Chapter-2

Antenna Basics

Antenna is usually characterized by some common fundamental parameters. These fundamental parameters help in concluding the behavior of an antenna when it is used in a communication system. The values of these parameters depend upon the physical dimension, current distribution and configuration of antenna.

1. Radiation Pattern

In antenna problems we are primarily interested in the far-zone fields. These are also called ***radiation fields.*** No physical antennas radiate uniformly in all directions in space. The graph that describes the relative far-zone field strength versus direction at a fixed distance from an antenna is called the ***radiation pattern*** of the antenna, or simply the ***antenna pattern.*** In general, an antenna pattern is three-dimensional, varying with both θ and ϕ in a spherical coordinate system. The difficulties of making three-dimensional plots can be avoided—as is the usual practice—by plotting separately the magnitude of the normalized field strength (with respect to the peak value) versus θ for a constant ϕ (an ***E-plane pattern)*** and the magnitude of the normalized field strength versus ϕ for $\theta = \pi / 2$ (the ***H-plane pattern).***

EXAMPLE-1: Plot the E-plane and H-plane radiation patterns of a Hertzian dipole.

Solution: Since E_θ and H_ϕ in the far zone are proportional to each other, we need only consider the normalized magnitude of E_θ.

a) ***E-plane pattern:*** At a given R, E_θ is independent of ϕ; and from Eq.(19b) the normalized magnitude of E_θ is

$$\text{Normalized } |E_\theta| = |\sin\theta|. \qquad \text{.... (31)}$$

This is the E-plane ***pattern function*** of a Hertzian dipole. For any given Eq.(31) represents <u>a pair of circles</u>, as shown in Fig.3(a).

b) ***H-plane pattern.*** At a given R and for $\theta=\pi/2$, the normalized magnitude of E_θ is $|\sin\theta| = 1$. The H-plane pattern is then simply a circle of unity radius centered at the z-directed dipole, as shown in Fig.3(b).

The radiation patterns of practical antennas are usually more complicated than those shown in Fig.3. A typical H-plane pattern might look like the one illustrated in Fig.4(a), which is plotted in ***polar coordinates*** with normalized $|E_\theta|$ versus ϕ. It generally has a major maximum and several minor maxima. The region of maximum radiation between the first null points around it is the *main beam*, and the regions of minor maxima are ***sidelobes***.

