Radio-Telescope Antennas

6.1 Introduction An antenna may be defined as the region of transition between a free-space wave and a guided wave (receiving case) or vice versa (transmitting case). The antenna of a radio telescope acts as a collector of radio waves. The antenna is analogous to the lens or mirror of an optical telescope.

The response of an antenna as a function of direction is given by the antenna pattern. By reciprocity this pattern is the same for both receiving and transmitting conditions.

The pattern commonly consists of a number of lobes, as suggested in Fig. 6-1a. The lobe with the largest maximum is called the main lobe, while the smaller lobes are referred to as the minor lobes or side and back lobes.

If the pattern is measured at a sufficient distance from the antenna so that an increase in the distance causes no change in the pattern, the pattern is the far-field pattern. Measurements at lesser distances yield near-field patterns, which are a function of both angle and distance. The pattern may be expressed in terms of the field intensity (field pattern) or in terms of the Poynting vector or radiation intensity (power patterns). Figure 6-1a is a power pattern in polar coordinates. To show the minor-lobe structure in more detail the pattern can be plotted on a logarithmic or decibel scale (lobes below main-lobe maximum). Figure 6-1b is an example of a pattern on a decibel scale in rectangular coordinates. The pattern in Fig. 6-1b is the same as the one in Fig. 6-1a.

A single pattern, as in Fig. 6-1, would be sufficient to completely specify the variation of radiation with angle provided the pattern is symmetrical. This would mean, in the case of Fig. 6-1a, that the three-dimensional pattern is a figure of revolution of the one shown around the pattern axis. If the pattern is not symmetrical, a three-dimensional diagram or a contour map is required to show the pattern in its entirety. However, in practice two patterns, one like that in Fig. 6-1a through the narrowest part of the lobe and another perpendicular to it through the widest part of the lobe, may suffice. These mutually perpendicular patterns through the main-lobe axis are called the principal-plane patterns. The above statement assumes that the antenna is linearly polarized in one of the principal planes. If this is not the case, more patterns may be required.

As an example, the dominant radiation from an antenna might be linearly polarized in one principal plane, but the radiation from some minor lobes might be cross-polarized, i.e., linearly polarized in the principal plane at right angles. Or the antenna might be elliptically polarized. A discussion of such patterns and their measurement is given by Kraus (1955, Chap. 15).
Thus, the directivity of an antenna is equal to the solid angle of a sphere (4π) divided by the antenna beam solid angle.

The directivity of an antenna is a fixed numerical (dimensionless) quantity. Multiplying the directivity by the normalized power pattern yields the directive gain, a quantity which is a function of angle. Thus,

\[ D_p(\theta, \phi) = D(\theta, \phi) \]

(6-8)

where \( D(\theta, \phi) \) = directive gain, dimensionless

since \( P_{\nu}(\theta, \phi)_{\text{max}} = 1 \), it follows that

\[ D = D(\theta, \phi)_{\text{max}} \]

(6-9)

from (6-7) and (6-8) it is also clear that

\[ \int_0^{2\pi} \int_0^\pi D(\theta, \phi) \sin \theta \, d\theta \, d\phi = 4\pi \]

(6-10)

Antenna patterns may be plotted in terms of directive gain, as in Fig. 6-3. For a nondirectional antenna the pattern would be everywhere equal to the isotropic level, \( D = 1 \). This is called the isotropic level. In specifying the minor-axis structure of an antenna the isotropic level is often a convenient reference.

In the foregoing discussion the directivity has been expressed entirely as a function of the antenna pattern with no reference to the size or geometry of the antenna. To show that the directivity is a function of the antenna size consider the far electric-field intensity \( E \) at a distance \( r \) in a direction broadside to a radiating aperture, as in Fig. 6-4. If the field intensity in the aperture is constant and equal to \( E_0 \) (volts per meter), the power \( W \) radiated is given by

\[ W = \frac{E_0^2}{Z} A \]

(6-11)

where \( A = \) antenna aperture, \( m^2 \)

\( Z = \) intrinsic impedance of the medium, ohms square^{-1}

The power radiated may also be expressed in terms of the field intensity \( E \) (volts m^{-1}) at a distance \( r \) by

\[ W = \frac{E_0^2}{Z} r^2 \Omega_k \]

(6-12)

where \( \Omega_k = \) beam solid angle of antenna, rad^2

\[ \text{Fig. 6-4. Radiation from aperture } A \text{ with uniform field } E_0. \]

It is shown in Sec. 6-7 that the field intensities \( E \) and \( E_0 \) are related by

\[ |E_0| = \frac{|E|}{r^\lambda} \]

(6-13)

where \( \lambda = \) wavelength, \( m \)

Substituting (6-13) in (6-12) and equating (6-11) and (6-12) yields

\[ \lambda^2 = A \Omega_k \]

(6-14)

where \( \lambda = \) wavelength, \( m \)

\( A = \) antenna aperture, \( m^2 \)

\( \Omega_k = \) beam solid angle, \( \text{rad}^2 \)

In (6-14) the aperture \( A \) is the physical aperture \( A_p \) if the field is uniform over the aperture, as assumed, but in general \( A \) is the effective aperture \( A_e \). Thus, more generally,

\[ \lambda^2 = A_e \Omega_k \]

(6-15)

where \( A_e = \) effective aperture, \( m^2 \)

According to this important relation, the product of the effective aperture of the antenna and the antenna beam solid angle is equal to the wavelength squared. From (6-15) and (6-7) we have that

\[ D = \frac{4\pi}{\lambda^2 A_e} \]

(6-16)