CHAPTER-1

INTRODUCTION

1.1 BACKGROUND

The antennas used for specific applications in satellite communications, remote sensing, radar and radio astronomy have several special requirements. One of the essential requirements is to achieve very high cross-polarization discrimination over a specified bandwidth, while maintaining the compactness of the overall antenna system [1]. In other words, the two orthogonal antenna polarizations, i.e., two perpendicular linear polarizations or right-hand (RHCP) and left-hand (LHCP) circular polarizations should remain totally uncoupled. Generally, for the antennas of practical applications, it is expected that its cross-polarization should be at least 30dB below the reference polarization.

The cross-polarization refers to the radiation of electromagnetic energy into the polarization other than the desired polarization. It can also be considered as the loss of energy in the unintended direction. The presence of high cross-polarization may result in several undesirable effects. It degrades the overall performance of the system and restricts its use for many applications. For example, in microwave radiometers, it reduces the beam efficiency and results in poor spatial resolution [2]-[3]. In communication link, the high cross-polarization produces undesired interference between the two adjacent channels [4]. In case of monopulse tracking radar, the high cross-polarization can create boresight-jitter (boresight uncertainty). Boresight uncertainty or boresight fluctuations affect the tracking accuracies and result into unsatisfactory operation of the radar. To overcome these problems, it is necessary to
carry out detailed investigations to find out a suitable cross-polarization suppression technique. The investigations are focused mainly on offset parabolic reflector antenna.

The parabolic reflector antenna is the most preferred antenna system for many applications including a few mentioned in the beginning of this chapter. This is because of its capability of providing higher gain over a wide bandwidth, availability of accurate modeling techniques and design maturity [5]. Parabolic reflectors are classified as: (a) front-fed parabolic reflectors, (b) symmetric dual reflectors (Cassegrainian and Gregorian configurations), (c) offset parabolic reflectors, and (d) dual offset reflectors. The cross-polar properties of various parabolic reflectors have been examined by many researchers and are thoroughly documented in the literature [6]-[24]. From these studies, it reveals that, the cross-polarization in a reflector type of antenna system depends on many parameters, e. g., the geometry of the reflector, the focal-length to diameter ratio (F/D) of the antenna system, the reflector surface imperfections, support struts, etc. The cross-polar performance of various parabolic reflector configurations are briefly discussed in the next few paragraphs.

It is well known that a front-fed parabolic reflector antenna does not generate cross-polar radiation in the principle planes [6]. Due to its structural symmetry, the cross-polar components of the adjacent quadrants of the reflector are 180° out of phase with one another and result in cancellation of cross-polarization. Also, further improvement in the cross-polar performance of an axially symmetric front-fed parabolic reflector can be achieved by selecting a larger F/D reflector configuration [4]. However, in practical applications, where it is difficult to accommodate a reflector with large F/D ratio due to mechanical constraints, a dual reflector antenna system can be used to suppress the cross-polarization [4, 7]. Watson and Ghobrial [7] have
reported that the cross-polar isolation of a symmetrical cassegrainian reflector is better than that of the equivalent prime-focal parabolic reflector antenna. As reported in [4, 12], ideally zero cross-polarization condition can be realized by illuminating the symmetrical parabolic reflector with the Huygens’ source. It is also found that a center-fed parabolic reflector antenna, illuminated by a hybrid-mode corrugated feed [25], can reduce the cross-polarization to a minimum level.

The axially symmetric parabolic reflectors as well as the symmetric dual reflectors (mentioned in the previous paragraph) suffer from a serious drawback of aperture blocking by the primary feed (located at the focal point of the reflector) or by the sub-reflector. Aperture blocking leads to scattered radiation which ultimately leads to a loss of antenna gain while increasing the sidelobe levels and cross-polarization. This limitation of the symmetric reflectors can be overcome by the offset parabolic reflector configuration [21]. The major advantages and limitations of an offset parabolic reflector antenna as compared to symmetrical parabolic reflector antenna are summarized briefly [21] as follows:

- In offset reflector antenna system, the feed does not obstruct the aperture of the main reflector. This advantage is very significant in case of a multiple-beam satellite antenna where the feed is an array of several elements [26]. The absence of feed blockage in an offset parabolic reflector antenna ensures high illumination efficiency as compared to the prime focal parabolic reflector antenna.

- For an offset reflector antenna, there is a high isolation between the primary feed and the main reflector.
In case of an offset reflector configuration, it is possible to use a larger focal-length to reflector ratios (F/D), at the same time maintaining structural rigidity of the antenna. As a result, the radiating apertures of the offset reflector primary feeds are larger as compared to those of the front-fed configuration. This in turn reduces the direct mutual coupling between the adjacent feed elements in case of a multiple feed illumination to the reflector. Also, the use of larger aperture primary feeds helps to improve the primary feed radiation pattern with an improved cross-polar performance.

