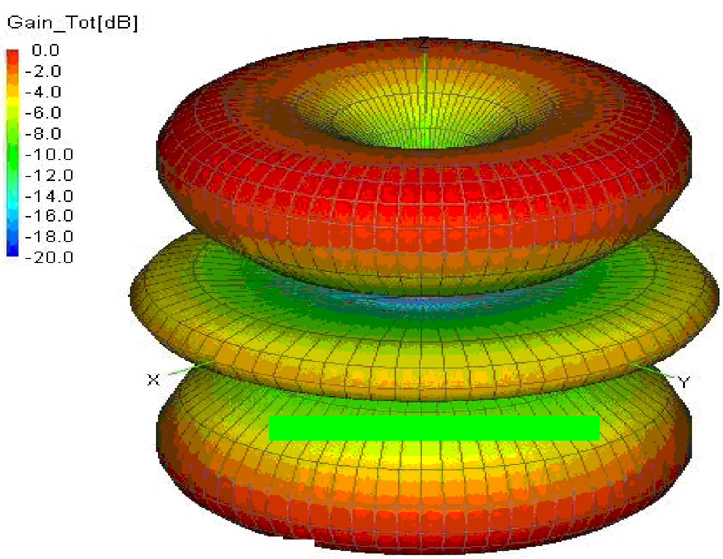


Figure . Normalized 3d radiation pattern for the 1.5-wavelength dipole.

The (peak) directivity of the dipole varies as shown in Figure .

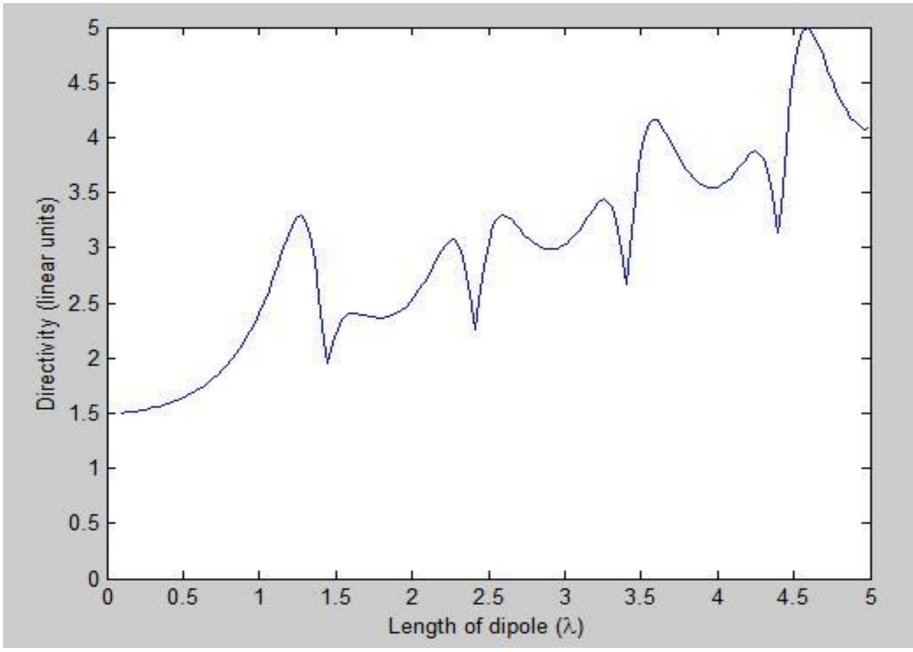
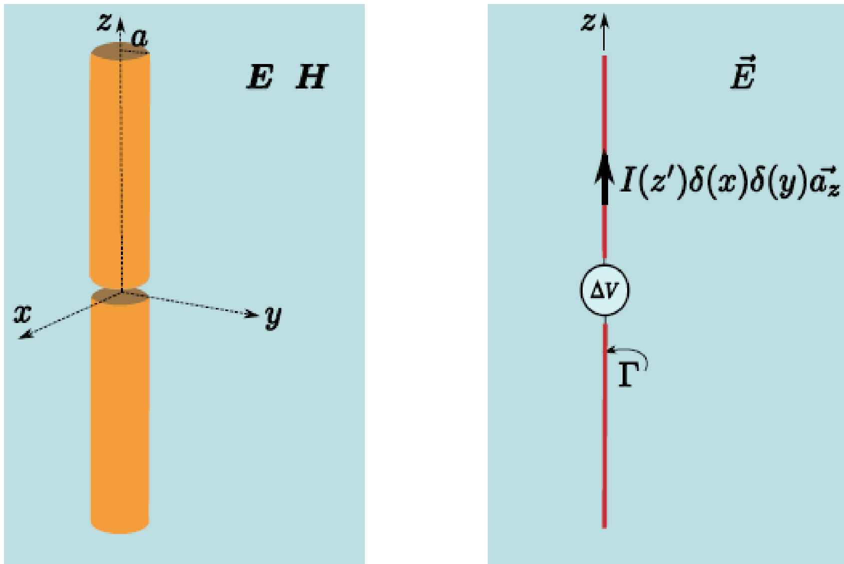


Figure Dipole directivity as a function of dipole length.

RADIATION FIELDS OF A LINEAR WIRE ANTENNA

Given a linear wire antenna, infinitesimal, small or finite length one, positioned symmetrically at the origin of the coordinate system and oriented along the z axis, as shown in Fig. 1. A known filamentary electrical current is supposed to exist in the form of $\vec{J} = I(z')\delta(x)\delta(y)\vec{a_z}$. The form of $I(z')$ has been studied intensively and widely.



(a) (b)

A generic linear wire antenna. (a) Cylindrical antenna of radio $a \ll \lambda$. (b) When $a \ll \lambda$ the cylindrical antenna becomes a linear wire antenna.

To calculate the field radiated by the antena, the conductive wires are suppressed and the electrical current is let alone to generate an electrical field $\vec{E}$ given by:

$$\vec{E} = -\jmath\omega\left[\frac{1}{\kappa^2}\nabla(\nabla\cdot\vec{A}) + \vec{A}\right] \tag{1}$$

where ω is the angular frequency, κ is the wave number and $\vec{A}$ is the Magnetic Vector Potential.

The Magnetic Vector Potential A is related to the current $I(z')$

by a convolutional integral

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi} \int_\Gamma I(z')\vec{a}_z \frac{\mathrm{e}^{-\jmath\kappa|\vec{r}-\vec{r}\,'|}}{|\vec{r}-\vec{r}\,'|}\, \mathrm{d}z' \tag{2}$$

where Γ is the locus of the electrical current.

The Magnetic Vector Potential is the solution of the inhomogeneous Helmholtz equation

$$\nabla^2\vec{A} + \kappa^2\vec{A} = -\mu_0 I(z')\delta(x)\delta(y)\vec{a}_z \tag{3}$$

where $I(z')$ radiates alone in free space as if the wire does not exist.

As seen in Eq. (1) the electrical field has two components: the quasi-static one, given by the expression: $-\frac{\jmath\omega}{\kappa^2}\nabla\nabla\cdot\vec{A}$, and the dynamic component, given by $-\jmath\omega\vec{A}$. The former varies with $\frac{1}{r^2}$, and the latter with $\frac{1}{r}$. In the far zone, the dynamic component predominates over the quasi-static one, and the electrical field can be approximated in the following way [3, 11]:

$$E_r(\vec{r}) \approx 0 \tag{4a}$$
$$E_\theta(\vec{r}) \approx -\jmath\omega A_\theta(\vec{r}) \tag{4b}$$
$$E_\varphi(\vec{r}) \approx -\jmath\omega A_\varphi(\vec{r}) \tag{4c}$$

where $\vec{r}$ must be in the far zone and $A_{\theta,\varphi} = \frac{\mu_0}{4\pi}\frac{\mathrm{e}^{-\jmath\kappa r}}{r}N_{\theta,\varphi}$, where $\vec{N}(\vec{r})$ is the Radiation Vector. The Radiation Vector is defined as:

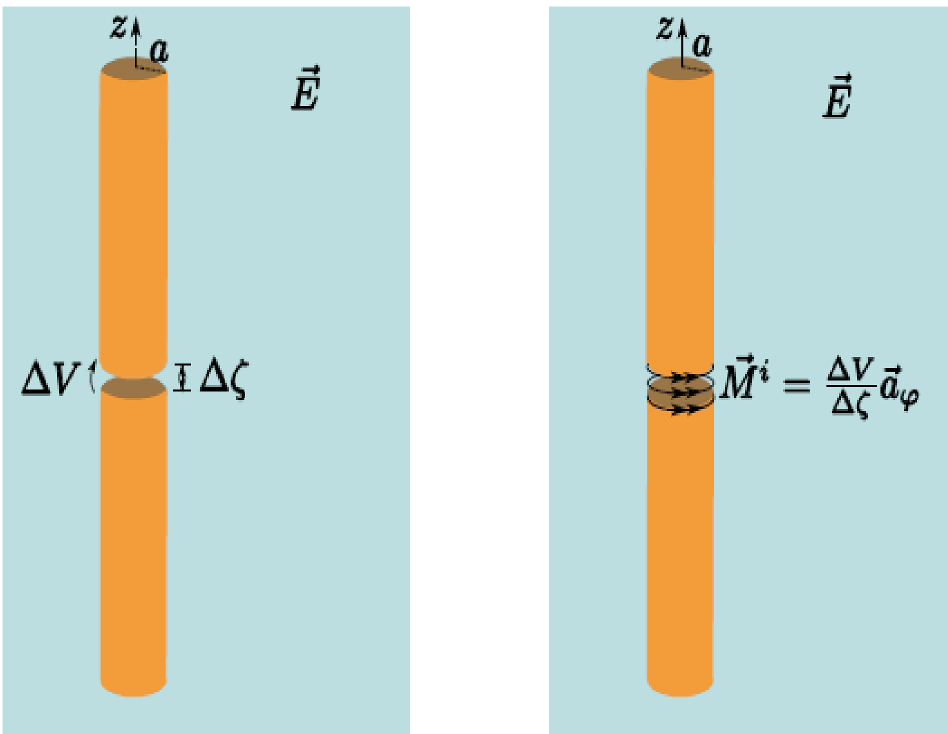
$$\vec{N} = \int_\Gamma I(z')\vec{a}_z \mathrm{e}^{\jmath\kappa z'\cos\theta}\, \mathrm{d}z' \tag{5}$$

By postulating a known function for the electrical current $I(z')$, or by measuring it, the Radiation Vector is calculated using Eq. (5) and then the Electrical Field $\vec{E}$ is obtained through Eqs. (4). The Magnetic Field is determined as $\vec{H} = \vec{a_r} \times \vec{E}/\eta$.

RADIATION FIELDS OF A LINEAR WIRE ANTENNA: A FORMAL APPROACH

Given a linear wire antenna, as shown in Fig. 2, fed across a small gap $\Delta\zeta$ with an impressed voltage ΔV, the excited field is the solution of a boundary value problem: an impressed source radiating in the presence of wires.

The resulting total electrical field $\vec{E}$ can be separated in two components: the impressed field $\vec{E}^i$ and the scattered field $\vec{E}^s$.



(a) (b)

A generic linear wire antenna fed across a small gap $\Delta\zeta$ with an impressed voltage ΔV. (a) Linear wire antenna $-a \ll \lambda-$. (b) Field equivalent source for the delta-gap voltage.

Assuming the wires as perfect electric conductor bodies, the impressed and scattered fields can be calculated by splitting the original problem in two sub-problems as shown in Fig. 3.

The impressed and scattered fields can be viewed like the particular and homogenous solutions, respectively, of the original boundary problem.

In sub-problem A (see Fig. 3(a)) the wires are suppressed and the impressed sources are retained so that they radiate in free space. This problem is governed by the equation:

$$\nabla^2 \vec{F}^i + \kappa^2 \vec{F}^i = -\varepsilon_0 \vec{M}^i \tag{6}$$

where $\vec{F}^i$ is the Electric Vector Potential and $\vec{M}^i = \frac{\Delta V}{\Delta \zeta} \vec{a}_\varphi$, for $-\Delta\zeta/2 \leq z' \leq \Delta\zeta/2 \leq$ and $\rho = a$ is an impressed magnetic current density equivalent to the delta-gap impressed voltage (see Fig. 2(b)) [1]. The solution of Eq. (6) is:

$$\vec{F}^i = \frac{\varepsilon_0}{4\pi} \int_{S_{gap}} \frac{\Delta V}{\Delta \zeta} \vec{a}_\varphi \frac{\mathrm{e}^{-\jmath\kappa|\vec{r}-\vec{r}'|}}{|\vec{r}-\vec{r}'|} \mathrm{d}s' \tag{7}$$

The impressed electric field is thus obtained as $\vec{E}^i = -\frac{1}{\varepsilon_0} \nabla \times \vec{F}^i$.

RECOMMENDED QUESTIONS

1. Derive an expression for intrinsic impedance of short dipole.
2. Derive the expression for electric & magnetic fields of linear antenna.
3. Derive the expression for radiation resistance of linear antenna.
4. Find the radiation resistance of Hertzian dipole whose wavelength is ?/8.
5. S.T directivity of short dipole is 1.5.
6. A thin dipole is ?/15 long. If its loss resistance is 1.5 ƒ¶, find its efficiency.
7. A short dipole antenna was observed to have Rr=2 ƒ¶ at 1MHz. Calculate its length.
8. Calculate the efficiency of an antenna operated at 500 KHz and having a resistance 12 ƒ¶ and effective height=30m.
9. 2m long vertical wire carries a current of 5A at 1MHz find the strength of the radiated field at 30Km in the direction at right angles to the axis of the wire. Assume that the wire is in free space.
10. A plain wave is incident on a short dipole. The wave is linearly polarized with electric field in the Y-direction. The current on the dipole is assumed constant and in the same phase over entire length. The antenna loss resistance=0. Find the dipole maximum effective aperture and directivity.

11. Starting from the concepts of magnetic vector and electric scalar potentials derive the expressions for field components of short dipole.

11. Derive the expression for radiation resistance of Hertzian dipole.

13.Distinguish between far field and near field.

14.Derive an expression for power density of short dipole.

UNIT – 4

LOOP, SLOT, PATCH AND HORN ANTENNA

Syllabus:

Introduction, small loop, comparison of far fields of small loop and short dipole, loop antenna general case, far field patterns of circular loop, radiation resistance, directivity, slot antenna, Babinet's principle and complementary antennas, impedance of complementary and slot antennas, patch antennas.

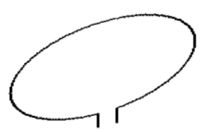
LOOP ANTENNAS :

All antennas discussed so far have used radiating elements that were linear conductors. It is also possible to make antennas from conductors formed into closed loops. There are two broad categories of loop antennas:

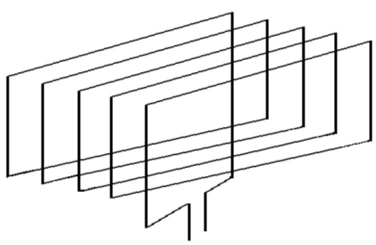
1. Small loops, which contain no more than 0.085 wavelengths ($\lambda/12$) of wire
2. Large loops, which contain approximately 1 wavelength of wire.