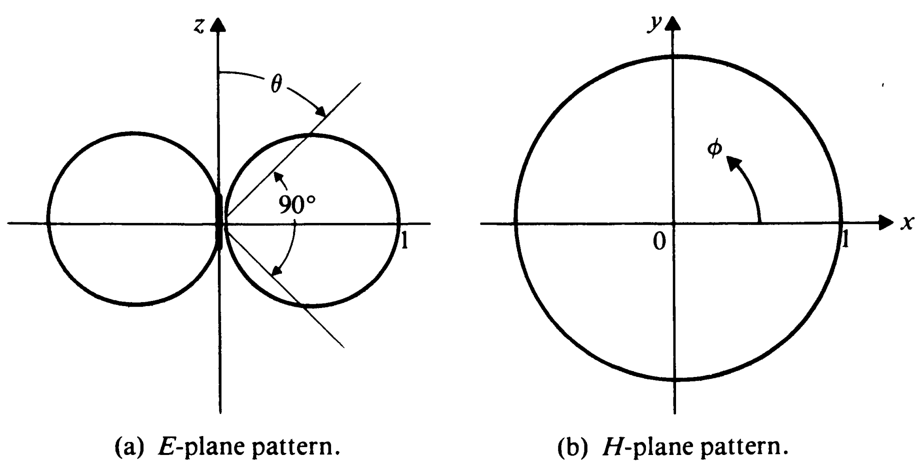
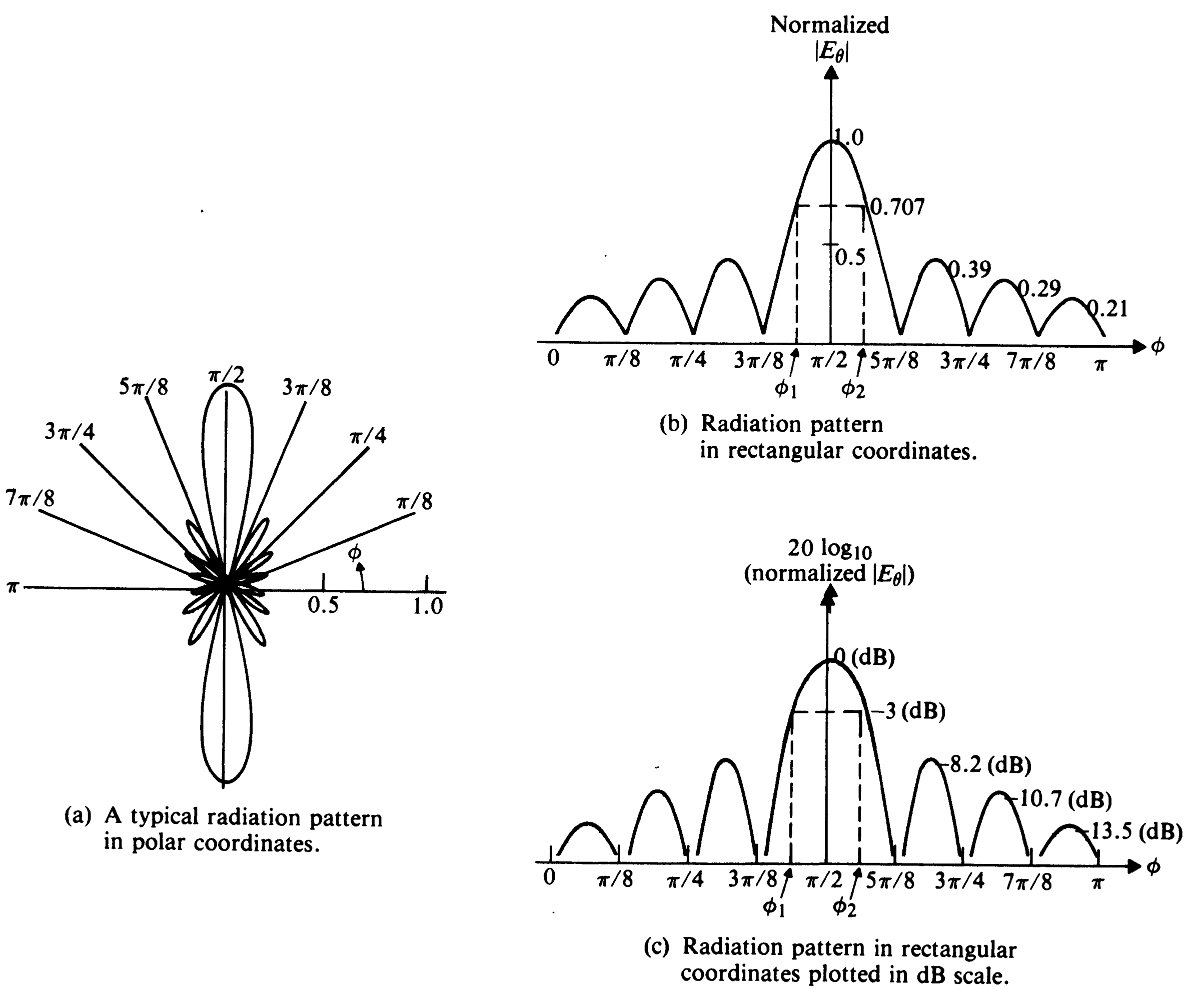


Fig.3: Radiation patten of a Hertzian dipole

Sometimes it is convenient to plot antenna patterns in ***rectangular coordinates***. The polar plot in Fig.4(a) will appear as Fig.4(b) in rectangular coordinates. Since the field intensities in the main-beam and sidelobe directions may differ by many orders of magnitude, antenna patterns are frequently plotted in a logarithmic scale measured in decibels down from the main-beam level. The pattern in Fig.4(b) converted to a decibel scale will have the shape shown in Fig.4(c).

