CHAPTER

2

FUNDAMENTAL PARAMETERS OF ANTENNAS

2.1 INTRODUCTION

To describe the performance of an antenna, definitions of various parameters are necessary. Some of the parameters are interrelated and not all of them need be specified for complete description of the antenna performance. Parameter definitions will be given in this chapter. Many of those in quotation marks are from the *IEEE Standard Definitions of Terms for Antennas* (IEEE Std 145-1983).* This is a revision of the IEEE Std 145-1973.

2.2 RADIATION PATTERN

An antenna *radiation pattern* or *antenna pattern* is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. 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 power flux density, radiation intensity, field strength, directivity phase or polarization." The radiation property of most concern is the two- or three-dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius. A convenient set of coordinates is shown in Figure 2.1. A trace of the received power at a constant radius is called the *power pattern.* On the other hand, a graph of the spatial variation of the electric (or magnetic) field along a constant radius is called an amplitude *field pattern.* In practice, the three-dimensional pattern is measured and recorded in a series of two-dimensional patterns. However, for most practical applications, a few plots of the pattern as a function of θ for some particular values of ϕ, plus a few plots as a function of ϕ for some particular values of θ, give most of the useful and needed information.

**IEEE Transactions on Antennas and Propagation,* Vols. AP-17, No. 3, May 1969; Vol. AP-22, No. 1, January 1974; and Vol. AP-31, No. 6, Part II, November 1983.

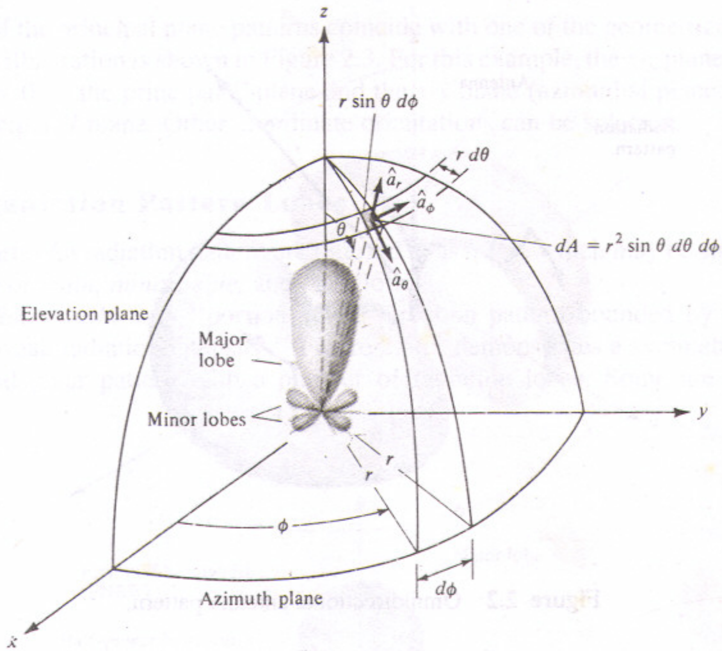


Figure 2.1 Coordinate system for antenna analysis.

2.2.1 Isotropic, Directional, and Omnidirectional Patterns

An *isotropic* radiator is defined as "a hypothetical lossless antenna having equal radiation in all directions." Although it is ideal and not physically realizable, it is often taken as a reference for expressing the directive properties of actual antennas. A *directional* antenna is one "having the property of radiating or receiving electromagnetic waves more effectively in some directions than in others. This term is usually applied to an antenna whose maximum directivity is significantly greater than that of a half-wave dipole." An example of an antenna with a directional radiation pattern is shown in Figure 2.2. It is seen that this pattern is nondirectional in the azimuth plane [$f(\phi)$, $\theta = \pi/2$] and directional in the elevation plane [$g(\theta)$, ϕ = constant]. This type of a pattern is designated as *omnidirectional,* and it is defined as one "having an essentially nondirectional pattern in a given plane (in this case in azimuth) and a directional pattern in any orthogonal plane (in this case in elevation)." An *omnidirectional* pattern is then a special type of a *directional* pattern.

