CHAPTER II
REVIEW OF THE PAST WORK IN THE FIELD

Radiation characteristics of electromagnetic horn antennas and corner reflector systems were studied theoretically and experimentally by several investigators. A bulk of such investigations have been reported in literature. This chapter provides a brief review of the work published in the field of electromagnetic horns and corner reflector antennas.

2.1 Electromagnetic Horn Antennas in General

Though, Barrow\(^{(2)}\) suggested the concept of electromagnetic horn in 1936, the actual experimental investigations on horn antennas were started only in 1939 by Barrow and Lewis\(^{(3)}\). They conducted elaborate experimental investigations on sectoral horns. Their studies revealed that electromagnetic horn antennas possessed broad bandwidth, high directivity and low side lobe level.

In a companion paper, Barrow and Chu\(^{(4)}\) gave theoretical analysis of the operation of the electromagnetic horns, based on Maxwell's equations. Though the analysis applies specifically to sectoral horns, it provides a clear physical picture of the operation of electromagnetic horns of any shape.
Using Huygens' principle, they calculated the shape of the radiation field at a large distance from the mouth of the horn, by assuming the distribution across the mouth to be same as if the sides of the horn were extended to infinity. The radiation patterns calculated on the basis of this analysis were found to be in satisfactory agreement with the experimental results reported by Barrow and Lewis(3).

Southworth and King(5) conducted experiments to determine the directive properties of circular waveguides and conical horns. Their investigations showed that conical horns can provide power improvements of some hundred times that of an ordinary simple half-wave antenna. They also studied the effect of horn dimensions on the directivity of the antenna and showed that there is an optimum angle of flare giving maximum directivity.

Some important principles for the design of sectoral and pyramidal horns were given by Chu and Barrow(6). According to them, for sufficiently great horn lengths, the beamwidth of the radiation pattern is almost equal in magnitude to the flare angle.

In another paper, Chu(7) gave a theoretical analysis for the radiation properties of hollow pipes and horns. Using vector Kirchhoff formula, he derived expressions for the
radiation fields from the transverse electric wave in hollow pipes of circular and rectangular cross section. The formulae for the radiation fields of $TE_{01}$ and $TE_{10}$ waves in a sectoral horn are also given in this paper.

A 'microwave lens' technique for phase correction of horn radiators was put forward by Rust$^{(8)}$ in 1946. He used metal partitions acting as sections of waveguides to obtain the correction. The partitions were arranged radially and the correction is effected by adjusting their length.

Extensive experimental investigations on the radiation patterns of electromagnetic horn antennas were carried out by Rhodes$^{(9)}$. He measured the radiation patterns of a number of horns with lengths ranging from zero to fifty wavelengths. His results showed that, as the aperture of the horn becomes very large, the $E$-plane pattern has large number of side lobes of considerable magnitude.

Bennett$^{(10)}$ analysed the sectoral horn antenna by considering it as one component of an over-all microwave transmission system. Equivalent network functions were derived on the assumption of the sectoral horn as a non-uniform transmission line. The physical significance of the derived normalised functions is also discussed in this paper.
A method for computing the radiation patterns of rectangular and circular horns for some common modes of vibration is developed by Horton\textsuperscript{(11)}. He argued that the radiation patterns derived for an open waveguide may be applied directly to an electromagnetic horn, as long as the flare angle is not too large. He also presented a few experimental observations to illustrate the fairly good agreement between theory and experiment.

King\textsuperscript{(12)} reported the experimental results observed with conical horn antennas employing waveguide excitation. Conical horns giving maximum gain for a given axial length were considered by him as optimum horns. He gave the dimensional data in terms of wavelength for the design of optimum horns.

In the same year, Schorr and Beck\textsuperscript{(13)} published a paper in which they calculated the radiation from conical horn in integral form. The calculated radiation patterns showed fairly good agreement with experimental results, for horns of small flare angle and moderate length.

Jakes\textsuperscript{(14)} performed experimental investigations to calculate the gain of pyramidal horns. By measuring the power transmitted between two identical horns, he estimated the error experimentally in the theoretical value of the gain and found it to be less than 0.2 db.
Braun\textsuperscript{(15)} gave further experimental verification for the variations in the measured gain with aperture separation of horns. He also developed a theory which was found to be in good agreement with experimental data. He presented a set of curves from which the error in gain can be directly determined.