In the comparison of various antenna patterns the following characteristic parameters are of importance: ***width of main beam, sidelobe levels, and directivity.***
The significance of each of these parameters is explained below.



(a) A typical radiation pattern in polar coordinates.

(b) Radiation pattern in rectangular coordinates.

(c) Radiation pattern in rectangular coordinates plotted in dB scale.

Fig.4: Typical H-plane radiation pattern

2. Half-Power beamwidth

The half-power beamwidth describes the sharpness of the main radiation region. It is generally taken to be the angular width of a pattern between the half-power, or -3 (dB) points. In electric-intensity plots it is the angular width between points that are (l/√2) or 0.707 times the maximum intensity. Thus, the H-plane pattern in Fig.4 has a 3 (dB) beam width equal to (ϕ_1-ϕ_2) and the E-plane pattern of the Hertzian dipole in Fig.3(a) has a 3 (dB) beamwidth of 90°. Occasionally the angular width of the main beam between -10 (dB) points or between the first nulls is also of interest. Of course, the main beam must point in the direction where the antenna is designed to have its maximum radiation.

3. Sidelobe levels

Sidelobes of a directive (nonisotropic) pattern represent regions of unwanted radiation; they should have levels as low as possible. Generally, the levels of distant sidelobes are lower than the levels of those near the main beam. Hence, when one talks about the sidelobe level of an antenna pattern, one usually refers to the first (the nearest and highest) sidelobe. In modern radar applications, sidelobe levels of the orders of minus 40 or more decibels are required. In practical applications the locations of the sidelobes are also of importance.

4. Directivity

The beamwidth of an antenna pattern specifies the sharpness of the main beam, but it does not provide us with any information about the rest of the pattern. For example, the sidelobes may be very high—an undesirable feature. A commonly used parameter to measure the overall ability of an antenna to direct radiated power in a given direction is ***directive gain,*** which may be defined in terms of ***radiation intensity***.

Radiation intensity is the time-average power per unit solid angle. The SI unit for radiation intensity is watt per steradian (W/sr). Since there are R^2 square meters of spherical surface area for each unit solid angle, radiation intensity, U equals R^2 times the time-average power per unit area or R^2 times the magnitude of the time-average Poynting vector $\mathscr{P}_{av}$

$$U = R^2 \mathscr{P}_{av} \qquad \text{(W/sr)}. \qquad \text{.... (32)}$$

The total time-average power radiated is

$$P_r = \oint \mathscr{P}_{av} \cdot d\mathbf{s} = \oint U \, d\Omega \qquad \text{(W)}, \qquad \text{.... (33)}$$

where $d\Omega$ is the differential solid angle, $d\Omega = \sin\theta d\theta d\phi$.

Directive gain, $G_D(\theta, \phi)$, of an antenna pattern is the ratio of the radiation intensity in the direction (θ, ϕ) to the average radiation intensity:

$$G_D(\theta, \phi) = \frac{U(\theta, \phi)}{P_r/4\pi} = \frac{4\pi U(\theta, \phi)}{\oint U \, d\Omega}. \qquad \text{.... (34)}$$

Obviously, the directive gain of an i***sotropic*** or ***omnidirectional*** antenna (an antenna that radiates uniformly in all directions) is unity. However, <u>an isotropic antenna does not exist in practice.</u>

The maximum directive gain of an antenna is called the *directivity* of the antenna. It is the ratio of the maximum radiation intensity to the average radiation intensity and is usually denoted by D:

$$D = \frac{U_{\max}}{U_{av}} = \frac{4\pi U_{\max}}{P_r} \qquad \text{(Dimensionless)}. \qquad \text{.... (35)}$$

In terms of electric field intensity, D can be expressed as

$$D = \frac{4\pi |E_{\max}|^2}{\int_0^{2\pi} \int_0^{\pi} |E(\theta, \phi)|^2 \sin\theta \, d\theta \, d\phi} \qquad \text{(Dimensionless)}. \qquad \text{.... (36)}$$

Directivity is frequently expressed in decibels, referring to unity.