2.2.2 Principal Patterns

For a linearly polarized antenna, performance is often described in terms of its principal *E*- and *H*-plane patterns. The *E-plane* 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." Although it is very difficult to illustrate the principal patterns without considering a specific example, it is the usual practice to orient most antennas so that at

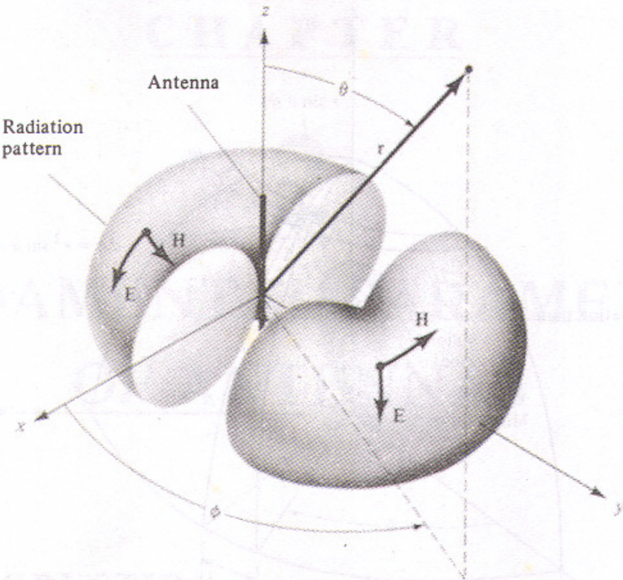


Figure 2.2 Omnidirectional antenna pattern.

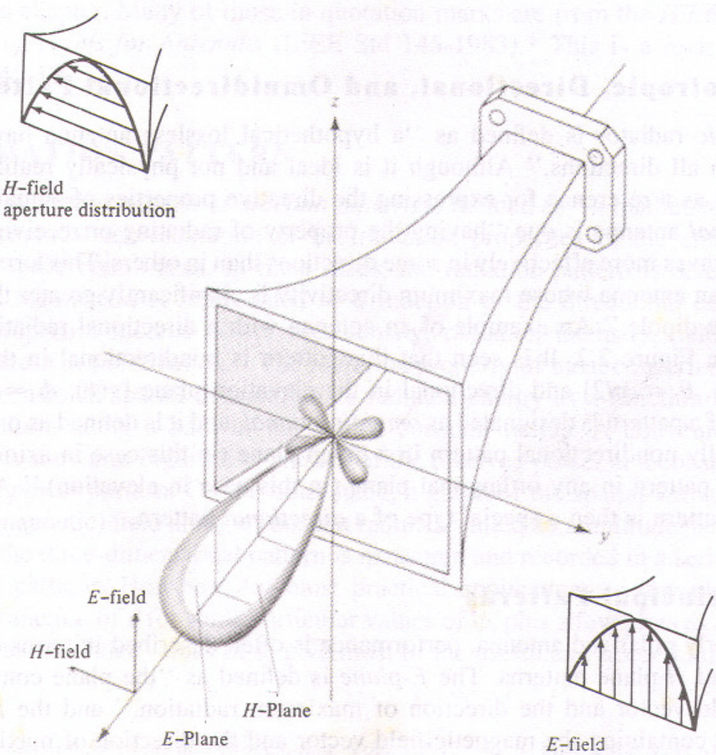


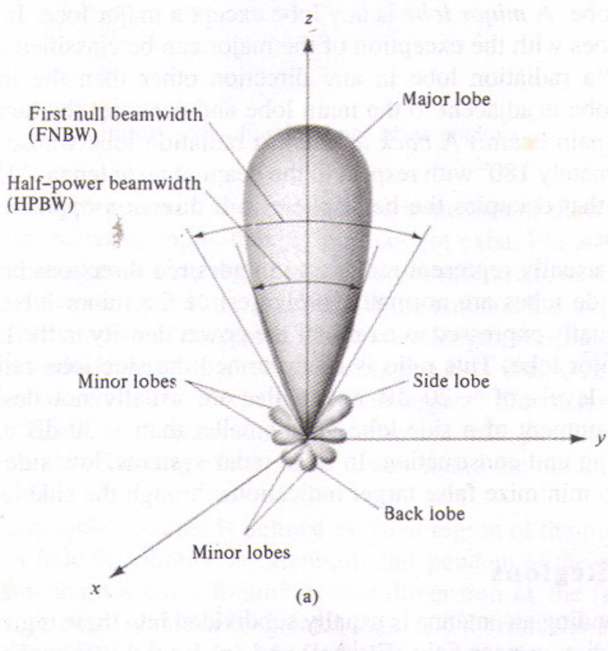
Figure 2.3 Principal E- and H-plane patterns for a pyramidal horn antenna.