In a subsequent paper, Braun\textsuperscript{(16)} presented a table from which the gain of sectoral horns can be readily determined by knowing their aperture dimensions. He gave a simple procedure for the design of optimum horns having specified characteristics.

Epis\textsuperscript{(17)} employed several aperture modifications to conical and square-pyramidal horns, for obtaining an axially symmetric radiation pattern. The important advantage of these types of horns, called compensated horns, is that the equalisation of E- and H-plane patterns is present for all polarizations.

Walton and Sundberg\textsuperscript{(18)} suggested a method to increase the bandwidth of operation of ridged horns. The large phase error occurring at the mouth of the horn is the basic reason for the low bandwidth of these types of horns. According to their design, a dielectric lens can be easily used to reduce the phase error to a minimum.
A method for calculating the E-plane pattern of horn antennas using diffraction theory was put forward by Russo et al(19) in 1965. When the diffraction theory is applied to horns, the radiation from the horn is considered to be due to the diffraction by the E-plane edges and by direct radiation from apex of the horn. Theoretical and experimental patterns were found to be in excellent agreement. In another paper, Yu et al(20) used the same edge diffraction techniques to analyse the radiation from typical horn antennas. In their paper, the higher order diffraction at the edge and the reflection inside the antenna had also been taken into consideration.

Using near field power transmission formula, Chu and Semplak(21) calculated correction ratios for the far zone gain of pyramidal horns. They applied these calculated corrections in the absolute gain measurement of a standard horn. Using these corrections they achieved an accuracy well below 0.1 db in the gain measurement of pyramidal horns.

Jull(22) gave some revised corrections to determine the gain measurements more accurately. He also estimated the accuracy of Schelkunoff's(23) gain-expression. In another paper, Jull(24) incorporated the finite-range effects in the Fresnel zone into Schelkunoff's gain-formula for pyramidal horns. Thus he obtained a more accurate expression for the
gain of pyramidal horn antennas. The gain of E- and H-plane sectoral horns could be easily found by omitting certain terms from this expression. Jull\(^{(25)}\) also used the geometrical theory of diffraction to account for the small oscillations observed in the gain versus wavelength curve of horns.

Hamid\(^{(26)}\) applied the geometrical theory of diffraction by Keller, to investigate the gain and radiation pattern of conical horns. In his analysis the edge rays excited at the aperture plane of the horn were also taken into account. The predicted results for the gain and radiation pattern of conical horns of various dimensions showed excellent agreement with the experimental results of King\(^{(12)}\).

Muehldorf\(^{(27)}\) calculated the phase centres of different antennas, based on a vector approach. He also gave graphs to show the dependence of the phase centres on the horn dimensions.

Kerr\(^{(28)}\) reported the design of short axial length broadband horns which find extensive use for electromagnetic compatibility measurements.

Using geometrical theory of diffraction, Jull\(^{(29)}\) derived the complex reflection coefficient of a long E-plane sectoral horn which agrees well with experiment.
Jull\textsuperscript{(30)}, in another paper, developed a new gain formula in accordance with one of his earlier proposals\textsuperscript{(31)}. This new formula was found to agree much more with experiment.

Mentzer\textsuperscript{(32)} used slope diffraction function to evaluate the H-plane pattern of a horn antenna. The computed patterns showed excellent agreement with experimental results.

2.2 Corrugated Horns

Investigations by Simmons and Kay\textsuperscript{(33)}, in the United States, indicated that grooved walls in a horn can produce a tapered aperture field distribution in all planes. The characteristic of such a grooved wide flare angle horn, called 'scalar feed', is that the radiated energy is confined to the angular sector determined by the horn's flare angle. Besides, the beamwidth of the horn is a constant over a wide frequency band. His studies also showed that the gain of the 'scalar feed' is 0.6 to 0.8 dB higher than that of a standard feed.

Lawrie and Peters\textsuperscript{(34)} have demonstrated that the use of a corrugated structure in the walls of a horn can reduce the back lobe level of the antenna. Such a horn was found to produce an equal E- and H-plane pattern.