EXAMPLE-2: Find the directive gain and the directivity of a Hertzian dipole.

Solution: For a Hertzian dipole the magnitude of the time-average Poynting vector is:

$$\mathscr{P}_{av} = \tfrac{1}{2}\mathscr{R}e\left|\mathbf{E} \times \mathbf{H}^*\right| = \tfrac{1}{2}\left|E_\theta\right|\left|H_\phi\right|. \qquad \text{.... (37)}$$

Hence from Eqs.(19a,b) and (32),

$$U = \frac{(I\,d\ell)^2}{32\pi^2}\eta_0\beta^2 \sin^2\theta. \qquad \text{.... (38)}$$

The directive gain can be obtained from Eq.(34):

$$G_D(\theta, \phi) = \frac{4\pi \sin^2\theta}{\int_0^{2\pi}\int_0^{\pi}(\sin^2\theta)\sin\theta\,d\theta\,d\phi} = \tfrac{3}{2}\sin^2\theta.$$

The directivity is the maximum value of $G_D(\theta,\phi)$:

$$D = G_D\left(\frac{\pi}{2}, \phi\right) = 1.5,$$

which corresponds to $10\log_{10} 1.5$ or 1.76 (dB).

5. Power Gain and Efficiency

We note that beamwidth, sidelobe levels, and directive gain are parameters of an antenna pattern; they do not convey information about the efficiency or the input impedance of the antenna. A measure of antenna efficiency is the power gain. The ***power gain,*** or simply the ***gain,*** G_P, of an antenna referred to an isotropic source is the ratio of its maximum radiation intensity to the radiation intensity of a lossless isotropic source with the same power input. The directive gain as defined in Eq.(34) is based on radiated power P_r. Because of ohmic power loss, P_l , in the antenna itself as well as in nearby lossy structures including the ground, P_r is less than the total input power P_i. We have:

$$P_i = P_r + P_\ell. \qquad \text{.... (39)}$$

The power gain of an antenna is then

$$G_P = \frac{4\pi U_{\max}}{P_i} \qquad \text{(Dimensionless).} \qquad \text{.... (40)}$$

The ratio of the gain to the directivity of an antenna is the ***radiation efficiency,*** η_r:

$$\eta_r = \frac{G_P}{D} = \frac{P_r}{P_i} \qquad \text{(Dimensionless).} \qquad \text{.... (41)}$$

Normally, the efficiency of well-constructed antennas is very close to 100%.

6. Radiation Resistance

A useful measure of the amount of power radiated by an antenna is radiation resistance. The ***radiation resistance*** of an antenna is the value of a hypothetical resistance that would dissipate an amount of power equal to the radiated power P_r , when the current in the resistance is equal to the maximum current along the antenna. Naturally, a high radiation resistance is a desirable property for an antenna.

EXAMPLE-3: Find the radiation resistance of a Hertzian dipole.

Solution: If we assume no ohmic losses, the time-average power radiated by a Hertzian dipole for an input time-harmonic current with an amplitude I is:

$$P_r = \frac{1}{2}\int_0^{2\pi}\int_0^{\pi} E_\theta H_\phi^* R^2 \sin\theta \, d\theta \, d\phi. \qquad \text{.... (42)}$$

Using the far-zone fields in Eqs.(19a,b), we find

$$P_r = \frac{I^2(d\ell)^2}{32\pi^2}\eta_0\beta^2 \int_0^{2\pi}\int_0^{\pi} \sin^3\theta \, d\theta \, d\phi$$

$$= \frac{I^2(d\ell)^2}{12\pi}\eta_0\beta^2 = \frac{I^2}{2}\left[80\pi^2\left(\frac{d\ell}{\lambda}\right)^2\right]. \quad \text{.... (43)}$$

In this last expression we have used 120π for the intrinsic impedance of free space, η_o and substituted $2\pi/\lambda$ for β.

