CHAPTER 1

Antennas

1.1 Introduction

An antenna is defined as "a means for radiating or receiving radio waves." In other words the antenna is the transitional structure between free-space and a guiding device, as shown in Figure 1.1.

The guiding device or transmission line may take the form of a coaxial line or a hollow pipe (waveguide), and it is used to transport electromagnetic energy from the transmitting source to the antenna, or from the antenna to the receiver. In the former case, we have a transmitting antenna and in the latter a receiving antenna.

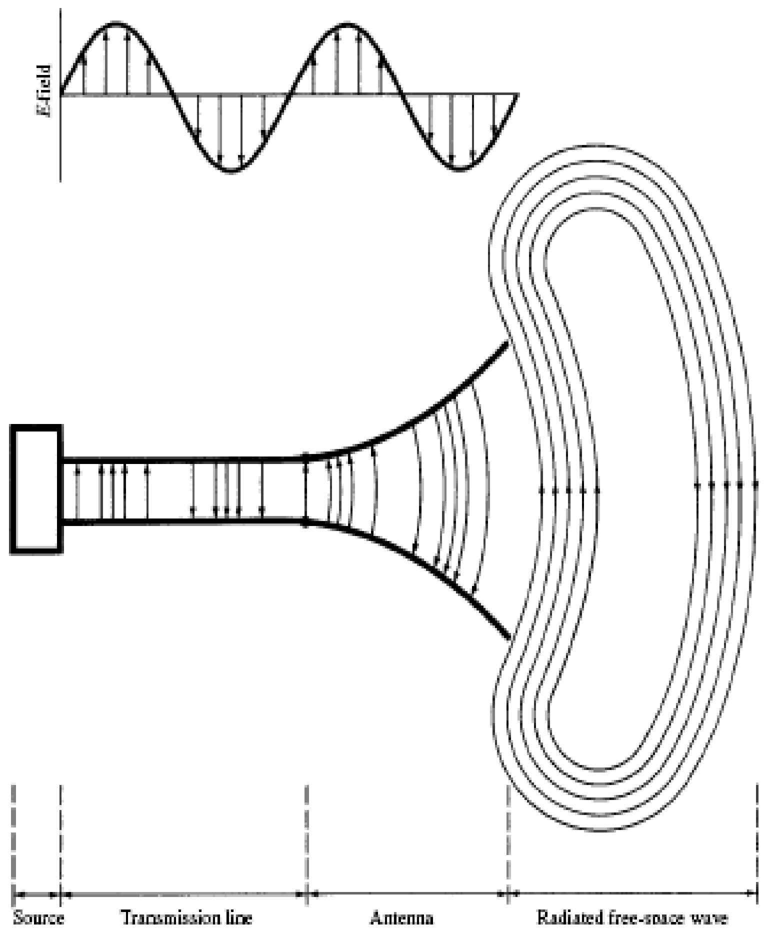


Figure 1.1 Antenna as a transition device.

A transmission-line Thevenin equivalent of the antenna system of Figure 1.1 in the transmitting mode is shown in Figure 1.2 where the source is represented by an **ideal generator**, the transmission line is represented by a line with characteristic impedance Z_c, and the antenna is represented by a load Z_A [$Z_A = (R_L + R_r) + j X_A$] connected to the transmission line. The load resistance R_L is used to represent the conduction and dielectric losses associated with the antenna structure while R_r , referred to as the radiation resistance, is used to represent radiation by the antenna. The reactance X_A is used to represent the imaginary part of the impedance associated with radiation by the antenna. Under ***ideal conditions***, energy generated by the source should be totally transferred to the radiation resistance R_r, which is used to represent radiation by the antenna. However, in a practical system there are conduction-dielectric losses due to the lossy nature of the transmission line and the antenna, as well as those due to reflections losses at the interface between the line and the antenna. Taking into account the internal impedance of the source and neglecting line and reflection losses, maximum power is delivered to the antenna under conjugate matching.

