Module 3: ANTENNA BASICS

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INTRODUCTION

An antenna is used to radiate electromagnetic energy efficiently and in desired directions. Antennas act as matching systems between sources of electromagnetic energy and space. 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):

A rough outline of some major antennas and their discovery /fabrication dates are listed:

- Yagi-Uda Antenna,1920s
- Horn Antennas,1939
- Antenna Arrays 1940s
- Parabolic Reflectors late 1940s, early 1950s.
- Patch Antennas,1970s
- PIFAs 1980s.

OBJECTIVES:

1. Introduction about the antenna parameters in terms of antenna language
2. Antenna field zones utilization.
3. Link budget calculation for any communication link.

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 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

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

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 Rr, called Radiation resistance.

b) As Receiving Antenna: Active radiation by other Antenna or Passive radiation from distant objects raises the apparent temperature of Rr. 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. Rr 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.

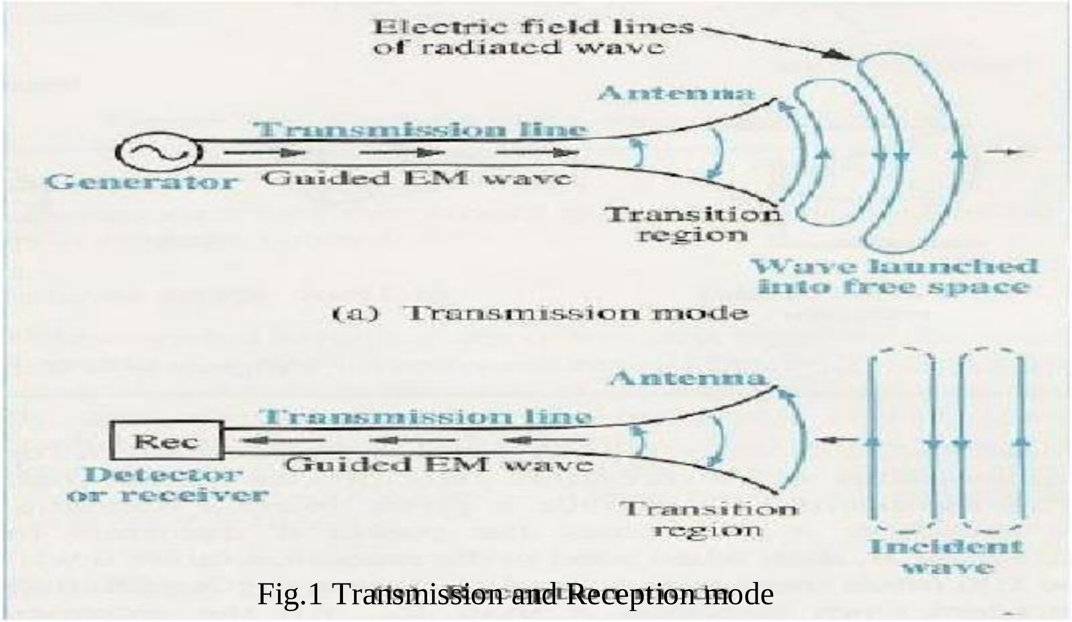


Fig.1 Transmission and Reception mode

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

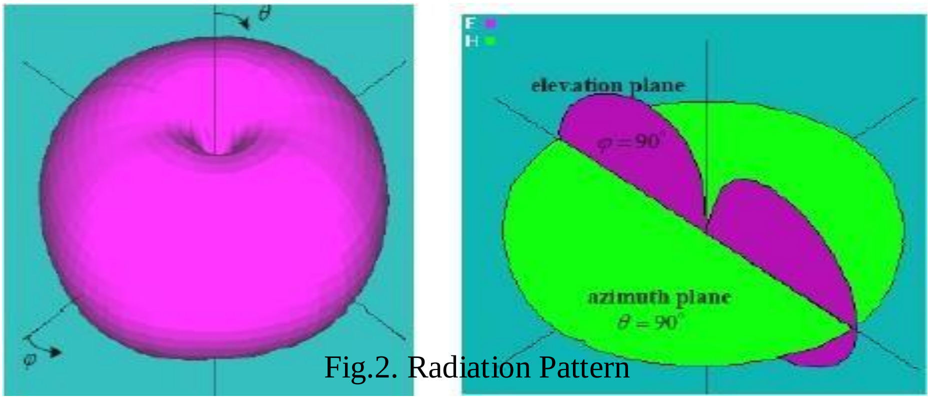


Fig.2. Radiation Pattern

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

$$E_\Phi(\theta,\Phi)\ n = E_\Phi(\theta,\Phi) / E_\Phi(\theta,\Phi)\ \max \qquad (2)$$

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.

$$Pn(\theta,\Phi)n = S(\theta,\Phi)/ S(\theta,\Phi)max \qquad (3)$$

Where, $S(\theta,\Phi)$ is the Poynting vector = $[\ E_\theta^2(\theta,\Phi) + E_\Phi^2(\theta,\Phi)\ ] / Z0$ Wm-2

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

Z0 is the intrinsic impedance of free space = 376.7Ω.

