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Design of a Special Feed for an Offset Parabolic Reflector Antenna with Wide Cross-pol Suppression Bandwidth

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***Abstract*- This paper presents the design of a special tri-mode feed, which suppresses the unwanted high cross-polarization of a linearly polarized offset parabolic reflector antenna over a wide frequency band. The same feed when used to illuminate a circularly polarized offset reflector antenna, removes the beam squinting effects. The offset reflector performance with the proposed tri-mode feed is compared with that of the conventional Potter horn feed.**

Index Terms **– beam-squinting, cross-polarization, offset reflector antenna, tri-mode matched feed.**

I. INTRODUCTION

Over the past three decades, offset parabolic reflector antennas are extensively used for many practical applications including satellite communications. This is because of their attractive features, such as, reduced aperture blockage, isolation between the reflector and the feed, suppressed side lobes and high aperture efficiency [1]. However, due to the structural asymmetry, the offset reflector configuration suffers from two serious drawbacks: (i) it generates high cross-polarization, when illuminated by a linearly polarized feed and (ii) displacement of the main beam (beam squinting) from the boresight, when illuminated by a circularly polarized feed [1]. These limitations have made the offset reflector configuration unsuitable for the applications, where the modern frequency re-use concept is applied to increase the data capacity of a satellite communication link.

Frequency re-use is the technique of transmitting two separate signals using the same frequency in two orthogonal polarizations. For such applications, either two perpendicular linear polarizations or right-hand (RHCP) and left-hand (LHCP) circular polarizations are used. In either case, the high antenna cross-polarization results in to interference between the two adjacent channels. In order to avoid such interference, it is essential that the two polarizations remain completely uncoupled. This is only possible, when the antenna chosen for the frequency re-use application, radiates very low cross-polarization over a specified bandwidth. In other words, for an antenna to qualify for the frequency re-use application, its cross-polarization should be at least 30-35 dB below the reference polarization.

In case of an offset reflector antenna, the conventional technique to reduce the unwanted high cross-polarization is to select reflector geometry with a large focal length to diameter ratio (F/D) and small feed-pointing angle [2]. However, the larger F/D ratio results into a heavy and bulky antenna structure and may not be preferred for the satellite communication applications, where the available space for the antenna structure is limited. The other practical solution to reduce the cross-polarization is to use a special primary feed to illuminate the offset reflector. Such a special feed can be a multi-mode feed, designed based on the 'conjugate field matching (matched feed)' concept [3-4].

Rudge and Adatia introduced the concept of matched feed to suppress the unwanted high cross-polarization in a secondary radiation pattern of an offset parabolic reflector antenna. As reported in [3-4], for a prototype tri-mode cylindrical matched feed, additional suppression of 10 dB cross-polarization (as compared to a conventional feed) was achieved over a 4% bandwidth. In recent years, Bahadori and Rahmat-Samii [5] have used a tri-mode matched feed to illuminate a gravitationally balanced back-to-back reflector, and shown 10 dB improvement over a 2.5 % bandwidth. Although, these results are encouraging, such feed can not be of practical use due to its narrow cross-pol suppression bandwidth. To the best of authors' knowledge, no attempts were made in the past to increase the cross-pol suppression bandwidth of a tri-mode matched feed. Thus, efforts are required to increase the cross-pol suppression bandwidth of such a feed.

In this paper, a novel design of a tri-mode horn is proposed, which suppresses the high cross-polarization of an offset parabolic reflector over a wide bandwidth. The theory of tri-mode matched feed is briefly explained in section II, and the offset reflector performance with the proposed tri-mode feed is described in section III.

II. TRI-MODE FEED

A. Theory of Tri-mode Feed

As mentioned in the previous section, the basic principle of a matched feed was explained by Rudge and Adatia [3-4] in 1975. As described in [3-4], the undesirable high cross-polarization introduced by the offset geometry can be cancelled out by suitably matching the radiation fields of a primary feed with those of the reflector. To satisfy this matching condition, the primary feed should support appropriate higher order modes, in addition to the fundamental mode. Such modes in case of a smooth-walled cylindrical feed are TM_{11} and TE_{21} with the fundamental TE_{11} mode. Accordingly, in case of a cylindrical wave-guide structure, the matched feed is a tri-mode feed with three modes. Matched feed can also be considered as an extension of a well-known Potter horn [6] in which TM_{11} mode is added with the fundamental TE_{11} mode. However, in case of a tri-mode feed, the additional TE_{21} mode compensates the asymmetric cross polarization introduced by the offset geometry. It is to be noted that, there should be in-phase relationship between TE_{11} and TM_{11} mode and quadrature-phase relationship between TE_{11} and TE_{21} mode.