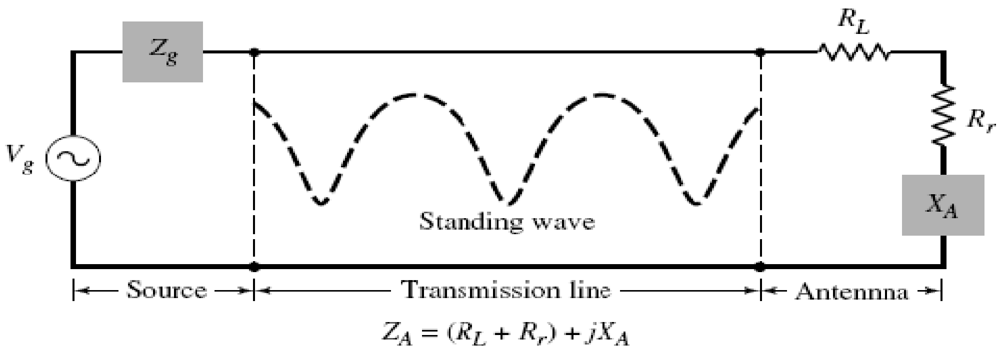


Figure 1.2 Transmission-line Thevenin equivalent of antenna in transmitting mode.

The reflected waves from the interface create, along with the traveling waves from the source toward the antenna, constructive and destructive interference patterns, referred to as standing waves, inside the transmission line which represent pockets of energy concentrations and storage, typical of resonant devices. A typical standing wave pattern is shown dashed in Figure 1.2. If the antenna system is not properly designed, the transmission line could act to a large degree as an energy storage element instead of as a wave guiding and energy transporting device. If the maximum field intensities of the standing wave are sufficiently large, they can cause arching inside the transmission lines.

The losses due to the line, antenna, and the standing waves are undesirable. The losses due to the line can be minimized by selecting low-loss lines while those of the antenna can be decreased by reducing the loss resistance represented by R_L in Figure 1.2. The standing waves can be reduced, and the energy storage capacity of the line minimized, by ***matching*** the impedance of the antenna (load) to the characteristic impedance of the line. This is the same as matching loads to transmission lines, where the load here is the antenna.

1.2 Types of Antennas

We will now introduce and briefly discuss some forms of the various antenna types in order to get a glance as to what will be encountered in the remainder of the book.

1.2.1 Wire Antennas

Wire antennas are familiar to the layman because they are seen virtually everywhere on automobiles, buildings, ships, aircraft, spacecraft, and so on. There are various shapes of wire antennas such as a straight wire (dipole), loop, and helix which are shown in Figure 1.3. Loop antennas need not only be circular. They may take the form of a rectangle, square, ellipse, or any other configuration. The circular loop is the most common because of its simplicity in construction.

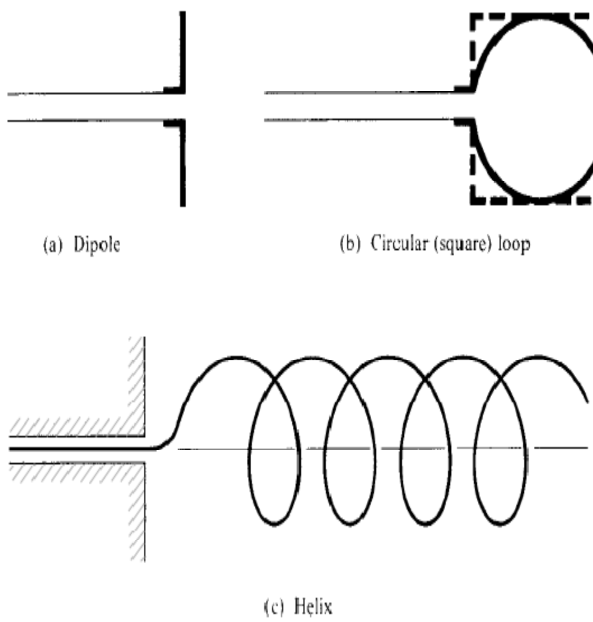


Figure 1.3 Wire antenna configurations.

