Antenna Terminology

6.1. INTRODUCTION

Antennas are basic components of any electric system and are connecting links between the transmitter and free-space or free space and the receiver. Thus antennas play very important role in finding the characteristics of the system in which antennas are employed. Antennas are employed in different systems in different forms. That is, in some systems the operational characteristic of the system are designed around the directional properties of the antennas or in some other systems, the antennas are used simply to radiate electromagnetic energy in an omnidirection or finally in some systems for point to point communication purposes in which increased gain and reduced wave interference are required.

Irrespective of type of application of an antennas or antenna system, all the antennas possessed certain basic properties which will now be discussed in this chapter. The important properties of an antenna are generally given in some terms like, **Radiation Pattern, Radiation Intensity, Polarization gain, directive gain or directivity, Power gain, Efficiency, Effective Aperture or Area, Self and Mutual impedance, radiation resistance, Beam width, Band width etc**. These antenna terminology will one by one be taken up. However, we shall start with another term Isotropic Radiator which will be needed subsequently for comparison purposes.

6.2. ISOTROPIC RADIATORS

(AMIETE, Nov. 1969)

An isotropic radiator is a fictitious radiator and is defined **as a radiator which radiates uniformly in all directions**. It is also called as **isotropic source or omnidirectional radiator or simply unipole**. An isotropic radiator is a hypothetical lossless radiator or antenna, with which the practical radiators or antennas are compared. Thus an isotropic antenna or radiator is used as **reference antenna**. Although, sometimes, a half-wave dipole antenna is also used as reference antenna but these days use of isotropic antenna as reference antenna is preferred.

Since all the practical antennas have atleast some directional properties i.e. directivity and hence there is no such thing as isotropic radiator of electromagnetic energy. However, in accoustics we have and a point source of sound is an example of isotropic radiator.

Let us now imagine that an isotropic radiator is situated at the centre of a sphere of radius (r). Then all the energy (power) radiated from it, must pass over the surface area of the sphere (assuming there is no obstruction to absorb the power) $4\pi r^2$. Further, as said earlier, the **Poynting vector or power density** at any point on the sphere gives **"Power radiated per unit area in any direction"**. Since radiated power from a isotropic source flows in radial lines, therefore, for a isotropic radiator, the magnitude of the Poynting vector **P** is equal to the radial component only (because $P_\theta = P_\varphi = 0$).

$$\therefore \qquad |\boldsymbol{P}| = P_r \qquad \text{...(6.1)}$$

Thus, if the Poynting vector is known as all points on a sphere of radius r from a point source in a lossless medium, the total power (W_t) radiated by the source is integral over the surface of the sphere of the radial component P_r of average Poynting vector. Symbolically,

$$W_t = \iint \boldsymbol{P} \cdot ds$$

$$= \iint P_r \cdot ds = P_r \iint ds \qquad \text{from 6.1} \because \theta = \varphi = 0 \text{ for isotropic radiator} \qquad \text{...(}$$

$$\boxed{W_t = P_r\, 4\pi r^2} \qquad \therefore \int \boldsymbol{P} = P_r \because \int \boldsymbol{ds} = 4\pi r^2 = \text{area of surface} \qquad \text{...6.}$$

or

$$\boxed{P_r = \frac{W_t}{4\pi r^2} \text{ Watts/m}^2} \qquad \text{... 6.}$$

Here W_t = Total power radiated, in Watts.

P_r = Radial component of average power density poynting vector, in W/m^2.

ds = Infinitesimal element of area of sphere of radius $r = r^2 \sin\theta\, d\theta\, d\varphi$.

and r = Radius of sphere, in metres.

6.3. RADIATION PATTERN (AMIETE, May 19

It is found, in practice, that radiated energy from an antenna is not of the same strength in all directions. Instead, it is more is one direction and less or zero is other direction. The energy radiated in a particular direction by an antenna is measured in terms of FIELD STRENGTH at a point which is at a particular distance from the antenna.

For the calculation of field strength, the voltages at two points on an electric lines of force, are taken and then it is divided by the distance between the two points. Hence the unit of radiation pattern is volt/metre or milli-volt/metre. The radiation pattern of an antenna is generally its most basic requirement because it determines the distribution of radiated energy in space. Once the operating frequency is known, the radiation pattern is the first property of an antenna that is specified.

Radiation Pattern of an antenna is nothing but **a graph which shows the variation in actual field strength of electromagnetic field at all points which are at equal distance from the antenna. Obviously the graph of radiation pattern will be three-dimensional and hence can not completely be represented on a plain paper.** In order to draw the radiation pattern of an antenna **field strengths** are measured at every point which lies on the surface of an imaginary sphere of a fixed radius treating antenna as centre and then three dimensional solid figure is constructed from the reading so obtained. In this case distance from centre (fixed points) to the surface of sphere represents the field strength in that direction. In order that radiation pattern of an antenna is represented on a plain paper, **the three dimensional solid figure so obtained is cut by a plane passing through the fixed point (say centre of sphere) and the figures now obtained used to represent the radiation pattern in a usual way. The radiation patterns are different for different antennas and are affected by the location of antenna w.r.t. ground.**

In fact, the graphical representation of radiation of an antenna as a function of direction is given the name radiation pattern of the antenna. If the radiation from the antenna is expressed in terms of field strength E (volt/metre), the **radiation pattern is called as the 'Field Strength Pattern'**. If, on other hand, the radiation in a given direction is expressed in terms of power per unit solid angle, then the resulting pattern is r **'Power Pattern'**. However, both are related to each other—a power pattern is proportional to square of the field strength pattern — and unless otherwise mentioned radiation patterns henceforth referred to will be field strength pattern.

Since the radiation pattern is a three dimensional figure and hence the co-ordinate system usually used for the same is the 'spherical co-ordinate' (r, θ, φ). The antenna is assumed to be located at origin of spherical co-ordinate system and the field strength is specified at points on the spherical surface of radius (r). The shape of the radiation pattern does not depend on the radius r provided $r >> \lambda$.

The direction of field strength (E) for the radiation field is always tangential to the spherical surface of imaginary sphere of radius r and for vertical dipole electric field strength E is in the direction θ and for the horizontal loop in the direction of φ.

In other words, radiation field strength may have components E_θ and E_φ as well which may or may not be in time phase or mathematically,

$$E = \sqrt{E_\theta^2 + E_\varphi^2} \quad \text{.... (6.4)}$$

where E = Total electric field strength.

E_θ = Amplitude of θ component.

E_φ = Amplitude of φ component.

The radiation characteristics for vertically and horizontal polarizations are different and hence shown by different radiation patterns.

A complete radiation pattern is a three dimensional solid figure and gives the radiation for all angles of the θ and φ. However to represent the radiation pattern on a plain paper (*i.e.* in two dimension) a cross-section through three dimensional pattern is taken. Cross-sections generally taken are in horizontal plane (when $\theta = 90°$) and in vertical plane (when φ = constant). Thus the two dimensional patterns so obtained from three-dimensional pattern by cutting with a horizontal and vertical planes are, respectively, known as *'Horizontal Pattern'* and *'Vertical Pattern'*.

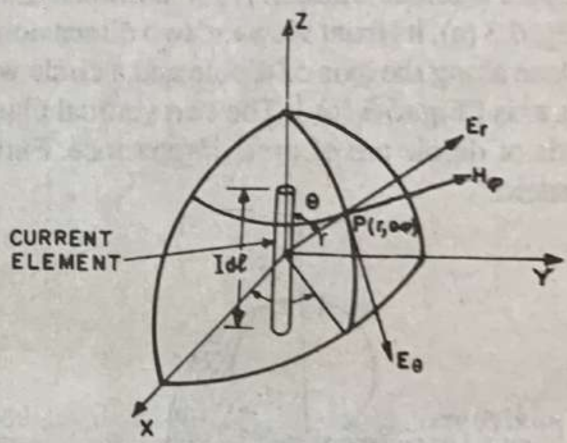


Fig. 6.1. Elementary dipole at the centre spherical co-ordinate system

Let us now come to see the radiation patterns in particular. For example, an elementary dipole antenna (Idl). The magnitude of **'radiation term'** for such an antenna is given by

$$E_\theta = \frac{60\,\pi\, Idl}{r\lambda} \cdot \sin\theta \quad \text{.... 6.5 (a)}$$

or

$$E_\theta \;\alpha\; \sin\theta \quad \text{... 6.5 (b)}$$

where θ = Angle between the axis of the dipole and the radius vector to the point where the field strength E is measured (Fig. 6.2).

Thus as seen from eqn. 6.5 (b) E_θ (and so also the H_φ) is proportional to sin θ. Therefore, the field strength is maximum when $\theta = 90°$ (because sin 90° = 1) in the ⊥ direction of axis of dipole and minimum when $\theta = 0$ (because sin 0° = 0) in the direction of axis of dipole. The variation of E_θ (or H_φ) with angle can be drawn by a field pattern as shown in Fig. 6.2 (b).