Decibel level is given by $dB = 10 \log10 Pn(\theta,\Phi)$

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, ΩA
3. Bema Efficiency, εM
4. Directivity D, Gain G
5. Effective Aperture, Ae
6. Radiation Intensity

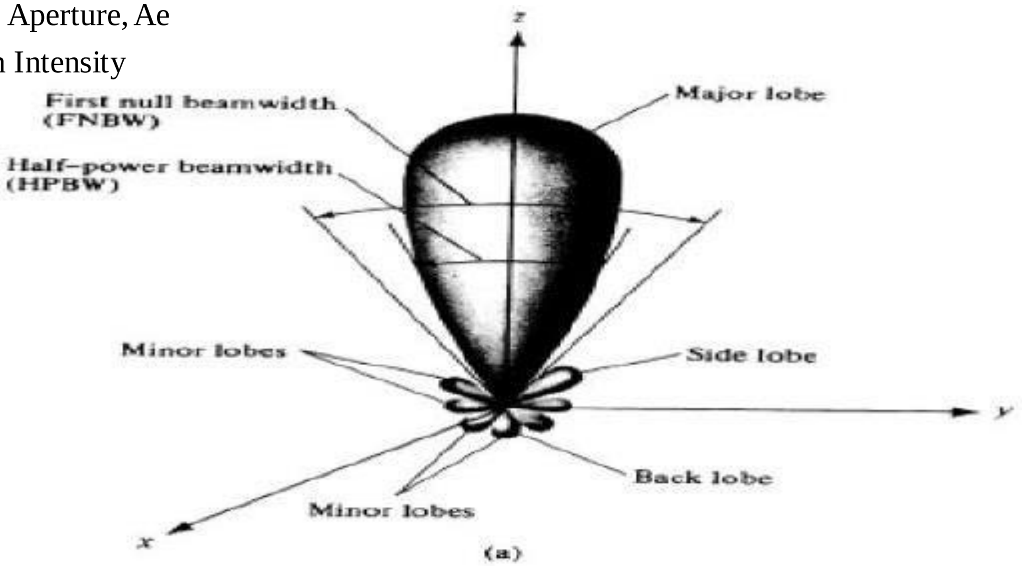


Fig.3 Pattern in spherical co-ordinate system

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.

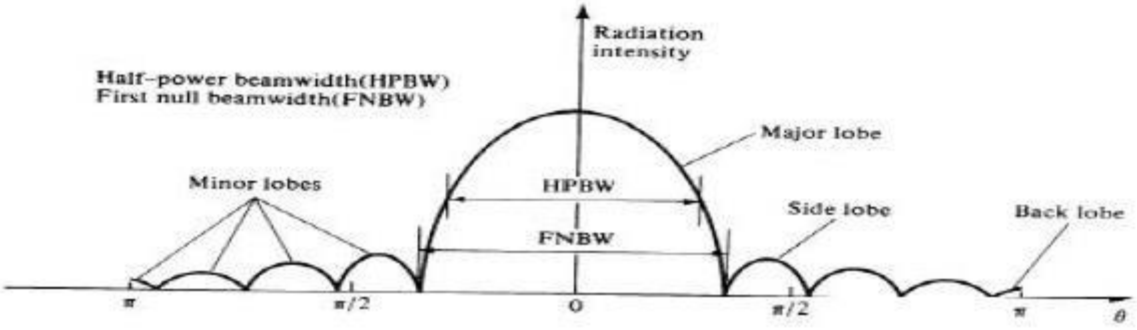


Fig.4 Pattern in Cartesian co-ordinate system

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.

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

$$\Omega A = \int_{\phi=0}^{\phi=2\pi} \int_{\theta=0}^{\theta=2\pi} Pn\,(\theta,\Phi)\,\sin\theta\, d\theta\, d\Phi \qquad (4)$$

Beam area ΩA is the solid angle through which all of the power radiated by antenna would stream if P(θ, Φ) maintained its maximum value over ΩA and was zero.

$$\text{Total power radiated} = P(\theta, \Phi)\,\Omega A \text{ watts}$$

Beam area is the solid angle ΩA 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)

$$\Omega A = \theta HP\ \Phi HP$$

Radian and Steredian: Radian is plane angle with its vertex a the center 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.

