REFLECTOR ANTENNAS

INTRODUCTION

The radiation pattern of a radiating antenna element is modified using reflectors. A simple example is that the backward radiation from an antenna may be eliminated with a large metallic plane sheet reflector. So, the desired characteristics may be produced by means of a large, suitably shaped, and illuminated reflector surface. The characteristics of antennas with sheet reflectors or their equivalent are considered in this chapter.

Some reflectors are illustrated in Figure 3.1. The arrangement in Figure 3.1a has a large, flat sheet reflector near a linear dipole antenna to reduce the backward radiation. With small spacing between the antenna and sheet this arrangement also yields an increase in substantial gain in the forward radiation. The desirable properties of the sheet reflector may be largely preserved with the reflector reduced in size as long as its size is greater than that of the antenna.

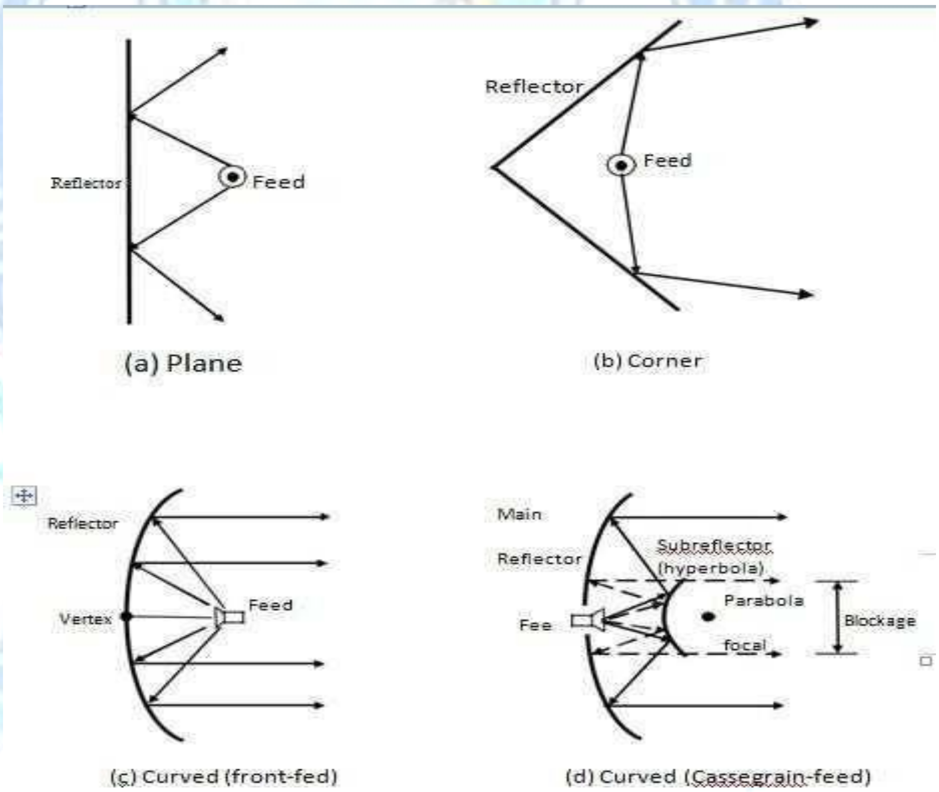


Figure 3.1 Some configurations of reflector antennas

With two flat sheets intersecting at an angle □ (<180) as in Figure 3.1b, a sharper radiation pattern than from a flat sheet reflector (□ =180) can be obtained. This arrangement, called *corner reflector antenna*, is most practical where apertures of 1 or 2□ are of convenient size. A corner reflector without an exciting antenna can be used as a *passive reflector* or target for radar waves. In this application the aperture may be many wavelengths, and the corner angle is *always* 90 . Reflectors with this angle have the property that an incidence wave is reflected back toward its source, the corner acting as a *retroreflector*.