B. Design of Tri-mode Feed

The geometry of the proposed tri-mode feed is shown in Fig. 1. Using the HFSS software, the horn dimensions were optimized to achieve the required aperture field distribution. The input waveguide of the horn was excited by a pure TE_{11} mode. The diameter of the input waveguide was selected by satisfying a condition D1 $\geq$ $(x_{np}.\lambda) / \pi$. Where, x_{np} is the cut-off wave number of the TE_{11} mode (= 1.84118), and λ is the operating wavelength. The TE_{21} mode can be generated by inserting three identical pins [5], but it has been found that use of such pins restrict the cross-pol suppression bandwidth. Therefore, in the present design, three symmetrical strips are used to excite TE_{21} mode. The TM_{11} mode is introduced by a step discontinuity (D2/D3). The diameter D2 allows TE_{21} mode to propagate, while D3 supports TM_{11} mode and cuts off all higher order modes above TM_{11} mode.

C. Performance of Tri-mode Feed

The simulated return-loss characteristic of the proposed tri-mode feed is shown in Fig. 2. From the results it is clear that the return-loss is better than 22 dB over a wide bandwidth. Next, the far-field radiation patterns of a feed were computed. As shown in Fig. 3, the high cross-polarization observed in the, Phi=90^0 plane will ultimately cancel out the cross-polarized fields of the offset reflector in the secondary radiation pattern.

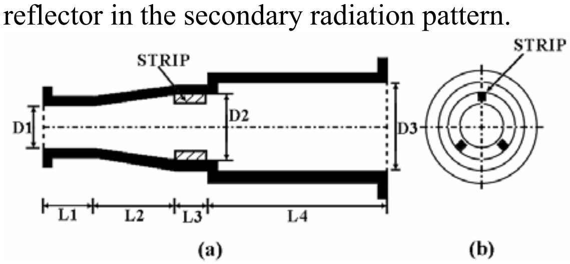

Fig. 1 The geometry of a tri-mode matched feed
(a) Front view (b) Side view.

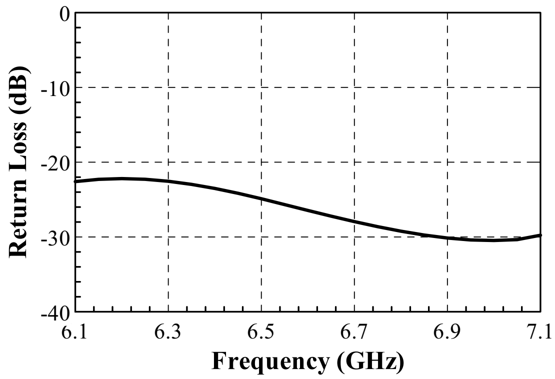

Fig. 2 Return-loss characteristics of a proposed tri-mode feed.

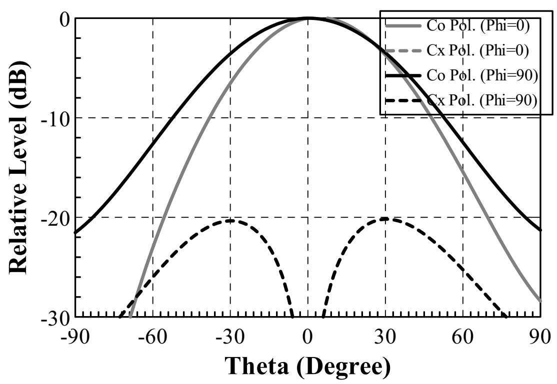

Fig. 3 The normalized radiation pattern of a tri-mode feed.

II. REFLECTOR PERFORMANCE WITH A TRI-MODE FEED

In this section, the radiation characteristics of the tri-mode feed illuminated offset reflector are discussed. The offset parabolic reflector geometry under consideration is shown in Fig. 4. The diameter of the projected aperture was chosen to be 1.242 m, with F/D=0.82. The offset angle (θ_0) was kept 34.8^0. The said offset reflector was illuminated by a linearly polarized conventional feed (case-I) and by a special tri-mode feed (case-II). For both the cases the secondary radiation patterns were estimated and the results were compared (see Fig. 5 and Fig. 6) From comparison of Fig. 5 and Fig. 6, it is evident that the peak cross-polarization is -25 dB, in case of a conventional Potter horn fed reflector, whereas approximately -43 dB for a tri-mode feed illuminated reflector. This in turn, confirms approximately 18 dB cross-polarization improvement as compared to a conventional feed. Following this, extensive simulations were carried out to estimate the cross-pol suppression bandwidth of a tri-mode horn fed offset parabolic reflector antenna. As shown in Fig. 7, the offset reflector in conjunction with a tri-mode feed provides better than 30 dB cross-polarization isolation (CPI) over a 15 % bandwidth.

Finally, the same offset reflector was illuminated by circularly polarized feeds. The estimated secondary radiation patterns of a circularly polarized conventional Potter feed illuminated reflector are shown Fig. 8, while that of a tri-mode feed illuminated reflector are shown in Fig. 9. From comparison of results, it is observed that, there is no beam squinting in case of a tri-mode feed illuminated reflector as compared a Potter horn fed reflector.