Steredian is solid angle with its vertex at the center 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 4π steredians

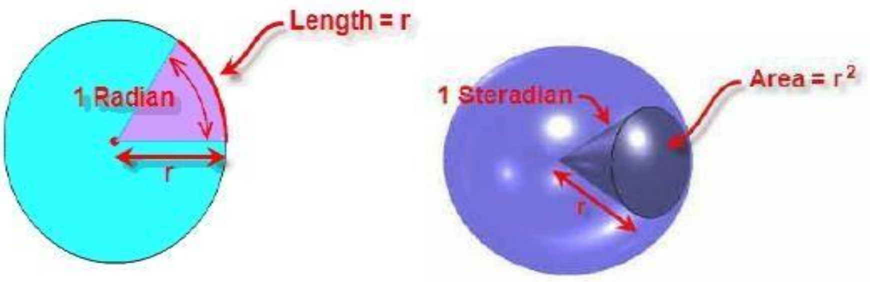


Fig.5 Beam Area

1steradian = $(1\text{radian})^2$
= $(180 / \pi)^2$
= 3282.8064 square degrees
4π steradians = 3282.8064 x 4π
= 41,253 square degree

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.

1.7 Beam Efficiency $Pn(\theta,\Phi)n = S(\theta,\Phi)/ S(\theta,\Phi)max$

Beam Efficiency

The total beam area ΩA consists of the main beam area ΩM plus the minor lobe area Ωm .

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

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 εm

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

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

$$D=U(\theta,\varphi)_{max}/U(\theta,\varphi)_{avg}$$

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 Pin is the sum of the Radiated power Prad and losses Ploss

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

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)

$$G = KD, where\ 0 \leq K \leq 1$$

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

$$G=4\pi U/Pin$$

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 dependent 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 radiatedor 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

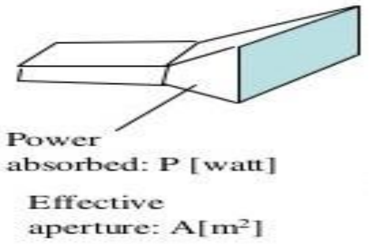


Fig.6 Aperture

Let the Poynting vector or power density of the plane wave be S watts/sq –m and let the area or physical aperture be Ap sq-m.

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

$$\varepsilon_{ap}=Ae/Ap$$

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 Ae which radiates all of it’s power in a conical pattern of beam area ΩA, assuming uniform field Ea over the aperture, power radiated is

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

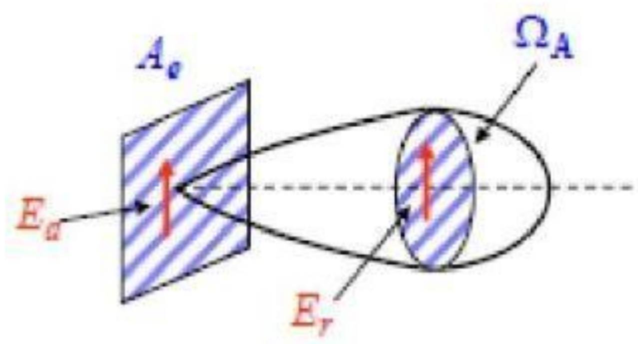


Fig.7 Effective Aperture

Assuming a uniform field Er in far field at a distance r. Power radiated is also given by

$$P=Er^2/Z0\ r^2\ \Omega A$$

Equating the two and noting that Er = Ea Ae/r λ we get Aperture Beam Area relation

$$\Lambda 2 = Ae\ \Omega A$$

At a Given wavelength if effective aperture is known, Beam Area can be determined or vice versa

1. 10 Effective height

The effective height is another parameter related to the apertures. Multiplying the effective height, he(meters), times the magnitude of the incident electric field E (V/m) yields the voltage V induced. Thus V=he E or he= 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/π=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