1.2.2 Aperture Antennas

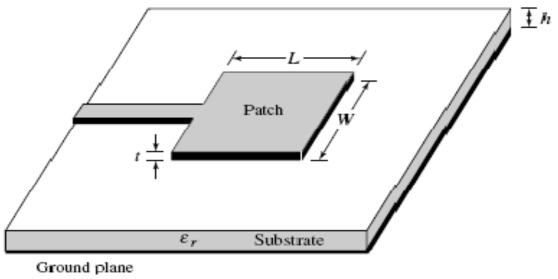
Aperture antennas may be more familiar to the layman today than in the past because of the increasing demand for more sophisticated forms of antennas and the utilization of higher frequencies. Some forms of aperture antennas are shown in Figure 1.4. Antennas of this type are very useful for aircraft and spacecraft applications.

(a) Pyramidal horn (b) Conical horn (c) Rectangular waveguide

Figure 1.4 Aperture antenna configurations.

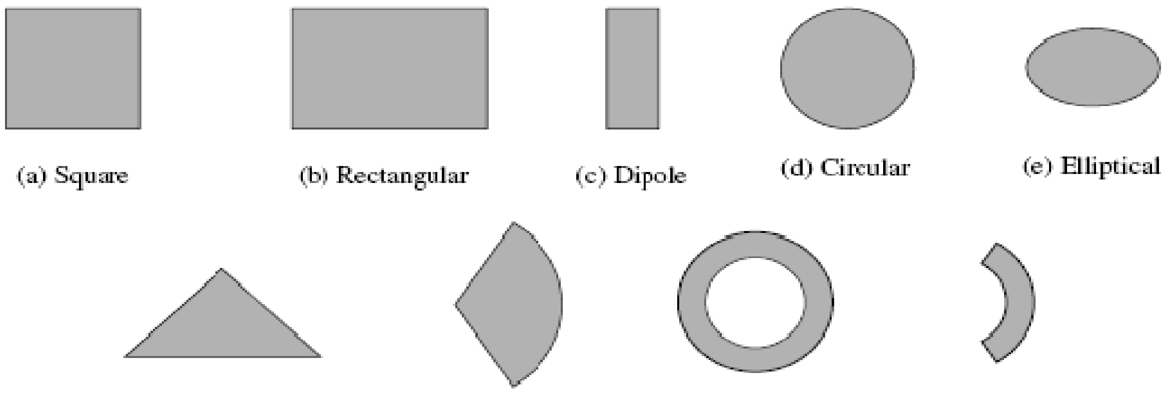
1.2.3 Microstrip Antennas

Microstrip antennas became very popular in the 1970s primarily for space borne applications. Today they are used for government and commercial applications. These antennas consist of a metallic patch on a grounded substrate. The metallic patch can take many different configurations, as shown in Figure 1.5. However, the rectangular and circular patches, shown in Figure 1.6, are the most popular because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation. The microstrip antennas are low profile, comfortable to planar and non-planar surfaces,



(a) Rectangular patch (b) Circular patch

Figure 1.5 Rectangular and circular microstrip (patch) antennas.



(a) Square (b) Rectangular (c) Dipole (d) Circular (e) Elliptical

(f) Triangular (g) Disc sector (h) Circular ring (i) Ring sector

Figure 1.6 Representative shapes of microstrip patch elements.

1.2.4 Array Antennas

Many applications require radiation characteristics that may not be achievable by a single element. It may, however, be possible that an aggregate of radiating elements in an electrical and geometrical arrangement (an array) will result in the desired radiation characteristics. The arrangement of the array may be such that the radiation from the elements adds up to give a radiation maximum in a particular direction or directions, minimum in others, or otherwise as desired. Typical examples of arrays are shown in Figure 1.7.