SMALL LOOP ANTENNAS:

A small loop antenna is one whose circumference contains no more than 0.085 wavelengths of wire. In such a short conductor, we may consider the current, at any moment in time to be constant. This is quite different from a dipole, whose current was a maximum at the feed point and zero at the ends of the antenna. The small loop antenna can consist of a single turn loop or a multi-turn loop as shown below:

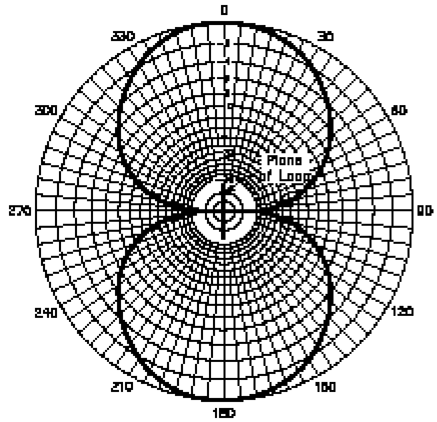


Single Turn Loop Antenna

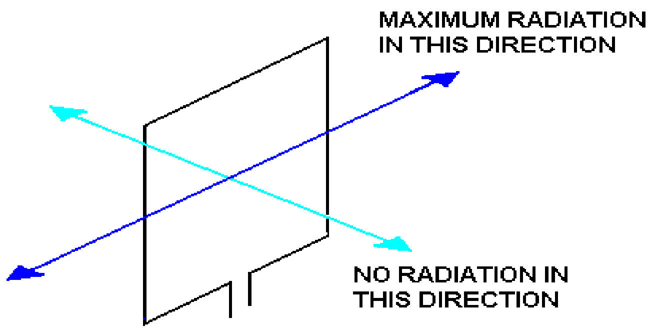


Multi-turn Loop Antenna

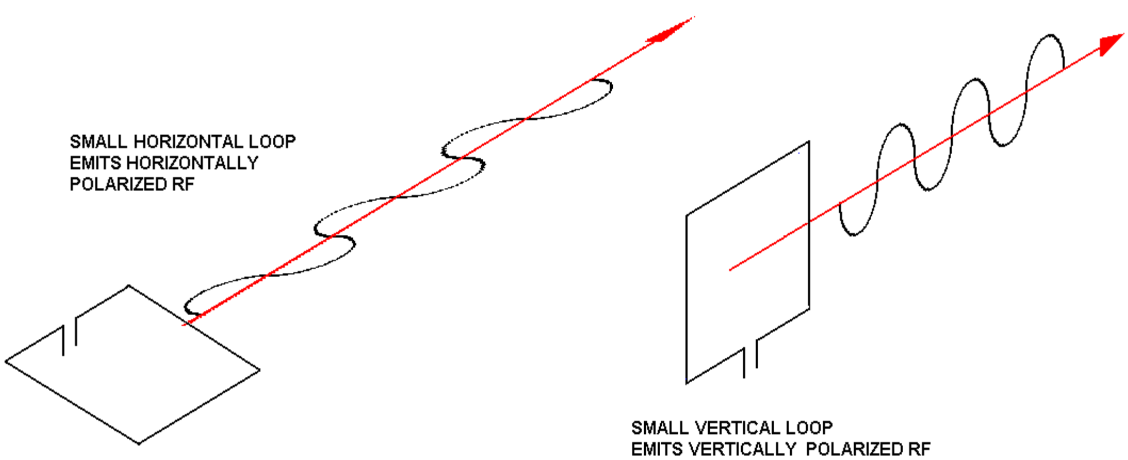
The radiation pattern of a small loop is very similar to a dipole. The figure below shows a 2-dimensional slice of the radiation pattern in a plane perpendicular to the plane of the loop. There is no radiation from a loop



There is no radiation from a loop along the axis passing through the center of the loop, as shown below.



When the loop is oriented vertically, the resulting radiation is vertically polarized and vice versa:



The input impedance of a small loop antenna is inductive, which makes sense, because the small loop antenna is actually just a large inductor. The real part of the input impedance is very small, on the order of 1 ohm, most of which is loss resistance in the conductor making up the loop. The actual radiation resistance may be 0.5 ohms or less. Because the radiation resistance is small compared to the loss resistance, the small loop antenna is not an efficient antenna and cannot be used for transmitting unless care is taken in its design and manufacture.

While the small loop antenna is not necessarily a good antenna, it makes a good receiving antenna, especially for LF and VLF. At these low frequencies, dipole antennas are too large to be easily constructed (in the LF range, a dipole's length ranges from approximately 1600 to 16,000 feet, and VLF dipoles can be up to 30 miles long!) making the small loop a good option. The small loop responds to the magnetic field component of the electromagnetic wave and is deaf to most man-made interference, which has a strong electric field. Thus the loop, although it is not efficient, picks up very little noise and can provide a better SNR than a dipole. It is possible to amplify the loop's output to a level comparable to what one might receive from a dipole.

When a small loop is used for receiving, its immunity and sensitivity may be improved by paralleling a capacitor across its output whose capacitance will bring the small loop to resonance at the desired receive frequency. Antennas of this type are used in AM radios as well as in LF and VLF direction finding equipment used on aircraft and boats.

Loop antennas may be combined to form arrays in the same manner as dipoles. Arrays of loop antennas are called "quad arrays" because the loops are most often square. The most common type of quad array is a Yagi-Uda array using loops rather than dipoles as elements. This type of array is very useful at high elevations, where the combination of high voltage at the element tips of the dipoles in a standard Yagi array and the lower air pressure lead to corona discharge and erosion of the element . In fact, the first use of a quad array was by a broadcaster located in Quito, Ecuador (in the Andes Mountains) in the 1930's.

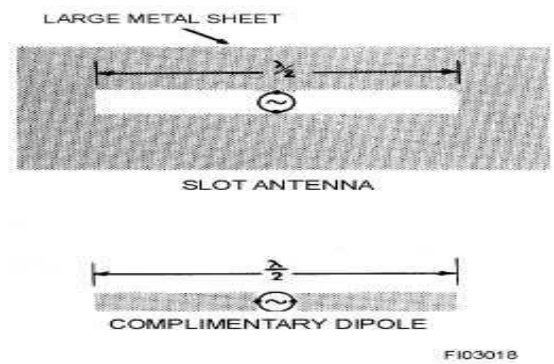
The input impedance of a loop depends on its shape. It ranges from approximately 100 ohms for a triangular loop to 130 ohms for a circular loop. Unlike the dipole, whose input impedance presents a good match to common 50 or 75 ohm transmission lines, the input impedance of a loop is not a good match and must be transformed to the appropriate impedance. Impedance matching will be the topic of the next unit.

SLOT ANTENNA:

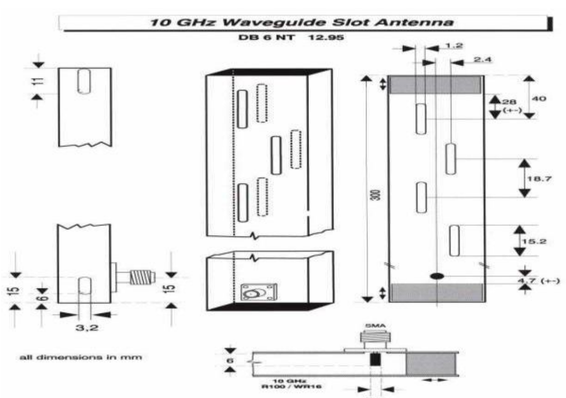
These antennas find applications where low profile or flush installations are required. eg High Speed Aircraft. Relation of slot and their complimentary dipole forms. Any slot has its complementary form in wires or strips. Pattern and impedance data can be used to predict the pattern and impedance of corresponding slots. Two resonant $\lambda/4$ stubs connected to two wire transmission line form inefficient radiator. The two wires are closely spaced and carry currents of opposite phase so that the fields tend to cancel. The end wires carry currents in the same phase but they are too short to radiate efficiently. Hence enormous current is required to radiate appreciable amount of power. $\lambda/2$ slot cut in a flat metal sheet. Currents are not confined to the edges but spreads out of the sheet. Radiation occurs equally from both sides of the sheet.
Slot antenna can be energized with coaxial transmission line. They are Omni directional microwave antennas. Feature gain around the azimuth with horizontal polarization.

Waveguide slot antennas, usually with an array of slots for higher gain, are used at frequencies from 2 - 24 GHz. Simple slotted-cylinder antennas are more common at the UHF and lower microwave frequencies where the size of a waveguide becomes unwieldy. They are simple, rugged, and fairly easy to build. A thin slot in an infinite ground plane is the complement to a dipole in free space. The slot is a magnetic dipole rather than an electric dipole. Radiation from a vertical slot is polarized horizontally.

A vertical slot has the same pattern as a horizontal dipole of the same dimensions.
A longitudinal slot in the broad wall of a waveguide radiates just like a dipole perpendicular to the slot.



The slot is a magnetic dipole rather than an electric dipole. Radiation from a vertical slot is polarized horizontally. A vertical slot has the same pattern as a horizontal dipole of the same dimensions. A longitudinal slot in the broad wall of a waveguide radiates just like a dipole perpendicular to the slot. A waveguide slot antenna has a vertical row of slots along the length of a vertical waveguide. The array of slots increases the gain by flattening the vertical beam. Since the slots are oriented vertically along the guide, the polarization is horizontal. A comparable dipole antenna would be a stack of horizontal dipoles.



Increasing the number of slots provides more gain but flattens the beam into a narrower elevation angle. Since a slot in one side of the physical waveguide does not radiate uniformly on both sides like a theoretical slot in infinite plane. An identical row of slots is added on the far side of the waveguide to make the radiation pattern more uniform.

Design of an antenna array involves a number of details:

- Cutting the elements to resonance.
- Spacing the elements properly.
- Splitting the power to distribute to the elements.
- feeding the elements in phase through a harness of transmission lines.
- Providing a mounting structure for each element.

For traditional arrays, each of these items may be attacked separately, but the waveguide slot antenna combines them all into a single piece of waveguide. we must find a set of dimensions that satisfies all the requirements simultaneously.

A longitudinal slot cut into the wall of a waveguide interrupts the transverse current flowing in the wall, forcing the current to travel around the slot, which induces an electric field in the slot. The position of the slot in the waveguide determines the current flow. That is the position determines the impedance presented to the transmission line and the amount of energy coupled to the slot and radiated from the slot. The current in the walls of the guide must be proportional to the difference in electric field between any two points. A slot in the exact center of the broad wall of the waveguide will not radiate at all. Since the electric field is symmetrical around the center of the guide and thus is identical at both edges of the slot. As the slot is positioned away from the centerline, the difference in field intensity between the edges of the slot is larger, so that more current is interrupted and more energy is coupled to the slot, increasing radiated power.

As we approach the sides of the waveguide, the field is very small, since the sidewalls are short circuits for the electric field. The induced current must also be small; longitudinal slots far from the center or in the sidewall will not radiate significantly. However, angled slots in the sidewalls can be effective radiators. From the point of view of the waveguide, the slot is a shunt impedance across the transmission line, or an equivalent admittance loading the transmission line (admittance is the reciprocal of impedance). Slots further from the centerline of the guide present a larger admittance (lower impedance) to the transmission line. When the admittance of the slot (or combined admittance of all the slots) equals the admittance of the guide, then we have a matched transmission line, or low VSWR.

In a circular waveguide, the point of maximum electric field is needed to be located to make a slot antenna .In a rectangular waveguide, the maximum electric field is conveniently located at the centerline of the broad wall, while in circular guide the maximum electric field is on a line through the center but may be oriented in any direction. The slots are resonant so that they provide a resistive load to the (waveguide) transmission line. It is desirable for an omni directional antenna to radiate in a horizontal (azimuth) plane. This is achieved by feeding all the slots in phase.

The radiation pattern may be tilted upward or downward (visualize a shallow cone) by changing the phasing of the slots, if desired. So we would require a mechanism to fix the alignment of the electric field in the circular waveguide, and to keep it from rotating when encountering a discontinuity such as a slot. This difficulty makes rectangular waveguide much more attractive for slot antennas. The slots are fed in phase by spacing their centers at electrical half-wavelength intervals along the waveguide. Far field is produced by three sources one at the slot of strength 1sinωt Two at the edges of the sheet with a strength ksin(ωt-δ) , where k«1 and δ gives the phase difference of the edge sources with respect to the source 1 at the slot.

The relative field intensity is

$E=\sin\omega t+ k\sin(\omega t-\delta-\varepsilon)+k\sin(\omega t-\delta+\varepsilon)$ where $\varepsilon=(\pi/\lambda)L \cos \varphi$

By expansion and rearrangement

$$E=(1+2k\cos \delta \cos \varepsilon)\sin \omega t - (2k \sin \delta \cos \varepsilon)\cos \omega t$$

$|E|= \sqrt{(1+2k\cos \delta \cos \varepsilon)^2 - (2k \sin \delta \cos \varepsilon)^2}$

$|E|= \sqrt{1+4k\cos \delta \cos \varepsilon}$

Maxima and minima occurs when $\varepsilon=n \pi$.

Babinet Principle:

•To find complementary impedances.

It states (in optics) that when a field behind a screen with an opening is added to the field of a complementary structure (that is a shape covering the screen hole), then the sum is equal to the field where there is no screen.

The end result of practical interest for antenna engineers is the following formula:

$$Z_{metal} Z_{slot} = \eta^2 /4$$

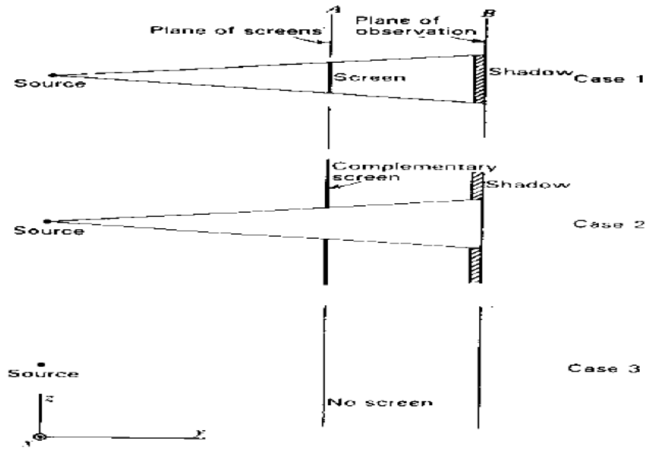
•Z_{metal} and Z_{slot} are input impedances of the metal and slot radiating pieces.

•η is the intrinsic impedance of the media in which the structure is immersed.

•Z_{slot} is not only the impedance of the slot, but can be viewed as the complementary structure impedance (a dipole or loop in many cases).

In addition, Z_{metal} is often referred to as Z_{screen} were the screen comes from the optical definition.

Eta or intrinsic impedance, $\eta = \sqrt{\mu/\varepsilon}$



Let a perfectly absorbing field screen be placed in plane A. In plane B there is a region of shadow .Let the field behind this screen be some function f1 of x, y and z.

$F_s = f_1(x,y,z)$

If the screen is replaced by its complementary screen. The field behind is given by

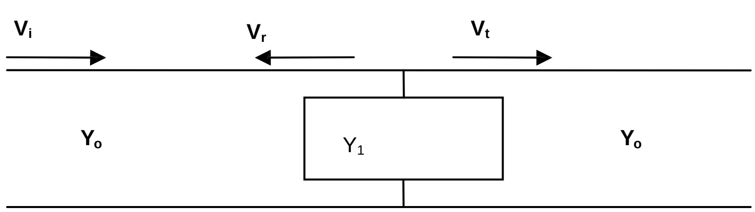
$$F_{cs}= f_2(x,y,z)$$

With no screen present the field $F_o= f_3(x,y,z)$

Then Babinet's principle asserts that at the same point x_1, y_1, z_1,

$$F_s+ F_{cs}= F_o$$

IMPEDANCE OF COMPLEMENTARY SCREEN



Consider the infinite transmission line of characteristics impedance Z_0 or admittance $Y_0 = 1/ Z_0$. Neglecting impedance of the admittance

$$Y_1=I/V$$

Y is same for any square section of the sheet.The field intensities of the wave reflected and transmitted normally to the screen are E_r and E_t.Let the medium surrounding the screen be free space. It has a characteristics admittance Y_0 which is a pure conductance G_0.

$$Y_0=1/Z_0=1/377=G_0$$

The ratio of the magnetic to electric field intensity of any plane traveling wave in free space has the valve

$$Y_0=H_i/E_i=-H_r/E_r=H_t/E_t$$

The transmission coefficient for the voltage of transmission line is

$$V_t/V_i=2Y_0/2Y_0+Y_1$$

The transmission coefficient for the electric field is

$$E_t/E_i=2Y_0/2Y_0+Y_1$$

If the original screen is replaced by the complimentary screen with an admittance

$$E_t'/E_i=2Y_0/2Y_0+Y_2$$

Applying Babinet's principal we have

$$E_t/E_i+E'_t=1$$

Therefore

$$2Y_0/2Y_0+Y_1 \quad + 2Y_0/2Y_0+Y_2=1$$

We obtain Bookers result

$$Y_1Y_2=4Y_0^2$$

$$Z^1Z^2=Z_0^2/4 \text{ or } \sqrt{Z_1Z_2}=Z_0/2$$

For free space

$$Z_0=376.7\Omega$$

$$Z_1=35476/Z2\ \Omega$$

IMPEDANCE OF SLOT ANTENNAS

Let a generator be connected to the terminals of the slot.The driving point impedance Z_s at the terminal is V_s/I_s.Let E_s and H_s be the electric and magnetic fields of the slot at any point P. Then V_s at the terminal FF is given

$$\text{Lim} \int_{c1} E_s \, dl$$

Current I_s of the slot is given by $2 \lim \int_{c2} H_s \, dl$

Let the generator be connected to the terminals of the dipole. The driving point impedance

$$Z_d = V_d/I_d$$

Let E_d and H_d be the electric and magnetic fields of the slot at any point P.