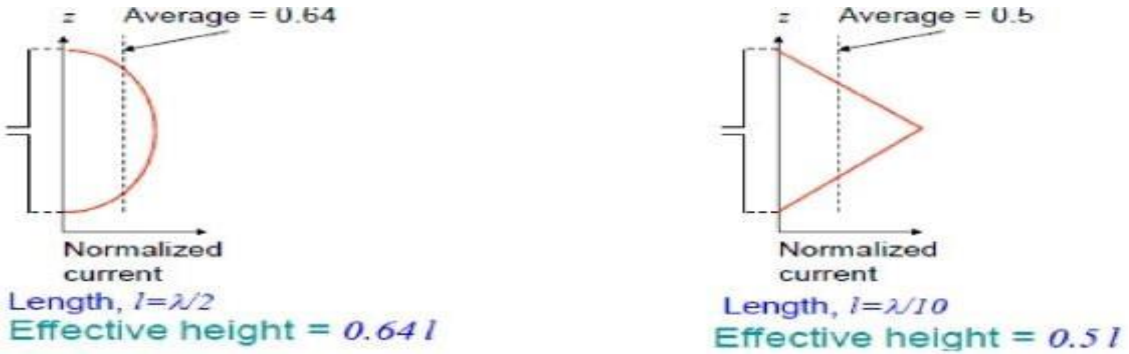


Fig.8 Effective Height

For an antenna of radiation resistance Rr matched to it’d load , power delivered to load is

$$P = V^2/4r \text{ and}$$

voltage is given by $V=h_eE$

Therefore, $P=(h_eE)^2/(4Rr)$

In terms of Effective aperture the same power is given by

$$P=SAe= (E^2/z_0)Ae$$

Equating the two,

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

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 fH is 10 times greater than fL

2. Narrow band antennas-BW is expressed as percentage of frequency difference over center frequency eg:5% means (fH –fL) /fo is .05. Bandwidth can be considered to be the range of frequencies on either sides of a center 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

$$FBW = \frac{f_{max}}{f_{min}}$$

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

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

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

The characteristics such as Zi, G, Polarization etc of antenna does not necessarily vary in the same manner. Sometimes 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
Where, 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 th eantenna 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

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

where

TP is the physical temperature of the object in K (Kelvin degrees); and k is

Boltzmann's constant (1.38x10^{-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

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

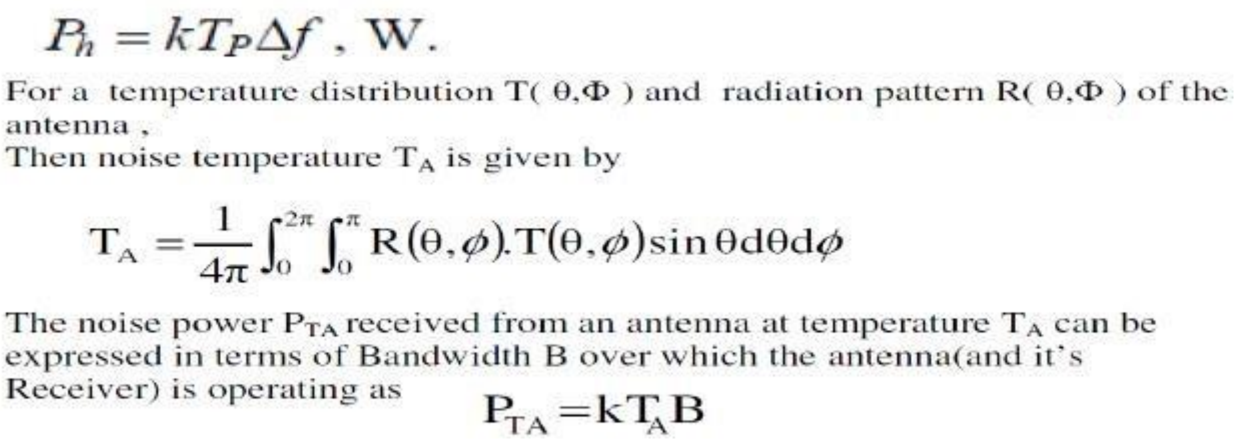
Where,

k is Boltzmann's constant (1.38x10^{-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



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

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 $P_{TA} = kT_AB$

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

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

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

And total noise power in the system is

THE RADIO COMMUNICATION LINK

The usefulness of the aperture concept is well illustrated by using it to derive the important Friis transmission formula published in 1946 by Harald T. Friis (1) of the Bell Telephone Laboratory.