When it is feasible to build antennas with apertures of many wavelengths, parabolic reflectors can be used to provide highly directional antennas. A parabolic reflector antenna is shown in Figure 3.1c. The parabola reflects the waves originating from a source at the focus into a parallel beam, the parabola transforming the curved wave front from the feed antenna at the focus into a plane wave front. A front fed and a cassegrain –feed parabolic reflectors are depicted in Figures 3.1c and d. Many other shapes of reflectors can be employed for special applications. For instance, with an antenna at one focus, the elliptical reflector produces a diverging beam with all reflected waves passing through the second focus of the ellipse. Examples of reflectors of other shapes are the hyperbolic and the spherical reflectors.

The plane sheet reflector, the corner reflector, the parabolic reflector and other reflectors are discussed in more detail in the following sections. In addition, feed systems, aperture blockage, aperture efficiency, diffraction, surface irregularities, gain and frequency-selective surfaces are considered.

PLANE REFLECTORS

Let an omnidirectional antenna is placed at a distance h above an infinite, flat, perfect electric conductor as shown in Figure 3.2. Power from the actual source is radiated in all directions in a manner determined by its unbounded medium directional properties. For an observation point p_1 ,there is a direct wave. In addition, a wave from the actual source radiated toward point R_1 of the interface undergoes a reflection. The direction is determined by the law of reflection which assures that the energy in homogeneous media travels in straight lines along the shortest paths. This wave will pass through the observation point p_1 . By extending its actual path below the interface, it will seem to originate from a virtual source positioned a distance h below the boundary. For another observation point p_2 the point of reflection is R_2 , but the virtual source is the same as before. The same is concluded for all other observation points above the interface.The amount of reflection is generally determined by the respective constitutive parameters of the media below and above the interface. For a perfect electric conductor below the interface, the incidence wave is completely reflected and the field below the boundary is zero. According to the boundary conditions, the tangential components of the electric field must vanish at all points along the interface. Thus for an incident electric field with vertical polarization shown by the arrows, the polarization of the reflected waves must be as indicated in the figure to satisfy the boundary conditions.

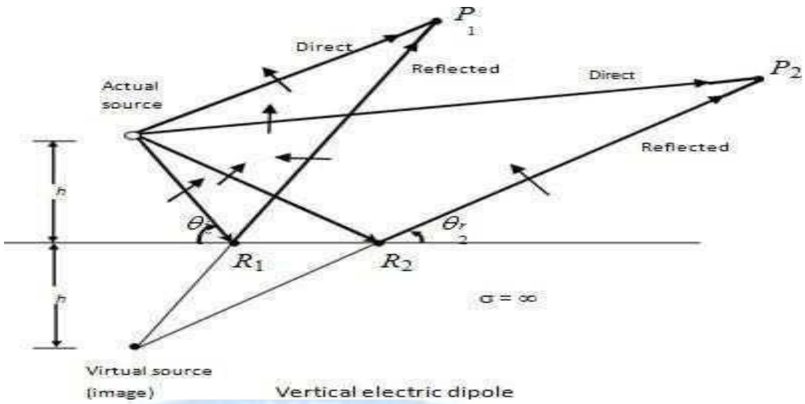
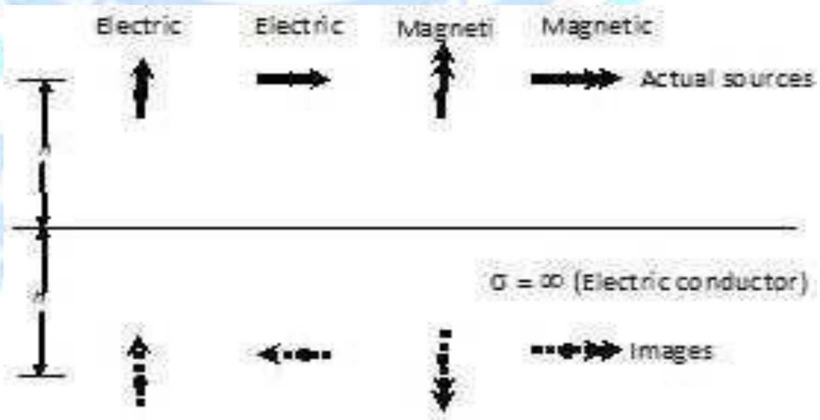


Figure 3.2 Antenna above an infinite, flat, perfect electric conductor.