The terminal voltage at the dipole is $\mathbf{V_d = \lim \int_{c2} E_d \, dl}$

and current is $\mathbf{I_d} = 2 \lim \int_{c2} H_d \, dl$

However $\mathbf{\lim \int_{c2} E_d dl = Z_0}$ $\lim \int_{c2} H_S \, dl$ and $\lim \int_{c1} H_d dl = 1/z_0$ $\mathbf{\lim \int_{c1} E_s \, dl}$

Full λ Dipole **Z_0=intrinsic impedance of surrounding medium**

$$V_d = Z_0/2 * I_s \text{ and } V_s = Z_0/2 * I_d$$

Multiplying V_d and V_s we have

$$V_d V_s / I_d I_s = Z_o^2/4$$

$$Z_s Z_d = Z_o^2/4 \text{ or } Z_s = Z_o^2/4Z_d$$

For free space

$$Z_0 = 376.7,$$

$$Z_s = 3547/Zd \ \Omega$$

Impedance of the slot is propositional to admittance of the dipole

$$Z_s = 35476/R_d + jX_d$$

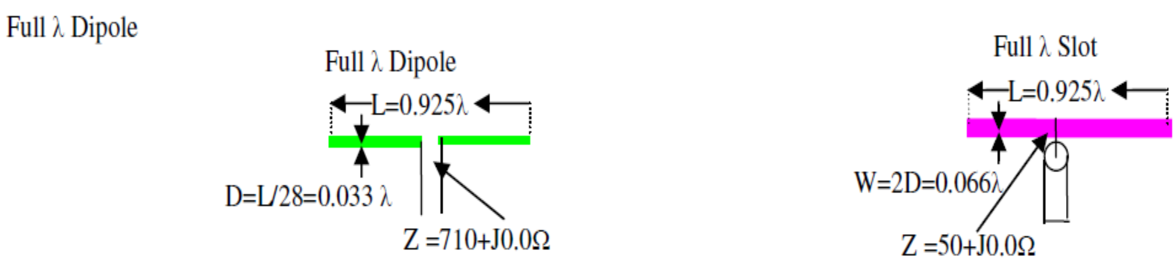
$$= 35476/R_d^2 + X_d^2 (R_d - jX_d)$$

If the dipole antenna is inductive the slot is capacitative. The impedance of infinitesimal thin λ/2 antenna is 73+j42.5 Ω.Therefore the terminal impedance of the infinitesimally thin λ/2 slot antenna L=0.5 λ and L/w=infinity is

Z1=35476/73+j42.5=363-j211 Ω

A cylindrical antenna with length diameter ratio of 100 is resonant when the length is about 0.475 λ.The terminal impedance is resistive and equal to about 67 Ω.
The terminal resistance of the complementary slot antenna is then

Z1=35476/67=530+j0 Ω



The complementary slot has a length L=0.475 λ same as dipole but width twice the diameter of the cylindrical dipole. The width of complementary dipole is 0.01 λ

A cylindrical dipole with an L/D ratio of 28 and length of about 0.925λ has a terminal resistance of about 710+j0 Ω. The terminal resistance of the complementary slot is then 50+j0 Ω.

The bandwidth or selectivity characteristics of the slot antenna are same as for the complementary dipole. Smaller L/w ratio increases the bandwidth of the slot antenna. Increasing the thickness of dipole (smaller L/D) increases the bandwidth.

UNIT – 5 & 6

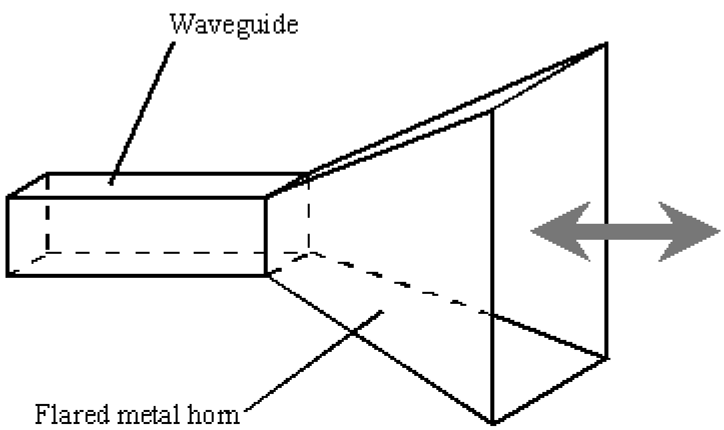
ANTENNA TYPES

Syllabus:

Horn Antennas, rectangular horn antennas, Helical antenna, yagi-uda array, corner reflector, parabolic reflector, log periodic antenna, lens antenna, antenna for special applications-sleeve antenna, turnstile antenna, omni directional antennas, antennas for satellite, antenna for ground penetrating radars, embedded antennas, ultra wideband antennas, plasma antennas.

Horn antenna:

A horn antenna is used for the transmission and reception of microwave signals. It derives its name from the characteristic flared appearance. The flared portion can be square, rectangular, or conical. The maximum radiation and response corresponds with the axis of the horn. In this respect, the antenna resembles an acoustic horn. It is usually fed with a waveguide.



In order to function properly, a horn antenna must be a certain minimum size relative to the wavelength of the incoming or outgoing electromagnetic field. If the horn is too small or the wavelength is too large (the frequency is too low), the antenna will not work efficiently.

Horn antennas are commonly used as the active element in a dish antenna. The horn is pointed toward the center of the dish reflector. The use of a horn, rather than a dipole antenna or any other type of antenna, at the focal point of the dish minimizes loss of energy (leakage) around the edges of the dish reflector. It also minimizes the response of the antenna to unwanted signals not in the favored direction of the dish.

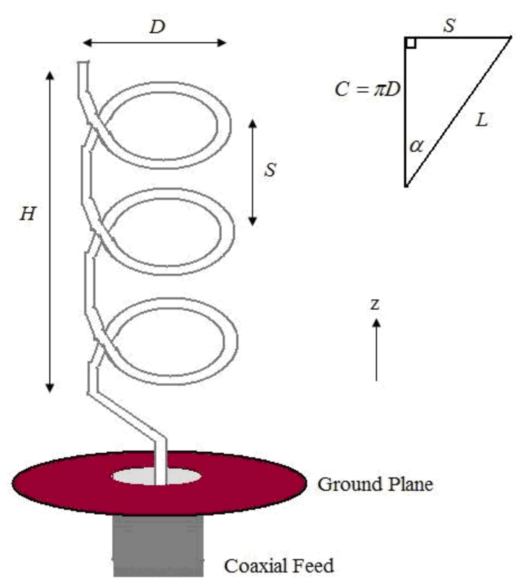
Horn antennas are used all by themselves in short-range radar systems, particularly those used by law-enforcement personnel to measure the speeds of approaching or retreating vehicles.

Helical antenna

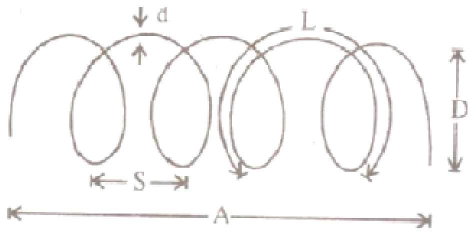
A helical antenna is a specialized antenna that emits and responds to electromagnetic fields with rotating (circular)polarization. These antennas are commonly used at earth-based stations in satellite communications systems. This type of antenna is designed for use with an unbalanced feed line such as coaxial cable. The center conductor of the cable is connected to the helical element, and the shield of the cable is connected to the reflector.

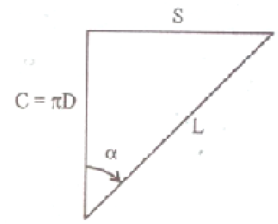
To the casual observer, a helical antenna appears as one or more "springs" or helixes mounted against a flat reflecting screen. The length of the helical element is one wavelength or greater. The reflector is a circular or square metal mesh or sheet whose cross dimension (diameter or edge) measures at least 3/4 wavelength. The helical element has a radius of 1/8 to 1/4 wavelength, and a pitch of 1/4 to 1/2 wavelength. The minimum dimensions depend on the lowest frequency at which the antenna is to be used. If the helix or reflector is too small (the frequency is too low), the efficiency is severely degraded. Maximum radiation and response occur along the axis of the helix.

The most popular helical antenna (often called a 'helix') is a travelling wave antenna in the shape of a corkscrew that produces radiation along the axis of the helix. These helixes are referred to as axial-mode helical antennas. The benefits of this antenna is it has a wide bandwidth, is easily constructed, has a real input impedance, and can produce circularly polarized fields. The basic geometry is shown in Figure



Geometry of Helical Antenna.





The helix parameters are related by

$$(\pi D)^2 = L^2 - S^2$$

Let S = Spacing between each turns
N= No. of Turns
D= Diameter of the helix
L'=A=Ns=Total length of the antenna
L= Length of the wire between each turn = $\sqrt{(\pi D)^2 + s^2}$
L_n= LN = Total length of the wire
C =πD= Circumference of the helix
α = Pitch angle formed by a line tangent to the helix wire and a plane perpendicular to the helix axis.

$$\alpha = \tan^{-1}\frac{s}{c} = \tan^{-1}\frac{s}{\pi D}$$

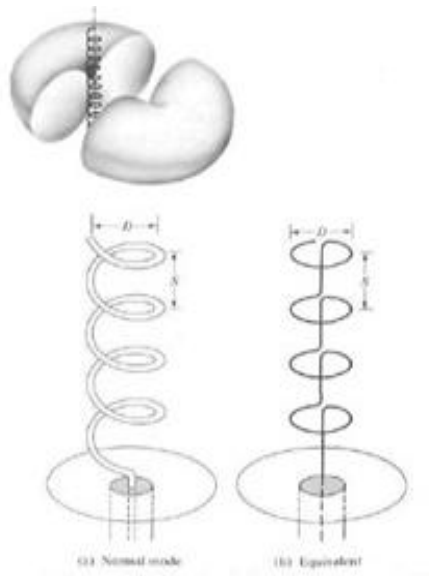
The radiation characteristics of the antenna can be varied by controlling the size of its geometrical properties compared to the wavelength.

Mode of Operation

- Normal Mode
- Axial Mode

Normal Mode:-

If the circumference, pitch and length of the helix are small compared to the wavelength, so that the current is approximately uniform in magnitude and phase in all parts of the helix, the normal mode of radiation is excited.



In normal mode as shown in fig 6.2 the radiation is maximum in the plane normal to the helix axis. The radiation may be elliptically or circularly polarized depending upon helix dimensions.

Disadvantages:

- Narrow Bandwidth
- Poor Efficiency

The radiation pattern in this mode is a combination of the equivalent radiation form a short dipole positioned along the axis of the helix and a small co-axial loop.

The radiation pattern of these two equivalent radiators is the same with the polarization at right angles and the phase angle at a given point in space is at 90^0 apart. Therefore the radiation is either elliptically polarized or circularly polarized depending upon the field strength ratio of the two components. This depends on the pitch angle α

When 'α' is very small, the loop type of radiation predominates, when it becomes very large, the helix becomes essentially a short dipole. In these two limiting cases the polarization is linear. For intermediate value of the polarization is elliptical and at a particular value of 'α' the polarization is circular

Analysis of normal mode

Field due to short dipole is given by

$$E_\theta(\theta) = \frac{j60\pi Is\sin\theta}{\lambda r}$$

Field of a small loop

$$E_\phi(\theta) = \frac{j60\pi^2 IA\sin\theta}{\lambda^2 r}$$

Magnitude of $E_\theta(\theta)$ and $E_\phi(\theta)$ ratio defines axial ratio

$$\text{Axial ratio} = \frac{|E\theta|}{|E\phi|} = \frac{s\lambda}{2\pi A} = \frac{s}{\beta A}$$

The field is circularly polarized if S = βA

$$\therefore s = \frac{2\pi}{\lambda}\frac{\pi D^2}{4} = \frac{(\pi D)^2}{2\lambda}$$

$\frac{2s}{\lambda} = \left(\frac{\pi D}{\lambda}\right)^2$ From figure 6.1 $L^2 - s^2 = (\pi D)^2$

$$\therefore \left(\frac{L}{\lambda}\right)^2 - \left(\frac{s}{\lambda}\right)^2 = \left(\frac{\pi D}{\lambda}\right)^2 = \frac{2s}{\lambda}$$

$$1 + \left(\frac{L}{\lambda}\right)^2 = 1 + \frac{2s}{\lambda} + \left(\frac{s}{\lambda}\right)^2 = \left(1 + \frac{s}{\lambda}\right)^2$$

$$1+\frac{s}{\lambda}=\sqrt{1+\left(\frac{L}{\lambda}\right)^2}$$

$$\left(\frac{s}{\lambda}\right)=-1+\sqrt{1+\left(\frac{L}{\lambda}\right)^2}$$

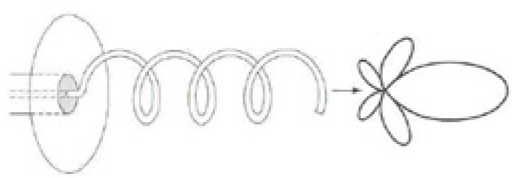
This is the condition for circular polarization

The pitch angle is given by

$$\tan\alpha=\frac{s}{\pi D} \quad \text{but} \quad s=\frac{(\pi D)^2}{2\lambda}$$

$$\tan\alpha=\frac{(\pi D)^2}{2\lambda\pi D}=\frac{\pi D}{2\lambda}$$

Axial Mode:-



If the dimensions of the helix are such that the circumference of one turn is approximately λ, the antenna radiates in the axial mode, which is as shown in fig 6.3.

Advantages:

Large Bandwidth and Good Efficiency

The Radiation is circularly polarized and has a max value in the direction of helix axis. The directivity increase linearly with the length of the helix. It also referred as "helix beam antenna".

It acts like end fire array. The far field pattern of the helix can be developed by assuming that the helix consists of an array of N identical turns with an uniform spacing 's' between them.

The 3db bandwidth is given by $f_{3db}=\frac{52}{C}\sqrt{\frac{\lambda^3}{NS}}$ deg

Directivity is given by $D_{max} = \frac{15 N S C^2}{\lambda^3}$

N= Number of turns

C= Circumference

S=Spacing between turns

λ=Wavelength

Applications:-

Used in space telemetry application at the ground end of the telemetry link for satellite and space probes at HF and VHF.

Low Frequency, Medium Frequency and High Frequency Antennas:

The choice of an antenna for a particular frequency depends on following factors.

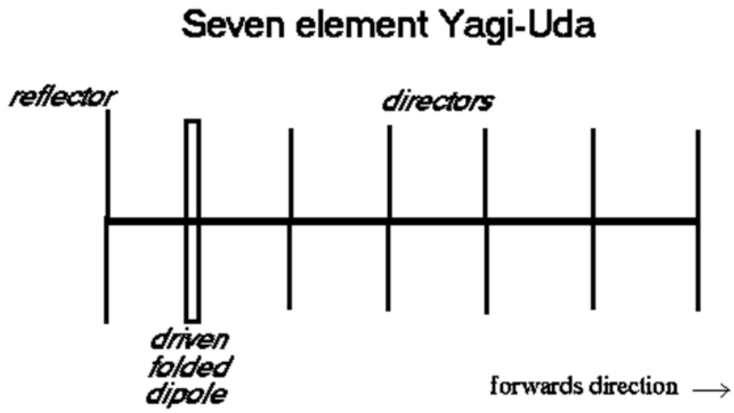
- Radiation Efficiency to ensure proper utilization of power.
- Antenna gain and Radiation Pattern
- Knowledge of antenna impendence for efficient matching of the feeder.
- Frequency characteristics and Bandwidth
- Structural consideration

Yagi uda array:

Yagi-Uda or Yagi is named after the inventors Prof. S.Uda and Prof. H.Yagi around 1928.

The basic element used in a Yagi is $\lambda/2$ dipole placed horizontally known as driven element or active element. In order to convert bidirectional dipole into unidirectional system, the passive elements are used which include reflector and director. The passive or parasitic elements are placed parallel to driven element, collinearly placed close together as shown in fig 6.4.

The Parasitic element placed in front of driven element is called director whose length is 5% less than the drive element. The element placed at the back of driven element is called reflector whose length is 5% more than that of driver element. The space between the element ranges between 0.1λ to 0.3λ.



For a three element system,

Reflector length = 500/f (MHz) feet

Driven element length = 475/f (MHz) feet

Director length = 455/f (MHz) feet.

The above relations are given for elements with length to diameter ratio between 200 to 400 and spacing between 0.1 λ to 0.2 λ.

With parasitic elements the impedance reduces less than 73 Ω and may be even less than 25 Ω. A folded $\lambda/2$ dipole is used to increase the impedance.

System may be constructed with more than one director. Addition of each director increases the gain by nearly 3 dB. Number of elements in a yagi is limited to 11.

Basic Operation:

The phases of the current in the parasitic element depends upon the length and the distance between the elements. Parasitic antenna in the vicinity of radiating antenna is used either to reflect or to direct the radiated energy so that a compact directional system is obtained.

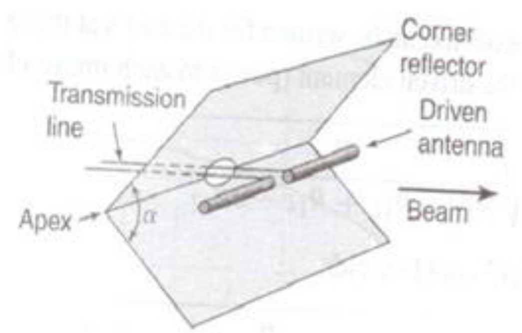
A parasitic element of length greater than $\lambda/2$ is inductive which lags and of length less than $\lambda/2$ is capacitive which leads the current due to induced voltage. Properly spaced elements of length less than $\lambda/2$ act as director and add the fields of driven element. Each director will excite the next. The reflector adds the fields of driven element in the direction from reflector towards the driven element.