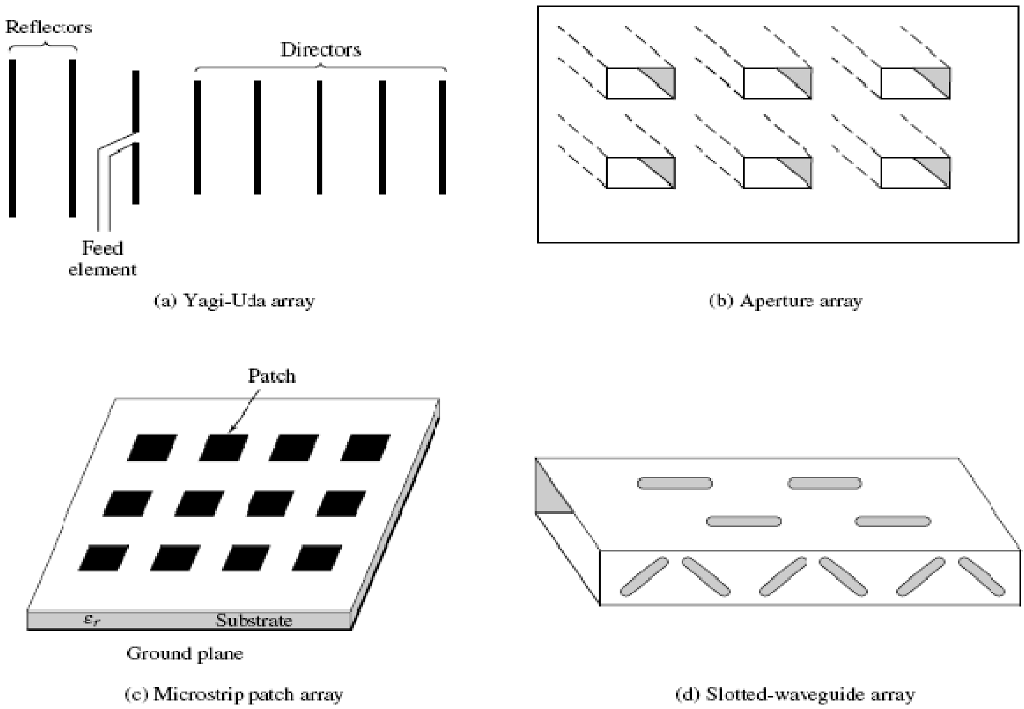


Figure 1.7 Typical wire, aperture, and microstrip array configurations.

1.2.5 Reflector Antennas

The success in the exploration of outer space has resulted in the advancement of antenna theory. Because of the need to communicate over great distances, sophisticated forms of antennas had to be used in order to transmit and receive signals that had to travel millions of miles. A very common antenna form for such an application is a parabolic reflector shown in Figure 1.8. Antennas of this type have been built with diameters as large as **305 m**. Such large dimensions are needed to achieve the high gain required to transmit or receive signals after millions of miles of travel.