Fig. 6.2 (a) is one half of a three dimensional pattern illustrates that fields are functions of θ and does not depend on the angle while Fig. 6.2 (b) is a two dimensional pattern obtained by cutting the three-dimensional pattern by a vertical plane along the axis of dipole. In other words Fig. 6.2 (b) is the front view of Fig. 6.2 (a). Fig 6.2 (c) is also two dimensional pattern obtained by cutting **three dimensional pattern by a horizontal plane at the centre of the dipole.** As seen, three dimensional pattern of a short dipole is **Doughnut**

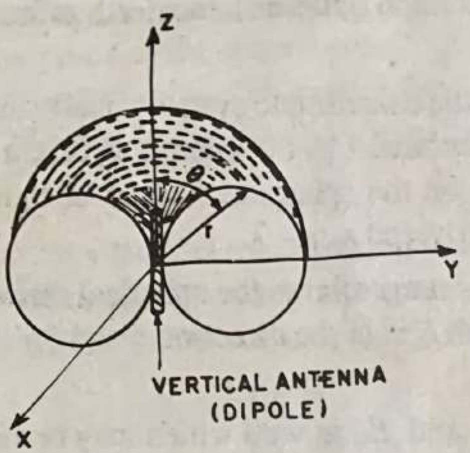


Fig. 6.2. (a) Half of the three-dimensioanl pattern (Doughnut shape)

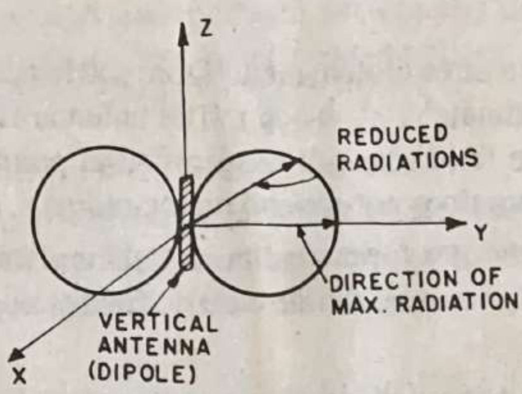


Fig. 6.2 (b) Two dimensioanl pattern obtained by cutting three dimensional pattern with a vertical plane along the axis of dipole (vertical pattern)

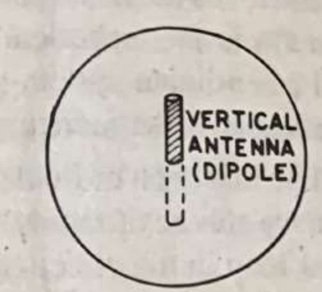


Fig. 6.2 (c) Two dimensional pattern when cut by a horizontal plane at the centre of dipole

shaped [Fig. 6.2 (a)], two dimensional pattern is a figure of eight ∞ [Fig. 6.2 (b)] when cut by a vertical plane and a circle [Fig. 6.2 (c)] when cut by a horizontal plane. Above patterns are of course, for a vertically placed dipole antenna. Similarly, for a horizontally placed dipole antenna, three dimensional pattern is as shown in Fig. 6.3 (a), its front view *i.e.* two dimensional pattern is a figure of eight 8 [Fig. 6.3 (b)] when cut by a vertical plane along the axis of dipole and a circle when cut by a vertical plane at the centre of dipole perpendicular to its axis [Fig. 6.3 (c)]. The two vertical planes *i.e.* one along the axis of dipole and the other perpendicular to axis of dipole are of great importance. Further increase in length of antenna changes the shape of radiation pattern.

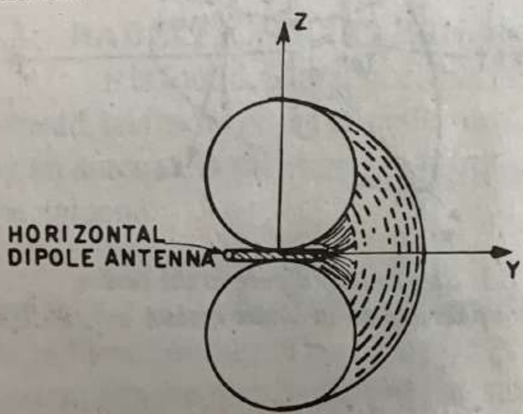


Fig. 6.3. (a). Half of the three dimensional pattern (Dipole placed horizontally).

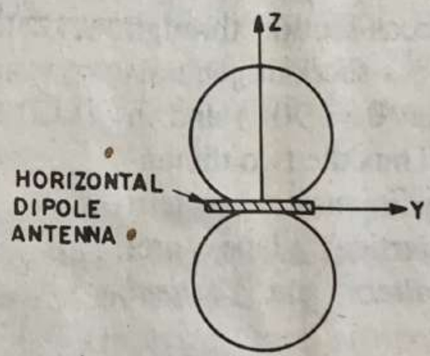


Fig. 6..3. (b) Two dimensional pattern obtained by cutting three-dimensional pattern with a vertical plane along the axis of dipole (vertical pattern)

Fig. 6.3 (c) Two dimensional pattern when cut by a vertical plane at the centre of dipole perpendicualr to its axis.

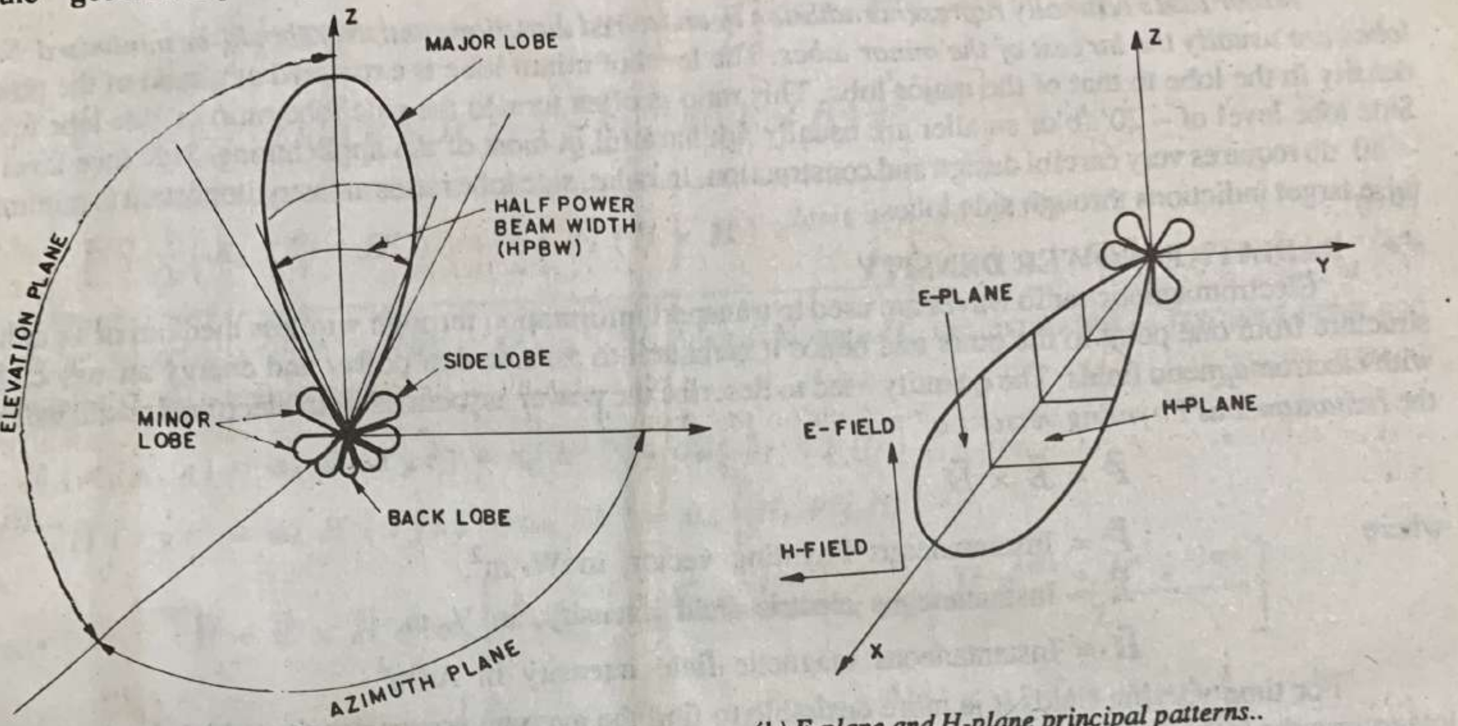
Since an isotropic radiator radiates uniformly in all direction and hence its radiation pattern is a sphere. The common types of radiation patterns can be classified as

(i) Omnidirectional or Broadcast-type pattern.
(ii) Pencil Beam pattern.
(iii) Fan-Beam Pattern.
(iv) Shaped Beam Pattern.