For a vertical dipole, to excite the polarization of the reflected waves, the virtual source must also be vertical and with a polarity in the same direction as that of the actual source (thus a reflection coefficient of +1). Another orientation of the source will be to have the radiating element in a horizontal position, as shown in Figure 3.3. As shown in Figures 3.3, the virtual source (image) is also placed at a distance *h* below the interface. For horizontal polarized antenna, the image will have a 180 polarity difference relative to the actual source (thus a reflection coefficient of -1).

In addition to electric sources, artificial equivalent —magneticĀ sources have been introduced to aid in the analyses of electromagnetic boundary value problems. Figure 3.3 displays the sources and their images for an electric plane conductor. The single arrow indicates an electric element and the double a magnetic one. The direction of the arrow identifies the polarity.



Electric conductor

Figure 3.3 Electric and magnetic sources and their images near electric conductors

CORNER REFLECTOR

For better collimination of the power in the forward directions, an arrangement can be made with two plane reflectors joined so as to form a corner, as shown in Figure 3.10 (a). This is known as the corner reflector. Because of its simplicity in construction, it has many unique applications. For example, if the reflector is used as a passive target for radar or communication applications, it will return the signal exactly in the same direction as it received it when its included angle is 90 . This is illustrated geometrically in Figure 3.10(b). Because of this unique feature, military ships and vehicles are designed with minimum sharp corners to reduce their detection by enemy radar.