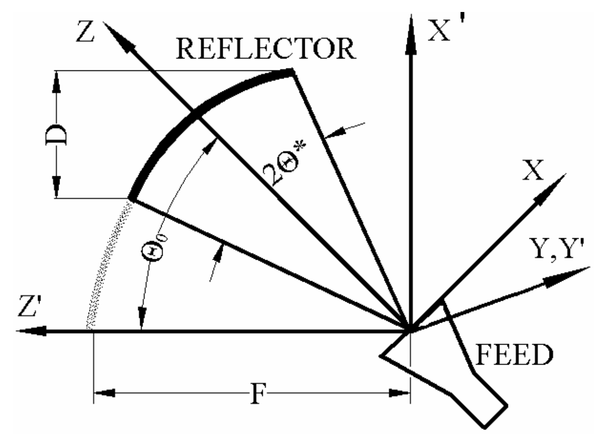

Fig. 4 The offset reflector geometry.

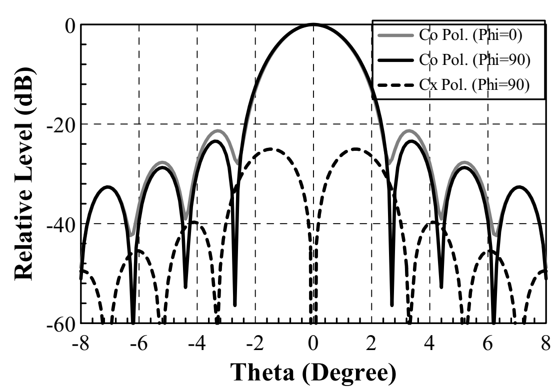

Fig. 5 Secondary radiation pattern (offset parabolic reflector fed by a linearly polarized Potter horn).

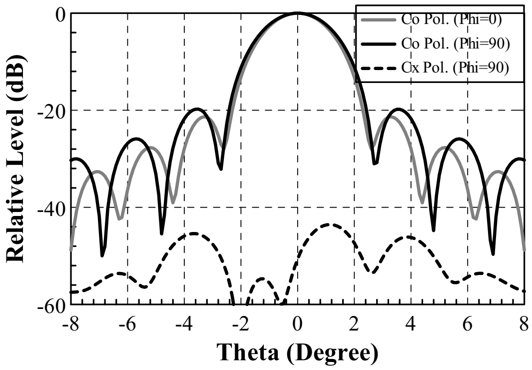

Fig. 6 Secondary radiation pattern (offset reflector fed by a linearly polarized tri-mode feed).

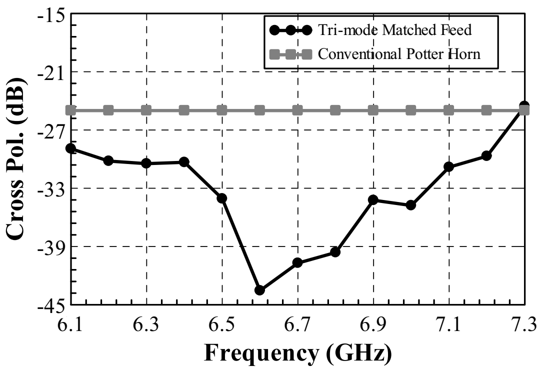

Fig. 7 Cross-pol suppression bandwidth of the proposed tri-mode horn

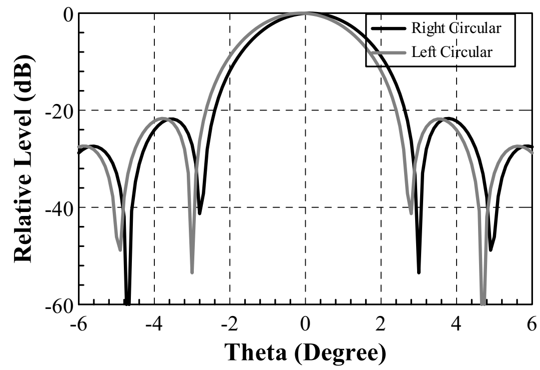

Fig. 8 Secondary radiation pattern (offset reflector fed by a circularly polarized Potter horn).

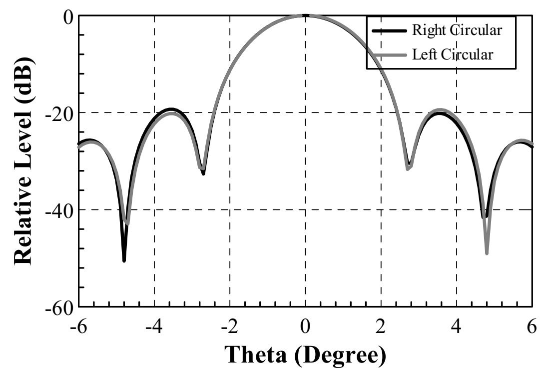

Fig. 9 Secondary radiation pattern (offset reflector fed by a circularly polarized tri-mode horn).

IV. CONCLUSION

In the present paper, the design of a tri-mode matched feed is discussed. It has been observed that such a feed when used as a primary feed with an offset reflector antenna, suppresses the cross-polarization over a wide frequency band. The feed also removes beam squinting effects in case of a circularly polarized antenna.

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