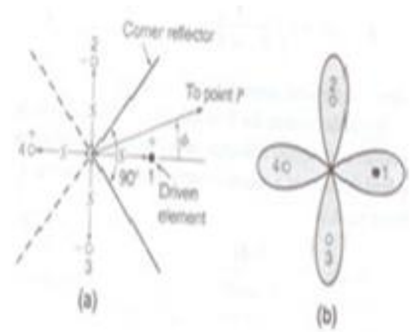
The greater the distance between driven and director elements, the greater the capacitive reactance needed to provide correct phasing of parasitic elements.Hence the length of element is tapered-off to achieve reactance.

A Yagi system has the following characteristics.

1. The three element array (reflector, active and director) is generally referred as "beam antenna"
2. It has unidirectional beam of moderate directivity with light weight, low cost and simplicity in design.
3. The band width increases between 2% when the space between elements ranges between 0.1λ to 0.15λ.
4. It provides a gain of 8 dB and a front-to-back ratio of 20dB.
5. Yagi is also known as super-directive or super gain antenna since the system results a high gain.
6. If greater directivity is to be obtained, more directors are used. Array up to 40 elements can be used.
7. Arrays can be stacked to increase the directivity.
8. Yagi is essentially a fixed frequency device. Frequency sensitivity and bandwidth of about 3% is achievable.
9. To increase the directivity Yagi's can be staked one above the other or one by side of the other.

Corner reflector:





Two flat reflecting sheets intersecting at an angle or corner as in figure 6.5 form an effective directional antenna. When the corner angle $\alpha=90^0$, the sheets intersect at right angles, forming a square- corner reflector. Corner angles both greater or less than 90^0 can be used although there are practical disadvantages to angles much less than 90. A corner reflector with $\alpha=180^0$ is equivalent to a flat sheet reflector and may be considered as limiting case of the corner reflector.

Assuming perfectly conducting reflecting sheets infinite extent, the method of images can be applied to analyze the corner reflector antenna for angle α = 180°/n, where n is any positive integer. In the analysis of the 90° corner reflector there are 3 image elements, 2, 3 and 4, located shown in Figure.The driven antenna 1the 3 images have currents of equal magnitude. The phase of the currents in I and 4 is same. The phase of the currents in 2 and 3 is the same but 180° out of phase with respect the currents in 1and 4. All elements are assumed to be λ/2 long.

At the point P at a large distance D from the antenna. The field intensity is

$$E(\phi) = 2kI_1 \| [\cos(S_r \cos\phi) - \cos(S_r \sin\phi)] |$$

Where
I_1= current in each element
S_r = spacing of each element from the corner, rad
=$2\pi S/\lambda$
K=constant involving the distance D,

For arbitrary corner angles, analysis involves integrations of cylindrical functions. The emf *Vt* at the terminals at the center of the driven element is
$V_1=I_1Z_{11}+I_1R_{1L}+I_1Z_{14} - 2I_1Z_{12}$

Where

Z_{11}= Self-Impedance of driven element R_{1L}=Equivalent loss resistance of driven element
Z_{12}=Mutual impedance of element 1 and 2
Z_{14}=Mutual impedance of element 1 and 4

If 'P' is the power delivered to the driven element, then from symmetry

$$I_1 = \sqrt{\frac{P}{R_{11} + R_{1L} + R_{14} - 2R_{12}}}$$

$$E(\phi) = 2k\sqrt{\frac{P}{R_{11} + R_{1L} + R_{14} - 2R_{12}}} |[\cos(S_r \cos\phi) - \cos(S_r \sin\phi)]$$

The Field Intensity at 'P' with reflector removed

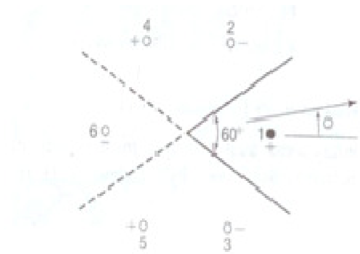
$$E_{HW}(\phi) = 2k\sqrt{\frac{P}{R_{11} + R_{1L}}}$$

The Gain in the field intensity of a square corner reflector antenna over a single λ/2 antenna

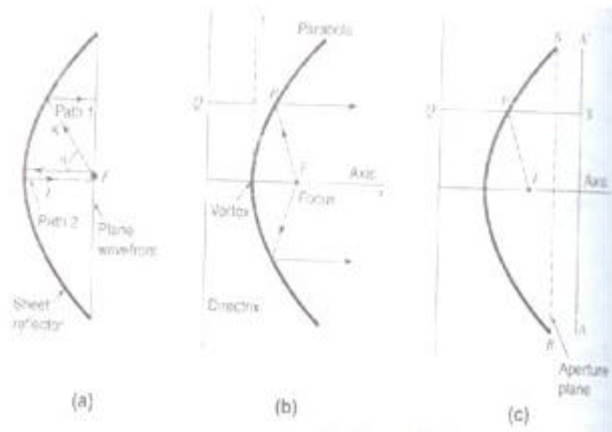
$$G_f(\phi) = \frac{E(\phi)}{E_{HW}(\phi)}$$

$$G_f(\phi) = 2\sqrt{\frac{R_{11} + R_{1L}}{R_{11} + R_{1L} + R_{14} - 2R_{12}}} |[\cos(S_r \cos\phi) - \cos(S_r \sin\phi)]$$

Where the expression in brackets is the pattern factor and the expression included under the radical sign is the coupling factor. The pattern shape is a function of both the angle , and the antenna- to-corner spacing S. For the 60° corner the analysis requires a total of 6 elements, 1 actual antenna and *5* images as in Figure.



Parabolic reflectors



Suppose that we have a point source and that we wish to produce a plane-wave front over a large aperture by means of a sheet reflector. Referring to Fig(a), it is then required that the distance from the source to the plane-wave front via path 1 and 2 be equal or

The parabola-general properties

$$2L = R(1+\cos\theta)$$

$$R = \frac{2L}{1+\cos\theta}$$

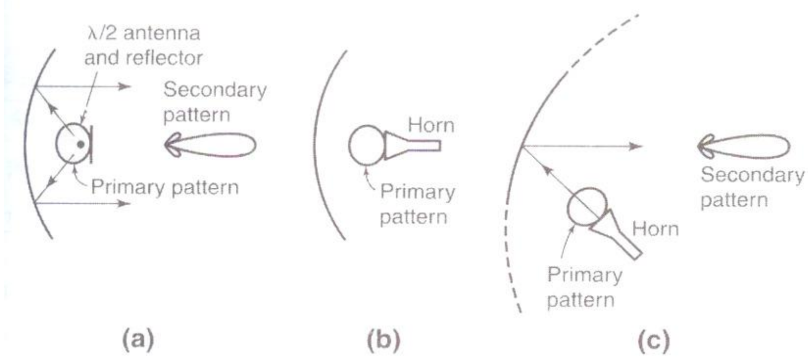
Referring to Fig. (b), the parabolic curve may be defined as follows. The distance from any point P on a parabolic curve to a fixed point F, called the focus, is equal to the perpendicular distance to a fixed line called the directrix. Thus, in Fig.(b), PF = PQ. Referring now to Fig.(c), let AA' be a line normal to the axis at an arbitrary distance QS from the directrix. Since PS = QS — PQ and PF =PQ, it follows that the distance from the focus to S is

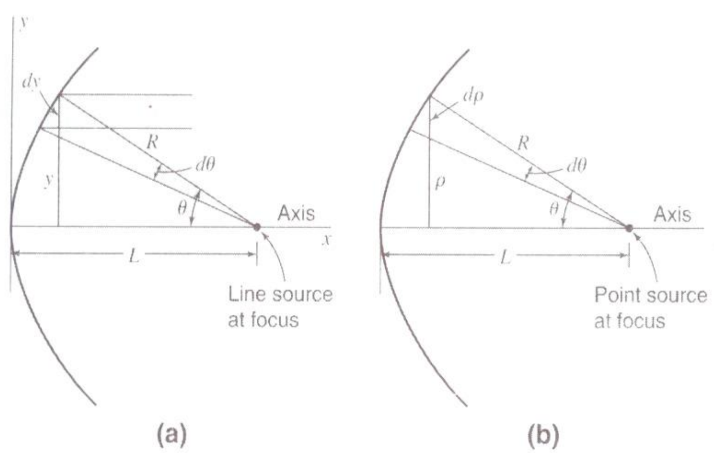
PF+PS=PF+QS-PQ=QS

Thus, a property of a parabolic reflector is that waves from an isotropic source at the focus that are reflected from the parabola arrive at a line AA' with equal phase. The "image" of the focus is the directrix and the reflected field along the Jine A A' appears as though it originated at the directrix as a plane wave. The plane BB' (Fig. 6.7c) at which a reflector is cut off is called the aperture plane.

A cylindrical parabola converts a cylindrical wave radiated by an in-phase line source at the focus, as in Fig. 6.7a, into a plane wave at the aperture, or a paraboloid-of-revolution converts a spherical wave from an isotropic source at the focus, as in Fig. 6.7b, into a uniform plane wave at the aperture. Confining our attention to a single ray or wave path, the paraboloid has the property of directing or collimating
radiation from the focus into a beam parallel to the axis.

The presence of the primary antenna in the path of the reflected wave, as in the above examples, has two principle disadvantages. These are, first, that waves reflected from the parabola back to the primary antenna produce interaction and mismatching. Second, the primary antenna acts as an obstruction, blocking out the central portion of the aperture and increasing the minor lobes. To avoid both effects, a portion of the paraboloid can be used and the primary antenna displaced as in Fig below This is called an offset feed.





Let us next develop an expression for the field distribution across the aperture of a parabolic reflector. Since the development is simpler for a cylindrical parabola, this case is treated first, as an introduction to the case for a paraboloid. Consider a cylindrical parabolic reflector with line source as in Fig.a. The line source is isotropic in a plane perpendicular to its axis (plane of page). For a unit distance in the z direction the power P in a strip of width dy is

$$P = dyS_y$$

Where S_y= the power density ay y, W m^{-2}

$$P = U'd\theta$$

U'=the power per unit angle per unit length in the direction

$$S_y dy = U'd\theta$$

$$\frac{S_y}{U'} = \frac{1}{(d/d\theta)(R\sin\theta)}$$

$$R = \frac{2L}{1+\cos\theta}$$

$$S_y = \frac{1+\cos\theta}{2L}U'$$

The ratio of the power density

$$\frac{S_\theta}{S_0} = \frac{1+\cos\theta}{2}$$

The field intensity ratio in the aperture plane is equal to the square root of the power ratio

$$\frac{E_\theta}{E_0} = \sqrt{\frac{1+\cos\theta}{2}}$$

$$P = 2\pi\rho d\rho S\rho$$

$$P = 2\pi \sin\theta d\theta U$$

Equating the above two equations, we get,

$$\rho d\rho S\rho = \sin\theta d\theta U$$

$$\frac{S_\rho}{U} = \frac{\sin\theta}{\rho(d\rho/d\theta)}.$$

$$S_\rho = \frac{(1+\cos\theta)^2}{4L^2}U$$

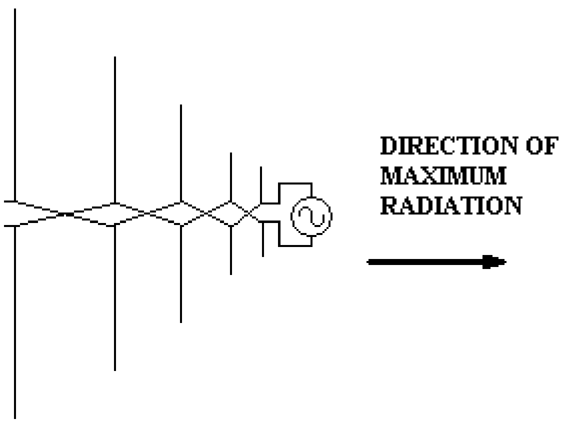
$$\frac{S_\theta}{S_0} = \frac{(1+\cos\theta)^2}{4}$$

$$\frac{E_\theta}{E_0} = \frac{1+\cos\theta}{2}$$

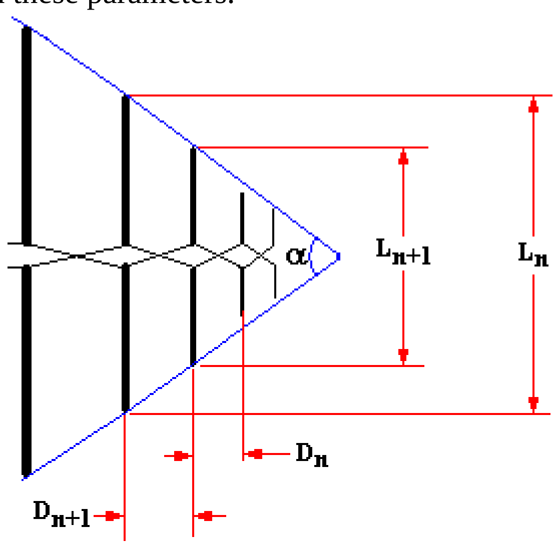
LOG PERIODIC DIPOLE ARRAY:

The log periodic dipole array (LPDA) is one antenna that almost everyone over 40 years old has seen. They were used for years as TV antennas. The chief advantage of an LPDA is that it is frequency-independent. Its input impedance and gain remain more or less constant over its operating bandwidth, which can be very large. Practical designs can have a bandwidth of an octave or more.

Although an LPDA contains a large number of dipole elements, only 2 or 3 are active at any given frequency in the operating range. The electromagnetic fields produced by these active elements add up to produce a unidirectional radiation pattern, in which maximum radiation is off the small end of the array. The radiation in the opposite direction is typically 15 - 20 dB below the maximum. The ratio of maximum forward to minimum rearward radiation is called the Front-to-Back (FB) ratio and is normally measured in dB.



The log periodic antenna is characterized by three interrelated parameters, α, σ and τ as well as the minimum and maximum operating frequencies, f_{MIN} and f_{MAX}. The diagram below shows the relationship between these parameters.



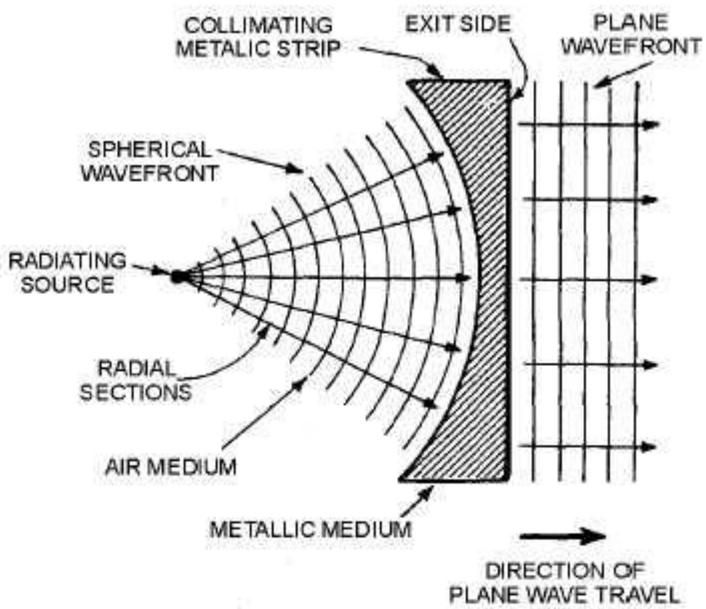
$$L_N = \frac{500}{f_{MIN}} \quad L_1 = \frac{360}{f_{MAX}} \quad \sigma = \frac{1-\tau}{4\tan(\alpha)} \quad \tau = \frac{D_n}{D_{n+1}} = \frac{L_n}{L_{n+1}}$$

Unlike many antenna arrays, the design equations for the LPDA are relatively simple to work with. If you would like to experiment with LPDA designs, click on the link below. It will open an EXCEL spreadsheet that does LPDA design.

LENS ANTENNAS

With a LENS ANTENNA you can convert spherically radiated microwave energy into a plane wave (in a given direction) by using a point source (open end of the waveguide) with a COLLIMATING LENS. A collimating lens forces all radial segments of the spherical wavefront into parallel paths. The point source can be regarded as a gun which shoots the microwave energy toward the lens. The point source is often a horn radiator or a simple dipole antenna.

Waveguide Type The WAVEGUIDE-TYPE LENS is sometimes referred to as a conducting-type. It consists of several parallel concave metallic strips which are placed parallel to the electric field of the radiated energy fed to the lens, as shown in figure 3-10A and 3-10B. These strips act as waveguides in parallel for the incident (radiated) wave. The strips are placed slightly more than a half wavelength apart.



(A)

Advantages of Lens Antenna

Can be used as Wide band Antenna since its shape is independent of frequency.

Provides good collimation.

Internal dissipation losses are low, with dielectric materials having low loss tangent.

Easily accommodate large band width required by high data rate systems.