In addition to these, there are other pattern shapes too which are utilized in direction finding work. For example, **Limacon or Cardioid,** figure of eight patterns etc.

On Summarising – An antenna radiation pattern is, therefore, defined as **"a graphical representation of radiation properties of the antenna as a function of space co-ordinates. In most cases, the radiation pattern is determined in the far field region and is represented as a function of the directional coordinates. Radiation properties include radiation intensity field strength, phase or polarisation"** radiation property of most concern is the three dimensional spatial distribution of radiated energy as a fun of the observer's position along a constant radius. **A trace of the received power at a constant radius is called the "power pattern" and a graph of the spatial variation of the electric or magnetic field along a constant radius is called a "field pattern".**

6.3.1. ***Principal Patterns.*** The performance of the antenna is usually described in terms of its **principal E-plane and H-plane patterns.** For a linearly polarised antenna, the *E*-plane pattern is defined as **"the plane containing the electric-field vector and the direction of maximum radiation"** and the H-plane as **"the plane containing the magnetic-field vector and the direction of maximum radiation"**. It is normal practice to orient most antennas in such a way that atleast one of the principal plane patterns coincide with one of the **"geometric principal planes.** This is illustrated in Fig. 6.4 (a, b)



(a) Radiation lobes and BW of an antenna *(b) E-plane and H-plane principal patterns..*

Fig. 6.4.

In this, the x–z plane is the principal *E*-plane (elevation plane $\varphi = 0$) and the x–y plane is the principal H-plane (azimuth plane $\theta = \pi/2$).

6.3.2. ***Radiation Pattern Lobes.*** Different parts of radiation pattern are referred to as "Lobes". This may be sub-classified as major lobe, minor lobe, side lobe and back lobe. A radiation lobe is a portion of the radiation pattern bounded by regions of relatively weak radiation intensity. This is illustrated in Fig. 6.5 where a symmetrical three-dimensional polar pattern with a number of radiation lobes. Although all are known as lobes but some are having greater radiation intensity and some are lesser radiation intensity. A linear two-dimensional pattern of the Fig. 6.4 (a) is shown in Fig. 6.5 where only one plane of Fig. 6.4 (a) is indicated.

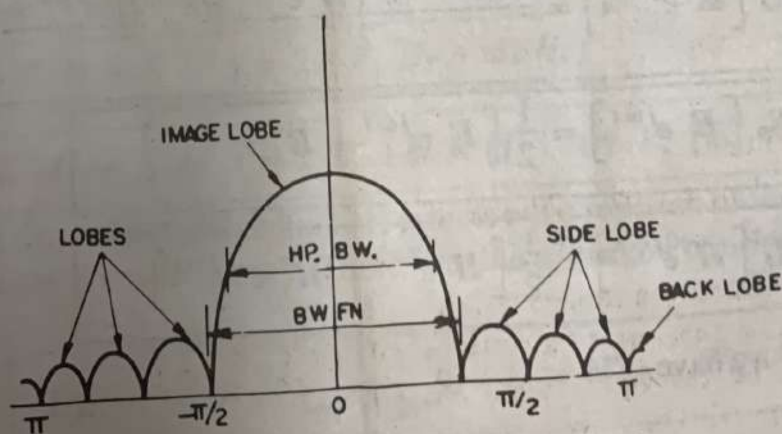


Fig. 6.5. Linear plot of power patterns.

(i) **Major Lobe** is also called as main beam and is defined as **"the radiation lobe containing the direction of maximum radiation"**. In some antennas, there may exist more than one major lobe.

(ii) **Minor Lobe** is any lobe except a major lobe *i.e.* all the lobes except the major lobes are called minor lobe.

(iii) **Side Lobe** is a radiation lobe in any direction other than the intended lobe. Normally a side lobe is adjacent to the main lobe and occupies the hemisphere in direction of the main lobe.

(iv) **Back Lobe** Normally refers to a minor lobe that occupies the hemisphere in a direction opposite to that of the major (main) lobe.

Minor lobes normally represent radiation in undesired directions and they should be minimised. Side lobes are usually the largest of the minor lobes. The level of minor lobe is expressed as a ratio of the power density in the lobe to that of the major lobe. This ratio is often termed the side lobe ratio or side lobe level. Side lobe level of – 20 db or smaller are usually not harmful in most of the applications. Side lobe level of – 30 db requires very careful design and construction. In radar, side lobe ratios are very important to minimise false target indictions through side lobes.

6.4. RADIATION POWER DENSITY

Electromagnetic radio waves are used to transport information through wireless medium or a guiding structure from one point to the other and hence it is natural to assume that power and energy are associated with electromagnetic fields. The quantity used to describe the power associated with electromagnetic wave is the *Instantaneous Poynting vector i.e.*

$$\tilde{P} = \tilde{E} \times \tilde{H} \quad \text{...(6.6)}$$

where $\tilde{P}$ = Instantaneous Poynting vector, in W/m^2.

$\tilde{E}$ = Instantaneous electric field intensity, in V/m.

$\tilde{H}$ = Instantaneous magnetic field intensity in A/m^2.

For time varying fields it is more desirable to find the average power density which is obtained by integrating the instantaneous Poynting vector over one period and dividing by the period.

For time harmonic variations of the form $e^{j\omega t}$, the complex fields $\tilde{E}$ and $\tilde{H}$ are related by their instantaneous counterparts $\tilde{E}$ and $\tilde{H}$ as

$$\tilde{E}_{(x, y, z, t)} = R_e\left[E_{(x, y, z)}\, e^{j\omega t}\right] \quad \text{...6.7}$$

$$\tilde{H}_{(x, y, z, t)} = R_e\left[H_{(x, y, z)}\, e^{j\omega t}\right] \quad \text{...6.7}$$

The above equations can also be written as

$$\boxed{R_e\left[E\, e^{j\omega t}\right] = \frac{E\, e^{j\omega t} + (E\, e^{j\omega t})^*}{2} = \frac{E\, e^{j\omega t} + E^*\, e^{-j\omega t}}{2}}$$

$$\boxed{R_e\left[E\, e^{j\omega t}\right] = \frac{1}{2}\left[E\, e^{j\omega t} + E^*\, e^{-j\omega t}\right]} \quad \text{...6.8}$$

Similarly

$$\boxed{R_e\left[H\, e^{j\omega t}\right] = \frac{1}{2}\left[H\, e^{j\omega t} + H^*\, e^{-j\omega t}\right]} \quad \text{...6.8}$$

Putting eqn. 6.7 into eqn. 6.6 we have

$$\tilde{P} = \tilde{E} \times \tilde{H} = R_e \left[E\, e^{j\omega t} \times H\, e^{j\omega t} \right]$$ ... by eqn 6.6 & 6.7

$$= \frac{1}{2}\left[E\, e^{j\omega t} + E^*\, e^{-j\omega t} \right] \times \frac{1}{2}\left[H\, e^{j\omega t} + H^*\, e^{-j\omega t} \right]$$ ... by eqn. 6.8

$$= \frac{1}{4}\left[(E \times H)\, e^{2j\omega t} + (E^* \times H) + (E \times H^*) + (E^* \times H^*)\, e^{-2jwt} \right]$$

$$= \frac{1}{4}\left[\{(E^* \times H) + (E \times H^*)\} + \{(E \times H)\, e^{2j\omega t} + (E^* \times H^*)\, e^{-2j\omega t}\} \right]$$

$$= \frac{1}{2}\left[\frac{1}{2}\{(E^* \times H) + (E \times H^*)\} + \frac{1}{2}\{(E \times H)\, e^{2j\omega t} + (E \times H)\, e^{+2j\omega t}\} \right]$$

$$= \frac{1}{2}\left[\frac{1}{2}\{2 R_e\, (E \times H^*)\} + \frac{1}{2} R_e \{2 R_e (E \times H)\, e^{2j\omega t}\} \right]$$

$$\boxed{\tilde{P} = \frac{1}{2}\left[R_e\, (E \times H^*) \right] + \frac{1}{2}\left[R_e\, (E \times H)\, e^{2j\omega t} \right]} \qquad \text{... (6.9)}$$

since $(E^* \times H^*)\; e^{-2j\omega t} \equiv (E \times H)\; e^{+j\omega t}$. For, if E and H are expressed in complex polar and rectangular form, we may write

$$\tilde{E}\,(x, y, z) \equiv a_e\, E\,(xyz) = a_e\, E^{j\theta_e} = a_e \left[E_r + j\, H_i \right]$$

and $$\tilde{H}\,(xyz) \equiv a_h\, H\,(xyz) = a_h\, E^{j\theta_h} = a_h \left[H_r + j\, H_i \right]$$

Hence $$\tilde{P} = \tilde{E} \times \tilde{H} = a_e \left[\frac{E\, e^{j\omega t} + E^*\, e^{-j\omega t}}{2} \right] \times a_h \left[\frac{H\, e^{j\omega t} + H^*\, e^{-j\omega t}}{2} \right]$$

$$= a_e \times a_h \times \frac{1}{4}\left[E\, H\, e^{j2\omega t} + E^*\, H^*\, e^{-2j\omega t} + E^*\, H + E\, H^* \right]$$

