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REMOVAL OF BEAM SQUINTING EFFECTS IN A CIRCULARLY POLARIZED OFFSET PARABOLIC REFLECTOR ANTENNA USING A MATCHED FEED

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Abstract—This paper presents the design of a tri-mode matched feed horn to remove the beam squinting effects in a circularly polarized offset parabolic reflector antenna. In a conical horn, three modes i.e., TE_{11}, TM_{11} and TE_{21} are combined in proper amplitude and phase proportion to obtain a tri-mode matched feed configuration. The proposed tri-mode horn is then used as a primary feed device to illuminate the circularly polarized offset parabolic reflector antenna. The simulated data on radiation characteristics of the offset reflector are used to estimate the magnitude of beam squinting and the results are compared with that of a conventional potter horn fed offset reflector. The experimental results on secondary radiation pattern are also incorporated in the paper.

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1. INTRODUCTION

The use of an offset parabolic reflector configuration becomes limited due to its serious drawback of introducing the beam squinting effects [1–3], when illuminated by a circularly polarized primary feed. The beam squinting occurs when two mutually orthogonal linear cross polar components add to a co-polar circular component [2]. The magnitude of the beam squinting can be estimated by a mathematical formula as derived by Rudge and Adatia [4]. Beam squinting displaces the main beam, reduces the gain [3], limits the accuracy in case of radio astronomical observations [5], and degrades the performance of the overall system. Also, the problem of high beam squinting puts a major limitation of its use especially, in frequency re-use applications. Thus, it is necessary to find out a suitable practical solution to remove the squinting effects in a circularly polarized offset reflector antenna.

As reported by Chu and Turrin [1], the beam squinting strongly depends on the offset reflector geometry, i.e., the offset angle (θ_0) and the F/D ratio. As reported in [1], a large value of offset angle and a small F/D ratio results into high beam squinting. Thus, by selecting relatively small offset angle and a high F/D ratio configuration, it is possible to minimize the beam squinting effects. However, the large F/D ratio results into a heavy and bulky antenna structure, and may not be preferred; where the available space for the antenna structure is limited, e.g., satellite structure for the space-borne payloads.

In order to remove the beam squinting effects, the alternative solution is to use an improved primary feed known as 'Matched Feed' to illuminate the offset parabolic reflector. The concept of matched feed was originally proposed by Rudge and Adatia [6] to reduce the unwanted high cross polarization in a linearly polarized offset reflector antenna. In a matched feed, the tangential electric fields in the aperture of a primary feed is to be matched with the focal region fields of an offset reflector antenna to remove the undesirable beam squinting. This matching condition can be achieved by adding appropriate higher order mode(s) in proper amplitude and phase to the fundamental mode. In case of a smooth-walled cylindrical feed structure such modes are TM_{11} and TE_{21} along with the fundamental TE_{11} mode [3].

Prasad and Shafai [7] have used the linearly polarized matched feed to improve the symmetry of the radiation pattern of an offset parabolic reflector. In a recent paper [8], the linearly polarized matched feed has been used to illuminate the gravitationally balanced back-to-back reflectors. The performance comparison of a matched feed illuminated offset reflector with a conventional potter horn fed offset parabolic reflector is found in [9].

To the best of authors' knowledge, the use of circularly polarized matched feed has not been reported in open literature. The primary objective of this paper is to apply the concept of a tri-mode matched feed to remove the beam squinting effects in a circularly polarized offset parabolic reflector antenna. The proposed tri-mode matched feed is designed using HFSS software and is included in the paper. The designed feed is then used as a primary feed to illuminate the offset parabolic reflector antenna and the far field radiation pattern has been estimated using the commercially available antenna design software GRASP-8W. The results are compared with a conventional potter horn fed offset parabolic reflector. The measured secondary radiation patterns are also included in the paper.