Quite in-expensive and have good fabrication tolerance

Disadvantages of Lens Antenna

Bulky and Heavy

Complicated Design

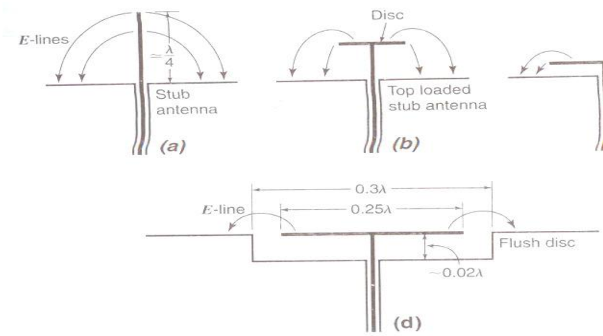
Refraction at the boundaries of the lens

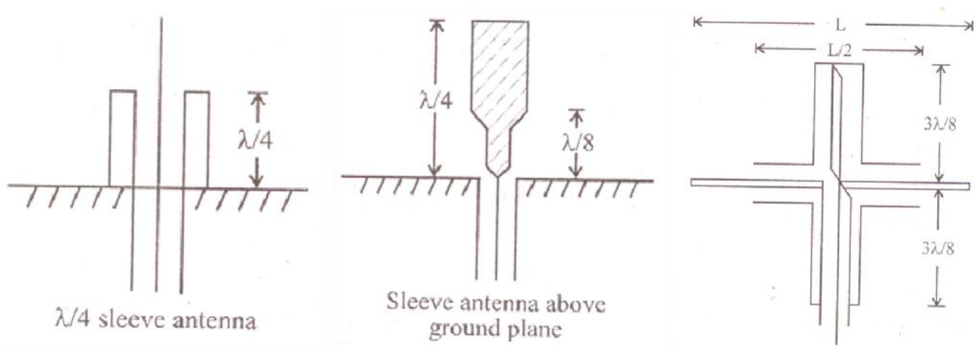
Sleeve antenna

Ground plane or sleeve type λ/4 long cylindrical system is called a sleeve antenna. The radiation is in a plane normal to the axis of this antenna.

The second variety of sleeve is similar to stub with ground plane having the feed point at the centre of the stub. The lower end of the stub is a cylindrical sleeve of length λ/8.

A balanced-sleeve dipole antenna corresponding to the sleeve stub is shown in fig. This is fed with a coaxial cable and balance to unbalance transformer or balun. For L ranging between λ/2 to λ, the operating frequency ranges through 2 to 1.





Evolution of flush-disk antenna from vertical λ/4 stub antenna

It is the modified ground plane antenna.

Here the ground plane has de-generated into a sleeve or cylinder λ/4 long.

Maximum radiation is normal to the axis.

Turn Stile Antenna

The Antenna is similar to stub antenna with ground plane but with a feed point moved to approximately the center of the stub.

A basic turn stile consists of two horizontal short dipoles placed normal to each other as shown in fig.The individual field patterns are 'figure of eight' fitted by 90^0. The total field pattern is given by

$$E = \sin\theta \cos\omega t + \cos\theta \sin\omega t$$

$$E = \sin(\theta + \omega t)$$

$$\omega t = -\theta$$

$$|E| = \sqrt{\cos^2 \omega t + \sin^2 \omega t} = 1$$

$$E = \frac{\cos(90^0 \cos\theta)}{\sin\theta} \cos\omega t + \frac{\cos(90^0 \sin\theta)}{\cos\theta} \sin\omega t$$

$$I_1 = \frac{V}{70 + j70}$$

$$I_2 = \frac{V}{70 - j70}$$

Where

V = Impressed emf

I_1 = current at terminals of dipole 1

I_2 = current at terminals of dipole 2

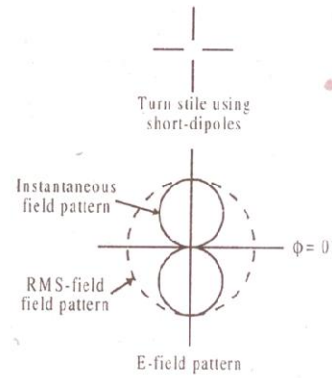
Thus

$$I_1 = \frac{V}{99} \angle -45^0$$

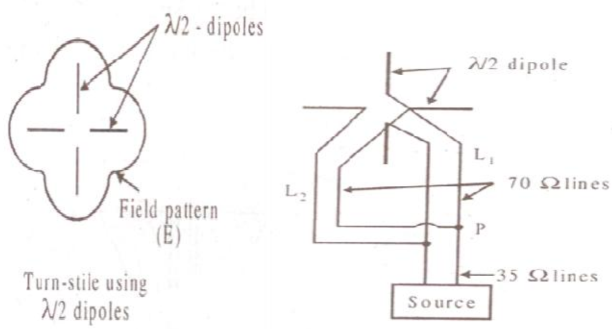
$$I_2 = \frac{V}{99} \angle +45^0$$

$$Z = \frac{1}{Y} = \frac{1}{\left[1/(70 + j70)\right] + \left[1/(70 - j70)\right]} = 70 + j0\,(\Omega)$$

The Antenna is similar to stub antenna with ground plane but with a feed point moved to approximately the center of the stub

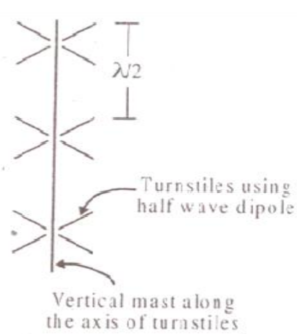


Turn stile array with individual field pattern



Turn stile array with resultant field pattern

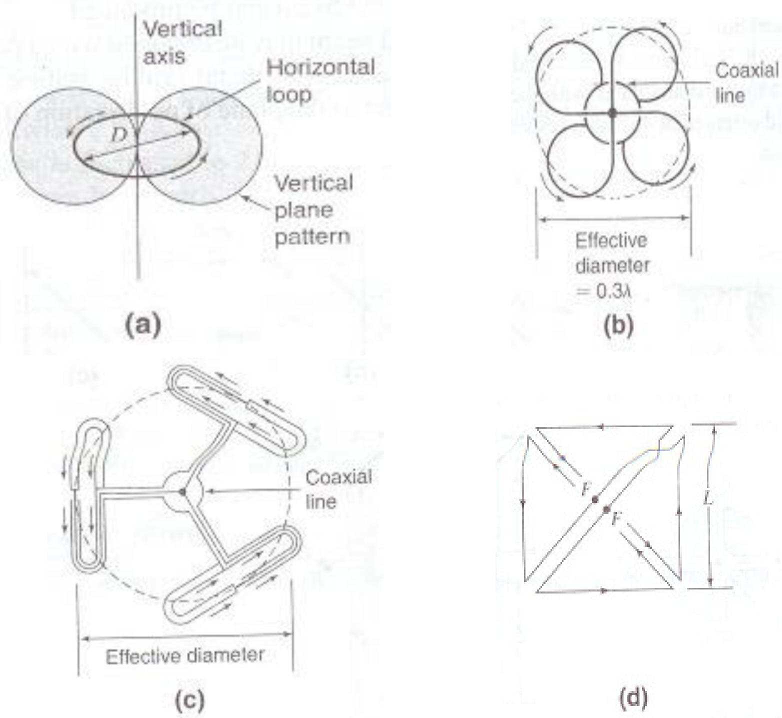
The turn stile is most suited for TV transmission for frequency from 50 MHz. Directivity can be increased by stacking super turn stiles one above the other as asshown in figure.



Stack of turn stile array

Omni-directional antennas

Slotted cylinder, and turnstile are almost omni-directional in horizontal plane. Clover-leaf is one more type of omni-directional whose directivity is much higher than that of turnstile. The system basically contains horizontal dipole which is bidirectional in vertical plane. A circular loop antenna as shown in fig can be used to obtain omni directional radiation pattern.

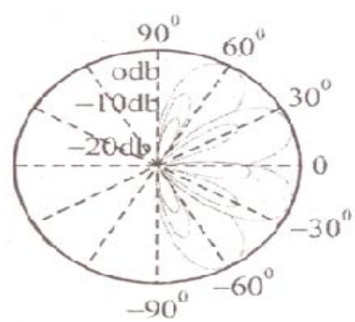


a) Circular Loop Antenna b) Approximately equivalent arrangements of "clover-leaf" type c) "triangular-loop" type Antenna d) Square or Alford loop

Antenna for Mobile Application

Switched Beam Antenna:

The base station antenna has several selectable beams of which each covers a part of the cell area as shown in the figure 6.24. The switched beam antenna is constructed based on Butler matrix, which provides one beam per antenna element. The system operation is very simple but has limited adaptability.

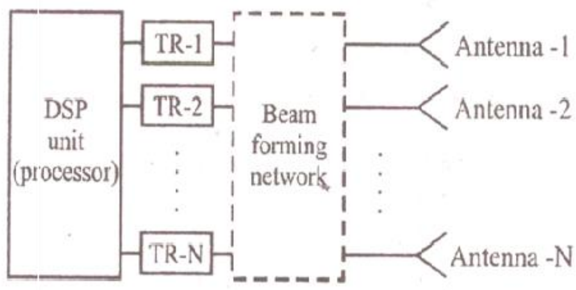


Switched Beam Pattern

Adaptive Antenna:

Adaptive array is the most comprehensive and complex configuration. The system consists of several antennas where each antenna is connected to separate trans-receiver and

Digital Signal Processor as shown in fig. DSP controls the signal level to each element depending upon the requirements. Butler matrix can be adapted for the improvement of SNR during reception. Direction of arrival finding and optimization algorithms are used to select the complex weights for each mobile users. For frequency domain duplexing the transmission weights are estimated based on Direction of arrival information.



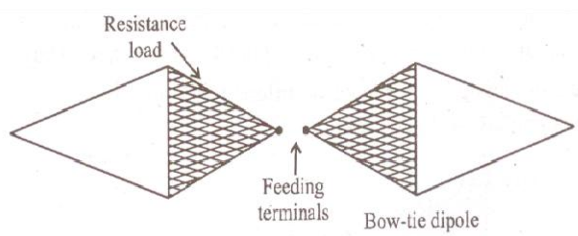
Adaptive Antenna

Antenna for satellite

- High Frequency Transmitting Antenna
- Parabolic Reflector

Antennas for Ground Penetrating Radar (GPR)

•Like Earth Surface Radars, the radars can be used to detect underground anomalies both natural and Human Made.
•The anomalies include buried metallic or nonmetallic objects, earth abnormalities etc.,
•Pulse and its echo pulse are used for processing.
•Far field radar equation to be modified as distance travelled by wave is less.
•Power required is more since ground is lossy medium.
•Mismatch at air-ground interface.
•Pulse width should be less.



Ground Penetrating Radar (GPR) Antenna

Antennas for Mobile Handsets

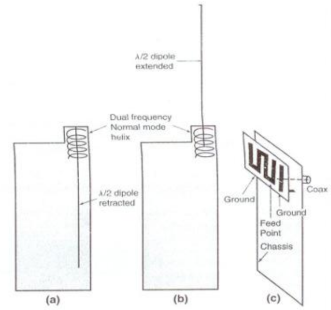


Figure (*a*) Handset with dual frequency normal-mode helix and $\lambda/2$ dipole retracted. (*b*) Handset with $\lambda/2$ dipole extended, (*c*) Planar internal multiband antenna.

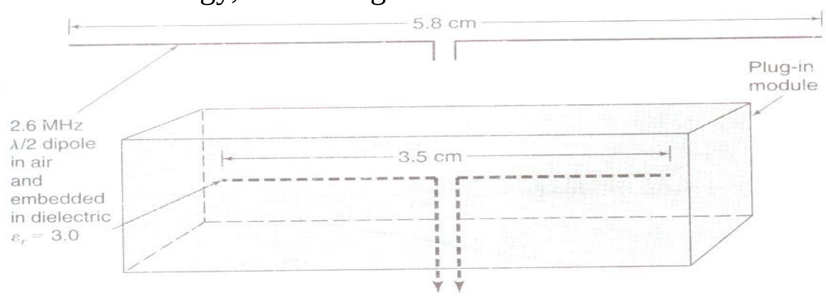
Embedded Antennas

•If dipole is embedded in a dielectric medium of relative permitivity ε_r (>1), then its length can be reduced.

•A $\lambda/2$ dipole resonates at the same frequency when embedded in a dielectric medium having a length 0.5λ/sq root of εr

•If $\varepsilon_r = 4$, length required is half.

•Used in Bluetooth technology, interfacing RF Networks.



Half-wavelength dipole embedded in a dielectric for Bluetooth Application

Ultra Wide Band Antenna

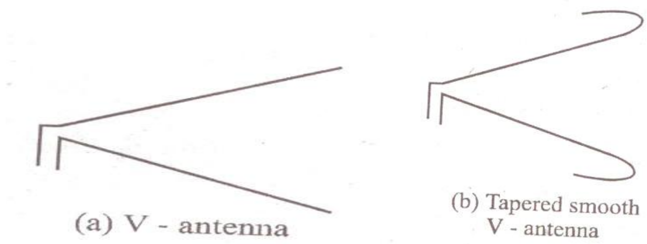
•Used for digital Applications

•Pulse Transmission which results in Large bandwidth.

•Phase dispersion of pulse (transmitted at different instant of time)

•Degrading of signals

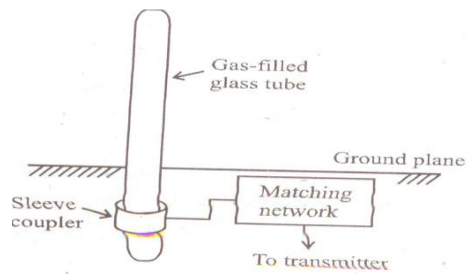
V Antenna used for Communication



Ultra Wide Band Antenna

Plasma antenna

• A plasma surface wave can be excited along a column of low-pressure gas by adequate RF power coupled to the column in a glass tube.
• It is a system in which the radar cross section is only the thin wall glass tube when not transmitting.
• With a laser beam producing the plasma the radar cross section becomes zero when laser is off.



Plasma antenna

RECOMMENDED QUESTIONS

1. Write a note on loop antenna.
2. Derive electric and magnetic fields of a loop antenna.
3. Compare far fields of small loop and short dipole.
4. Derive an expression for radiation resistance of a loop antenna.
5. Write a note on helical antenna and helical geometry.
6. Derive the relation between circumference spacing turn lengths and pitch angle of a helix.
7. Show the limiting cases of a helix when :
    i. Spacing is zero.
    ii. Diameter is zero.
8. Explain helix modes of operation.
9. Explain the following parameters of monoflair axial helix antenna: (a) Gain (b) Bam width (c) Impedance.
10. Write short note on Yagi-Uda array antenna.

11.Write short note on:

    iii. 1 Slot antenna.
    iv. Complementary antenna.
    v. Horn antenna and its types.
    vi. Log periodic antenna.
    vii. Broad band frequency independent antenna.
    viii. Antennas for terrestrial mobile communication systems.
    ix. Antennas for ground penetrating Radar.
    x. Embedded antennas.
    xi. Ultra Wide band antennas for digital applications.
    xii. Plasma antenna.

12. Explain different types of reflectors.

13 Explain parabolic reflectors.

14 Explain the types of feed systems for a reflector.

15 Differentiate between circular and rectangular horn antenna

UNIT – 7

RADIO WAVE PROPAGATION

Syllabus:

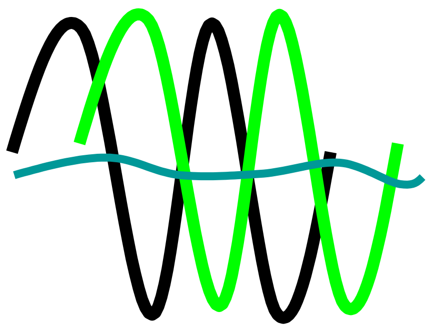
Introduction, ground wave propagation, free space propagation, ground reflection, surface wave, diffraction.

Radio Propagation:

What is Radio?

Radio is a Transmitter or a Receiver. The Radio Transmitter induces electric and magnetic fields. The electrostatic field Components is µ 1/d3, induction field components is µ 1/d2 and radiation field components is µ 1/d. The radiation field has E and B Component. Surface area of sphere centered at transmitter, the field strength at distance d = E×B µ 1/d2.

Two main factors affect signal at the Receiver. One is distance (or delay) that results in path attenuation, second is multipath that results in Phase differences



Green signal travels 1/2λ farther than Black to reach receiver, who sees Blue. For 2.4 GHz, λ (wavelength) =12.5cm.

Your ability to work with radio is based on 4 factors:

1. Your skill as a radio operator (knowing your regions, etc.)
2. Your equipment and how you use it
3. The antennas you use
4. Understanding radio wave propagation.

Antennas:

The antennas are the transducers. The transmitting antenna changes the electrical energy into electromagnetic energy or waves. The receiving antenna changes the electromagnetic energy back into electrical energy. These electromagnetic waves propagate at rates ranging from 150 kHz to 300GHz.