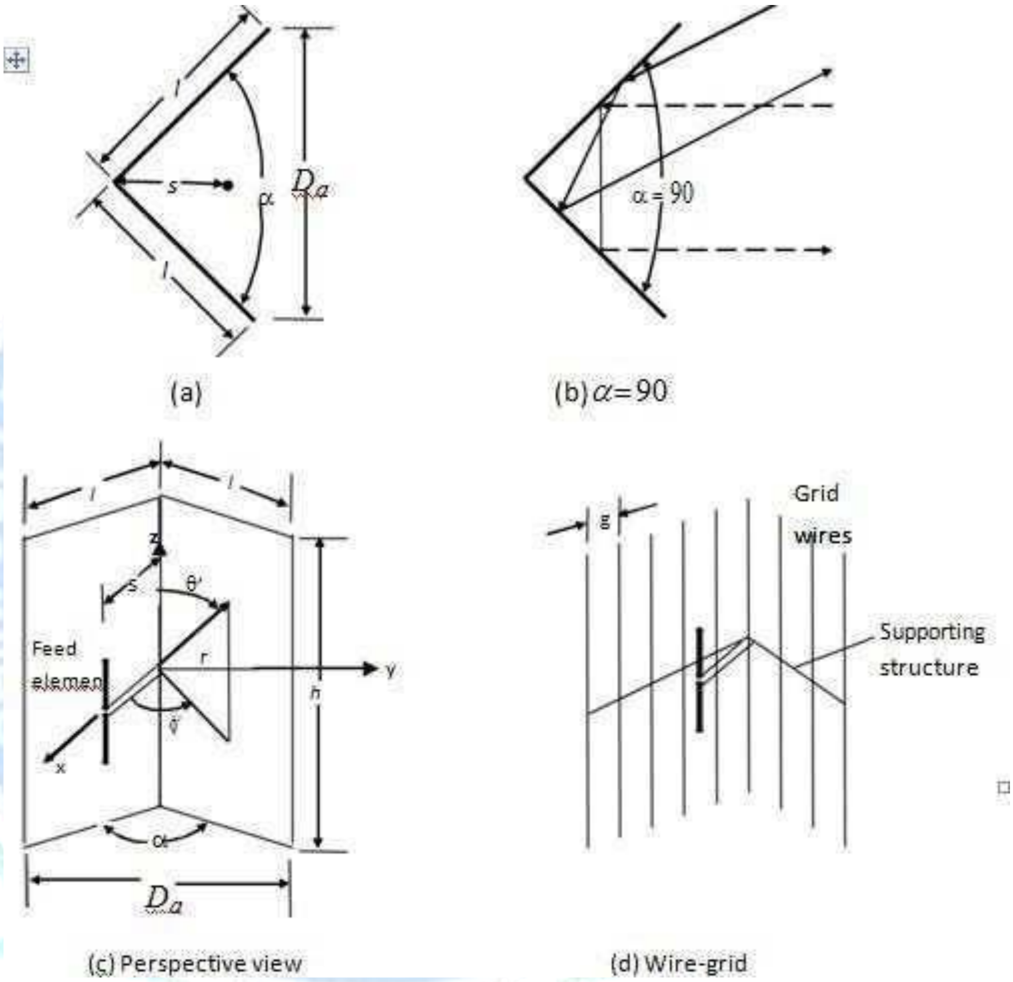


Figure 3.10 Side and perspective views of solid and wire-grid corner reflectors

In most practical applications, the included angle formed by the plates is usually 90 ; however other angles are also used. To maintain a given system efficiency, the spacing between the vertex and the feed element must increase as the included angle of the reflector decreases, and vice- versa. For reflectors with infinite sides, the gain increases as the included angle between the planes decreases. This, however, may not be true for finite size plates. For simplicity, in this chapter it will be assumed that the plates themselves are infinite in extent ($l = \infty$). However, since in practice the dimensions must be finite, guidelines on the size of aperture D_a , length (l), height (h) is given.

The feed element for a corner reflector is almost always a dipole or an array of collinear dipoles placed parallel to the vertex distance s away. Greater bandwidth is obtained when the feed elements are cylindrical or biconical dipoles instead of thin wires.

In many applications, especially when the wavelength is large compared to tolerable physical dimensions, the surfaces of the corner reflector are frequently made of grid wires rather than solid sheet metal.One of the reasons for doing that is to reduce wind resistance and overall system weight. The spacing g between wires is made a small fraction of a wavelength (usually g □ □/10).

For wires that are parallel to the length of the dipole, as is the case for the arrangement of Figure 3.10(d), the reflectivity of the grid-wire surface is as good as that of a solid surface. In practice, the aperture of the corner reflector (D_a) is usually made between one and two wavelengths □□ □ D_a □ 2□□. The length of the sides of a 90 corner reflector is most commonly taken to be about twice the distance from the vertex to the feed □l 2s□.

For reflectors with smaller included angles, the sides are made larger. The feed-to-vertex distance (s) is usually taken to be between □/3 and 2□/3 (□/3 < s < 2□/3). For each reflector, there is an optimum feed-to-vertex spacing. If the spacing becomes too small, the radiation resistance decreases and becomes comparable to the loss resistance of the system which leads to an inefficient antenna. For very large spacing, the system produces undesirable multiple lobes, and it loses its directional characteristics. It has been experimentally observed that increasing the size of the sides does not greatly affect the beam width and directivity, but it increases the bandwidth and radiation resistance. The main lobe is somewhat broader for reflectors with finite sides compared to that of infinite dimensions. The height (h) of the reflector is usually taken to be about 1.2 to 1.5 times greater than the total length of the feed element, in order to reduce radiation toward the back region from the ends.

The analysis for the field radiated by a source in the presence of a corner reflector is facilitated when the included angle (□) of the reflector is □ = □/n, where n is an integer (□ = □, □/2, □/3,

□/4, etc.). For these cases □□ □ 180 , 90 , 60 , 45 , *etc.*□it is possible to find a system of images, which when properly placed in the absence of the reflector plates, form an array that yields the same field within the space formed by the reflector plates as the actual system.

The number of images, polarity, and position is controlled by included angle and the polarization of the feed element. The geometrical and electrical arrangement of the images for corner reflectors with included angles of 90, 60, 45 and 30.