Then using the complex rectangular form we may write,

$$E H e^{2j\omega t} + E^* H^* e^{-2j\omega t} = 2\left[(E_r H_r - E_i H_i) \cos 2\,\omega t - (E_i H_r + E_r H_i) \sin 2\,\omega t \right]$$

$$\boxed{E\, H\, e^{2j\omega t} + E^*\, H^*\, e^{-2j\omega t} = 2\, R_e \left[(E \times H)\, e^{2j\omega t} \right]} \qquad \text{... (6.10)}$$

and $$E^* H = (E_r - j E_i)\,(H_r + j H_i) = E_r H_r + E_i H_i + j\,(E_r H_i - E_i H_r)$$ ... 6.11 (a)

and $$E H^* = (E_r + j E_i)\,(H_r - j H_i) = E_r H_r + E_i H_i - j\,(E_r H_i - E_i H_r)$$ ... 6.11 (b)

Adding eqns. 6.11 (a) and 6.11 (b) we get

$$\boxed{(E^*\, H + E\, H^*) = 2\,(E_r\, H_r + E_i\, H_i)} \qquad \text{... 6.12 (a)}$$

or $$\boxed{(E^*\, H + E\, H^*) = 2\, R_e\, [E \times H^*] = 2\, R_e\, [E^* \times H]} \qquad \text{... 6.12 (b)}$$

Now it is evident from eqn. 6.9 that the first term is not a function of time and the time variations of the second term are twice the given frequency. Therefore, **the average Poynting vector (or average power density) is written as**

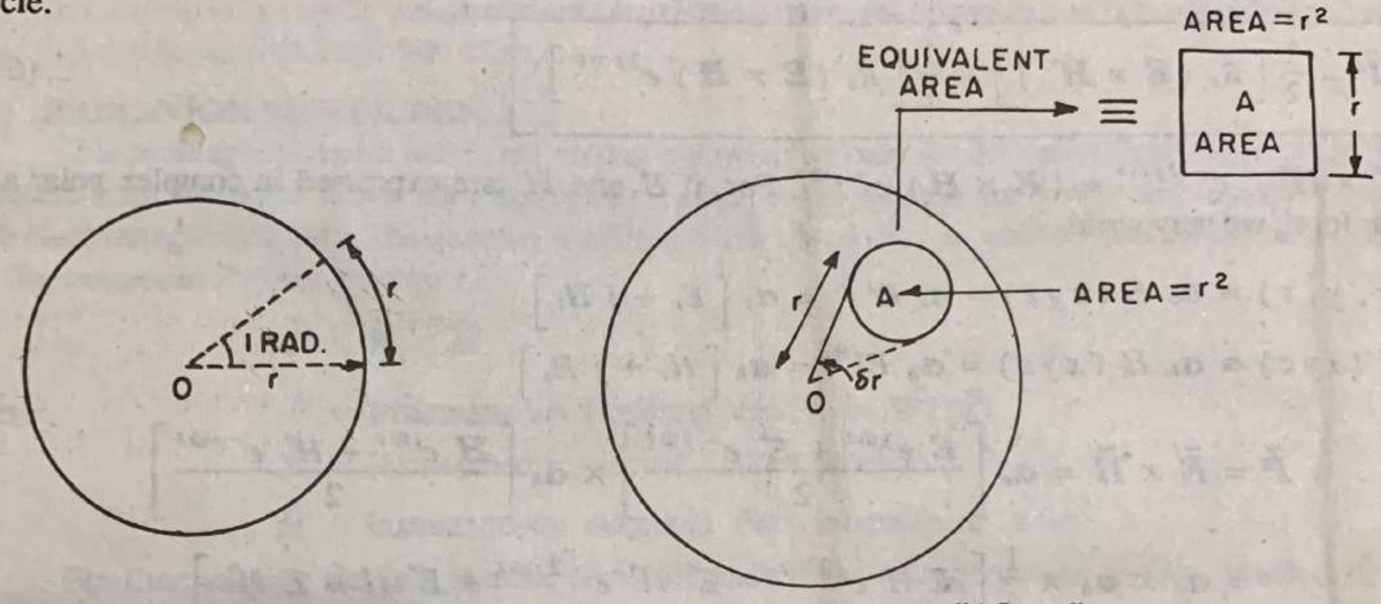
$$\boxed{P_{av} = (\tilde{E} \times \tilde{H})_{av} = \frac{1}{2}\, R_e\, (E \times H^*) \quad \text{W/m}^2} \qquad \text{... (6.13)}$$

where E and H are peak value and the term $\frac{1}{2}$ is omitted when converted to RMS value. Hence *the real pa*
of eqn. 6.9 represents the average (real) power density and the imaginary part of the same quantity represe
the reactive (stored) power density associated with the electromagnetic fields. The power density associat
with the electromagnetic fields of an antenna in its far field region is predominantly real which is referred
as **radiation density**. Further the average power radiated by an antenna (radiated power) is given by

$$\boxed{P_{rad.} = P_{av} = \oint_S P_{rad} \cdot ds = \oint P_{av} \cdot ds = \frac{1}{2} \oint_S R_e\,(E \times H^*) \cdot ds} \quad \text{... (6.1}$$

6.5. RADIAN AND STERADIAN

In order to measure a plane angle radian is used. One radian is defined as the plane angle with i **vertex at the centre of a circle of radius r that is subtended by an arc whose length is r**, as shown i Fig. 6.6 (a). As the circumference of a circle radius r is $c = 2\pi r$, there are 2π radian *i.e.* $\left(\frac{2\pi r}{r}\right)$ in a fu circle.



(a) Radian. *(b) Steradian.*

Fig. 6.6 (a, b). Radian and Steradian.

In a similar way **the measure of a solid angle is a steradian.** One steradian is defined as the soli **angle with its vertex at the centre of a sphere of radius r *i.e.* subtended by a spherical surface area equ to that of a square with each side of length r.** This is illustrated in Fig. 6.6 (b). As the area of a sphere o radius r is $A = 4\pi r^2$, there are 4π steradian *i.e.* $\left(\frac{4\pi r^2}{r^2}\right)$ in a closed sphere. **The infinitesimal area** ds o the surface of a sphere of radius r is

$$\boxed{ds = r^2 \sin\theta \, d\theta \, d\varphi \quad m^2} \quad \text{... 6.15 (}$$

so the element of solid angle $d\Omega$ of a sphere is written as

$$\boxed{d\Omega = \frac{ds}{r^2} = \sin\theta \, d\theta \, d\varphi \quad (Sr)} \quad \text{... 6.15 (}$$

6.6. RADIATION INTENSITY

(AMIETE, Nov. 1976, May 1976, 1978)

Radiation intensity is a quantity which does not depend upon the distance from the radiator and is denoted by a letter capital U or Φ. It helps in defining various antenna terms like Antenna gain or simply gain or directive gain or power gain or directivity. **Radiation intensity** is **defined as "Power per unit solid angle"**. Since unit of power and solid

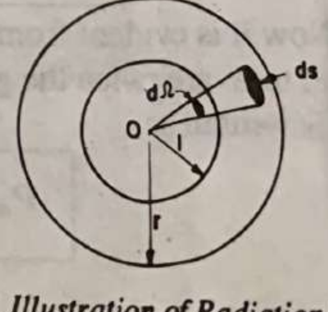


Fig. 6.7. Illustration of Radiation Inten

angle in S.I. units are 'Watts' and 'Steradian' respectively and hence unit of radiation intensity is Watts/steradian or Watts/ radian^2.

In order to express radiation intensity mathematically, let us consider the Fig. 6.7.

It is clear from Fig. 6.7 that solid angle $d\,\Omega$ is given by solid angle definition explained above.

$$\boxed{d\,\Omega = \frac{ds}{r^2}} \qquad \text{... 6.16 (a)}$$

or
$$ds = r^2\, d\,\Omega$$

ds = elemental surface area

$d\Omega$ = differential solid angle.

or
$$\boxed{\frac{ds}{d\,\Omega} = r^2} \qquad \text{... 6.16 (b)}$$

Thus there are r^2 metres of surface area per unit solid angle Eqn. 6.12 (b). Further it is known that the power radiated per unit area in any direction is given by the Poynting vector.

$$\boldsymbol{P} = \boldsymbol{E} \times \boldsymbol{H} \left(\frac{\text{Volt}}{\text{m}} \times \frac{\text{Amp}}{\text{m}} = \text{Watts/m}^2 \right)$$

where
$\boldsymbol{E}$ = Electric field Intensity, in volts/m.

$\boldsymbol{H}$ = Magnetic field Intensity, in A/m.

$\boldsymbol{P}$ = Instantaneous Poynting vector, in Watts/m^2.