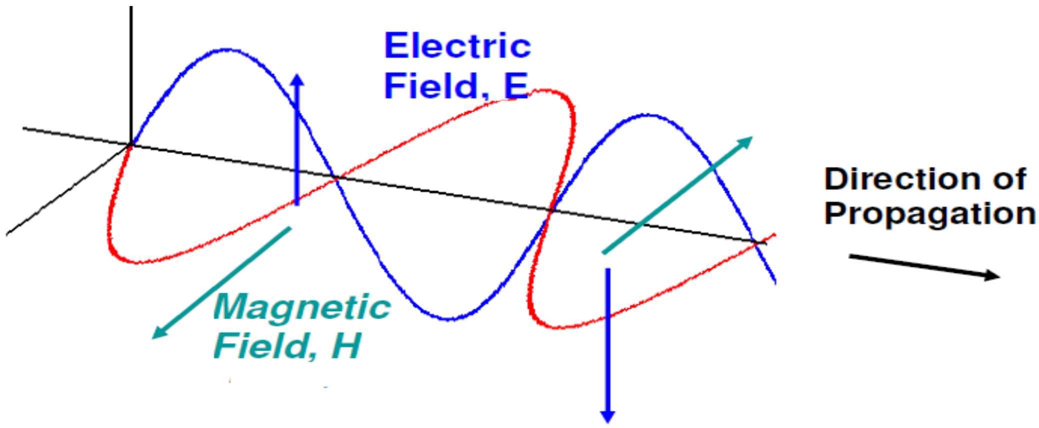
Polarization:

The polarization of an antenna is the orientation of the electric field with respect to the Earth's surface and is determined by the physical structure of the antenna and by its orientation. Radio waves from a vertical antenna will usually be vertically polarized and that from a horizontal antenna are usually horizontally polarized.

Propagation:

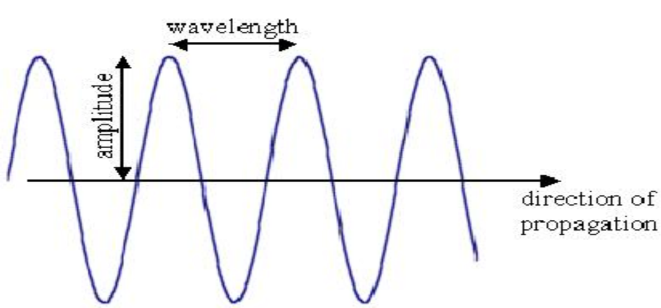
Propagation means how radio waves travel from one point A to another point B. What are the events that occur in the transmission path and how they affect the communications between the points?

Electromagnetic Waves (EM waves) are produced when the electrons in a conductor i.e., antenna wire are made to oscillate back and forth. These waves radiate outwards from the source at the speed of light (300 million meters per second). Electromagnetic Waves are of two types (i) Light Waves (waves we see) (ii) Radio Waves (waves we hear).Both of these EM Waves differ only in frequency and wavelength. EM waves travel in straight lines, unless acted upon by some outside force. They travel faster through a vacuum than through any other medium. As EM waves spread out from the point of origin, they decrease in strength in what is described as an inverse square relationship.



The two fields are at right-angles to each other and the direction of propagation is at right-angles to both fields. The Plane of the Electric Field defines the polarization of the wave.

The radio waves can further be classified as Transverse and longitudinal. The Transverse Waves Vibrates from side to side, i.e, at right angles to the direction in which they travel for eg: A guitar string vibrates with transverse motion. EM waves are always transverse.



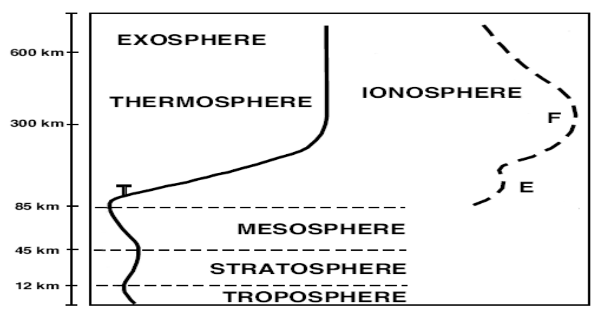
For Longitudinal radio waves vibrations are parallel to the direction of propagation. Sound and pressure waves are longitudinal and oscillate back and forth as vibrations are along or parallel to their direction of travel.

Factors affecting the propagation of radio wave are:

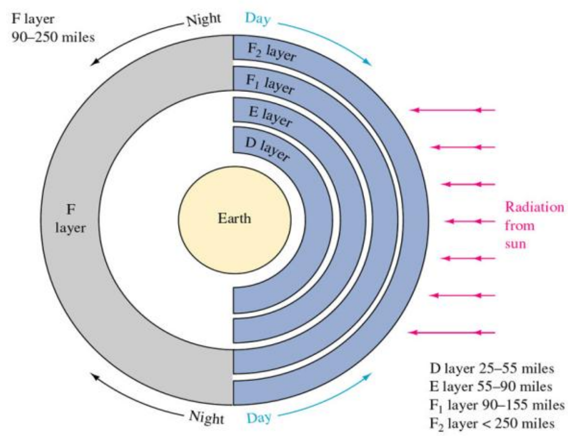
1. Spherical shape of the earth:-For Free Space RW travel in straight line. But communication on the earth surface is limited by distance to horizon and requires change in propagation.
2. Atmosphere-Height of about 600km.Is divided into layers. RW near the surface is affected by troposphere. Higher up RW is influenced by ionosphere.
3. Interaction with the objects.

Atmosphere:

Is divided into Troposphere(earth's surface to about6.5mi),Stratosphere(extends from the troposphere upwards for about 23 mi), Ionosphere(extends from the stratosphere upwards for about 250mi) Beyond this layer is Free Space.

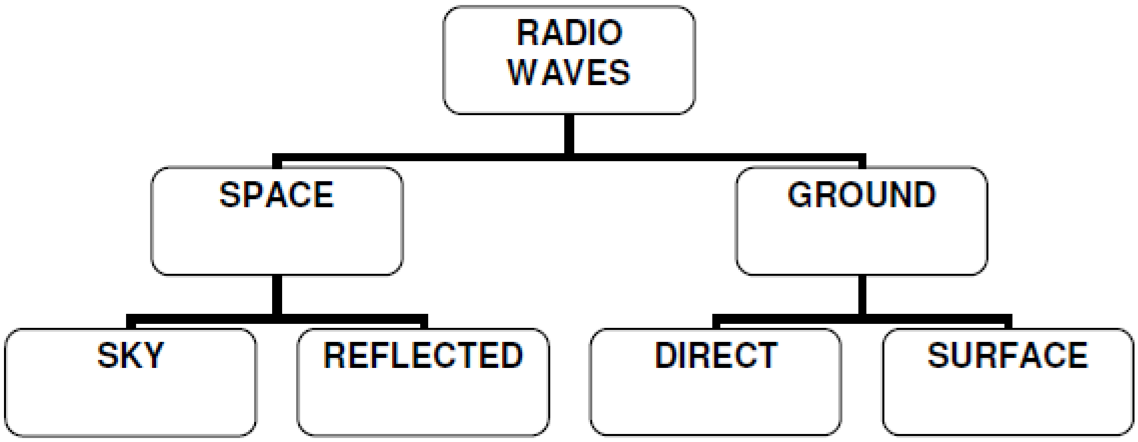


The ionosphere is the uppermost part of the atmosphere and is ionized by solar radiation. Ionization is the conversion of atoms or molecules into an ion by light (heating up or charging) from the sun on the upper atmosphere. Ionization also creates a horizontal set of stratum (layer) where each has a peak density and a definable width or profile that influences radio propagation. The ionosphere is divided into layers.



About 120 km to 400 km above the surface of the Earth is the F layer. It is the top most layer of the ionosphere. Here extreme ultraviolet (UV) (10-100 nm) solar radiation ionizes atomic oxygen (O). The F region is the most important part of the ionosphere in terms of HF communications. The F layer combines into one layer at night, and in the presence of sunlight (during daytime), it divides into two layers, the F1 and F2.The F layers are responsible for most sky wave propagation of radio waves, and are thickest and most reflective of radio on the side of the Earth facing the sun**.** The E layer is the middle layer, 90 km to 120 km above the surface of the Earth. This layer can only reflect radio waves having frequencies less than about 10MHz. It has a negative effect on frequencies above 10 MHz due to its partial absorption of these waves. At night the E layer begins to disappear because the primary source of ionization is no longer present. The increase in the height of the E layer maximum increases the range to which radio waves can travel by reflection from the layer. The D layer is the innermost layer, 50 km to 90 km above the surface of the Earth when the sun is active with 50 or more sunspots. During the night cosmic rays produce a residual amount of ionization as a result high-frequency (HF) radio waves aren't reflected by the D layer. The D layer is mainly responsible for absorption of HF radio waves, particularly at 10 MHz and below, with progressively smaller absorption as the frequency gets higher. The absorption is small at night and greatest about midday. The layer reduces greatly after sunset. A common example of the D layer in action is the disappearance of distant AM broadcast band stations in the daytime.

Radio Propagation Modes:



Ground Wave Propagation:

Propagation of EM wave near earth surface (including troposphere).When the Transmit and Receive antenna are on earth there can be multiple paths for communication. If the Transmit and Receive antenna are in line of sight (LOS) then direct path exist. The propagating wave is called direct wave. When EM wave encounters an interface between two dissimilar media, a part of energy will flow along the interface Known as Surface Wave. At LF and MF this is predominant mode of energy transfer for vertically polarized radiation. Interaction with the objects on ground will manifest as, Reflection, Refraction, Diffraction, Scattering. Waves are collectively called as Space Wave.

Free Space:

Implies an infinite space without any medium or objects that can interact with the EM wave. Antenna is kept in free space and radiation fields are in the form of spherical waves with angular power distribution given by the antenna pattern. It assumes far-field (Fraunhofer region) $d >> D$ and $d >> \lambda$, where D is the largest linear dimension of antenna, λ is the carrier wavelength. With no interference and obstructions. The received power at distance d is

$$P_r = K P_t / d^2$$

where Pt is the transmitter power in Watts, a constant factor K depends on antenna gain, a system loss factor, and the carrier wavelength.

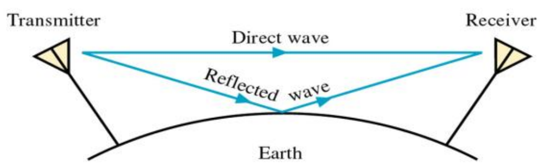
$$P_r = P_t G_t G_r \lambda^2 / (4\pi R)^2$$

Where P_t=Transmit power, G_t=Transmit gain antenna, G_r=Receive gain antenna
Transfer of electromagnetic energy from transmit antenna to receive antenna take place in a straight line path such communication link is called line of sight link.

The factor [λ / (4πR)]2 is due propagation and is called free space path loss.It represents the attenuation of the signal due to the spreading of the power as function of distance are 'R'.In decibel units the path loss is expressed as:

$P_L=10\log_{10}(4\pi R/\lambda)^2$ dB

Ground Reflection:

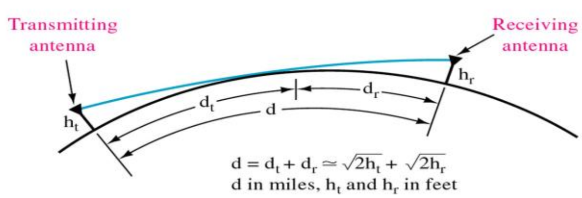


In LOS model, the assumption is that there is only one path for propagation of EM Wave from transmit antenna to receive antenna. The two antennas are kept in free space with no other objects intersecting radiation from transmitter antenna. If two antennas are situated close the ground due to discontinuity in the electrical properties at the air ground interface any wave that falls on the ground is reflected. The amount of reflection depending on factors like angle of incidence, Polarization of wave, Electrical Properties of the Ground i.e conductivity and dielectric constant, the frequency of the propagating wave. Thus, the field at any point above the ground is a vector sum of the fields due to the direct and the reflected waves.

Direct Wave:

It is limited to "line-of sight" transmission distances .The limiting factors are antenna height and curvature of earth. The Radio horizon is about 80% greater than line of sight because of diffraction effects. A Part of the signal from the transmitter is bounced off the ground and reflected back to the receiving antenna. If the phase between the direct wave and the reflected wave are not in phase can cause problems

Detune the antenna so that the reflected wave is too weak to receive



To compute the fields of a transmit antenna above an imperfect ground. Used to design of communication links. To select the locations of the transmit and receive antennas and their patterns. Consider a transmit antenna located at point P at a height ht. Receive antenna located at point Q at a height hr from the surface of the ground. Let the horizontal distance between the two antenna be d.

The electromagnetic wave from transmit antenna can reach the receive antenna by two possible paths(a) direct path (b) ground reflected path. The total electric field at the field point Q is given by the vector sum of the electric field due to the direct wave and ground reflected wave.

Assumptions:-

1. The transmit antenna and the field points are located in the y-z plane.
2. The transmit antenna is an infinitesimal dipole oriented along the x-axis.

The electric field is of infinitesimal dipole oriented along the x-axis is given by

$E = -jk\eta(I_0\ dl/4\pi)(e^{-jkR}/R)(a_\theta\cos\theta\cos\varphi - a_\varphi\sin\varphi)$

- R is the distance from the antenna to the field point.

In the y-z plane, φ=90o .Since cos90o= 0. The θ-component of the electric field is zero. The φ-component of the electric field at Q due to the direct wave is given by

$E1= -jk\eta(I_0\ dl/4\pi)(e^{-jkR1}/R1)$

The field at Q also has a contribution from the wave that travels via the reflected path PXQ. The location of the point of reflection X depends on h_t, h_r, and d. At X the incident and reflected rays satisfy snell's law of reflection (angle of incidence is equal to angle of reflection).The incident ray PX the reflected ray XQ and the normal to the surface are all contained in the y-z plane. The y-z plane is also known as the plane of incidence. The incident field at X is given by

$$Ei= -jk\eta(I_0\ dl/4\pi)(e^{-jkR'}{}_2/R'_2)$$

•- R'2 is the distance from the transmitter to X and the incident E field vector is perpendicular to the plane of incidence. At X the reflection co-efficient ,Γ is given by

$\Gamma = Er/Ei= (\sin\psi-\sqrt{(\ \ r-j\ \chi)-\cos2\psi}))/ \sin\psi+\sqrt{(\ \ r-j\ \chi)-\cos2\psi})$

Electric field is perpendicular to the plane of incidence. At Q is given by

$E = E1+E2$

$E = jk\eta I_0 \, dl/4\pi(e^{-jkR_1}/R_1 + \Gamma \quad e^{-jkR_2}/R_2)$

Field point Q is far away from the transmitter R2≈R1.Total electric field

$E = E1+E2$

$E = jk\eta (I_0 \, dl/4\pi)(e^{-jkR_1}/R_1) (1+\Gamma \quad e^{-jk(R_2 - R_1)})$

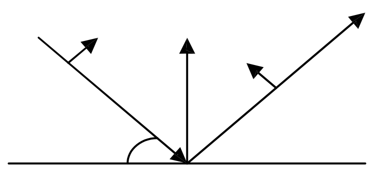
A product of the free space field and an environmental factor, F Γ given by

$$F\Gamma = (1+\Gamma \quad e^{-jk(R_2 - R_1)})$$

The total field at Q due to an infinitesimal dipole at (0, 0, ht) oriented along the z-direction. The electric field of a z-directed infinitesimal dipole is

$$E = a_\theta jk\eta(I_0 \, dl\sin\theta/4\pi)(e^{-jkR_1}/R_1)$$

Electric field is parallel to the plane of incidence



The electric field is parallel to the plane of incidence and the reflection coefficient, Γ at X is given by

$\Gamma = ((_r\text{-}j\,\chi)\sin\psi\text{-}\sqrt{(\ _r\text{-}j\,\chi)\text{-}\cos2\psi}) / ((\ _r\text{-}j\,\chi)\sin\psi+\sqrt{(\ _r\text{-}j\,\chi)\text{-}\cos2\psi})$ The total field at point Q

is given by

$$E = jk\eta(I_0 \, dl\sin\theta/4\pi)(e^{-jkR_1}/R_1) \, F$$

Where $F = (1+\Gamma \ e^{-jk(R_2 - R_1)})$

$R_1 = \sqrt{d^2 + (h_r - h_t)^2} \approx d\sqrt{1+(h_r - h_t/d)^2}$

For $d \gg h_r$ and $d \gg h_t$

Using the first two significant terms in the binomial expansion of $\sqrt{1+x}$,

$\sqrt{1+x} \approx 1+x/2$ for $x \ll 1$;

$R_1 \approx d[\sqrt{1+1/2*(h_r - h_t/d)^2}]$ $R_2 \approx$

$d[\sqrt{1+1/2*(h_r + h_t/d)^2}]$

The path difference $R_2 - R_1$ is given as $R_2 - R_1 = 2\, h_r\, h_t/d$

For $(h_r\ h_t/d) \ll \lambda$;

$\Delta\theta = k(R_2 - R_1) = 4\pi\, h_r\ h_t/d\lambda$

The path difference is small so that sinx≈x and cosx≈1 ;

$e^{-jk(R_2 - R_1)} = \cos(\Delta\theta) - j\sin(\Delta\theta)$

$\approx 1 - jk2\, h_r\ h_t/d$

For low angle of incidence $\Gamma \approx \Gamma \approx -1$

$F = F = F \approx jk2\, h_r\ h_t/d$

Taking into account the ground reflection, the power received by the receive antenna can be written as

Pr=PtGtGr λ2 / (4πR)2 F 2

For h_r and h_t small compared to d

$R_1 \approx d$

Therefore the received power is approximately given by

$$P_r \approx P_t G_t G_r\ (h_r\ h_t)^2/d^4$$

For large d the received power decreases as d^4. This rate of change of power with distance is much faster than that observed in the free space propagation condition. Taking into account the ground reflection, the power received by the receive antenna can be written as

$P_r = P_t G_t G_r\ \lambda^2 / (4\pi R)^2\ \ F\ ^2$

For h_r and h_t small compared to d

$R_1 \approx d$

Therefore the received power is approximately given by

$P_r \approx P_t G_t G_r\ (h_r\ h_t)^2/d^4$

Surface Wave:

Travels directly without reflection on ground. Occurs when both antennas are in LOS
Space wave bend near ground follows a curved path. Antennas must display a very low angle of emission. Power radiated must be in direction
of the horizon instead of escaping in sky. A high gain and horizontally polarized antenna is recommended.