However, the offset-parabolic reflector configuration suffers from a few drawbacks as mentioned below:

- The asymmetry of the offset configuration results in high cross-polarization when illuminated by a linearly polarized primary feed [21]. It is to be noted that in the plane of asymmetry the cross-polarization is considerably high as compared to that in the plane of symmetry.

- If the feed is circularly polarized, the cross-polarized components will be eliminated, but the antenna main beam will be squinted away from the boresight [21].

The problem of inherent high cross-polarization of an offset configuration puts a major limitation of its use, especially, in microwave radiometers where the high beam efficiency of the order of 95-97 % is essential as well as in modern satellite communication where high cross-polarization can create cross-talk between the channels. Similarly, the problem of beam squinting displaces the main beam and reduces the antenna gain [21].
The research work described in the thesis was carried out with the objective of finding out a suitable technique to suppress the unwanted high cross-polarization and of eliminating the beam squinting introduced by an offset parabolic reflector antenna.

1.2 LITERATURE SURVEY

The cross-polar properties of offset parabolic reflector antennas have been studied by many researchers [8]-[12], [27]-[32]. However, very few researchers have attended the problem of suppressing the cross-polarization of an offset parabolic reflector antenna.

Chu and Turrin [8] were the first to publish the numerical data on the variation of maximum cross-polarization (linearly polarized feed) and beam squinting (circularly polarized feed) as a function of F/D ratio and offset angle ($\theta_0$). Based on the graphical data published in [8], it can be concluded that the cross-polarization and the beam squinting increase as the offset angle ($\theta_0$) increases. Also, the cross-polarization of an offset parabolic reflector is satisfactory only for large F/D ratio (i.e., F/D >1). This has also been verified by the experimental results.

Jacob Dijk et al. [9] presented a detailed analysis of polarization losses of offset paraboloid antennas. They have derived expressions to represent polarization losses in terms of the polarization efficiency. For the offset paraboloid antennas losses increase at an increasing subtended angle ($\theta^*$) and increasing offset angle ($\theta_0$). It was also shown that the offset reflector excited by Huygens’ source results into significant polarization losses as compared to the symmetrical parabolic reflectors.

Gans and Semplak [10] demonstrated that a single offset reflector with small offset angle ($\theta_0$) can provide low cross-polarization and low sidelobes. They also presented a detailed theoretical analysis to compute the cross-polarization in the
reflector aperture and extended the same to study the cross-polar performance of the offset reflector in the far-field.

**Rudge** [11] has presented physical optics (PO) based two mathematical models to predict the co-polar and cross-polar radiation patterns of an offset reflector antenna with offset feeds. Their results are very useful to design the multiple-beam antennas.

**Hirokazu Tanaka** and **Motoo Mizusawa** [12] have presented the analysis of dual-offset reflector antenna consisting of a main reflector and a sub-reflector. In a dual-offset reflector, the cross-polarization introduced by the offset geometry is compensated by the cross-polarized fields contributed by the feed sub-reflector structure. In order to achieve minimum cross-polarization with a dual-offset configuration, **Mizugutch** [16] proposed a condition (Mizugutchi condition) which relates the tilting of the axis of the sub-reflector with the axis of the main reflector. However, in some practical applications, the dual reflector configuration may not be preferred as it is too complicated for the deployment process. Also the extra weight introduced by the sub-reflector and the supporting arms may not be affordable in case of the satellite structure for the space-borne payloads.

**Jacobsen** [19] has suggested the techniques to design low cross-polarized feeds for the offset reflectors. Two separate feeds, one based on mode matching technique and the other based on Huygens’ source technique have been reported in [19]. However, no experimental verification of the designs was presented by the authors. Also, these types of feeds may not be suitable to suppress the cross-polarization introduced by the asymmetry of the reflector structure.

**Chu** [27] suggested mounting of polarization-selective grids between the reflector and the feed to obtain larger cross-polarization discrimination. In this method,
the cross-polarization suppression depends on the size and location of the grid. He has used a straight strip grid while Dragone [28] proposed a curved strip grid for cross-polarization cancellation. However, the polarization selective grids may add to the complexity of the antenna system and also increase the cost of the overall system.

As reported by Strutzman and Terada [29], in a single offset reflector, the cross-polarization and the beam squinting strongly depend on the offset reflector geometry, i.e., the offset angle ($\theta_0$) and the F/D ratio. They also observed that the orientation of the feed also affect the cross-polar performance of an offset reflector. Selection of relatively small feed-pointing angle can reduce the cross-polarization, but increases the spill-over losses. Further, it was confirmed that low cross-polarization can be achieved by choosing a large F/D ratio offset reflector antenna. But, the larger F/D configuration results in a bulky antenna structure and may not be suitable for spacecraft antennas, where the available space for the antenna is limited.