Here $\boldsymbol{E} \times \boldsymbol{H}$ is a vector product and the mutually perpendicular components $\boldsymbol{E}$ and $\boldsymbol{H}$ contribute anything to the power flow and the direction of the flow is normal to the plane containing $\boldsymbol{E}$ and $\boldsymbol{H}$. But when $\boldsymbol{E}$ and $\boldsymbol{H}$ are changing with time then average. Poynting vector ($\boldsymbol{P_{av}}$), instead of simple $\boldsymbol{P}$, is of great interest. In order to find ($\boldsymbol{P_{av}}$) complex notation has to be followed. In complex notation Poynting vector is given by

$$\boldsymbol{P} = \frac{1}{2}\,(\boldsymbol{E} \times \boldsymbol{H}^*) \qquad \left(\because W = \frac{1}{2}\, VI \right)$$

where
$$\boldsymbol{E} = \boldsymbol{a_e}\;\; E_0\, e^{j\omega t} \qquad \text{... 6.14 (a)}$$

and
$\boldsymbol{H}^*$ = complex conjugate of $\boldsymbol{H}$.

$$\boldsymbol{H}^* = \boldsymbol{a_h}\, H_0\, e^{-j(\omega t - \delta)} \qquad \text{... 6.14 (b)}$$

Here $\boldsymbol{a_e}$ and $\boldsymbol{a_h}$ are unit vectors in the direction of $\boldsymbol{E}$ and $\boldsymbol{H}$ respectively. Also

$$\boldsymbol{H} = \boldsymbol{a_h}\, H_0\, e^{j(\omega t - \delta)}$$

and
δ = Phase angle between $\boldsymbol{E}$ and $\boldsymbol{H}$.

Now we are in position to give average Poynting vector ($\boldsymbol{P_{av}}$) which is given by the real part of the complex Poynting vector *i.e.*

$$\boldsymbol{P_{av}} = \text{Real part of } \boldsymbol{P} \text{ (complex)} = R_e\, \boldsymbol{P}$$

$$\boldsymbol{P_{av}} = \frac{1}{2}\, R_e \left\{ \boldsymbol{E} \times \boldsymbol{H}* \right\} \text{ Watts} \qquad \text{.... (6.13)}$$

In this $\boldsymbol{E}$ and $\boldsymbol{H}$ are instantaneous values. If r.m.s. values are taken then the term $\left(\frac{1}{2}\right)$ will be omitted.

Alternatively, $\boldsymbol{P_{av}}$ *can also be found by integrating the instantaneous Poynting vector over one period and dividing the same by one period.*

It is known for radiation field that $\boldsymbol{E}$ and $\boldsymbol{H}$ are orthogonal in a plane normal to radius vector and this case.

$$\boldsymbol{E} = 120\ \pi\ \boldsymbol{H} \quad \text{... 6.15}$$

$$\boldsymbol{E} = \eta_0\ \boldsymbol{H} \quad \text{... 6.15}$$

where η_0 = Intrinsic Impedance of space.

Thus power flow per unit area can now be written as

$$P = EH = E\ \frac{E}{\eta_0} \qquad \text{from above}$$

or

$$\boxed{P = \frac{E^2}{\eta_0} \quad \text{W/m}^2} \quad \text{... 6.16}$$

In the far field, Poynting vector is entirely radial *i.e.* $|\ \boldsymbol{P}\ | = P_r$. Fields are entirely transverse a E and H are varying as $1/r$ so that, radiation intensity is independent of distance. Instead radiation Intens depends on the angle θ and Φ. Therefore, the relation between average Poynting vector and electric field a point of the far field is given by

$$\boxed{P_r = \frac{1}{2}\ \frac{E^2\ (\theta\ ,\ \varphi)}{\eta_0}} \quad \text{... 6.16}$$

If now the magnitude of Poynting vector P_r is multiplied by the square of radius r at which radiati intensity is measured, then we get the *power per unit solid angle i.e.* the radiation Intensity.

$\therefore$ Radiation Intensity $\equiv \Phi\ (\theta\ ,\ \Phi) = P_r \cdot r^2 \equiv \Phi$

or

$$\boxed{\Phi = P_r \cdot r^2} \quad \text{... 6.17}$$

or

$$\boxed{\Phi = \frac{1}{2}\ \frac{E^2\ (\theta\ ,\ \varphi)\ r^2}{\eta_0}} \qquad \text{from eqn. 6.16 (b)} \quad \text{... 6.17}$$

The total power radiated (W_r) from a radiator is calculated from

$$\Phi = \frac{\text{Differential Power } (d\,W_r)}{\text{Differential element of solid angle } (d\,\Omega)} \quad \text{.... (6.}$$

or

$$d\,W_r = \Phi\ d\,\Omega$$

Total power radiated is obtained by integrating eqn. 6.18

i.e.

$$W_r = \int d\,W_r = \int d\,\Omega \cdot \Phi$$

or

$$\boxed{W_r = \int \Phi\ d\,\Omega \quad \text{Watts}} \quad \text{.... (6.}$$

Also for a isotropic radiator, total solid angle contains $4\ \pi$ steradians

$\therefore$

$$W_r = \int \Phi \cdot 4\ \pi\ \ \text{Watts} = 4\ \pi \int \Phi \qquad \Phi = \Phi_{av}$$

$$W_r = 4\ \pi \cdot \Phi_{av} \quad \text{..... 6.20}$$

or

$$\boxed{\Phi_{av} = \frac{W_r}{4\ \pi} \quad \text{W/Sr}} \quad \text{... 6.20}$$

where Φ_{av} = Radiation Intensity produced by an isotropic radiator, radiating the same total power W_r.

Since radiation intensity $\Phi_{(\theta\ ,\ \Phi)}$ depends upon the angle θ and φ therefore, it can be represented any from as

$$\Phi = \Phi_m \sin\theta$$
$$\Phi = \Phi_m \cdot \cos\theta$$
$$\ldots = \ldots\ldots\ldots\ldots$$

or in general
$$\Phi = \Phi_a f(\theta, \varphi) \quad \ldots (6.21)$$
where Φ_a = constant

and $f(\theta, \Phi)$ = Any function of θ and Φ

Also, in general, the total power radiated is given by from eqn. 6.19 by generalising as

$$\boxed{W_r = \int \Phi_a f(\theta, \Phi)\, d\Omega} \quad \ldots 6.22\ (a)$$
$$\boxed{W_r = \int \Phi_a f(\theta, \Phi) \cdot \sin d\theta\, d\varphi} \quad \ldots 6.22\ (b)$$

6.7. GAIN (AMIETE, May 1973, 74, 75, 76, 78, Nov. 1965, 66)

The gain of an antenna is a basic property which is frequently used as figure of merit. Gain is closely associated with **directivity** and directivity itself dependent entirely upon the shape of **radiation** patterns of an antenna. The ability of an antenna or antenna system to concentrate the radiated power in a given direction or conversely to absorb effectively the incident power from that direction is specified by various antenna terms *e.g.* Antenna gain or simply gain or directive gain or power gain or directivity. Since the antenna is a **passive element**, thus gain of an antenna is not the same as the gain of an amplifier in which case it is the ratio of Output to Input. The **term passive** means a system or device which functions only when acted upon by an external signal where as the term **"active"** means a system device which generates its own signal. Therefore, in case of an antenna, gain is a relative term in which actual antenna is compared with a 'reference antenna'. The reference antenna normally used is a hypothetical lossless isotropic radiator or antenna which radiates uniformly in all directions. Although half wave dipole is also, sometimes, used as reference antenna but isotropic antenna as reference antenna is preferred. If all the available power is radiated in a desired direction, then naturally there is a gain in that direction. Thus gain of antenna may be defined in any one of the following way.

1. Gain of antenna without involving the antenna efficiency is defined as "*the ratio of maximum radiation intensity in given direction to the maximum radiation intensity from a reference antenna produced in the same direction with same power input*" *i.e.* Symbolically.

$$\text{Gain}\,(G) = \frac{\text{Maximum Radiation Intensity from Subject or Test antenna}}{\text{Maximum Radiation Intensity from a reference antenna with same power input}} \quad \ldots 6.23\ (a)$$

Here, effect of losses are involved in both, the subject (antenna under consideration) antenna and the reference antenna. When reference antenna is taken as isotropic antenna (having 100% efficiency), then gain of subject antenna is denoted by G_0 (instead of G) and is known as Gain w.r.t. isotropic antenna. Thus,

$$\text{Gain}\,(G_0) = \frac{\text{Maximum Radiation Intensity from test antenna}}{\text{Radiation Intensity from Isotropic antenna (lossless) with same power input}}.$$

or Symbolically

$$\boxed{G_0 = \frac{\Phi'_m}{\Phi_0}} \quad \ldots 6.24\ (b)$$

where Φ'_m = Max. Radiation from test antenna

and Φ_0 = Radiation Intensity from a lossless isotropic antenna

This definition is favoured for microwave antennas.