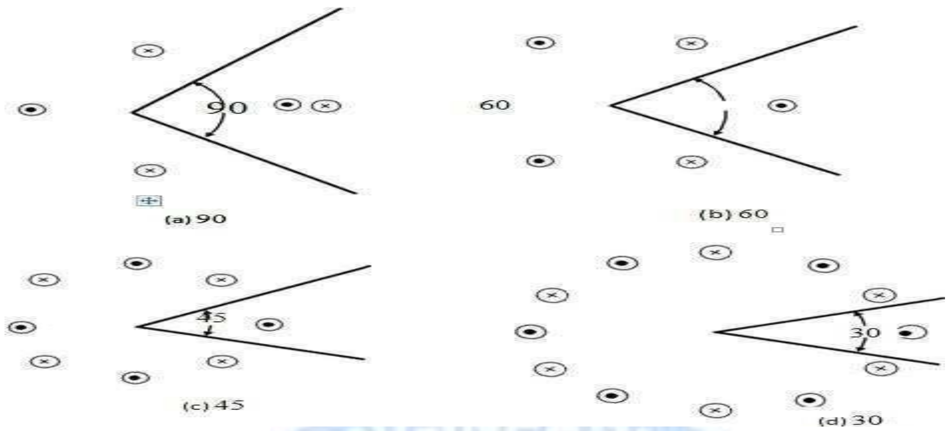


Figure3.11 Corner reflectors and their images (with perpendicularly polarized feeds) for angles of 90 , 60 , 45 *and* 30 **.**

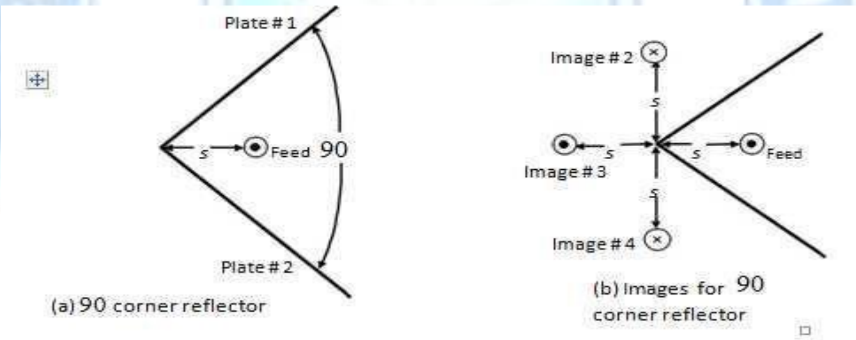


Figure4.12 Geometrical placement and electrical polarity of images for a 90 corner reflector with a parallel polarized feed.

PARABOLIC REFLECTOR

If a beam of parallel rays is incident upon a reflector whose geometrical shape is a parabola, the radiation will converge or get focused at a spot which is known as the *focal point*. In the same manner if a point source is placed at the focal point, the rays reflected by a parabolic reflector will emerge as a parallel beam. The symmetrical point on the parabolic surface is known as the *vertex*. Rays that emerge in a parallel formation are usually said to be *collimated*. In practice, collimation is often used to describe the highly directional characteristics of an antenna even though the emanating rays are not exactly parallel. Since the transmitter (receiver) is placed at the focal point of the parabola, the configuration is usually known as *front fed*.

A parabolic reflector can take two different forms. One configuration is that of the parabolic right cylinder, whose energy is collimated at a line that is parallel to the axis of the cylinder through the focal point of the reflector. The most widely used feed for this type of a reflector is a linear dipole, a linear array, or a slotted waveguide. The other reflector configuration is that which is formed by rotating the parabola around its axis, and it is referred to as a *paraboloid* (parabola of revolution). A pyramidal or a conical horn has been widely utilized as a feed for this arrangement.

CASSEGRAIN REFLECTORS

The disadvantage of the front-fed arrangement is that the transmission line from the feed must usually be long enough to reach the transmitting or the receiving equipment, which is usually placed behind or below the reflector. This may necessitate the use of long transmission lines whose losses may not be tolerable in many applications, especially in low-noise receiving systems. In some applications, the transmitting or receiving equipment is placed at the focal point to avoid the need for long transmission lines. However, in some of these applications, especially for transmission that may require large amplifiers and for low-noise receiving systems where cooling and weatherproofing may be necessary, the equipment may be too heavy and bulky and will provide undesirable blockage.