Clarricoats and Saha\textsuperscript{(35)} analysed the propagation behaviour of corrugated cylinder and presented results which
help to the design of horns with narrow-flare-angles and of circular cross sections. A procedure for obtaining a balanced hybrid condition in the horn aperture was also discussed by him.

The effect of frequency on the symmetry properties of the balanced-hybrid-mode fields propagating in corrugated conical horns were studied by MacA. Thomas\(^{(36)}\).

Narasimhan and Rao\(^{(37,38)}\) derived expressions for the radiation pattern and gain of corrugated conical horns. Their theoretical results were in close agreement with the experimental results of Jeuken\(^{(39,40)}\).

Clarricoats and Saha\(^{(41,42)}\) in a long two-part paper, reported an exhaustive theoretical and experimental investigation of the propagation and radiation behaviour of corrugated feeds. The first part of these papers deals with the analysis of corrugated waveguides. In the second part, the radiation patterns of corrugated conical horns obtained by a Kirchhoff-Huygen aperture integration method and a new method, called modal expansion, are presented.

Clarricoats et al\(^{(43)}\), in another paper, analysed the near-field radiation characteristics of corrugated horns by a spherical-mode-expansion method. Typical results
obtained for horns with flare semiangles of $12^\circ$ and $70^\circ$ are also presented in this paper.

Considering the radiation from the finite aperture of a corrugated horn, Baldwin and McInnes (44) checked experimentally an expression derived by Anderson (45) for the radiation pattern of a surface wave antenna.

Mentzer and Peters (46) studied the influence of corrugation parameters on the power loss, surface current and the scattering from a groundplane-corrugated surface junction. The same authors, in another paper (47), analysed the radiation patterns of corrugated horns using aperture integration and diffraction theory. Their method could predict the E-plane side lobe and back lobe levels of corrugated horns.

Baldwin and McInnes (48) studied the propagation and radiation characteristics of moderate-flare-angle rectangular horns which have transverse corrugations on two walls. In the same year, these authors published another paper (49) which described the design of a corrugated horn to produce an elliptical beam for either of two orthogonally polarized signals.

Bielli et al (50) developed a new method for computing the phase centre of corrugated horns. The same authors (51)
also analysed the characteristics of corrugated conical horns radiating in a balanced hybrid mode.

2.3 Beam Shaping and Polarization Characteristics of Horn Antennas

Pao\(^{(52)}\) from his elaborate study on horn antennas, observed that small pins and other obstacles placed at the mouth of H-plane sectoral horns are useful in narrowing the primary H-plane patterns of the antenna. The impedance matching was also found to be improved by the presence of the pins.

Hariharan and Nair\(^{(53-54)}\) conducted a series of experiments on sectoral horn antennas fitted with grills. Their investigations indicated that the grill system modifies the E-plane radiation patterns of E-plane sectoral horns with considerable improvement in impedance conditions. Nair et al\(^{(55-56)}\) analysed the effect of grills on the radiation patterns of sectoral horns. Their theoretical results were in good agreement with experimental observations.

Owen and Reynolds\(^{(57)}\) were the first to study the effect of flanges on the E-plane patterns of H-plane sectoral horns. Later Butson and Thompson\(^{(58)}\) conducted an exhaustive study on flange mounted sectoral horns and waveguides. They
derived an expression for the far field radiation patterns from these antennas, assuming the aperture of sectoral horn as a linear source.

Nair and Srivastava\textsuperscript{(59)} observed that the position of flanges from the aperture of horn affects tremendously the shape of the radiation pattern. A bulk of experimental and theoretical investigations were reported by Nair et al\textsuperscript{(59-67)} to establish the effect of flanges on the radiation characteristics of sectoral horns. They also found\textsuperscript{(68)} that the H-plane pattern of E-plane sectoral horns could be controlled with metallic flanges.

Ching and Wickert\textsuperscript{(69)} developed a multimode rectangular horn antenna generating a circularly polarized beam. Polarization properties of this antenna reveal that it has a very low off-axis polarization axial ratio.