Since gain denotes concentration of energy, the high values of gain are associated with narrow beam width (to be discussed). Further gain of an antenna is closely related to **Directivity** (D) (to be discussed). Gain is equal to directivity provided antenna efficiency is 100%. In other words for antennas without any internal losses, gain and directivity are same otherwise not. **When efficiency is cent percent, then gain (G)** **Directivity (D) are interchangeably used.**

Although gain may be given in any direction from the antenna but generally gain in the directio maximum gain is taken. The gain in a direction for which the radiation intensity Φ is not maximum ma designated by specifying the angle Φ at which it is measured. In general, the symbol $G_0\ (\theta\ ,\ \Phi)$ ma utilized for the purpose and is given by

$$G_0\ (\theta\ ,\ \Phi) \cdot \frac{\Phi_m}{\Phi} = G_0$$

or

$$\boxed{G_0\ (\theta\ ,\ \varphi) = \frac{\Phi}{\Phi_m}\ G_0}$$

where

Φ_m = Maximum Radiation Intensity

Φ = Radiation Intensity in the direction of θ and φ

Angle θ = Angle of Colatitude.

Angle φ = Polar angle.

2. The power radiated by any practical antenna is concentrated more in one direction and les other directions. The field in the direction of maximum radiation is greater than that produced by an isotrd radiator emitting the same total power. Therefore all the practical antennas are having **directivity.** Thu directivity is represented by the shape of its radiation pattern or polar diagram while the increased signal particular direction indicates that the practical antenna has a gain in that particular direction. For all the po available is deflected and radiated in that particular direction and thus, obviously, there is a gain in direction.

Hence in terms of signal power received by a receiver at a distant point in the direction of maxim radiation, the gain of any antenna can be defined as

$$\text{Gain}\ (G) = \frac{\text{Maximum power received from given antennas}\ (P_1)}{\text{Maximum power received from reference antenna}\ (P_2)} \qquad \ldots 6.2$$

for the same input power in both the cases of subject antenna and reference antenna

or

$$\boxed{G = \frac{P_1}{P_2}} \qquad \ldots 6.26$$

The signal power is proportional to the square of the radiation field at the point.

3. Let certain amount of power is supplied to an isotropic antenna and let us assume that it prod a certain field strength (E) at a given distance from the antenna. Now if this isotropic antenna is replace any practical antenna under the same condition, then practical antenna will also radiate the same power as being radiated by isotropic (reference) antenna. But now intensity of radiation is zero and in many direct will be smaller than **the field strength produced** by isotropic antenna at the same distance. In fact this p just can not disappear but appears as **increased field strength** over that produced by the isotropic antenn the most favoured direction.

Thus if field strength at a given distance from the practical antenna in its most favoured directi say E_1 and the field strength from an isotropic antenna at the same distance is say E_2 , then gain of any pra antenna in terms of field strength is given by the ratio of the two, *i.e.*

$$\boxed{G_\theta = \frac{E_1}{E_2}} \qquad \ldots$$

In other words, gain is the ratio of voltages produced at a given point by a practical antenna hypothetical antenna.

Often gain of an antenna is expressed in decibel ratio i.e.

$$\boxed{db\ \text{gain} = 10 \log_{10} G} \quad \text{... (6.28)}$$

Gain (G_0) defined w.r.t. isotropic antenna is necessarily theoretical concept. That is gain (G_0) is to be calculated rather than to be measured because an isotropic antenna has no existence in electromagnetic theory. Instead, a half wave dipole antenna is used for the purpose of gain measurement. A half wave dipole antenna has theoretical gain of 1.64 or 2.15 db over an isotropic antenna.

6.8. DIRECTIVE GAIN

(AMIETE, June 1981, 87, 88)

All practical antenna concentrate its radiated energy to more or less extent in certain preferred directions. *The extent to which a practical antenna concentrates its radiated energy relative to that of some standard antenna is termed as directive gain*. Thus the directive gain (G_d) in a given direction is defined as *the ratio of the radiation intensity in that direction to the average radiated power.*

The directive gain is a function of a angles (θ and φ) which should be specified. Let

$\Phi(\theta, \varphi)$ = Radiation Intensity in a particular direction.

and Φ_{av} = Average Radiation Intensity in that direction $= \dfrac{W_r}{4\pi}$ from eqn. 6.20 (b)

Then by definition, directive gain (G_d) is given by

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

$$G_d(\theta, \varphi) = \frac{\Phi(\theta, \varphi)}{\Phi_{av}} = \frac{\Phi(\theta, \varphi)}{\dfrac{W_r}{4\pi}} \quad \text{... (6.29)}$$

$$= \frac{4\pi\,\Phi(\theta, \varphi)}{W_r} \quad \text{.... 6.30 (a)}$$

$$G_d(\theta, \varphi) = \frac{4\pi\,\Phi(\theta, \varphi)}{\int \Phi\, d\Omega} \quad \text{... 6.30 (b)}$$

when directive gain is expressed in decibels, then

$$db\ G_d = 10 \log_{10} G_d(\theta, \varphi)$$

$$\boxed{db\ G_d = 10 \log_{10} \left\{ \frac{4\pi\,\Phi(\theta, \varphi)}{\int \Phi\, d\Omega} \right\}} \quad \text{... 6.31 (a)}$$

The directive gain is a qualitative measure of the extent to which the total power radiated is concentrated in one direction. It is also expressed either as a power ratio or in terms of the equivalent number of decibles.

The directive gain solely depends on the distribution of radiated power in space. In does not depend upon the power input to the antenna, antenna losses or the power consumed in a terminating resistance.

Thus, stating in another words the directive gain of an antenna is defined, **in a particular direction, as the ratio of the power density (i.e. Poynting vector) in that particular direction at a given distance, to the power density that would be radiated at the same distance by an isotropic antenna, radiating the same total power"**, symbolically

$$G_d = \frac{\text{Power density radiated in a particular direction by subject antenna}}{\text{Power density radiated in that particular direction by an isotropic antenna}} \quad \text{... 6.31 (b)}$$

for the **same total radiated power** and at the same given distance. The directive gain of an antenna has defined now as a quantity that may be different in different directions. As a matter of fact, the *relative power density pattern,* of an antenna becomes *a directive gain power pattern, provided the power density reference value is taken as the power density of an isotropic antenna radiating the same total power instead of using a reference of the power density of the antenna in its maximum radiation direction.*

6.9. POWER GAIN

(AMIETE, May 1972, Nov. 196

The directive gain defined by Eqn. 6.31 (b) compares the two power densities of actual and isotropic antenna on the assumption that both are **radiating the same total power**. Another concept of gain known as **power gain** compares the radiated power density of the actual antenna and that of an isotropic antenna on basis of the **same input power to both** *i.e.*

$$G_p = \frac{\text{Power density radiated in a particular direction by the subject antenna}}{\text{Power density radiated in that direction by an isotropic antenna}}$$

for the same **total input power** and at the same given distance. Hence, in the definitions of directivity (or directive gain) and power gain only difference is seen that for directivity the **radiated power** is considered for the directive antenna, whereas for power gain the **power fed** (*i.e.* **power input**) to the antenna is taken. In other words directive gain and power gain are identical except that power gain takes into account the antenna losses. It may be written as

$$\boxed{G_p = \eta\ G_d}$$

where η = Efficiency factor lies between 0 to 1

Thus when $\eta = 1$,

$$\boxed{G_p = G_d}$$

i.e., power gain equal directive gain as happens frequently in VHF and UHF etc.

The formal distinction between the definitions of directive gain and power gain has not always existed and in the past years the term **"antenna gain"** was used to mean sometimes one thing and some-times another. The proper terminology is still not always used in some of the current literature. Hence it may be better to keep in mind that some authors may mean either **"directive gain"** or **"power gain"** when they use the simple term **"Antenna gain"**. However, the definitions given above are according to the Institute of Electrical and Electronics Engineers (IEEE).

Now obviously the power gain is of greatest important to a radio system designer, whereas the concept of 'directive gain' is most convenient to Antenna theorist because it depends only upon the antenna pattern. A theorist can compute the directive gain of a half wave dipole, for example, by application of Maxwell's equation on the assumption that dipole has no ohmic loss. The directive gain of an isotropic antenna is equal to unity and the power gain of an isotropic antenna with efficiency factor η is equal to G_d.

(2) Power gain in a given direction is also defined as *the ratio of the radiation intensity in that direction to the average total input power, i.e.*

$$G_p = \frac{\text{Radiation intensity in a given direction}}{\text{Average total input power}}$$

$$G_p = \frac{\Phi(\theta, \varphi)}{\frac{W_T}{4\pi}} \quad \ldots 6$$

where $W_T = W_r + W_l$ = Total input power $\quad W_l$ being ohmic loss in the a

$$\therefore \quad \boxed{G_p = \frac{4\pi\,\Phi(\theta, \varphi)}{W_T}} \quad \ldots ($$

(3) In terms of power input, power gain is given by

$$\text{Power gain } (G_p) = \frac{\text{Power input supplied to subject antenna in the direction of maximum radiation}}{\text{Power input supplied to reference antenna}} \quad \text{... (6.34)}$$

for the same field strength at the same given point.