Since the current along the short Hertzian dipole is uniform, we refer the power dissipated in the radiation resistance R_r to I. Equating $(I^2 R_r/2)$ to P_r, we obtain

$$R_r = 80\pi^2\left(\frac{d\ell}{\lambda}\right)^2 \quad (\Omega). \quad \text{.... (44)}$$

As an example, *if* $d\ell = 0.01\lambda$, R_r is only about 0.08 (Ω), an extremely small value. Hence a short dipole antenna is a poor radiator of electromagnetic power. However, it is erroneous to say without qualification that the radiation resistance of a dipole antenna increases as the square of its length because Eq.(44) holds only if $d\ell \ll \lambda$.

Radiation resistance may be quite different from the real part of the input impedance because the latter includes ohmic losses in the antenna structure itself as well as losses in the ground. The input impedance of a short dipole antenna has a large capacitive reactance, which makes it difficult to match and therefore difficult to feed power to the antenna efficiently.

EXAMPLE-4: Find the radiation efficiency of an isolated Hertzian dipole made of a metal wire of radius *a*, length *d*, and conductivity *σ*.

Solution: Let I be the amplitude of the current in the wire dipole having a loss resistance R_l. Then the ohmic power loss is

$$P_\ell = \tfrac{1}{2}I^2R_\ell. \quad \text{.... (45)}$$

In terms of radiation resistance R_r, the radiated power is

$$P_r = \frac{1}{2} I^2 R_r. \quad \text{.... (46)}$$

From Eqs.(39) and (41) we have

$$\eta_r = \frac{P_r}{P_r + P_\ell} = \frac{R_r}{R_r + R_\ell} = \frac{1}{1 + (R_\ell / R_r)}, \quad \text{.... (47)}$$

where R_r has been found in Eq.(44). The loss resistance R_e of the metal wire can be expressed in terms of the surface resistance R_s

$$R_\ell = R_s \left(\frac{d\ell}{2\pi a} \right), \quad \text{.... (48)}$$

where

$$R_s = \sqrt{\frac{\pi f \mu_0}{\sigma}} \quad \text{.... (49)}$$

Using Eqs.(44) and (48) in Eq.(47), we obtain the radiation efficiency of an isolated Hertzian dipole:

$$\eta_r = \frac{1}{1 + \frac{R_s}{160\pi^3} \left(\frac{\lambda}{a} \right) \left(\frac{\lambda}{d\ell} \right)}. \quad \text{.... (50)}$$

Assume that a = 1.8 (mm), $d\ell$ = 2 (m), operating frequency f = 1.5 (MHz), and σ (for copper) = 5.80 x 10^7 (S/m). We find that

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{1.5 \times 10^6} = 200 \quad (\text{m}),$$

$$R_s = \sqrt{\frac{\pi \times (1.50 \times 10^6) \times (4\pi 10^{-7})}{5.80 \times 10^7}} = 3.20 \times 10^{-4} \quad (\Omega),$$

$$R_\ell = 3.20 \times 10^{-4} \times \left(\frac{2}{2\pi 1.8 \times 10^{-3}}\right) = 0.057 \quad (\Omega),$$

$$R_r = 80\pi^2\left(\frac{2}{200}\right)^2 = 0.079 \quad (\Omega),$$

and,

$$\eta_r = \frac{0.079}{0.079 + 0.057} = 58\%,$$

which is very low. Equation (50) shows that smaller values of *(a/λ)* and *(dℓ/λ)* lower the radiation efficiency.