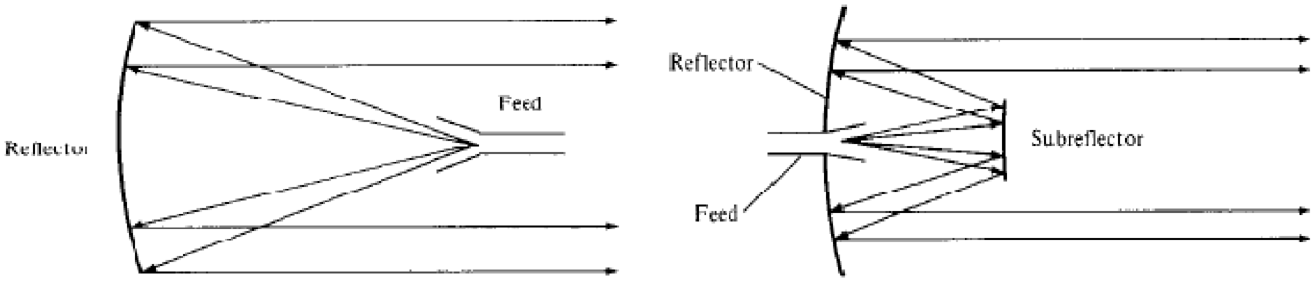


Figure 1.8 Typical reflector configurations

1.2.6 Lens Antennas

Lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions. By properly shaping the geometrical configuration and choosing the appropriate material of the lenses, they can transform various forms of divergent energy into plane waves. They can be used in most of the same applications as are the parabolic reflectors, especially at higher frequencies.

Their dimensions and weight become exceedingly large at lower frequencies. Lens antennas are classified according to the material from which they are constructed, or according to their geometrical shape. Some forms are shown in Figure 1.9.

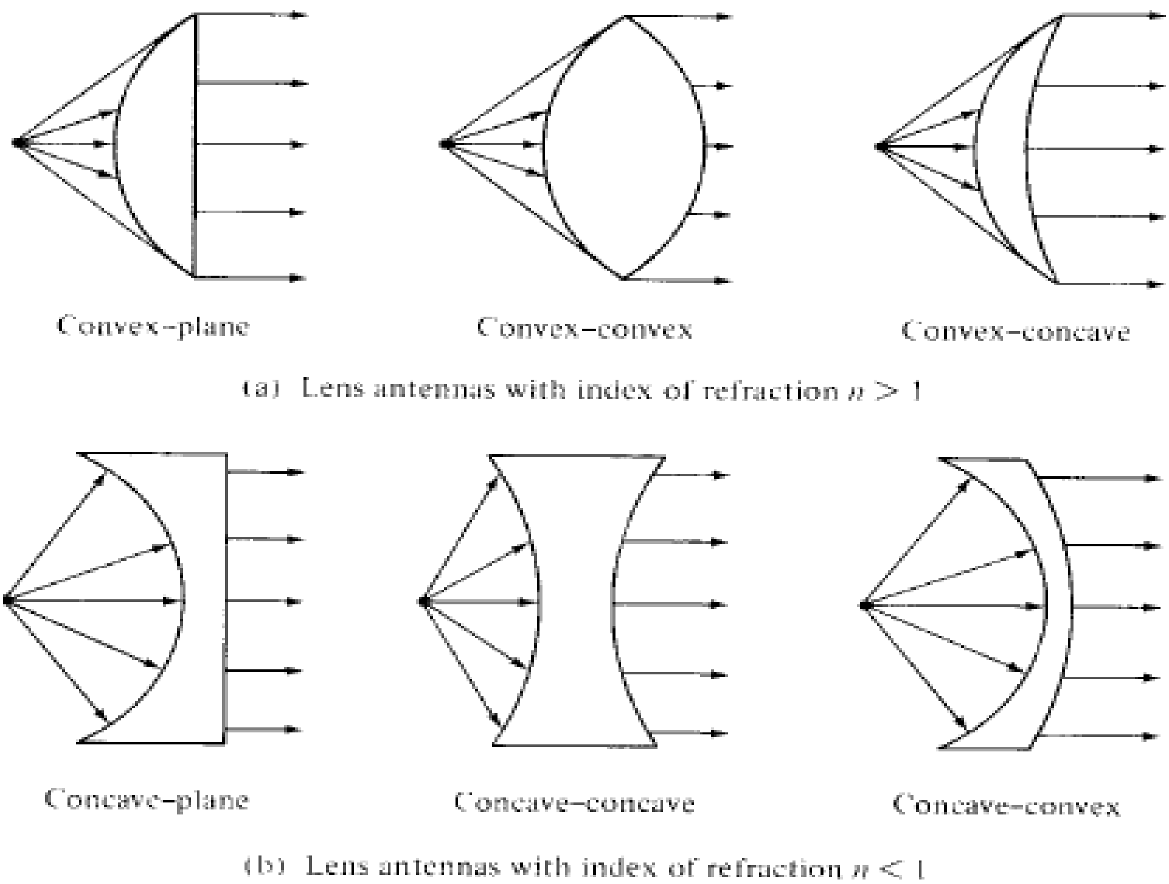


Figure 1.9 Typical lens antenna configurations.

