CHAPTER I
INTRODUCTION

Antennas play an important role in determining the characteristics of any electronic system which depends on free space as the propagation medium. Basically, an antenna can be considered as the connecting link between free space and the transmitter or receiver. For radar and navigational purposes the directional properties of an antenna is its most basic requirement as it determines the distribution of radiated energy. Hence the study of directional properties of antennas has got special significance and several useful applications.

Scientific investigators have turned their attention to electromagnetic antennas ever since Hertz launched the decimeter radiation from a parabolic mirror antenna fed by a dipole in 1888. Since antennas are employed for a variety of applications, many different types of antennas had been developed, each suited to a particular type of application.

1.1 Types of Antennas

Antennas may be broadly categorised into dipole and aperture types. Simple one dimensional antennas like short and long wires, monopoles, dipoles and loops come...
under the category of dipole antennas. Aperture antennas concentrate, confine and guide the radiated energy so that it appears as though passing through an aperture.

1.1(i) Dipole Antennas

One dimensional linear wire antenna is the simplest form of an antenna. This type of short and long wires which provide information for comparing other antennas, have a uniform current distribution over its entire length.

One of the most commonly used antennas is the centre-fed dipole which consists of a wire whose length is an appreciable portion of a wavelength. This wire is fed by a voltage generator at its centre. The current distribution on these types of antennas is approximately sinusoidal with zero currents at the ends of the antennas. For short dipoles, the current distribution is approximately triangular, instead of sinusoidal.

Another type of antenna that is widely used for broadcast applications, is the monopole antenna. This is a modification of the dipole in which a plane conducting screen is placed at the centre of the antenna at right angles to the antenna axis. Currents flowing in the conducting screen simulate the missing half of dipole to create an image in the same way as a mirror forms an optical
image. The monopole antenna is usually preferred to a dipole for situations requiring an omnidirectional, vertically polarized antenna because the monopole is cheaper to construct and the earth can be easily used as the conducting ground plane.

Folded dipole is a modification of ordinary dipole and it consists of two or more electric dipoles joined at the ends. In this case the antenna terminals are located at the centre of one of the conductors. Another important antenna which finds extensive application in direction finding is the loop antenna. It is made up of one or more turns of highly conducting wire around a frame that may have a circular, square or rectangular shape. A small loop antenna is also used as a probe for measuring magnetic fields.

Many other types of antennas have been developed for special applications. Turnstile antenna, consisting of two dipoles oriented at right angles to each other, is widely used for producing elliptically and circularly polarized beams. A few of the different types of dipole antennas are shown in Fig.1.1(i)(a).

1.1(ii) Aperture Antennas

Dipole antennas have low gain and omnidirectional radiation patterns. Hence antennas having larger effective
Ordinary dipole  Folded dipole  Biconical dipole

Fig. 1.1(i)(a) Sketch of different types of half-wave dipole antennas.

Horn  Lens  Reflector

Fig. 1.1(ii)(a) Sketch of different aperture type antennas. $S_a$ is the aperture surface.
area, called aperture antennas, are employed for situations requiring higher gain and more directive radiation patterns.

There are many types of aperture antennas for which the electromagnetic radiation may be considered as passing through a physical aperture. The horn, lens and reflector antennas, shown in Fig.1.1(ii)(a), belong to these class of antennas.

Horn antennas have a variety of shapes in order to control the different antenna characteristics like gain, radiation pattern and impedance. An important advantage of horns is that it can eliminate feed-to-radiator transition losses\(^{(98)}\). A detailed discussion of these types of antennas will be presented in the next section.

Reflector antennas are used with radar and communication systems in which a large gain is required. These antennas consist of a relatively small feed and a large reflecting surface and produce pencil, fan or specially shaped radiation patterns. For paraboloidal reflector antennas, which is generally used for many applications, the reflector is conventionally a symmetrical, cylindrical or offset parabola. In order to avoid the aperture blocking due to the feed and losses encountered with a small driven element, a special type of reflector antennas, called
Cassgrain antennas, are employed. In this system, the energy is fed through the rear of the centre of the main parabolic surface.