2. REFLECTOR AND FEED CONFIGURATION

The offset reflector geometry and the associated coordinate system are illustrated in Fig. 1. The diameter of the projected aperture (D) was chosen to be 1.2 m, with F/D = 0.6. The offset angle (θ_0) was kept 50°. To study the beam squinting effects, the offset reflector was illuminated by a circularly polarized tri-mode matched feed, and a conventional potter horn [10].

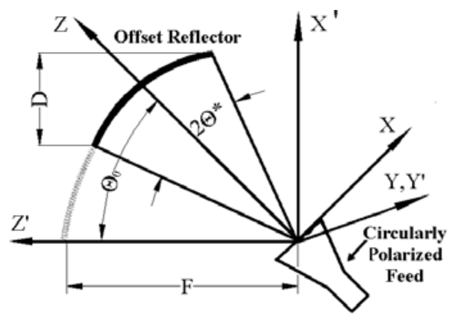


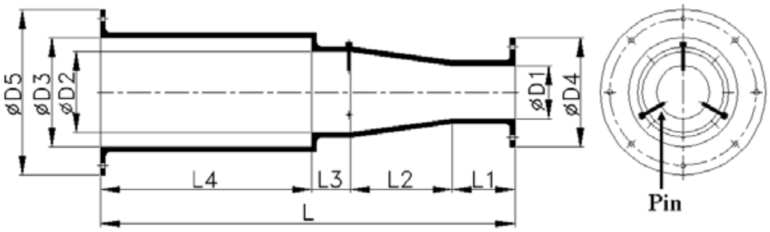
Figure 1. The offset reflector geometry and the associated coordinate system.

In case of a cylindrical wave-guide structure, the matched feed is a 'tri-mode feed' with three modes such as TE_{11}, TM_{11} and TE_{21}. For such a tri-mode matched feed, the θ and ϕ components of the far field radiation pattern can be expressed as,

$$E_\theta = E_\theta^{TE11} + \alpha_1 \cdot E_\theta^{TM11} + j \cdot \alpha_2 \cdot E_\theta^{TE21} \tag{1}$$

$$E_\phi = E_\phi^{TE11} + j \cdot \alpha_2 \cdot E_\phi^{TE21} \tag{2}$$

where, α_1 and α_2 are the arbitrary constants defining the relative power in the TM_{11} and the TE_{21} mode with respect to the fundamental TE_{11} mode. The expressions for E_θ^{TE11}, E_θ^{TM11}, E_θ^{TE21}, E_ϕ^{TE11}, and E_ϕ^{TE21}, can be obtained using the general expressions from [11].



(a) (b)

Figure 2. HFSS simulated design of a proposed tri-mode matched feed. (a) Front view. (b) Side view ($D1 = 34$ mm, $D2 = 52$ mm, $D3 = 70$ mm, $L1 = 40$ mm, $L2 = 65$ mm, $L3 = 25$ mm, $L4 = 135$ mm).

The geometry of the proposed tri-mode matched feed (see Fig. 2) was designed using the commercial HFSS software. HFSS employs finite element method (FEM) to calculate the 3D electromagnetic fields inside a structure. The horn parameters were optimized to achieve the desired performance. The diameter $D1$ was selected in such a way, so that the fundamental TE_{11} mode can easily propagate at the operating frequency of 6.6 GHz. The TE_{21} mode was generated by three cylindrical pins. The height of the pins can be adjusted to obtain the desired performance in terms of squint-free secondary radiation pattern. The diameter $D2$ was chosen such that the TE_{21} mode can be easily supported. In order to obtain the desired return loss (better than 20 dB) characteristics, a tapered section was introduced between the waveguide sections of diameter $D1$ to $D2$ instead of a sharp step junction. The TM_{11} mode was introduced by a step discontinuity ($D2/D3$). The diameter $D3$ supports TM_{11} mode and cuts off all higher order modes above TM_{11}.