Lier and Skyttemyr [30] proposed a single offset reflector antenna illuminated by a phase-correcting lens horn, which provides a secondary radiation pattern with high efficiency and low cross-polarization. Cross-polarization below -50 dB is reported for an antenna (F/D = 0.74) with a high permittivity lens ($\varepsilon_r = 10$). For such type of a feed horn, the dielectric material of the lens may result into losses and reduce the antenna gain, increases the antenna noise temperature, and reduce the bandwidth.

Rudge and Adatia [31]-[32] proposed a very innovative concept of ‘Matched Feed’ to suppress the undesired cross-polarization of an offset parabolic reflector antenna. This kind of feed makes use of higher order mode(s), in addition to the fundamental mode to compensate the undesired cross-polarization introduced by the asymmetry of the reflector. It is interesting to note that the same feed when used with a
circularly polarized offset reflector, removes the beam squinting. However, the essential design details of matched feed are not accurately reported in the published literature. Also, no experimental results have been found in the available literature.

On the basis of this exhaustive literature survey, it is clear that very limited efforts have been made to overcome the limitations of an offset parabolic reflector antenna. Further, the matched feed concept is very interesting and needs further investigations to explore the same in different feed structures, such as rectangular, cylindrical, corrugated, etc. Also, the research can be extended to improve the cross-polar bandwidth of the matched feed. Considering all these aspects, the present research work is focused on the development of practically realizable multi-mode matched feeds to overcome the limitations of an offset parabolic reflector antenna.

1.3 PROBLEM STATEMENT

The prime objective of this thesis is to develop a practical solution to overcome the limitations of single offset parabolic reflector antenna with low F/D (F/D <1). In order to solve this challenging problem, the conjugate matched feed concept based on the ‘field matching theory’ is adopted. For clarity, the problem undertaken is stated below:

To design a matched feed for an offset parabolic reflector antenna to suppress the undesired high cross-polarization in case of a linearly polarized excitation and to remove the beam-squinting effects, when the excitation is circularly polarized.

Three different feed structures, i.e., rectangular, cylindrical, and corrugated have been considered for detailed investigations.
1.4 ORGANIZATION OF THE THESIS

The research work carried out during the course of time has been presented in total six chapters.

In the first chapter, the relevance of the present investigations and a brief literature survey on ‘The low cross-polarized antenna system’ have been presented. The objectives of the thesis are also laid out in this chapter.

The matched feed concept is explained in the second chapter. In a matched feed, the tangential electric fields in the aperture of a primary feed are to be matched with the focal region fields of an offset reflector to suppress the high cross-polarization. To understand this matching process, fields at the focal region of an offset parabolic reflector have been computed and the results are presented in the form of contour plots. The higher order modes required to achieve the focal-field matching are summarized in this chapter.

Chapter 3 deals with the implementation of ‘matched feed’ concept in a rectangular feed structure. In the pyramidal horn, the higher order TE\(_{11}\) mode has been added in appropriate amplitude and phase with respect to the dominant mode (TE\(_{01}\)). The details of feed design and the method of higher order mode (TE\(_{11}\)) excitation are discussed at length. Parametric study on the secondary radiation patterns has been carried out for different values of offset angle (\(\theta_0\)) and the F/D ratios. The numerical results have been presented on radiation patterns for both linearly polarized and circularly polarized rectangular matched feed. The measured cross-polar performance of a rectangular matched feed has been also included in this chapter.

Chapter 4 presents the design and development of a tri-mode matched feed. In a smooth-walled cylindrical waveguide, three modes i.e., TE\(_{11}\), TM\(_{11}\) and TE\(_{21}\) are
combined in proper amplitude and phase to configure a tri-mode conjugate matched feed. The design details of the feed and the techniques to generate the higher order TM_{11} and TE_{21} modes are elaborated in this chapter. The designed tri-mode matched feed has been fabricated and used as a primary feed device to illuminate the offset parabolic reflector antenna. For the proposed tri-mode matched feed illuminated offset reflector, the radiation characteristics have been measured at CATF (compact antenna test facility) and the results are compared with that of a conventional Potter-horn fed offset reflector. In addition, a novel technique has been explored to improve the cross-polar bandwidth of the proposed tri-mode matched feed and the corresponding results are summarised in this chapter. The practical applications of the proposed conjugate matched feed in multiple-beam offset parabolic reflector antenna and beam scanning have been discussed with simulated results.

Chapter 5 elaborates the design of a dual-mode corrugated matched feed to cancel the unwanted high cross-polarization and beam squinting in an offset parabolic reflector antenna. The matched feed concept has been implemented in a cylindrical corrugated structure by adding a higher order HE_{21} mode to the fundamental HE_{11} mode. Different design options have been discussed in this chapter. The measured return-loss characteristics and the primary radiation patterns of the prototype horn are also included in this chapter. Finally, the feed has been used to illuminate the offset reflector antenna and the effectiveness of the same has been validated by showing the improvement of the cross-polarization in the secondary radiation pattern.

The conclusions drawn from the investigations and the scope for the future work have been discussed in chapter 6.
PUBLICATION RELATED TO THE CHAPTER