For example, let the field produced by a subject antenna is twice to that produced by an isotropic antenna, *i.e.*

$$G_0 = \frac{v_1}{v_2} = 2$$

$\therefore$ Power gain

$$G_p = \left(\frac{v_1}{v_2}\right)^2 = 2^2 = 4$$

This shows that to produce the same field strength at the same distance, four times as much power would have to be supplied to an isotropic radiator in comparison to the practical antenna.

It may, however, be noted that in gain or power gain antenna efficiency is involved and an account is taken **for the input power** antenna losses, and power consumed in terminating resistance. The power gain depends on the following two things :

(i) **Sharpness of lobe**. Sharper the lobe higher will be the power gain.

(ii) **Volume of the solid radiation pattern.** Since decibel is the excellent practical unit for measuring power ratio and hence power gain of antenna system is generally expressed in decibels. The number of decibels corresponding to any power ratio is equal to 10 times the common logarithm of the power ratio, *i.e.*

$$G_p\,(db) = 10 \log_{10} Gp$$

$$\boxed{G_p\,(db) = 10 \log_{10} \frac{P_1}{P_2}} \quad \text{... 6.35 (a)}$$

or

$$G_p\,(db) = 10 \log_{10} \left(\frac{v_1}{v_2}\right)^2 = 10 \times 2 \log_{10} \left(\frac{v_1}{v_2}\right) \quad \text{if voltage ratio is involved}$$

or

$$\boxed{G_p\,(db) = 20 \log_{10} \left(\frac{v_1}{v_2}\right)} \quad \text{.... 6.35 (b)}$$

6.9.1. ***Practical Importance of Power Gain.*** For a given amount of input power to an antenna, the power density at a given point in the space is proportional to the power gain of the antenna in that direction. Hence the signal available to a receiving antenna at that location can be increased by increasing the transmitted power without increasing the transmitted power. For example, transmitter with a power out of 1000 W and an antenna with a power gain of 10 (*i.e.* $Gdb = 10 \log_{10} 10$ or $Gdb = 10 \times 1.000 = 10\ db$) will give the same power density at a receiving point as will be a transmitter of 500 W power output and an antenna of power gain of 20 (*i.e.*. $10 \log_{10} 20 = 10 \times 1.3010 \approx 13.0\ db$). *Therefore this relationship is of great economic importance, obviously*. Sometimes it may be much less expensive to double the gain of the antenna and add 3 *db*, rather than to double the transmitted power (Although converse may also be true at other times). However, it is desirable to use as much antenna gain as may possibly be obtained, when it is desirable to give the maximum possible field strength in a particular direction.

Sometimes when it is desirable to radiate equally in all horizontal directions, then maximum gain obtainable is limited due to the connection between antenna gain and antenna pattern. Thus determination of gain which is required in a given application is a matter of engineering judgement.

(AMIETE, May 1974,

6.10. DIRECTIVITY (D)

The maximum directive gain is called as directivity of an antenna and is denoted by D. In a particular direction the directivity D is a constant.

(1) Directivity of an antenna is defined as *the ratio of Maximum radiation intensity to its average radiation intensity i.e.*

$$\text{Directivity } (D) = \frac{\text{Maximum Radiation Intensity of test antenna}}{\text{Average Radiation Intensity of test antenna}}$$

or

$$D = \frac{\Phi\,(\theta, \varphi)_{max}}{\Phi_{av}} \text{ both of test antenna.}$$

(2) **Directivity** D of an antenna may also be defined *as the ratio of maximum radiation intensity of the subject antenna to the radiation intensity of an isotropic or reference antenna radiating the same power i.e.*

$$\text{Directivity} = \frac{\text{Maximum Radiation Intensity of subject or test antenna}}{\text{Radiation Intensity of an isotropic antenna}}$$

or

$$\boxed{D = \frac{\Phi\,(\theta\,,\,\varphi)_{max}\,.\,(\text{ test antenna })}{\Phi_0\ (\text{ isotropic antenna })}}$$

(3) **Alternatively** still another way of expressing Directivity of an antenna is in terms of **radiated power.** It is ratio of *total radiated power by the subject antenna to the power radiated by an isotropic antenna for the same radiation intensity, i.e.*

$$\text{Directivity} = \frac{\text{Power radiated from a test antenna}}{\text{Power radiated from an isotropic antenna}}$$

For the same radiation intensity

or

$$\boxed{D = \frac{W'}{W^n} \quad \frac{(\text{ from a test antenna })}{(\text{ from an isotropic antenna })}}$$

Since the average radiation intensity (Φ_{av}) is obtained by dividing total power radiated W by steradian. Therefore eqn. 6.30 may be written as

$$D = \frac{\Phi\,(\theta\,,\,\varphi\,)_{max}}{W/4\pi}$$

$$\boxed{D = \frac{4\pi\,\Phi\,(\,\theta\,,\,\varphi\,)_{max}}{W}} \quad \text{... 6.3}$$

or

$$\boxed{D = \frac{4\pi\ (\textbf{maximum radiation intensity})}{\textbf{Total radiated power}}} \quad \text{... 6.3}$$

The directivity implies the maximum values for an antenna. The directivity D for which radiation intensity Φ is not maximum is designated by specifying an angle φ at which the directivity measured.

In general directivity may be represented by D (θ, φ) and is given by

$$D\ (\theta\,,\varphi\,) = \frac{\Phi_{max}}{\Phi} = D$$

or

$$\boxed{D\ (\theta\,,\varphi\,) = \frac{\Phi}{\Phi_{max}}\ D}$$

where, $\Phi_{max.}$ = max. radiation intensity.

Φ = Radiation Intensity in direction of $(\theta\,,\ \varphi\,)$.

The directivity D is also expressed in decibels ratio as

$$(\text{Directivity})\ db = 10 \log_{10} D \qquad \text{... 6.41 (a)}$$

or

$$D\,(db) = 10 \log_{10} D \qquad \text{... 6.41 (b)}$$

The numerical value of directivity D always lies between 1 and ∞ *i.e.* $1 \le D \le \infty$. 1 being the directivity of an isotropic antenna and hence D can not be less than 1.

Let us now find a **general expression** for the directivity. For, the radiation intensity may be any function of θ and φ and hence, in general, represented as

$$\Phi = \Phi_a f(\theta, \varphi) \qquad \text{...(6.42)}$$

where Φ_a = a constant Φ = Radiation intensity

$\therefore$ Maximum value of Radiation intensity (eqn. 6.36) is given by

$$\Phi_{max} = \Phi_a f(\theta, \varphi)_{max} \qquad \text{... (6.43)}$$

As a special case, in case of anisotropic antenna $f(\theta, \varphi)_{max} = 1$ ... (6.44)

Then

$$\Phi_{max} = \Phi_a \qquad \text{... (6.45)}$$

Putting eqn. 6.45, in eqn. 6.42, we get

$$\boxed{\Phi = \Phi_m f(\theta, \varphi)} \qquad \text{... (6.46)}$$

Further, the average radiation intensity Φ_{av} is given by total power radiated divided by 4π steradian.

$$\therefore \quad \Phi_{av} = \frac{W_r}{4\pi} = \frac{\iint \Phi\, d\Omega}{4\pi}$$

$$\Phi_{av} = \frac{\iint \varphi_a f(\theta, \varphi) \cdot d\Omega}{4\pi} \qquad \text{... 6.46 (a)}$$

where $d\Omega = \sin\theta\, d\theta\, d\varphi$ = elements of solid angle.

Thus by definition, directivity

$$D = \frac{\text{Max. R.I. } (\Phi_{max})}{\text{Average R.I. } (\Phi_{av})} = \frac{\Phi_a f(\theta, \varphi)_{max}}{\iint \dfrac{\Phi_a f(\theta, \varphi)\, d\Omega}{4\pi}} \qquad \text{from eqn. 6.42}$$

$$= \frac{4\pi f(\theta, \varphi)_{max}}{\iint f(\theta, \varphi)\, d\Omega} \qquad \text{... (6.47)} \qquad \because \frac{f(\theta, \varphi)}{f(\theta_{max}\, \varphi)} = f_n(\theta, \varphi) = \text{normalized power pattern}$$

$$= \frac{4\pi}{\dfrac{\iint f(\theta, \varphi)\, d\Omega}{f(\theta, \varphi)_{max}}} = \frac{4\pi}{\iint f_n(\theta, \varphi)\, d\Omega}$$

$$\boxed{D = \frac{4\pi}{\text{B.A.}}} \qquad \text{... 6.48 (a)}$$

where

$$B.A. = \frac{\iint f(\theta, \varphi)\, d\Omega}{f(\theta, \varphi)_{max}} = \text{Beam Area} \qquad \text{... 6.48 (b)}$$

$$\boxed{D = \frac{4\pi}{\Omega_A}} \qquad \text{... 6.48 (c)}$$

where Ω_A = Beam solid angle

$$\Omega_A = \frac{\iint f(\theta, \varphi)\, d\Omega}{f(\theta, \varphi)_{max}} \qquad \text{... (6.49)}$$

Therefore, the directivity of an antenna is nothing but solid angle of a sphere (i.e. 4π sterad divided by the antenna beam solid angle Ω_A.