Using circular waveguide loaded with reactive irises, Gruner\textsuperscript{(70)} designed a circularly polarized feed horn. He obtained axial ratio below 1.65 db, over a wide frequency band. Ebisui et al\textsuperscript{(71)} also used flare-iris type dual-mode horn antenna to obtain a perfect circularly polarized radiation.
Ebisu(72), in another paper, described the theory of a circularly polarized flare-iris type dual-mode horn antenna and measured the radiation and polarization characteristics by a model antenna. They obtained an axial ratio below 0.3 db in the frequency band 3.9 to 4.2 GHz.

2.4 Corner Reflector Antennas

Kraus(73) found that a highly effective directional system results from the use of two flat, conducting sheets arranged to intersect at an angle forming a corner. The performance of such a beam antenna called corner reflector, was theoretically and experimentally studied by him. He used the method of images to calculate the radiation from corner reflector. The computed and measured directional patterns were in good agreement.

Moullin(74) gave more theoretical background and design data of corner reflector antennas. He proved that the directional pattern of a corner reflector system can be expressed in the form of a series of Bessel functions. Wait(75) showed that Moullin's theory can be extended to any angle by simply admitting multi-valued solutions of the wave equations in cylindrical coordinates.
Harris\(^{(76)}\) reported a detailed experimental investigation on the radiation patterns of corner reflector antennas. He studied in a systematic manner the variation in radiation patterns with different parameters of the corner reflector. He also investigated the beam tilting of the radiation pattern, when the driven dipole is kept off-axis.

Cottony and Wilson\(^{(77-78)}\) also conducted exhaustive experimental investigations on the gain and radiation patterns of finite-size corner reflectors. They made a detailed and systematic study of the effects of length and width of reflecting surfaces on the gain of the antenna. In their second paper, they summarised the effect of widths and lengths of the surfaces on the widths of the main lobe in a series of curves. Their results also revealed that quite low levels of secondary radiation may be obtained by the use of corner reflector antennas of moderate dimensions.

Using geometrical method of diffraction, Ohba\(^{(79)}\) calculated the gain and radiation patterns of corner reflector antennas finite in width. The results were compared with the experimental results of Cottony and Wilson\(^{(77-78)}\). In the rear direction, it was necessary to take into account the effects of the waves diffracted by the upper and lower edge of the reflector. His method can be used to compute the backscattering from an antenna having conducting plates finite in extent.
Proctor\(^{(80)}\) presented a series of computer derived design charts for maximising the radiated field from a corner reflector. He has also given the optimum feed positions for various corner reflector angles. According to him, the length of the reflector should not exceed around three times the spacing between the driven element and apex.

Aoki and Tsukiji\(^{(81)}\) reported an analytic method using field theory, for finding the radiation field of finite-size corner reflector antenna. The method is useful to analyse corner reflectors having arbitrary aperture angle and unsymmetrical structure.

Ja\(^{(82)}\) determined phase centres in the principal H-plane of corner reflector antennas from computed and measured phase patterns using numerical methods. Experimental and theoretical results compare favourably with each other. It is found that the distance between the phase centre and the apex increases when the aperture angle decreases from 180° to 60°.

Woodward suggested\(^{(83)}\) that circularly polarized radiation can be obtained from corner reflectors by tilting the orientation of the primary feed dipole. He used the method of images to develop the basic theory of the antenna producing circularly polarized radiation. Experimental
investigations have been carried out on the radiation characteristics as a function of the geometric parameters of the antenna. From this data, a circularly polarized corner reflector has been designed.

Klopfenstein(84) developed a theory for the corner reflector antenna excited by an infinitesimal dipole source which is tangent to a circular cylinder having the corner reflector as its axis. The results are applicable to reflectors of arbitrary apex angle. The various characteristics like electromagnetic field, directive gain etc. have been found in terms of an infinite series of Bessel functions. It has been shown that, for corner reflectors whose apex angles are sub-multiples of 90°, circular polarization is possible for every dipole-to-apex spacing except those for which horizontal or vertical gain becomes zero.

The importance of the study of radiation characteristics of sectoral horns and corner reflector systems can be understood from this review of the past work. It can be seen that no attempt has so far been made to conduct a detailed and systematic investigation on plane and corrugated corner reflector systems, and to present an exhaustive comparative study of the CR system with plane and corrugated flanged horns. The close similarity between the two systems is also not well established earlier. The work presented in this thesis is oriented towards these problems.