As reported in [12], for the optimum performance of the tri-mode horn, the TM_{11} mode amplitude level should be approximately -5 dB and TE_{21} mode amplitude level should be -20 dB relative to the fundamental TE_{11} mode. The total power of all the modes at the horn aperture should be 1 watt. Also, there should be in-phase relationship between TE_{11} and TM_{11} mode and quadrature-phase relationship between TE_{11} and TE_{21} mode. However, the modal amplitudes required to obtain the squint-free radiation pattern strongly depend on the offset geometry i.e., offset angle (θ_0), and F/D ratio.

For the proposed tri-mode horn, the required amounts of modal amplitudes of all the three modes were obtained by carefully selecting the diameter $D2$, $D3$, and pin dimensions. The desired phase relationship amongst the three modes was established by adjusting the lengths $L3$ and $L4$.

3. RESULTS

In order to study the beam squinting effects, the offset reflector antenna was illuminated by a circularly polarized conventional potter horn (dual — mode horn) and a circularly polarized HFSS designed tri-mode matched feed. The performance of the reflector was simulated for both the cases using the GRASP- 8W software. The GRASP-8W software uses the physical optics (PO) approximation to compute the total radiated fields from the reflector. The PO analysis is a three step procedure: (i) calculation of induced surface currents (ii) computation of the fields radiated by these currents, and (iii) addition of incident and the total fields to obtain the total field [13]. The simulated far-field radiation pattern of a conventional potter horn illuminated offset reflector is shown in Fig. 3. Results in Fig. 3 show a high beam squinting in the far-field pattern of the offset reflector.

For the same reflector configuration, the potter horn feed was replaced by a circularly polarized tri-mode matched feed and the far-field radiation patterns were estimated for different pin heights. Using the radiation pattern data, the beam squinting was calculated for each pin height. The variation of beam squinting as a function of pin height of the designed tri-mode horn is shown in Fig. 4. From Fig. 4, it

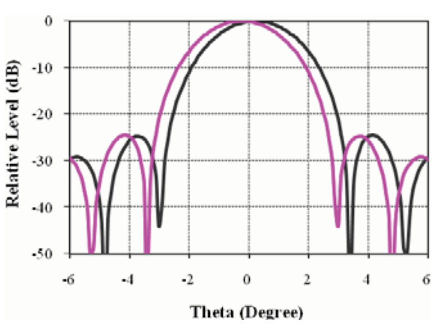


Figure 3. Secondary radiation pattern of an offset reflector fed by a circularly polarized conventional potter horn.

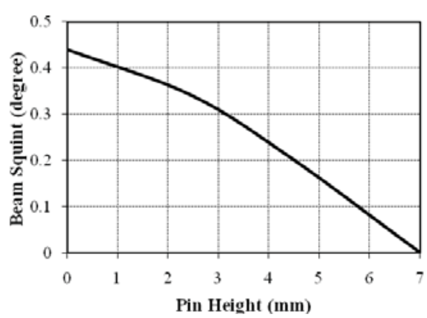


Figure 4. Beam squinting variation as a function of pin (discontinuity) height.

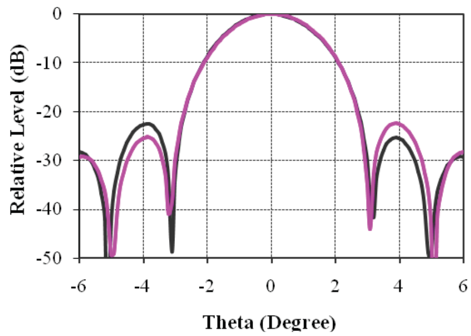


Figure 5. Secondary radiation pattern of an offset reflector fed by a circularly polarized tri-mode matched feed (7 mm pin height).