From the definition of directivity eqn. 6.36 and eqn. 6.48

$$D = \frac{\Phi_{max}}{\Phi_{av}} = \frac{4\pi}{\Omega_A}$$

or $$4\pi\,\Phi_{av} = \Omega_A\,\Phi_{max} \qquad \because \quad \Phi_{av} = \frac{W_r}{4\pi}$$

or $$4\pi \cdot \frac{W_r}{4\pi} = \Omega_A\,\Phi_{max}$$

$$\boxed{W_r = \Omega_A\,\Phi_{max}} \qquad ...(6$$

where W_r = Total power radiated.

Thus beam solid angle is the solid angle through which all the power radiated would stream if power per unit solid angle equal to the maximum value of radiation intensity Φ_{max} over the beam solid an

Directivity is a dimensionless (*i.e.* constant) quantity which indicates the effectiveness of concentr power into a limited solid angle. The narrower the solid angle, the higher the directivity.

It entirely depends on the far field pattern. Unlike gain or power gain, antenna efficiency is not invol in the directivity. *If an antenna has not any losses like ohmic, dielectric mismatch i.e. 100% efficient, directivity and gain are same.* However, for an antenna with losses, gain will be less than directivity b factor which corresponds to efficiency. The directivity and gain are related as

$$\boxed{G_0 = kD} \qquad ...(6$$

where G = gain

k = efficiency factor = 1 for 100% efficiency

< 1 if losses are present

D = Directivity

This is derived as follows. Let us assume that the maximum radiation intensity from the test anten is Φ_{max} and let this maximum radiation intensity Φ'_{max} be related to the maximum radiation intensity Φ_{max} 100% efficient test antenna by a factor k known as radiation efficiency factor as

$$\phi'_{max} = k\,\phi_{max} \qquad ...(6.5$$

where the values of k lies between 0 and 1 *i.e.* $0 \le k \le 1$

But the gain w.r.t. an isotropic antenna is

$$G_0 = \frac{\phi'_{max}}{\phi_0} \qquad \text{from Eqn. 6.24}$$

where Φ_0 = R.I. from a lossless isotropic antenna

or $$G_0 = \frac{k\,\phi_{max}}{\phi_0} \qquad \text{from Eqn. 6.}$$

From Eqn. 6.37 $$\boxed{G_0 = kD} \qquad ...\ 6.52$$

$$D = \frac{\phi_{max}}{\phi_0}$$

Since, in many antennas the antenna losses are extremely small and hence the value of gain is almo equal to the directivity. That is why, gain and directivity are interchangeably used.

6.11. DIRECTIVE GAIN AND GAIN OR POWER GAIN

(1) By definition, directive gain G_d is given by

$$\text{Directive gain } G_d = \frac{\text{Radiation Intensity}}{\text{Average Radiated Power}} = \frac{\Phi(\theta, \varphi)}{W_r/4\pi}$$

or

$$\boxed{G_d = \frac{4\pi\Phi(\theta, \varphi)}{W_r}} \quad \text{... (6.53)}$$

But the power gain is the ratio of two powers and the total power input is taken instead of simply radiated power *i.e.*

$$\text{Power gain or gain} = \frac{\text{Radiation intensity}}{\text{Total input power}}\; G_p = \frac{\Phi(\theta, \varphi)}{W_T/4\pi}$$

or

$$\boxed{G_p = \frac{4\pi\Phi(\theta, \varphi)}{W_T}} \quad \text{... (6.54)}$$

where

$$W_T = W_r + W_l$$

$$\text{Total Power} = \text{Radiated Power} + \text{Power loss in ohmic resistance}$$

(2) Directive gain depends entirely on the distribution of radiated power in space whereas gain or power gain depends on the sharpness of the lobe and volume of the solid radiation pattern.

(3) Directive gain is a qualitative measure of the extent to the *total power radiated is concentrated in one direction and it does not depend upon the power input to the antenna and antenna losses like dielectric losses, Cu losses, mismatch losses and power consumed in terminating resistance etc. whereas the power input and the antenna losses are accounted in the power gain.* Thus power gain takes *into account* the antenna efficiency as well as its directional properties.

(AMIETE, May 1978, Dec. 1973)

6.12. DIRECTIVE GAIN AND DIRECTIVITY

(1) By definition,

$$\text{Directive gain} = \frac{\text{Radiation intensity}}{\text{Average radiated power}}$$

$$G_d = \frac{\Phi(\theta, \varphi)}{W_r/4\pi} = \frac{4\pi\Phi(\theta, \varphi)}{W_r} \quad \text{... (6.53)}$$

or

The extent to which a practical antenna concentrates its radiated energy relative to that of some standard antenna is known as directive gain whereas the maximum directive gain is called as directivity D and is defined as

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

or

$$D = \frac{\Phi(\theta, \varphi)_{max} \text{ (test antenna)}}{\Phi_{av} \text{ (test antenna)}}$$

Alternatively,

$$\text{Directivity} = \frac{\text{Maximum Radiation Intensity of test antenna}}{\text{Radiation Intensity of an isotropic antenna}}$$

or

$$D = \frac{\Phi(\theta, \varphi)_{max} \text{ (test antenna)}}{\Phi_0 \text{ (isotropic antenna)}} \quad \text{... (6.37)}$$

(2) For a lossless isotropic antenna, directive gain and directivity is same.

In this case radiation efficiency factor $k = 1$.

$$G_0 = kD$$

$$G_0 = D \quad \text{if} \quad k = 1$$

(3) The numerical value of directive gain may lie between 0 and ∞ whereas that of directivity be 1 and ∞ and in case of directivity it can not be less than 1.

(4) Directive gain depends entirely on the distribution of radiated power in space whereas the of directivity depends on the solid angle of the far (radiated) field pattern.

(5) Directive gain does not depend on the power input to the antenna and antenna losses and true for the directivity. In other words antenna efficiency is not involved in these two.

(6) The numerical value of directivity of current element and half-wave dipole is respectively 1.76 *db*) and 1.64 (or 2.15 *db*).

∴ Directive gain of half-wave dipole over current element $= (2.15 - 1.76)\, db =$ **0.39 *db*.**

6.13. ANTENNA EFFICIENCY (η)

(Kanpur Univ. M.Sc. Phy. (Prev.) 1981, (AMIETE, May 1968, Dec. 1

The efficiency of an antenna is defined as the ratio of power radiated to the total input power su to the antenna and is denoted by η or k. Thus

$$\text{Antenna efficiency} = \frac{\text{Power Radiated}}{\text{Total Input Power}}$$

or
$$\eta = \frac{W_r}{W_T} = \frac{W_r}{W_r + W_l} = \frac{W_r}{W_T} \times \frac{4\pi\Phi(\theta,\varphi)}{4\pi\Phi(\theta,\varphi)}$$

$$= \frac{4\pi\Phi(\theta,\varphi)}{W_T} \cdot \frac{W_r}{4\pi\Phi(\theta,\varphi)} = G_p \cdot \frac{1}{G_d} = \frac{G_p}{G_d}$$

or
$$\boxed{\eta = \frac{G_p}{G_d} = \frac{W_r}{W_r + W_l}} \quad \text{...(6}$$

where W_r = Power radiated.

W_l = Ohmic losses.

If current flowing in the antenna is I, then $\eta = \dfrac{I^2 R_r}{I^2 (R_r + R_l)}$

or
$$\boxed{\eta\% = \frac{R_r}{R_r + R_l} \times 100} \quad \text{...(6}$$

where R_r = Radiation resistance ; R_l = Ohmic loss resistance of antenna conductor and $R_r + R_l$ = T effective resistance.

It is desirable to have a better radiation characteristics from the antenna and for this loss resista should be as small as possible. The loss resistances may consist of the following, in general.

(i) Ohmic loss in the antenna conductor.

(ii) Dielectric loss.

(iii) I^2R loss in antenna and ground system.

(iv) Loss in earth connections.

(v) Leakage loss in insulation.

Thus antenna efficiency η **represents the fraction of total energy supplied to the antenna wh is converted into electromagnetic waves.**

6.14. EFFECTIVE AREA OR EFFECTIVE APERTURE OR CAPTURE AREA

(AMIETE, Nov. 1977,

A transmitting antenna transmits electromagnetic waves and a receiving antenna receives a frac of the same. The concept of effective area or aperture is best understood by considering an antenna to hav