1.3 Radiation Mechanism

One of the first questions that may be asked concerning antennas would be ***"how is radiation accomplished?"*** In other words, how are the electromagnetic fields generated by the source, contained and guided within the transmission line and antenna, and finally "detached" from the antenna to form a free-space wave? The best explanation may be given by an illustration.

1.3.1 Single Wire

Conducting wires are material whose prominent characteristic is the motion of electric charges and the creation of current flow. Let us assume that an electric volume charge density, represented by q_v (Coulombs/m^3), is distributed uniformly in a circular wire of cross-sectional area *A* and volume *V*, as shown in Figure 1.10. The total charge Q within volume *V* is moving in the z-direction with a uniform velocity v_z (meters/sec). It can be shown that the current density J_z (Amperes/m^2) over the cross section of the wire is given by:

$$J_z = q_v\, v_z \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1-1a)$$

If the wire is made of an ideal electric conductor, the current density (J_s) (amperes/m) resides on the surface of the wire and it is given by:

$$J_s = q_s\, v_z \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1-1b)$$

where q_s (coulombs/m^2) is the surface charge density. If the wire is very thin (ideally zero radius), then the current in the wire can be represented by:

$$I_z = q_l\, v_z \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1-1c)$$

where q_l (coulombs/m) is the charge per unit length.

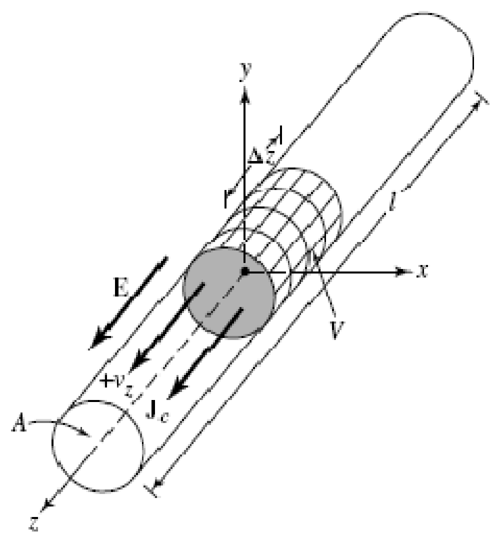


Figure 1.9 Charge uniformly distributed in a circular cross section cylinder wire.

Instead of examining all three current densities, we will primarily concentrate on the very thin wire. The conclusions apply to all three. If the current is time varying, then the derivative of the current of (1-1c) can be written as:

$$\frac{dI_z}{dt} = q_l \frac{dv_z}{dt} = q_l a_z \dots\dots\dots..(1-2)$$

where $\frac{dv_z}{dt} = a_z$ (meters/sec^2) is the acceleration. If the wire is of length (l), then Eq.(1-2) can be written as:

$$l\frac{dI_z}{dt} = lq_l \frac{dv_z}{dt} = lq_l a_z \dots\dots\dots..(1-3)$$

Equation (1-3) is the basic relation between current and charge, and it also serves as the fundamental relation of electromagnetic radiation. It simply states that to create radiation, there must be ***a time-varying current*** or an ***acceleration (or deceleration) of charge***.

References

1- Constantine A. Balanis, Antenna Theory analysis and Design, (3rd Edition), John Wiley & Sons, Inc, Hoboken, New Jersey, 2005.

2- Warren L. Stutzman and Gary A. Thiele, Antenna Theory and Design, (2nd Edition), John Wiley & Sons, Inc, N.Y., 1998.