CHAPTER 2

ANTENNA PRINCIPLES

The antenna is a basic component of any electronic system dependent upon free space as the propagating medium. It serves as the connecting link between free space and the transmitter or receiver and is, consequently, of primary importance in determining the performance of the system in which it is used.

Antenna performance is defined in terms of certain characteristics, nearly all of which are frequency dependent. The basic properties that determine the applications of antennas will be discussed briefly in this chapter with a more detailed theoretical treatment left to acknowledged standard texts such as references 24, 25 and 27 listed in appendix C.

2.1 CURRENT DISTRIBUTION

Current distribution on antennas is divided into two general classes: standing wave and traveling wave. Standing-wave distribution is similar to the current distribution along an open-ended transmission line in which the current amplitude varies sinusoidally along the length of the line and is zero at the end. Antennas with this type of current distribution are referred to as resonant antennas.

Traveling-wave distribution corresponds to the current distribution along a transmission line terminated in its characteristic impedance. In this case the current is uniform in amplitude along the line, but the phase changes continuously at the rate of 2π radians per wavelength. The traveling-wave type antenna, also known as a nonresonant antenna, is always terminated with a resistance in a manner similar to matching the character impedance of a transmission line.

2.2 RADIATION PATTERNS, GAIN AND DIRECTIVITY

The radiation pattern of an antenna is of interest as it shows the relative intensity of a radiated signal (or the relative sensitivity to a received signal) in various directions from an antenna. In other words, a radiation pattern is a representation of the directivity of the antenna and, as such, it can be used to select a type of antenna that has the maximum gain in the desired direction, horizontally, vertically, or both. Mathematical derivations of antenna patterns, and patterns for many of the more common types of antennas, are given in standard antenna texts.

The gain of an antenna is defined as the ratio of the maximum power density radiated by the antenna to the maximum power density radiated by a reference antenna when both antennas have equal input powers. The directivity of an antenna, which is sometimes confused with antenna gain, is the ratio of the maximum power density radiated by the antenna to the average power density radiated by the antenna. The distinction between the two terms arises from the fact that antenna gain takes account of antenna losses, whereas directivity does not. Since all antennas have some losses, the directivity of an antenna will exceed the antenna gain. The directivity of an antenna, which is expressed as a ratio, can be obtained from the antenna radiation pattern alone without consideration of antenna losses or absolute power values.

Rhombic antennas which dissipate portions of the antenna input power in the termination resistance will have lower gain values than directivity values by an amount approximately equal to the termination loss. Co-phased dipole arrays have low conductor losses, and directivity only slightly exceeds the gain for such antennas. However, antennas may be constructed to have a considerable difference between directivity and gain. These antennas usually have parallel elements, closely spaced in terms of wavelength, with out-of-phase currents in adjacent elements. In such antennas large currents flow in the elements, and conductor losses are quite appreciable unless large-diameter conductors are used. Both the dipole log-periodic array (LPA) and the Yagi have high directivity characteristics, and differences of a decibel or more between directivity and gain for these antennas are not uncommon.

A theoretically perfect isotropic radiator is used as the basic reference antenna for comparing gain measurements to obtain the gain of a particular antenna. A comparison of the isotropic radiator with several secondary standards is illustrated in figure 2-1. Any of the antenna types listed in the figure can be used as practical radiators for model range work, and for field comparison with other antennas. Usually, the half-wave dipole is considered the most practical reference antenna since it can be constructed from materials normally available at most shore activities, and because installation is relatively simple.

2.3 POLARIZATION

The polarization of the propagated wave is determined initially by the type and arrangement of the transmitting antenna. As a rule, a vertical conductor radiates a vertically polarized wave, and a horizontal conductor radiates a horizontally polarized wave. More complex forms, such as circular and elliptical polarization, in which the direction of maximum voltage rotates in space at the frequency of transmission, are also possible. These complex waves are generated by special antennas, or may be developed unintentionally when linearly polarized waves pass through nonuniform media such as the ionosphere. The wave polarization in free space is always in a plane perpendicular to the direction of propagation. The performance of a receiving antenna is improved if it can be oriented to take advantage of the polarization of the incident wave.

As a consequence of random changing of the polarization of high frequency waves as they travel through the ionosphere, the polarization of the transmitting antenna need not be determined by the characteristics of the remote receiving antennas. There are, however, other factors (discussed in chapter 3) that must be considered relative to the choice between a vertically or a horizontally polarized radiator. Where circuit requirements dictate ground-wave propagation, vertically polarized antennas provide the most effective coverage.