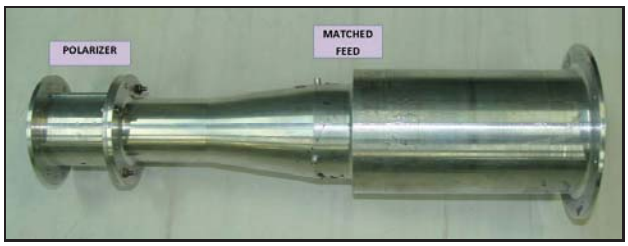


Figure 6. Tri-mode matched feed with a polarizer.

is observed that the beam squinting is minimum for a pin height of 7 mm. For the optimized 7 mm pin height, the modal amplitudes and the phases of all the three modes are listed in Table 1. The simulated secondary radiation pattern of the offset reflector with an optimized tri-mode horn is shown in Fig. 5. Comparison of Fig. 3 and Fig. 5, shows that a beam squinting is minimum in case of a tri-mode horn fed offset reflector as compared to a conventional potter horn fed reflector.

Table 1. The optimized modal amplitudes and phases of a HFSS simulated tri-mode horn optimized for squint-free radiation pattern (7 mm pin height).

Optimized mode values	TE_{11} mode	TE_{21} mode	TM_{11} mode
Amplitude (dB)	-1.17	-19.3	-6.54
Phase (degree)	50.8	-33.6	53

Figure 7. The offset reflector and a circularly polarized tri-mode matched feed under test at Compact Antenna Test Range (CATR).

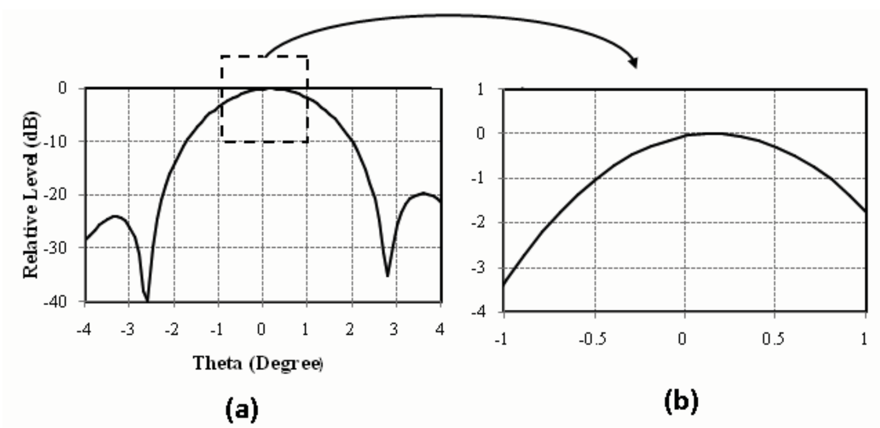


Figure 8. a) Measured secondary radiation pattern of an offset reflector fed by a circularly polarized tri-mode matched feed with pin height of 0 mm (For $F/D = 0.82$, $\theta_0 = 34.8°$) (b) Magnified section of a measured secondary radiation pattern.

For measurement with a circularly polarized matched feed, a separate polarizer was designed and fabricated. The said polarizer was first tested in an anechoic chamber and the performance was found satisfactory. The polarizer was then assembled with a tri-mode matched feed as shown in Fig. 6. The tri-mode matched feed (with polarizer) was then used to illuminate the circularly polarized offset parabolic reflector antenna as shown in Fig. 7. The secondary radiation pattern of the offset reflector was measured at the Compact Antenna