If dipole and the field points are on the surface of the earth but separated by a distance d, We have $R_2 = R_1 = d$ and $\psi=0$
If ground has finite conductivity (typically 10-3S/m-30*10-3S/m) then
$\Gamma\ = -1$,

The EF due to the direct and ground reflected wave will cancel each other. The EF due to the direct and ground reflected wave is also known as surface wave. Surface wave constitute the primary mode of propagation for frequencies in the range of few KHz-several MHz. In AM broadcast application, A vertical monopole above the ground is used to radiate power in the MW frequency band. The receivers are placed very close to the surface of the earth and hence they receive the broadcast signal via surface wave. Achieve Propagation over hundreds of kilometers. Attenuation factor of the surface wave depends on
1. Distance between the transmitter and receiver.
2. The frequency of the electrical properties of the ground over which the ground propagates. At the surface of the earth the attenuation is also known as the ground wave attenuation factor and is designated as A_{su}

The numerical distance $p=(\pi R/\lambda\chi)\cos b$, where b is the power factor angle

$$b=\tan-1(\ \ r+1/\chi)$$

Where R is the distance between the transmit and receive antennas and χ
is given as

$$\chi=\sigma/\omega\ \ 0$$

For χ» r the power factor angle is nearly zero and the ground is almost resistive.
For a 1MHz wave propagating over a ground surface with
σ =12*10-3S/m and ε_r=15
the valve of χ is 215.7 and is much greater than ε_r

The power factor angle is 4.25^0 . At higher frequency 100MHz the valve of χ is 2.157 and power factor angle becomes 82.32^0

For large numerical distance the attenuation factor decreases by a factor of 10 for every decade i.e 20dB/decade. Thus attenuation is inversely proportional to p and R.
The electric field intensity due to the surface wave is proportional to the product of Asu and e^{-jkR}/R. The EF due to the surface wave at large distance from vertically polarized antenna is inversely propositional to the surface of the distance or the power is inversely propositional to R^4.

The EF of a vertically polarized wave near the surface of the earth have a forward tilt. The magnitude of the wave tilt depends on the conductivity and permittivity of the earth. The horizontal component is smaller than the vertical component and they are not in phase. The EF is elliptically polarized very close to the surface of the earth.

Diffraction:

DIFFRACTION is the bending of the wave path when the waves meet an obstruction. The amount of diffraction depends on the wavelength of the wave. Higher frequency waves are rarely diffracted in the normal world. Since light waves are high frequency waves, they are rarely diffracted. However, diffraction in sound waves can be observed by listening to music. When outdoors, behind a solid obstruction, such as a brick wall, hear mostly low notes are heard. This is because the higher notes, having short wave lengths, undergo little or no diffraction and pass by or over the wall without wrapping around the wall and reaching the ears. The low notes, having longer wavelengths, wrap around the wall and reach the ears. This leads to the general statement that lower frequency waves tend to diffract more than higher frequency waves. Broadcast band(AM band) radio waves (lower frequency waves) often travel over a mountain to the opposite side from their source because of diffraction, while higher frequency TV and FM signals from the same source tend to be stopped by the mountain.

Diffraction, results in a change of direction of part of the wave energy from the normal line-of-sight path making it possible to receive energy around the edges of an obstacle. Although diffracted RF energy is usually weak, it can still be detected by a suitable receiver. The principal effect of diffraction extends the radio range beyond the visible horizon. In certain cases, by using high power and very low frequencies, radio waves can be made to encircle the Earth by diffraction.

Mechanism for Diffraction:

Diffraction arises because of the way in which waves propagate; this is described by the Hugyens-Fresnel Principle and the principle of superposition of waves. The propagation of a wave can be visualized by considering every point on a wavefront as a point source for a secondary spherical waves. The wave displacement at any subsequent point is the sum of these secondary waves. When waves are added together, their sum is determined by the relative phases as well as the amplitudes of the individual waves so that the summed amplitude of the waves can have any value between zero and the sum of the individual amplitudes. Hence, diffraction patterns usually have a series of maxima and minima.

There are various analytical models which allow the diffracted field to be calculated, including the Kirchoff-Fresnel diffraction equation which is derived from wave equation, the Fraunofer diffraction approximation of the Kirchhoff equation which applies to the far field and the Fresnel diffraction approximation which applies to the near field. Most configurations cannot be solved analytically, but can yield numerical solutions through finite element and boundary element methods.

It is possible to obtain a qualitative understanding of many diffraction phenomena by considering how the relative phases of the individual secondary wave sources vary, and in particular, the conditions in which the phase difference equals half a cycle in which case waves will cancel one another out.

The simplest descriptions of diffraction are those in which the situation can be reduced to a two-dimensional problem. For water waves, this is already the case; water waves propagate only on the surface of the water. For light, we can often neglect one direction if the diffracting object extends in that direction over a distance far greater than the wavelength. In the case of light shining through small circular holes we will have to take into account the full three dimensional nature of the problem.

Effect of Diffraction of Waves:
Speed…………………………does not change
Frequency………………………. does not change
Wavelength……………………..does not change
Amplitude ………………………decreases

If diffraction is due to mountain or a hill, Knife edge diffraction model is used to study the properties of the diffracted ray, and if is due to a building, rounded surface diffraction model is used.

Knife Edge Diffraction Model:

In EM wave propagation knife-edge effect or edge diffraction is a redirection by diffraction of a portion of the incident radiation that strikes a well-defined obstacle such as a mountain range or the edge of a building.

The knife-edge effect is explained by Hugyens- Fresnel principle which states that a well-defined obstruction to an electromagnetic wave acts as a secondary source, and creates a new wave front. This new wave front propagates into the geometric shadow area of the obstacle.

UNIT – 8

TROPOSPHERE WAVE PROPAGATION

Syllabus:

Tropospheric scatter, Ionosphere propagation, electrical properties of the ionosphere, effects of earths magnetic field.

Troposheric Propagation:

The lowest part of the earth's atmosphere is called the troposphere. Typically, the troposphere extends from the surface of the earth to an altitude of approximately 9 km at the poles and 17 km at the equator. This upper boundary is referred to as the tropopause and is defined as the point at which the temperature in the atmosphere begins to increase with height. Within the troposphere, the temperature is found to decrease with altitude at a rate of approximately 7o C per km . The earth's weather system is confined to the troposphere and the fluctuations in weather parameters like temperature, pressure and humidity cause the refractive index of the air in this layer to vary from one point to another. It is in this context that the troposphere assumes a vital role in the propagation of radio waves at VHF (30-300 MHz) and UHF (300-3000 MHz) frequencies. The meteorological conditions therefore influence the manner in which radio wave propagation occurs in the troposphere both on a spatial and temporal scale.

Refractive Index, Refractivity and Modified Refractivity:

["Transhorizon Radiowave Propagation due to Evaporation Ducting, The Effect of Tropospheric Weather Conditions on VHF and UHF Radio Paths Over the Sea", S D Gunashekar, D R Siddle and E M Warrington]

In general, the refractive index, n, of the troposphere decreases with altitude To simplify the mathematics involved variations in the horizontal are neglected and horizontal homogeneity of the refractive index of the troposphere is assumed in most discussions on this topic. A typical value for n at sea level is 1.000350. A few s above sea level, this might decrease to a value such as 1.000300. For all practical purposes, at this scale, this change in the refractive index is negligibly small, with hardly any visible deviation. However, immediately above the surface of the sea, it is often this small (but rapid) change in the refractive index profile that facilitates the formation of meteorological phenomena called evaporation ducts. A convenient way of expressing these unwieldy numbers is to use the concept of refractivity instead. Refractivity, N, is defined as follows:

$$N = (n-1)*10^6$$

So, for example, when n = 1.000350, N = 350.

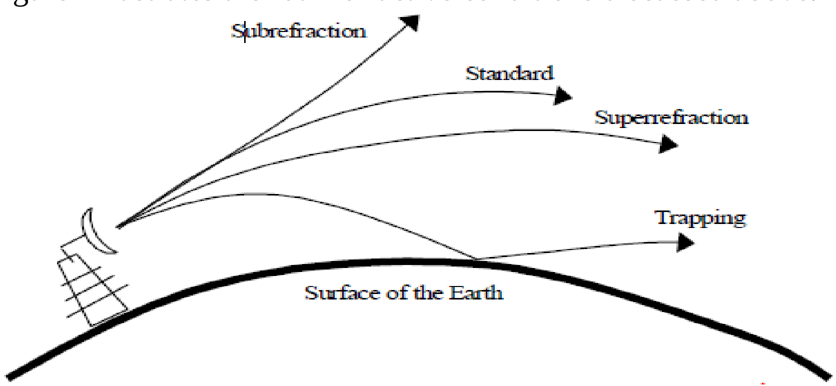
A well-known approximation for refractivity N is given below

$$N = \frac{77.6}{T}\left(P + \frac{4810 * e}{T}\right)$$

where P = total atmospheric pressure (in mb); T = atmospheric temperature (in K);

e = water vapour pressure (in mb).

All three terms, P, T and e fall with height in an exponential manner, resulting in a corresponding decrease in N with height. A standard atmosphere, therefore is one in which the refractivity varies with altitude according to equation. Using Snell's law, a radio ray projected into the atmosphere will have to travel from a denser to rarer medium and will refract downwards towards the surface of the earth. The curvature of the ray, however, will still be less than the earth's curvature. The gradient of refractivity in this case generally varies from 0 to –79 N-units per kilo. When the refractivity gradient varies from –79 to –157 N-units per kilo, a super refractive condition is said to prevail in the troposphere and the ray will refract downwards at a rate greater than standard but less than the curvature of the earth . A refractivity gradient that is even less than –157 N-units per kilo will result in a ray that refracts towards the earth's surface with a curvature that exceeds the curvature of the earth. This situation is referred to as trapping and is of particular importance in the context of evaporation ducts. Finally, if the refractivity gradient is greater than 0 N units per kilo, a sub refractive condition exists and a radio ray will now refract upwards, away from the surface of the earth. Depending on the existing conditions in the troposphere, a radio wave will undergo any of the types of refraction: sub refraction, standard refraction, super refraction or trapping. Figure1 illustrates the four refractive conditions discussed above.



While dealing with radio propagation profiles, the curved radio rays are replaced with linear rays for the purpose of geometric simplicity. To account for drawing radio rays as straight lines, the earth radius has to be increased. The radius of this virtual sphere is known as the effective earth radius and it is approximately equal to four-thirds the true radius of the earth (i.e. roughly 8500 km). A more classical form of representing n is that of modified refractivity, M. In this case, the surface of the earth is represented by a flat plane and the radio rays are constituted by curves that are determined by Snell's law and the corresponding value of M at each point along the radio link. The following is the expression for M

$$M = N + \left(\frac{h}{a}\right) * 10^6$$

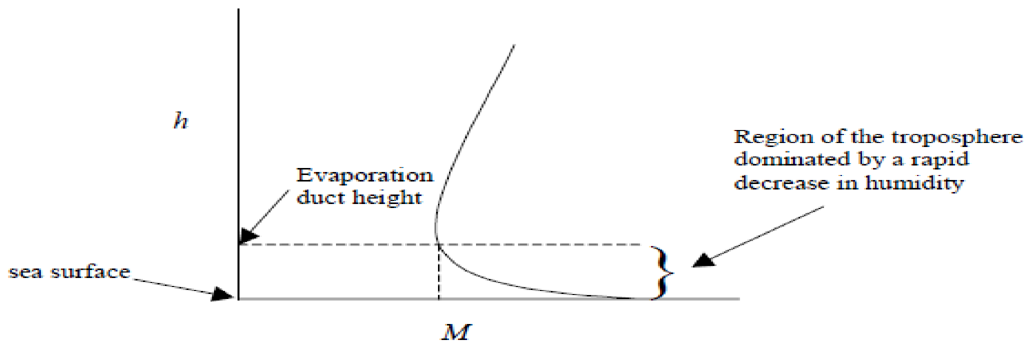
N + 0.157h,

where N = refractivity (in N-units), h = height above sea level (in s), a = radius of the earth (in s).

Formation of Evaporation Ducts:

The air that is in immediate contact with the sea surface is saturated with water vapour (i.e. the relative humidity is 100%). As the height increases, the water vapour pressure in the atmosphere rapidly decreases until it reaches an ambient value at which it remains more or less static for a further increase in height. Therefore, for the first few s above the surface of the sea, it is the water vapour pressure, e, in the expression for N that dominates. This rapid decrease in e causes a steep fall in N.

This is reflected in the modified refractivity, M, which also correspondingly decreases. (The height term h, which increases, is more than offset by the rapidly decreasing N term). This behaviour can be seen in the graph of h vs M



as that portion of the curve with a strong negative M gradient. Therefore, despite the fact that the height h is increasing, it is the sharp fall in the water vapour pressure, e, that contributes to the rapid decrease in M.

Once e has reached its ambient value at a given height, a further rise in altitude does not cause a substantial change in the humidity of the troposphere. Thus, as h increases further, N decreases more (since air pressure and temperature both decrease with height). But this decrease in N is very small over large height increments. Consequently, despite a decreasing N term, it is the h term that starts to dominate in the expression for M. Thus, M now gradually increases with height, and can be seen as the portion of the curve that has a positive M gradient.

The point at which the M gradient changes from negative to positive is referred to as the evaporation duct height (or thickness), and is a practical and realistic measure of the strength of the evaporation duct.

Evaporation Ducts and the Troposphere:

By virtue of their nature of formation, evaporation ducts are nearly permanent features over the sea surface. Typically, the height of an evaporation duct is of the order of only a few s; however, this can vary considerably with geographical location and changes in atmospheric parameters such as humidity, air pressure and temperature. In the lower regions of the troposphere where the earth's weather is confined, these parameters do, in fact, fluctuate significantly. The turbulent nature of the atmosphere contributes to its unpredictability and a variable atmosphere, in turn, is one of the major causes of unreliable wireless communications. Depending on their location and the prevailing climate, evaporation duct heights may vary from a few meters to few tens of meters. Additionally, it is observed that calm sea conditions are more conducive for the creation of ducts. As a consequence of sporadic meteorological phenomena, evaporation duct heights undergo significant spatial and temporal variations. Evaporation ducts are weather-related phenomena; their heights cannot easily be measured directly using instruments like refractometers and radiosondes. At best, the height of an evaporation duct can be deduced from the bulk meteorological parameters that are representative of the ongoing physical processes at the air-sea boundary. The dependence of evaporation ducts on the physical structure of the troposphere signifies that changing weather conditions can indeed result in alterations in radio wave propagation.

Evaporation Ducts and Radio Wave Propagation:

Over the years, much research has been undertaken to explain the mechanism of radio wave propagation in evaporation ducts. A key reason why evaporation ducts are so important for radio communications is because they are often associated with enhanced signal strengths at receivers. An evaporation duct can be regarded as a natural waveguide that steers the radio signal from the transmitter to a receiver that may be situated well beyond the radio horizon. The drop in the refractive index of the atmosphere within the first few meters above the surface of the sea causes incident radio waves to be refracted towards the earth more than normal so that their radius of curvature becomes less than or equal to that of the earth's surface. The sudden change in the atmosphere's refractivity at the top of the duct causes the radio waves to refract back into the duct, and when it comes in contact with the surface of the sea, it gets reflected upwards again. The waves then propagate long ranges by means of successive reflections (refractions) from the top of the duct and the surface of the earth.