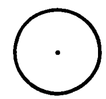
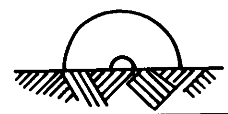
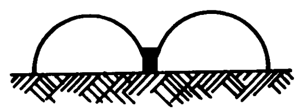
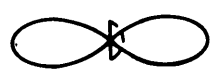
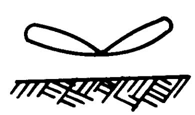
ANTENNA TYPE	VERTICAL PATTERN	mV/M AT 1MILE 1kW RADIATED POWER	POWER GAIN	dB GAIN
ISOTROPIC		107.6	1	0
HEMISPHERICAL		152.1	2	3.01
VERTICAL CURRENT ELEMENT		186.3	3	4.771
1/4 λ VERTICAL		194.9	3.282	5.161
1/2 λ VERTICAL		236.2	4.822	6.832
1/2 λ FREE SPACE		137.8	1.641	2.151
1/2 λ HORIZONTAL 1/2 λ ABOVE EARTH		278.0	6.56	8.17

Figure 2-1. Standard Reference Radiation Patterns

2.4 IMPEDANCE

The impedance of an antenna is comprised of the following components:

- Radiation resistance
- Conductor resistive losses
- Reactive storage field
- Coupled impedance effects from nearby conductors

The radiation resistance determines the amount of energy radiated, and the ratio of the radiation resistance to the radiation resistance plus all other losses determines the antenna efficiency. Although the radiation resistance and the total impedance can be calculated, the computations are extremely cumbersome for antennas other than the most simple types. Such computations are of interest primarily for antenna design.

In practical antenna work, the input impedance specified by the antenna manufacturer is verified at the time of installation by measurements with an impedance bridge. Subsequently, input impedance measurements are made to verify performance or to discover changes in input impedance that indicate the need for corrective maintenance.

The variation of antenna impedance with frequency depends upon the diameters and the electrical length of the antenna elements. Antennas that have small diameters in terms of wavelength have larger storage fields (greater reactive component of input impedance) than do larger diameter antennas. Standing-wave antennas generally exhibit a greater variation of reactive impedance than do traveling-wave antennas. For example, a dipole is capacitive for lengths shorter than one-half wavelength, zero at about a half wavelength, and inductive for lengths between one-half and one wavelength. The reactance continues to alternate cyclically as the dipole is extended in half-wavelength segments. Generally, this reactive behavior makes standing-wave antennas difficult to use at frequencies other than those near resonance where the reactance is zero. Some techniques have been used, however, to modify the impedance variation with frequency so as to extend the useful bandwidth of such antennas. For example, using biconical arms of proper taper for a dipole antenna reduces the reactance and makes the antenna useful over several octaves.

Traveling-wave antennas such as the rhombic and terminated vee have relatively constant input impedance compared to standing-wave antennas. For these antennas restrictions on the useful frequency range are determined by antenna radiation pattern changes with frequency rather than by impedance variations.

2.5 BANDWIDTH

A significant characteristic affecting the choice of an antenna for a particular application is its bandwidth, the frequency range over which the voltage standing wave ratio (VSWR) is within acceptable limits and over which the radiation pattern provides the required performance. The useful frequency range, or bandwidth, of an antenna is dependent upon the extent of the changes that occur in the input impedance or the radiation pattern as the frequency is varied. Either radiation-pattern or input-impedance changes can be the controlling factor. For some antennas, rhombics, for example, the input impedance is sufficiently constant to match the output impedance of a transmitter over a wide band of frequencies with an acceptable VSWR. Use of this type of antenna, however, often must be restricted to only a portion of this satisfactory "impedance bandwidth" because of unacceptable changes in the radiation pattern that occur as the frequency is changed. On the other hand, some antennas, such as the electrically short dipole or monopole, have essentially unchanging radiation patterns over a wide range of frequencies but their use is restricted to narrow frequency bands because the input impedance varies significantly with frequency.

The useful frequency band is determined to some extent by whether the antenna is used for transmitting or receiving. Input impedance limitations are generally more stringent for the transmitting case since a mismatch between a transmitter and its antenna may result in an excessive VSWR which can cause equipment failure. A greater degree of mismatch often is tolerated in the receiving case since, although signal reception may be degraded, a mismatch will not cause equipment failure.

2.6 GROUND EFFECTS

The free-space radiation pattern and the impedance of an antenna are modified when the antenna is placed near ground. The impedance change is small for antennas located at least one wavelength above ground, but the change becomes greater as the height is reduced. Since the ground appears as a lossy dielectric at medium and high frequencies, location of the antenna near ground may increase the losses considerably unless special means, such as ground wires or conductive mats, are used to reduce ground resistance.

Vertical antennas, which are often located with the antenna feed point at or near the ground surface, require a system of radial ground wires extending a sufficient distance from the antenna to provide a low-resistance return path for the ground currents produced by the induction fields. For most vertical antennas, the length of the radials is commonly one-quarter wavelength at the lowest design frequency. Additionally, on some vertical antennas where the fields are intense near the base, a grid-type ground mat, or screen, is used to increase the effectiveness of the connection to the earth. Ground plane radials and screens are discussed further in chapter 3.

Horizontal antennas are usually mounted at least a quarter wavelength above ground and do not require special treatment of the ground to reduce radiation losses.