Corner reflectors are another type of directive radiators which use a dipole as the primary radiator. Different characteristics of this type of antennas will be given later. There are several other reflectors like pill box, parabolic torus and hog horn designed for specific applications.

Microwave lens antennas employ dielectric material to focus the energy and to produce narrow pencil beam radiation. One of the advantages of the lens antennas over the reflector types is that it has considerably less rearward radiation.

Surface wave antennas, a type of aperture antennas, operate because of the discontinuity of guiding surface which causes the wave to give out power. Another type called slotted waveguide antenna radiates energy by virtue of the discontinuities introduced by insertion of longitudinal slots. By varying the length and position of the slots, the radiation from these antennas can be conveniently controlled.
Arrays of these aperture antennas are also widely used for obtaining higher directivity and gain.

1.2 Electromagnetic Horn Antennas

Electromagnetic horn antennas are the convenient form of directional antenna systems, capable of accommodating a broad band of frequencies. In the words of Southworth\(^{(1)}\)"An electrical horn not only possesses considerable directivity but it may also provide a moderately good termination for the pipe to which it is connected. In so doing, its function is probably quite analogous to that of a true acoustic horn which provides an efficient radiating load for its sound motor".

Since the directivity is proportional to the aperture size, it may seem that higher directivity can be achieved by increasing the waveguide dimensions. But, if the dimensions of the waveguide are sufficiently large, higher order modes will be generated. Greater directivities without higher order modes can be achieved by a gradual transition produced by flaring the terminal section of waveguide to form an electromagnetic horn. Though higher order modes are generated at the throat, the horn acts as a filtering device allowing only a single mode to be propagated freely to the aperture. The horn will not support
free propagation of a particular mode until roughly the transverse dimensions of the horn exceed those of a waveguide which would support the given mode. Thus, unless the flare angle is too large, all but the dominant mode will be attenuated to a negligible amplitude in the throat region before free propagation in the horn space is possible.

Horn antennas are constructed in a wide variety of shapes to suit specific requirements. Pyramidal horns, sectoral horns and circular horns are the most frequently used types of horns. Fig. 1.2(i) shows the different types of horns.

For a pyramidal horn, with flaring in both the principal planes, the gain can be calculated from its dimensions to a good degree of accuracy. Hence, these are commonly used as primary gain standard. Again, these are used to obtain certain specific radiation patterns independently in the two principal planes.

Sectoral horns are a special type of pyramidal horns where only one plane (E or H) is flared, with the other two opposite sides remaining parallel to each other. If the E-plane of a rectangular waveguide is flared, then it is called an E-plane sectoral horn and if the H-plane is flared it is called an H-plane sectoral horn. They are
Fig. 1.2(i) Sketch of the different types of horns that are generally used.
generally used to obtain beams of specified sharpness in the plane containing the flare. The pattern in the unflared plane will be the same as that of an open-ended waveguide.

Conical horns are simple antenna structures, capable of handling any polarization due to its complete axial symmetry. These are also used as primary gain standard because the gain of conical horns can be accurately calculated.

Another type of horn antenna which gives rotationally symmetric radiation patterns and broad band performance was realized by Simmons and Kay\(^{(33)}\) and is called 'scalar feed'. The 'scalar feed' is a conical horn antenna with grooves perpendicular to the wall of the horn.

The biconical horn finds use where an omnidirectional horizontal radiation pattern is desired. This type of antenna finds extensive use in the VHF-UHF band for broadcasting purposes.

Besides, there are different types of horns like hog horn and asymmetric horn which are used as efficient feeds for parabolic antennas.
1.3 Beam Shaping of Sectoral Horns

Several methods have been developed\(^{52-59}\) to modify the radiation from sectoral horn antennas. Corrugating the walls of sectoral horns is one method to obtain symmetric beam pattern and broadband performance.