Fig: Radio communication link

Referring to Fig.9, the formula gives the power received over a radio communi- cation link. Assuming lossless, matched antennas, let the transmitter feed a power P_t to a transmitting antenna of effective aperture A_{et} . At a distance r a receiving antenna of effective aperture A_{er} intercepts some of the power radiated by the transmitting antenna and delivers it to the receiver R. Assuming for the moment that the transmitting antenna is isotropic, the power per unit area available at the receiving antenna is

$$S_r = \frac{P_t}{4\pi r^2}$$

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

$$S_r = \frac{P_t G_t}{4\pi r^2}$$

Now the power collected by the lossless, matched receiving antenna of effective aperture

Aer is

$$P_t = S_r A_{er} = \frac{P_t G_t A_{er}}{4\pi r^2}.$$

The gain of the transmitting antenna can be expressed as

$$G = \frac{4\pi}{\lambda^2} A_e$$

Substituting this in the previous equation yields the ***Friis transmission formula***

ANTENNA FIELD ZONES

The fields around an antenna may be divided into two principal regions, one near the antenna called the near field or Fresnel zone and one at a large distance called the far field or Fraunhofer zone. Referring to Fig. 2–17, the boundary between the two may be arbitrarily taken to be at a radius

$R=2L^2/\lambda$

L = maximum dimension of the antenna, m

λ = wavelength, m

In the far or Fraunhofer region, the measurable field components are transverse to the ra- dial direction from the antenna and all power flow is directed radially outward. In the far field the shape of the field pattern is independent of the distance. In the near or Fresnel region, the longitudinal component of the electric field may be significant and power flow is not entirely radial. In the near field, the shape of the field pattern depends, in general, on the distance.

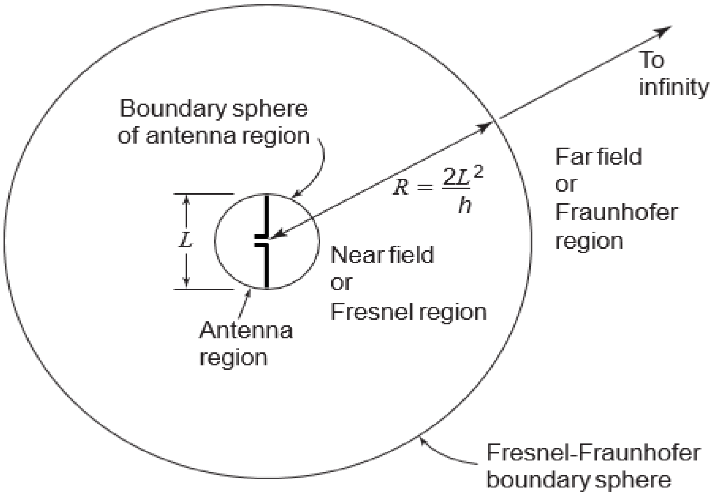


Fig 9. Antenna field zones

Enclosing the antenna in an imaginary boundary sphere as in Fig. 9 it is as though the region near the poles of the sphere acts as a reflector. On the other hand, the waves expanding perpendicular to the dipole in the equatorial region of the sphere result in power leakage through the sphere as if partially transparent in this region.

This results in reciprocating (oscillating) energy flow near the antenna accompanied by outward flow in the equatorial region. The outflow accounts for the power radiated from the antenna, while the reciprocating energy represents reactive power that is trapped near the antenna like in a resonator

Note that although the term *power flow* is sometimes used, it is actually *energy* which flows, power being the time rate of energy flow. A similar loose usage occurs when we say we pay a power bill, when, in fact, we are actually paying for electric energy.

Near Field (Fresnel's Region)

- Power flow is not entirely radiated.
- Shape of field pattern is dependent of radial distance.
- There is an energy reciprocating b/n antenna and space.
- Reactive energy.

Far field (Fraunhofer's region)

- Real power flow is directed radially outwork.
- Shape of the field pattern is independent of distance.
- The outward power flow represents radiated energy.

Measurable field components are transverse to the direction of propagation.

Recommended questions

1. With the help of Maxwell's equation, explain how radiation and reception of EM takes place?

2. Explain the following terms as related to antenna system:

(1) Directivity (2) HPBW (3) Effective length (4) Beam efficiency (5) Gain (6) Isotropic radiator (7) Beam area/Beam solid angle (8) Radiation resistance

3. Show that the directivity for unidirectional operation is 2(n+1) for an intensity variation of $u = u^m \cos^n\theta$.

4. Prove that maximum effective aperture for a λ/2 antenna is 0.13 λ2.

5. The effective aperture of transmitting and receiving antennas in a communication system are 8 λ2 and 12 λ2 respectively with a separation of 1.5 km between them. The E.M wave is travelling with a frequency of 6MHz and the total input power is 25KW. Find the power received by the receiving antenna.

6. Define the following with respect to antenna:

(1) Radiation pattern (power and field pattern) (2) field zones (3) Aperture

OUTCOMES

- Student will able to define the parameters and importance of all in communication systems
- Student able to solve link budget problems required for the applications
- Student able to describe the importance of Fraunhofer zone.

Further Readings

1. **Antenna Theory Analysis and Design** - C A Balanis, 3rd Edn, John Wiley India Pvt. Ltd, 2008