The arrangement that avoids placing the feed (transmitter and/or receiver) at the focal point is that shown in Figure 3.1(d) and it is known as the Cassegrain feed. Through geometrical optics, Cassegrain, a famous astronomer (N. Cassegrain of France, hence its name), showed that incident parallel rays can be focused to a point by utilizing two reflectors. To accomplish this, the main (primary) reflector must be a parabola, the secondary reflector (Subreflector) a hyperbola, and the feed placed along the axis of the parabola usually at or near the vertex. Cassegrain used this scheme to construct optical telescopes, and then its design was copied for use in radio frequency systems. For this arrangement, the rays that emanate from the feed illuminate the Subreflector and are reflected by it in the direction of the primary reflector, as if they originated at the focal point of the parabola (primary reflector). The rays are then reflected by the primary reflector and are converted to parallel rays, provided the primary reflector is a parabola and the subreflector is a hyperbola. Diffraction occurs at the edges of the subreflector and primary reflector and they must be taken into account to accurately predict the overall system pattern, especially in regions of low intensity. Even in regions of high intensity, diffraction must be included if an accurate formation of the fine ripple structure of the pattern is desired. With the Cassegrain-feed arrangement, the transmitting and/or receiving equipment can be placed behind the primary reflector. This scheme makes the system relatively more accessible for servicing and adjustments.

Cassegrain designs, employing dual reflector surfaces, are used in applications where pattern control is essential, such as in satellite ground-based systems, and have efficiencies of 65-80%. They supersede the performance of the single-reflector front-fed arrangement by about 10%. Using geometrical optics, the classical Cassegrain configuration, consisting of a paraboloid andhyperboloid, is designed to achieve a uniform phase front in the aperture of the paraboloid. By employing good feed designs, this arrangement can achieve lower spillover and more uniform illumination of the main reflector. In addition, slight shaping of one or both of the dual- reflector‘s surfaces can lead to an aperture with almost uniform amplitude and phase with substantial enhancement in gain. These are referred to as shaped reflectors. Shaping techniques have been employed in dual-reflectors used in earth station applications.

Two reflectors with ray geometry, with concept of equivalent parabola, are shown in Figure 3.19 The use of a second reflector, which is usually referred to as the subreflector or subdish, gives an additional degree of freedom for achieving good performance in a number of different applications. For an accurate description of its performance, diffraction techniques must be used to take into account diffractions from the edges of the subreflector, especially when its diameter is small.

In general, the Cassegrain arrangement provides a variety of benefits, such as the

1. ability to place the feed in a convenient location
2. reduction of spillover and minor lobe radiation
3. ability to obtain an equivalent focal length much greater than the physical length
4. capability for scanning and/or broadening of the beam by moving one of the reflecting surfaces

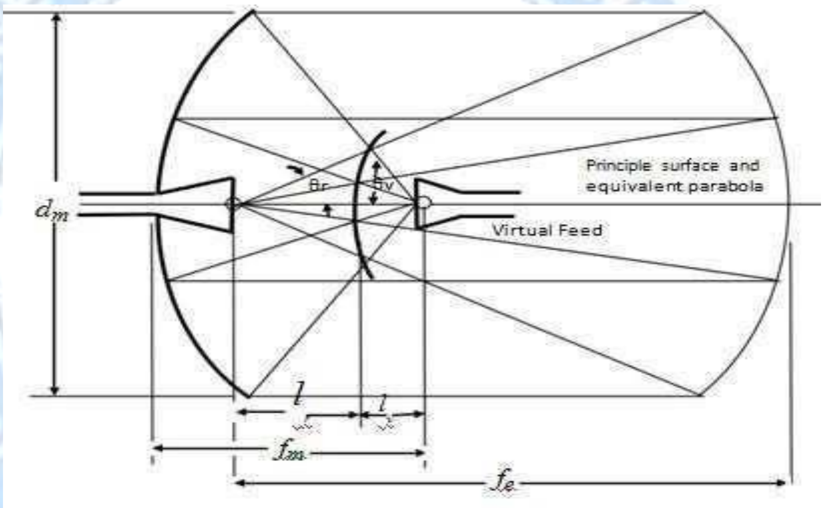


Figure 3.19 Equivalent parabola concepts.

To achieve good radiation characteristics, the subreflector must be few wavelengths in diameter. However, its presence introduces shadowing which is the principle limitation of its use as a microwave antenna. The shadowing can significantly degrade the gain of the system, unless the main reflector is several wavelengths in diameter. Therefore the Cassegrain is usually attractive for applications that require gains of 40 dB or greater. There are, however, a variety of techniques that can be used to minimize the aperture blocking by the subreflector. Some of them are minimum blocking with simple Cassegrain, and twisting Cassegrains for least blocking