least one of the principal plane patterns coincide with one of the geometrical principal planes. An illustration is shown in Figure 2.3. For this example, the x-z plane (elevation plane: $\phi = 0$) is the principal E-plane and the x-y plane (azimuthal plane; $\theta = \pi/2$) is the principal H-plane. Other coordinate orientations can be selected.

2.2.3 Radiation Pattern Lobes

Various parts of a radiation pattern are referred to as *lobes,* which may be subclassified into *major* or *main, minor, side,* and *back* lobes.

A *radiation lobe* is a "portion of the radiation pattern bounded by regions of relatively weak radiation intensity." Figure 2.4(a) demonstrates a symmetrical three-dimensional polar pattern with a number of radiation lobes. Some are of greater



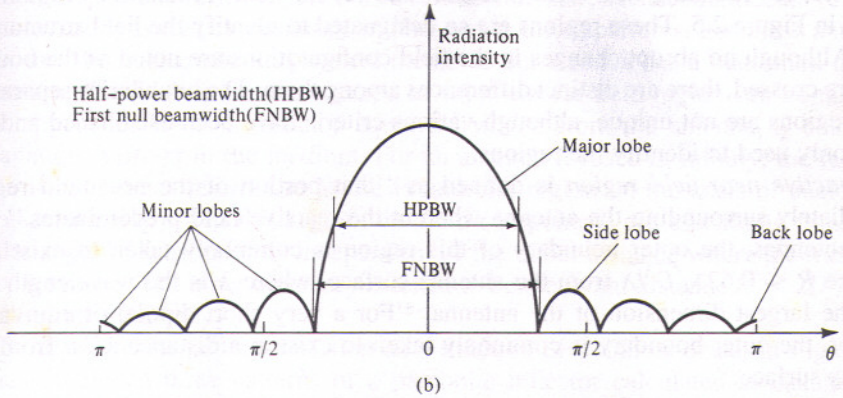


Figure 2.4 (a) Radiation lobes and beamwidths of an antenna pattern. (b) Linear plot of power pattern and its associated lobes and beamwidths.

radiation intensity than others, but all are classified as lobes. Figure 2.4(b) illustrates a linear two-dimensional pattern [one plane of Figure 2.4(a)] where the same pattern characteristics are indicated.

A computer program entitled *2-D ANTENNA PATTERN PLOTTER: RECTANGULAR-POLAR* [1] is included at the end of the chapter to plot two-dimensional *rectangular* and *polar* graphs, to represent single-plane antenna patterns similar to those exhibited in Figure 2.4(a,b) and elsewhere throughout the book. This program is well commented to assist the user in its implementation and only the executable part is included. Each pattern can be plotted in a linear or logarithmic (dB) scale. The program is provided courtesy of Dr. Elsherbeni and Taylor [1], and it is to be used only in conjunction with this book and for not any other purpose.

A *major lobe* (also called main beam) is defined as "the radiation lobe containing the direction of maximum radiation." In Figure 2.4 the major lobe is pointing in the $\theta = 0$ direction. In some antennas, such as split-beam antennas, there may exist more than one major lobe. A *minor lobe* is any lobe except a major lobe. In Figures 2.4(a) and (b) all the lobes with the exception of the major can be classified as minor lobes. A *side lobe* is "a radiation lobe in any direction other than the intended lobe." (Usually a side lobe is adjacent to the main lobe and occupies the hemisphere in the direction of the main beam.) A *back lobe* is "a radiation lobe whose axis makes an angle of approximately 180° with respect to the beam of an antenna." Usually it refers to a minor lobe that occupies the hemisphere in a direction opposite to that of the major (main) lobe.