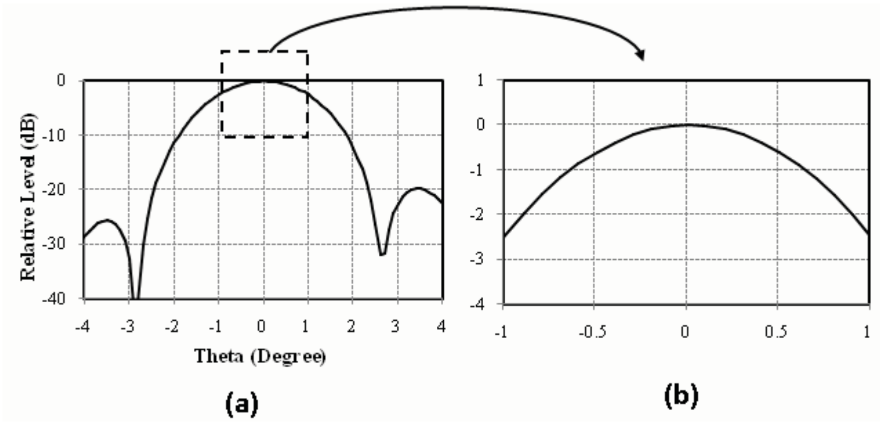


Figure 9. (a)Measured secondary radiation pattern of an offset reflector fed by a circularly polarized tri-mode matched feed with pin height of 6 mm (For$F/D = 0.82$, $\theta_0 = 34.8°$) (b) Magnified section of a measured secondary radiation pattern.

Test Range (CCR-75/60). Fig. 8 shows radiation pattern with a pin height of 0 mm (i.e., without pin). In this case a beam squint of 0.1° (from bore sight) was observed, which approximately matches with the theoretical value of 0.11° as derived by Rudge's formula [4]. For the same offset reflector antenna, when the pin height of the matched feed was adjusted to 6mm, a squint-free radiation pattern was resulted as shown in Fig. 9.

4. CONCLUSION

By using a tri-mode matched feed as a primary feed for the offset reflector, the beam squinting effects can be removed and the performance of the overall system can be improved. The tri-mode feed does not add any complexity or additional mass to the antenna structure as compared to the conventional feed. However, proper care must be taken in selecting the horn dimensions so as to obtain the desired performance.

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REFERENCES

1. Chu, T.-S. and R. H. Turrin, "Depolarization properties of offset reflector antennas," *IEEE Trans. on Antennas and Propagation*, Vol. 21, 339–345, 1973.
2. Jacobsen, J., "On the cross polarization of asymmetric reflector antenna for satellite applications," *IEEE Trans. on Antennas and Propagation*, 276–283, 1977.
3. Adatia, N. A. and A. W. Rudge, "Offset-parabolic reflector antennas: A review," *Proc. of IEEE*, Vol. 66, 1592–1618, 1978.
4. Adatia, N. A. and A. W. Rudge, "Beam squint in circularly polarised offset — Reflector antenna," *Electronics Letters*, Vol. 11, 513–515, 1975.
5. Fiebig, D., R. Wohlleben, A. Prata, and W. V. T. Rusch, "Beam squint in axially symmetric reflector antennas with laterally displaced feeds," *IEEE Trans. on Antennas and Propagation*, Vol. 39, 774–779, 1991.
6. Adatia, N. A. and A. W. Rudge, "New class of primary-feed antennas for use with offset parabolic reflector antennas," *Electronics Letters*, Vol. 11, 597–599, 1975.
7. Prasad, K. M. and L. Shafai, "Improving the symmetry of radiation patterns for offset reflectors illuminated by matched feeds," *IEEE Trans. on Antennas and Propagation*, Vol. 36, 141–144, 1988.
8. Bahadori, K. and Y. Rahmat-Samii, "A tri-mode horn feed for gravitationally balanced back-to-back reflector antennas," *IEEE Trans. on Antennas and Propagation*, Vol. 55, No. 10, 2654–2661, 2007.
9. Sharma, S. B., D. A. Pujara, S. B. Chakrabarty, and V. K. Singh, "Performance comparison of a matched feed horn with a potter feed horn for an offset parabolic reflector," *IEEE Antennas and Propagation Society International Symposium*, San Diego, 2008.
10. Potter, P. D., "A new horn antenna with suppressed side lobes and equal beamwidth," *Microwave Journal*, Vol. 6, 71–78, 1963.

11. Silver, S., *Microwave Antenna Theory and Design*, 336–338, McGraw-Hill, New York, 1949.
12. Watson, B. K., A. W. Rudge, and N. A. Adatia, "Dual-polarized mode generator for cross-polar compensation in parabolic reflector antennas," *8th European Microwave Conference*, 183–187, Paris, 1978.
13. Pontoppidan, K., "GRASP-technical description," TICRA Engineering Consultants, Denmark