Another method of improving the directivity of sectoral horns is the use of metal plate lenses suggested by Rust\(^8\). Dielectric pieces cut in specific shapes placed at the mouth of sectoral horns also have been found to be improving the radiation characteristics of sectoral horn antennas. The use of such dielectric loaded horn antennas can increase the directivity of the antenna in its flared plane.

For many applications like illuminating a paraboloidal reflector antenna, it is desirable that the radiation pattern of the feed should be symmetrical about their principal axes. Hence, in order to get a symmetrical radiation pattern from a sectoral horn, the beam shape in its unflared plane also should be modified. The flange technique, suggested by Owen and Reynolds\(^{57}\) and later modified by several other workers\(^{58-67}\), is an efficient and simple method to control the pattern shape in the unflared plane of sectoral horns. They have shown that,
by controlling the various flange parameters like flange width, flange angle etc., the radiation pattern in the unflared plane of H and E-plane sectoral horns can be conveniently adjusted.

1.4 Horn Antennas asCircularly Polarized Radiators

Circularly polarized radiators are often required by communication satellite antenna because it can respond to a linearly polarized wave of arbitrary orientation. A horn antenna can be used to produce circularly polarized radiation, if it is fed with waveguide capable of propagating vertically and horizontally polarized waves simultaneously.

When the horn is fed through a square waveguide with equal amplitude vertically and horizontally polarized modes arranged to be in quadrature, a circularly polarized field will be obtained at the peak of the radiation. At other points on the radiation pattern, the radiated field will not be circularly polarized because the beamwidths of the vertically and horizontally polarized radiation patterns will be different in any particular plane.

A diagonal horn antenna, suggested by Love(85) also can be used to produce circularly polarized waves. In a diagonal horn antenna, the mode of propagation within the horn is such that the electric vector is parallel to one of
the diagonals. By inserting a differential phase shifter in the waveguide, a phase quadrature between the two orthogonal modes in the diagonal horn can be obtained. A properly designed differential phase shift section can produce circular polarization over a wide range of frequencies.

1.5 Corner Reflector (CR) Antennas

This new type of antenna system was first suggested by Kraus(73). The corner reflector antenna, which consists of two conducting planes that intersect at an angle and a driven radiator (usually a half-wave dipole), has been widely used as a compact high gain antenna because of the simplicity of its construction. The dipole radiator of the CR antenna can be either vertically oriented (parallel to the apex of the CR system) or horizontally oriented (perpendicular to apex), as shown in Figs.1.5(i) and (ii) respectively. Assuming the reflector elements to be perfectly conducting and infinite in extent and by using the method of images Kraus derived analytical expressions for the gain and directional radiation patterns of the antenna.

The distance of the primary feed (usually dipole) from the apex of the reflectors and the corner angle of the CR system are important parameters determining the shape of the radiation pattern of the antenna. According to Kraus(73),
Fig. 1.5(i) Schematic representation of corner reflector antenna with vertically oriented dipole feed.

Fig. 1.5(ii) Schematic representation of corner reflector antenna with horizontally oriented dipole feed.
when the reflector elements have large dimensions, the width and length of the elements have negligible effect on the radiation pattern. One of the important effects of corner reflectors is to concentrate the radiation in the direction of the bisector of the corner and to produce a focused beam in the axial direction.

When the corner angle is 90°, the reflecting sheets intersect at right angles, forming a "square corner reflector". An interesting property of the square corner reflector is that, when the driven dipole is displaced to one side of the plane bisecting the corner angle, the maximum of the directional pattern is displaced to the opposite side. Thus, by using two suitably displaced dipoles, two directional patterns are obtained having their maxima displaced to opposite sides of the bisecting plane. Such an arrangement finds very useful applications in a single-course radio range beacon or an airport runway localizer.

An important characteristic of the CR antenna is that it will return a signal in the same direction exactly in which it was received. Because of this characteristic, military vehicles and ships avoid, in their design, sharp corners which can form corner reflectors. Such structures make it easier to be detected by enemy radars. Again, a uniform directional pattern in the horizontal plane, often
required in radio broadcasting, can be easily achieved by employing a number of CR antennas, oriented in different directions. Since the reflector dimensions are not critical regarding the frequency, the CR systems are well suited for transmission and reception of broad frequency bands, such as used in television and wideband frequency modulation.