Minor lobes usually represent radiation in undesired directions, and they should be minimized. Side lobes are normally the largest of the minor lobes. The level of minor lobes is usually expressed as a ratio of the power density in the lobe in question to that of the major lobe. This ratio is often termed the side lobe ratio or side lobe level. Side lobe levels of -20 dB or smaller are usually not desirable in most applications. Attainment of a side lobe level smaller than -30 dB usually requires very careful design and construction. In most radar systems, low side lobe ratios are very important to minimize false target indications through the side lobes.

2.2.4 Field Regions

The space surrounding an antenna is usually subdivided into three regions: (a) reactive near-field, (b) radiating near-field (Fresnel) and (c) far-field (Fraunhofer) regions as shown in Figure 2.5. These regions are so designated to identify the field structure in each. Although no abrupt changes in the field configurations are noted as the boundaries are crossed, there are distinct differences among them. The boundaries separating these regions are not unique, although various criteria have been established and are commonly used to identify the regions.

Reactive near-field region is defined as "that portion of the near-field region immediately surrounding the antenna wherein the reactive field predominates." For most antennas, the outer boundary of this region is commonly taken to exist at a distance $R < 0.62\sqrt{D^3/\lambda}$ from the antenna surface, where λ is the wavelength and D is the largest dimension of the antenna. "For a very short dipole, or equivalent radiator, the outer boundary is commonly taken to exist at a distance $\lambda/2\pi$ from the antenna surface."

Radiating near-field (Fresnel) region is defined as "that region of the field of an antenna between the reactive near-field region and the far-field region wherein radiation fields predominate and wherein the angular field distribution is dependent upon

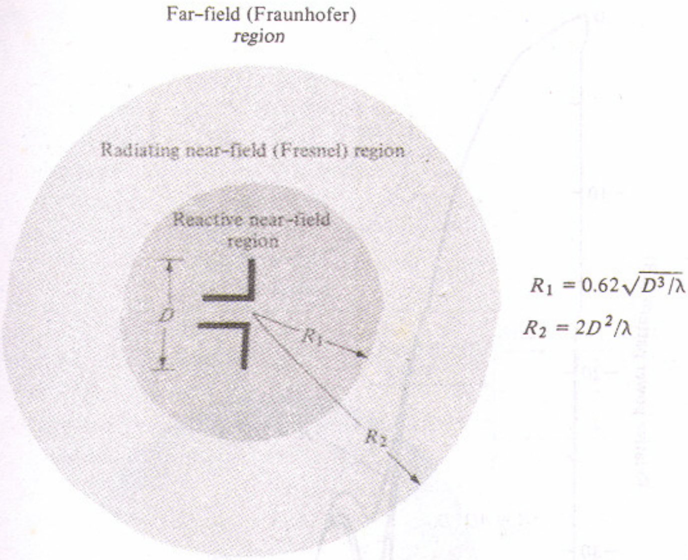


Figure 2.5 Field regions of an antenna.

the distance from the antenna. If the antenna has a maximum dimension that is not large compared to the wavelength, this region may not exist. For an antenna focused at infinity, the radiating near-field region is sometimes referred to as the Fresnel region on the basis of analogy to optical terminology. If the antenna has a maximum overall dimension which is very small compared to the wavelength, this field region may not exist.'' The inner boundary is taken to be the distance $R \geq 0.62\sqrt{D^3/\lambda}$ and the outer boundary the distance $R < 2D^2/\lambda$ where D is the largest* dimension of the antenna. This criterion is based on a maximum phase error of $\pi/8$. In this region the field pattern is, in general, a function of the radial distance and the radial field component may be appreciable.