Since the top of an evaporation duct is not 'solid' (as in the case of an actual waveguide), there will be a small but finite amount of energy leakage into the free space immediately above the duct .However, despite this escape of energy, radio waves are still capable of travelling great distances through the duct, with relatively small attenuation and path loss. The ducting effect often results in radio signals reaching places that are beyond the radio horizon with improved signal strengths. This naturally has far reaching implications on practical radio propagation patterns. For this reason, evaporation ducts and their impact on radio wave propagation have been studied extensively over the years. Numerous statistical models have been proposed to describe evaporation ducts and compute the duct heights under different atmospheric conditions.

The presence of evaporation ducts might not always indicate enhanced signal strengths. For instance, if there is an unwanted distant transmitter also located within the duct, then there is always the possibility of the system under consideration being susceptible to signal interference and interception. This is dependent on the location of the radio paths being investigated. Another scenario that might arise is the interference between the various propagation modes that exist within the evaporation duct itself. Depending on the separation of the transmitter and receiver and the prevailing atmospheric conditions, there could be destructive interference between the direct and reflected rays, the latter of which is comprised of the various multiple hop (one-hop, two-hop, and so on) propagation modes.

Additionally, signal degradation may also occur if there is destructive interference between various modes that arrive at the receiver after refraction from different heights in the troposphere. All these situations could possibly cause key problems in the domain of cellular mobile communication systems in littoral regions. Thus, in addition to aiding radio wave propagation, evaporation ducts could also be principal limiting factors in beyond line of sight over-the-sea UHF propagation.

Ionosphere Propagation:

The **ionosphere** is a part of the upper atmosphere, from about 85 km to 600 km altitude, comprising portions of the mesosphere, thermosphere, and exosphere, thermosphere and exosphere, distinguished because it is ionized by solar radiation. It plays an important part in atmospheric electricity and forms the inner edge of the magnetosphere. It has practical importance because, among other functions, it influences radio wave Propagation to distant places on the earth.

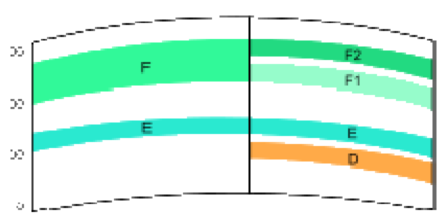
In a region extending from a height of about 90 km to over thousands of kms, most of the molecules of the atmosphere are ionized by radiation from the Sun. This region is called the *ionosphere*

At greater heights- intensity of ionizing radiation is very high, few molecules are available for ionization, ionization density is *low*

As height decreases- more molecules are available due to reduced atmospheric pressure, ionization density is higher (closer to the earth)

But as height decreases further, ionization density decreases though more molecules are available since the energy in the ionizing radiation has been used up to create ions.

Hence, ionization is different at different heights above the earth and is affected by time of day and solar activity



Ionospheric Layers

At the night the F layer is the only layer of significant ionization present, while the ionization in the D and E layers is extremely low. During the day, the D and E layers become much more heavily ionized, as does the F layer which develops an additional weaker region of ionization known as the F1 layer. The F2 layer persists by day and night and is the region mainly responsible for the refraction of radio waves.

D Layer:

The D layer is the innermost layer, 60 km to 90 km above the surface of the Earth. Ionization here is due to Lyman series alpha hydrogen radiation at a of 121.5 nanometer (nm).. In addition, with high solar activity hard X rays (wavelength < 1 nm) may ionize (N_2, O_2). During the night cosmic rays produce a residual amount of ionization. Recombination is high in the D layer, the net ionization effect is low, but loss of wave energy is great due to frequent collisions of the electrons (about ten collisions every msec). As a result high-frequency (HF) radio waves are not reflected by the D layer but suffer loss of energy therein. This is the main reason for absorption of HF radio waves, particularly at 10 MHz and below, with progressively smaller absorption as the frequency gets higher. The absorption is small at night and greatest about midday. The layer reduces greatly after sunset; a small part remains due to galactic cosmic rays. A common example of the D layer in action is the disappearance of distant AM broadcast band stations in the daytime.

E Layer:

The E layer is the middle layer, 90 km to 120 km above the surface of the Earth. Ionization is due to soft X-ray (1-10 nm) and far ultraviolet (UV) solar radiation ionization of molecular oxygen(O_2). Normally, at oblique incidence, this layer can only reflect radio waves having frequencies lower than about 10 MHz and may contribute a bit to absorption on frequencies above. However, during intense Sporadic E events, the E_S layer can reflect frequencies up to 50 MHz and higher. The vertical structure of the E layer is primarily determined by the competing effects of ionization and recombination. At night the E layer rapidly disappears because the primary source of ionization is no longer present. After sunset an increase in the height of the E layer maximum increases the range to which radio waves can travel by reflection from the layer.

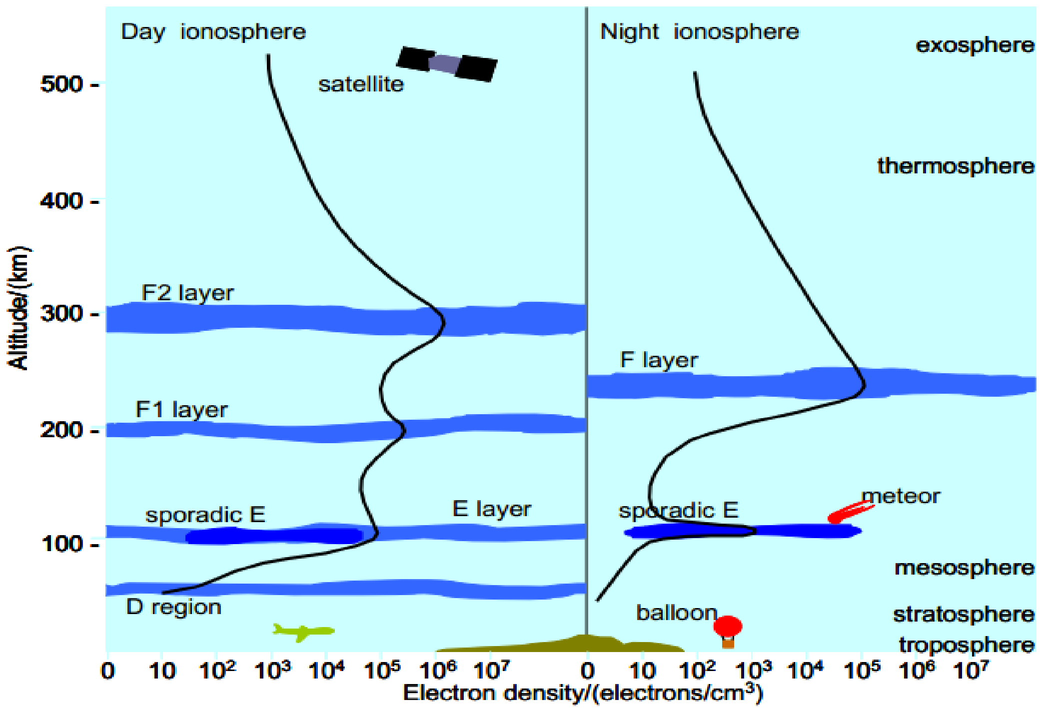
E_S

The E_S layer (sporadic E-layer) is characterized by small, thin clouds of intense ionization, which can support reflection of radio waves, rarely up to 225 MHz. Sporadic-E events may last for just a few minutes to several hours. Sporadic E propagation makes radio amateurs very excited, as propagation paths that are generally unreachable can open up. There are multiple causes of sporadic-E that are still being pursued by researchers. This propagation occurs most frequently during the summer months when high signal levels may be reached. The skip distances are generally around1,000 km (620 mi). Distances for one hop propagation can be as close as 900 km [500 miles] or up to 2,500 km (1,600 mi). Double-hop reception over 3,500 km (2,200 mi) is possible.

F Layer:

The F layer or region, also known as the Appleton layer extends from about 200 km to more than 500 km above the surface of Earth. It is the densest point of the ionosphere, which implies signals penetrating this layer will escape into space. At higher altitudes the amount of oxygen ions decreases and lighter ions such as hydrogen and helium become dominant, this layer is the topside ionosphere. Here extreme ultraviolet (UV, 10–100 nm) solar radiation ionizes atomic oxygen. The F layer consists of one layer at night, but during the day, a deformation often forms in the profile that is labeled F_1. The F_2 layer remains by day and night responsible for most skywave propagation of radio waves, facilitating high frequency (HF, or shortwave) radio communications over long distances.

Day and night structure of ionosphere:



VARIATIONS IN THE IONOSPHERE [Integrated Publishing, Electrical Engineering Training Series]

Because the existence of the ionosphere is directly related to radiations emitted from the sun, the movement of the Earth about the sun or changes in the sun's activity will result in variations in the ionosphere. These variations are of two general types:
(1) those which are more or less regular and occur in cycles and, therefore, can be predicted in advance with reasonable accuracy, and

(2) those which are irregular as a result of abnormal behavior of the sun and, therefore, cannot be predicted in advance. Both regular and irregular variations have important effects on radio wave propagation.

Regular Variations

The regular variations that affect the extent of ionization in the ionosphere can be divided into four main classes: daily, seasonal, 11-year, and 27-day variations.

DAILY. - Daily variations in the ionosphere are a result of the 24-hour rotation of the Earth about its axis. Daily variations of the different layers (fig. 2-14) are summarized as follows:

The D layer reflects VLF waves; is important for long range VLF communications; refracts lf and mf waves for short range communications; absorbs HF waves; has little effect on vhf and above; and disappears at night. In the E layer, ionization depends on the angle of the sun. The E layer refracts HF waves during the day up to 20 megahertz to distances of about 1200 miles. Ionization is greatly reduced at night. Structure and density of the F region depend on the time of day and the angle of the sun. This region consists of one layer during the night and splits into two layers during daylight hours.

• Ionization density of the F1 layer depends on the angle of the sun. Its main effect is to absorb hf waves passing through to the F2 layer.
• The F2 layer is the most important layer for long distance HF communications.

It is a very variable layer and its height and density change with time of day, season, and sunspot activity.

SEASONAL. - Seasonal variations are the result of the Earth revolving around the sun; the relative position of the sun moves from one hemisphere to the other with changes in seasons. Seasonal variations of the D, E, and F1 layers correspond to the highest angle of the sun; thus the ionization density of these layers is greatest during the summer. The F2 layer, however, does not follow this pattern; its ionization is greatest in winter and least in summer, the reverse of what might be expected. As a result, operating frequencies for F2 layer propagation are higher in the winter than in the summer.

Eleven Year Sun Spot Cycle:

One of the most notable phenomena on the surface of the sun is the appearance and disappearance of dark, irregularly shaped areas known as SUNSPOTS. The exact nature of sunspots is not known, but scientists believe they are caused by violent eruptions on the sun and are characterized by unusually strong magnetic fields. These sunspots are responsible for variations in the ionization level of the ionosphere. Sunspots can, of course, occur unexpectedly, and the life span of individual sunspots is variable; however, a regular cycle of sunspot activity has also been observed. This cycle has both a minimum and maximum level of sunspot activity that occur approximately every
11 years.
During periods of maximum sunspot activity, the ionization density of all layers increases. Because of this, absorption in the D layer increases and the critical frequencies for the E, F1, and F2 layers are higher. At these times, higher operating frequencies must be used for long distance communications.

27-DAY SUNSPOT CYCLE. - The number of sunspots in existence at any one time is continually subject to change as some disappear and new ones emerge. As the sun rotates on its own axis, these sunspots are visible at 27-day intervals, the approximate period required for the sun to make one complete rotation.

The 27-day sunspot cycle causes variations in the ionization density of the layers on a day-to-day basis. The fluctuations in the F2 layer are greater than for any other layer. For this reason, precise predictions on a day-to-day basis of the critical frequency of the F2 layer are not possible. In calculating frequencies for long- distance communications, allowances for the fluctuations of the F2 layer must be made.

Irregular Variations

Irregular variations in ionospheric conditions also have an important effect on radio wave propagation. Because these variations are irregular and unpredictable, they can drastically affect communications capabilities without any warning.
The more common irregular variations are sporadic E, sudden ionospheric disturbances, and ionospheric storms.

SPORADIC E: Irregular cloud-like patches of unusually high ionization, called sporadic E, often form at heights near the normal E layer. Exactly what causes this phenomenon is not known, nor can its occurrence be predicted. It is known to vary significantly with latitude, and in the northern latitudes, it appears to be closely related to the aurora borealis or northern lights.
At times the sporadic E is so thin that radio waves penetrate it easily and are returned to earth by the upper layers. At other times, it extends up to several hundred miles and is heavily ionized.

These characteristics may be either harmful or helpful to radio wave propagation. For example, sporadic E may blank out the use of higher, more favorable ionospheric layers or cause additional absorption of the radio wave at some frequencies. Also, it can cause additional multipath problems and delay the arrival times of the rays of rf energy.

On the other hand, the critical frequency of the sporadic E is very high and can be greater than double the critical frequency of the normal ionospheric layers. This condition may permit the long distance transmission of signals at unusually high frequencies. It may also permit short distance communications to locations that would normally be in the skip zone.

The sporadic E can form and disappear in a short time during either the day or night. However, it usually does not occur at the same time at all transmitting or receiving stations.

SUDDEN IONOSPHERIC DISTURBANCES: The most startling of the ionospheric irregularities is known as a SUDDEN IONOSPHERIC DISTURBANCE (SID). These disturbances may occur without warning and may prevail for any length of time, from a few minutes to several hours. When SID occurs, long distance propagation of hf radio waves is almost totally "blanked out." The immediate effect is that radio operators listening on normal frequencies are inclined to believe their receivers have gone dead.

When SID has occurred, examination of the sun has revealed a bright solar eruption. All stations lying wholly, or in part, on the sunward side of the Earth are affected. The solar eruption produces an unusually intense burst of ultraviolet light, which is not absorbed by the

F2, F1, and E layers, but instead causes a sudden abnormal increase in the ionization density of the D layer. As a result, frequencies above 1 or 2 megahertz are unable to penetrate the D layer and are usually completely absorbed by the layer.

IONOSPHERIC STORMS: Ionospheric storms are disturbances in the Earth's magnetic field. They are associated, in a manner not fully understood, with both solar eruptions and the 27-day intervals, thus corresponding to the rotation of the sun.

Scientists believe that ionospheric storms result from particle radiation from the sun. Particles radiated from a solar eruption have a slower velocity than ultraviolet light waves produced by the eruption. This would account for the 18-hour or so time difference between a sid and an ionospheric storm. An ionospheric storm that is associated with sunspot activity may begin anytime from 2 days before an active sunspot crosses the central meridian of the sun until four days after it passes the central meridian. At times, however, active sunspots have crossed the central region of the sun without any ionospheric storms occurring. Conversely, ionospheric storms have occurred when there were no visible spots on the sun and no preceding SID. As you can see, some correlation between ionospheric storms, sid, and sunspot activity is possible, but there are no hard and fast rules. Ionospheric storms can occur suddenly without warning.

The most prominent effects of ionospheric storms are a turbulent ionosphere and very erratic sky wave propagation. Critical frequencies are lower than normal, particularly for the F2 layer. Ionospheric storms affect the higher F2 layer first, reducing its ion density. Lower layers are not appreciably affected by the storms unless the disturbance is great. The practical effect of ionospheric storms is that the range of frequencies that can be used for communications on a given circuit is much smaller than normal, and communications are possible only at the lower working frequencies.

RECOMMENDED QUESTIONS

1. Write short notes on:

    Wave propagation.
    Scatter systems.
    Surface wave propagation.
    Surface wave tilting.
    Space wave propagation.
    Ionosphere propagation.
    Structure of ionosphere.
    Sky wave propagation.
    Duct propagation.

2. Derive an expression for tilt angle.
3. Derive an expression for distance of communication.
4. Obtain an expression for space wave field component taking into account a direct wave field component and a reflected wave from the earth surface.
5. Derive an expression for refractive index.
6. Define the following and derive the relevant expressions:
    i. Critical frequency.
    ii. Maximum usable frequency.
    iii. Virtual height.
    iv. Skip distance.

7. Briefly explain characteristics of different ionized layers in ionospheric propagation.
8. Calculate the critical frequency for a medium at which the wave reflects if the maximum electron density is $1.24*10^{6}$ electrons/cm^3.
9. Which propagation will aid the following frequencies and why. (a) 120KHz. (b) 10MHz. (c) 300 MHz. (d) 30GHz.
10. Estimate the surface wave tilt in degrees over an earth of 12mm conductivity and relative permittivity 20 at a wave length of 300m.
11. A transmitter radiates 100Wof power at a frequency of 50MHz, so that space wave propagation takes place. The transmitting antenna has a gain of 5 and its height is 50m. The receiving antenna height is 2m. It is estimated that a field strength of 100 ?V/m is required to give a satisfactory result. Calculate the distance between transmitter and receiver.