Corner reflector antennas also can be used for producing circularly polarised radiation by adjusting the various antenna parameters. For certain corner angles such that the horizontal and vertical components of radiation are in phase quadrature, the orientation of the dipole can be adjusted so that they have equal magnitude, and the resultant radiation is then circularly polarized. For corner reflectors whose apex angles are submultiples of 90°, circular polarization is found to be possible for every dipole-to-apex spacing except those for which the horizontal or vertical component of radiation becomes zero. Thus, by properly adjusting the distance of the primary feed dipole and its orientation, the simple CR antenna can be easily converted to a circularly polarized radiator.

1.6 Brief Sketch of the Present Work

Improving the performance of sectoral horns and corner reflector antennas have been a subject of interest
for many years, because of their suitability in communication and radar applications. The use of corrugated surfaces have already been proved to be effective in improving the radiation characteristics of sectoral horn antennas\textsuperscript{(33-35)}. In the present study, the possibility of controlling the different antenna characteristics like radiation patterns and matching conditions of sectoral horns and CR systems have been investigated in detail.

Investigations were carried out on the various antenna characteristics of plane flanged sectoral horns and plane CR systems. The important aspects taken for this study include the variations in beamshape, gain and impedance conditions with various parameters like frequency and included angle of flanges or reflectors. A comparative analysis between the results obtained with both systems have indicated an analogy between the behaviour of flanged horns and CR systems. Hence, intense study on both systems using corrugated flanges and corrugated reflectors were performed to investigate the validity of this analogy between the two systems and to improve the performance of these antennas. A method has also been developed to obtain elliptically and circularly polarized radiation from both flanged horns and CR systems using surfaces with inclined corrugations.
A theoretical analysis of the radiation from flanged sectoral horns is attempted on the basis of the Line Source Theory. For explaining the results obtained using CR system, the method of images have been employed. Radiation patterns were computed on the basis of these theories and they show fairly good agreement with the experimental results.

A brief outline of the work presented in this thesis is as follows: Chapter 2 presents a comprehensive study of the past work done in the field of electromagnetic horns and CR systems. In this chapter, various papers dealing with theoretical and experimental investigations on horns and corner reflectors are reviewed. Different methods to modify the radiation characteristics of these antennas are studied. The purpose of this chapter is to provide an insight into the different types of techniques employed for beam shaping of sectoral horns and corner reflectors.

Chapter 3 is exclusively devoted for describing the various experimental techniques employed in the present investigation. The important equipment and antenna components used in this study are also described in this chapter.
In chapter 4, the experimental results obtained using flanged sectoral horns and CR systems are presented. The results obtained using inclined corrugated flanges and reflectors for producing elliptically and circularly polarized radiation are also given in this chapter.

Theoretical aspects of flanged sectoral horns and CR systems are discussed in chapter 5. Radiation patterns, plotted using the theoretical expressions derived, have been compared with the experimental results. In analysing the radiation from the CR systems, the primary feed dipole has been approximated as an infinitesimal one.

In chapter 6, the final conclusions drawn from the study on flanged sectoral horns and CR systems are presented. The advantages obtained by the use of corrugated surfaces and the similarity in behaviour between the two systems are pointed out in this chapter. The scope for further work in this field is also indicated.

While taking antenna measurements inside an anechoic chamber, an antenna positioner (turn-table) has been used. The positioner is fully automatic and is operated from outside where recording instruments are arranged. This remote control system was designed and fabricated as an ancilliary work and a description of this is presented in Appendix I.
A major part of the work presented in this thesis was performed inside a microwave anechoic chamber, the design and fabrication of which is recently completed. The performance evaluation of this chamber was a part of the activity of the author. This evaluation procedure and the results therefrom are discussed in Appendix II.