Far-field (Fraunhofer) region is defined as ''that region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. If the antenna has a maximum* overall dimension D, the far-field region is commonly taken to exist at distances greater than $2D^2/\lambda$ from the antenna, λ being the wavelength. The far-field patterns of certain antennas, such as multibeam reflector antennas, are sensitive to variations in phase over their apertures. For these antennas $2D^2/\lambda$ may be inadequate. In physical media, if the antenna has a maximum overall dimension, D, which is large compared to $\pi/|\gamma|$, the far-field region can be taken to begin approximately at a distance equal to $|\gamma|D^2/\pi$ from the antenna, γ being the propagation constant in the medium. For an antenna focused at infinity, the far-field region is sometimes referred to as the Fraunhofer region on the basis of analogy to optical terminology.'' In this region, the field components are essentially transverse and the angular distribution is independent of the radial distance where the measurements are made. The inner boundary is taken to be the radial distance $R = 2D^2/\lambda$ and the outer one at infinity.

To illustrate the pattern variation as a function of radial distance, in Figure 2.6 we have included three patterns of a parabolic reflector calculated at distances of $R = 2D^2/\lambda$, $4D^2/\lambda$, and infinity [2]. It is observed that the patterns are almost identical,

*To be valid, D must also be large compared to the wavelength ($D > \lambda$).

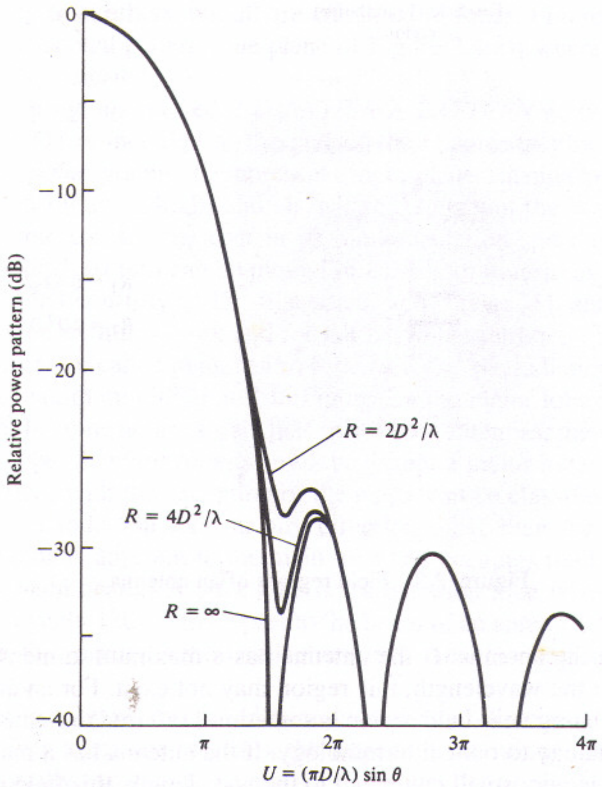


Figure 2.6 Calculated radiation patterns of a paraboloid antenna for different distances from the antenna. (SOURCE: J. S. Hollis, T. J. Lyon, and L. Clayton, Jr. (eds.), *Microwave Antenna Measurements,* Scientific-Atlanta, Inc., July 1970)

except for some differences in the pattern structure around the first null and at a level below 25 dB. Because infinite distances are not realizable in practice, the most commonly used criterion for minimum distance of far-field observations is $2D^2/\lambda$.

2.2.5 Radian and Steradian

The measure of a plane angle is a radian. One *radian* is defined as the plane angle with its vertex at the center of a circle of radius r that is subtended by an arc whose length is r. A graphical illustration is shown in Figure 2.7(a). Since the circumference of a circle of radius r is $C = 2\pi r$, there are 2π rad $(2\pi r/r)$ in a full circle.

The measure of a solid angle is a steradian. One *steradian* is defined as the solid angle with its vertex at the center of a sphere of radius r that is subtended by a spherical surface area equal to that of a square with each side of length r. A graphical illustration is shown in Figure 2.7(b). Since the area of a sphere of radius r is $A = 4\pi r^2$, there are 4π sr $(4\pi r^2/r^2)$ in a closed sphere.

The infinitesimal area dA on the surface of a sphere of radius r, shown in Figure 2.1, is given by

$$dA = r^2 \sin\theta \, d\theta \, d\phi \qquad (\text{m}^2) \tag{2-1}$$