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IMPROVING THE BEAM EFFICIENCY OF AN OFF-SET PARABOLIC REFLECTOR ANTENNA FOR SPACE-BORNE RADIOMETRIC APPLICATIONS

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Abstract—This paper presents a novel technique to improve the cross-polarization and the beam efficiency of an offset parabolic reflector antenna used for space borne radiometric applications. A special multi-mode primary feed (tri-mode conjugate matched feed) is used to illuminate the offset parabolic reflector antenna. The simulated data on the radiation characteristics of the offset parabolic reflector antenna with a matched feed has been compared with that of a conventional Potter horn. It is observed that the tri-mode feed suppress the unwanted high cross-polarization of an offset reflector antenna and improves the beam efficiency.

1. INTRODUCTION

Over the past three decades there has been a rapid evolution in the development of space-born microwave radiometers for remotely sensing various earth parameters from the space. Many essential geophysical parameters, such as sea-surface temperature, wind speed, wind direction, sea ice concentration and age, atmospheric water — vapor content, etc. have been successfully retrieved by the microwave radiometers. In the last few years, these data have been

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proved as key parameters for various applications such as, short-term weather forecasting and warning, climatology and oceanography studies, disaster management, etc. A microwave radiometer is basically a highly sensitive receiver designed to measure the noise power/brightness temperature radiated by a target [1]. It consists of three basic subsystems: (i) an antenna and scan subsystem to receive the incoming radiation, (ii) a radiometer receiver to detect and amplify the received radiation within a specified band of frequency; and (iii) a data control subsystem to provide timing and sequencing signals for the antenna and radiometer subsystems, and to perform digitizing, multiplexing, and formatting functions on the radiometric data to form the output data stream [2]. However, it has been observed that the overall design of an antenna plays a very important role in achieving the specified radiometric accuracy, sensitivity and the desired performance of the radiometer in the space.

Offset parabolic reflector is the most preferred antenna system for radiometric applications [3–7] due to many inherent advantages. This includes, reduced aperture blockage, high isolation between the antenna and the primary feed, suppressed side lobe levels, and options for large focal length to diameter (F/D) ratios [8]. However, the offset configuration has some disadvantages, like higher cross polarization when illuminated by a linearly polarized feed and beam squinting in case of a circularly polarized feed. The high cross polarization reduces the main beam efficiency and results into poor spatial resolution, radiometric sensitivity, and measurement accuracy.

Beam efficiency is a very fundamental antenna parameter used to judge the ability of an antenna system to discriminate between the signals received through its main lobe and those through the minor lobes [9]. Very high beam efficiency of the order of 95–98% ensures minimum contributions from the sidelobes and effectively high spatial resolution. To meet this challenging requirement of high beam efficiency ($> 95\%$), it is necessary to minimize the cross polarization level added by the offset geometry. There are two techniques to reduce the unwanted high cross polarization introduced by an offset reflector. The first technique suggests the design of an offset reflector antenna with a relatively larger F/D ratio. However, in case of radiometric applications, it may not be possible to increase the F/D ratio because of mechanical constraints like space availability, weight limitations, etc. The alternative practical solution is to use a very special type of primary feed, known as matched feed/tri-mode conjugate feed in place of a conventional Potter horn type feed to illuminate the offset reflector.

The concept of matched feed was proposed by Rudge and

Adatia [10]. However, very little information regarding the design of matched feed is found in [10]. Recently, the authors have carried out very specific investigations on the design and development on the matched feed, and reported its performance with a circularly polarized offset parabolic reflector antenna [11]. Tri-mode matched feed uses a higher order TE_{21} mode and a TM_{11} mode with a fundamental TE_{11} mode to compensate the cross polarization introduced by the offset geometry. In case of an offset reflector configuration, the cross-polar performance of a matched feed as a primary feed is even better than a corrugated feed, as a corrugated feed provides a good match to the only copolar fields but not to the cross polar fields. Shee and Smith [12] have presented an algorithm to suppress the cross polarization of single offset reflector antenna illuminated by a cluster of matched feed horns. In [12], it is shown that the matched feed horns provide significant improvement in cross polarization as compared to a dual-mode potter horn. In a recent paper [13], the matched feed has been used to illuminate the gravitationally balanced back- to- back reflector. To the best of authors' knowledge, no data on beam efficiency improvement using the tri-mode matched feed has been reported in the open literature.

In this paper, improvement in the cross-polar performance and in the beam efficiency of an offset parabolic reflector using a tri-mode matched feed has been discussed. The secondary radiation patterns of an offset reflector antenna with a matched feed horn and a conventional Potter horn have been obtained and the cross polarization data for both the cases have been compared. Followed this, the extensive simulations were carried out to find out the beam efficiency of a tri-mode matched feed illuminated offset parabolic reflector antenna. Finally, the variation of beam efficiency as a function of half-cone angle is presented.

2. ANALYSIS

The offset reflector geometry under consideration is shown in Fig. 1. The expressions of the polar and the azimuthal radiation pattern components of the TE and the TM waves, for a tri-mode matched feed horn are obtained as,

$$E_\theta = E_\theta^{TE11} + \alpha 1 \cdot E_\theta^{TM11} + j \cdot \alpha 2 \cdot E_\theta^{TE21} \quad (1)$$

$$E_\phi = E_\phi^{TE11} + j \cdot \alpha 2 \cdot E_\phi^{TE21} \quad (2)$$

where, α_1 and α_2 are the arbitrary constants defining the relative power in TM_{11} and TE_{21} mode with respect to the fundamental TE_{11} mode.

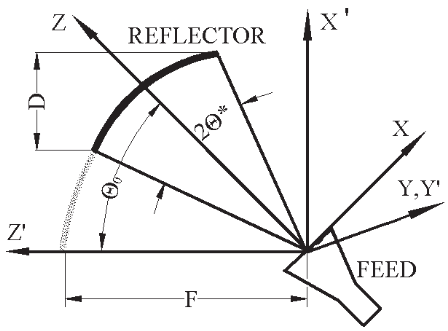

Figure 1. The offset reflector geometry under consideration.

For a tri-mode matched feed the values of constants α_1 and α_2 are required to be evaluated numerically for minimum cross polarization. The expressions for E_θ^{TE11}, E_θ^{TE21}, E_θ^{TM11}, E_Φ^{TE11}, and E_Φ^{TE21} can be obtained using the general expressions for E_θ and E_Φ from [14]. After obtaining the required expressions for the matched feed, the secondary radiation pattern for an offset parabolic reflector can be estimated using the mathematical model proposed by Rudge [15]. Finally, using the co and cross polarization data of far field secondary radiation patterns, the beam efficiency can be calculated for a specific value of half cone angle (θ_1) using the expression [16],

$$\text{Beam Efficiency } (\%) = \frac{P_{co}(\theta_1)}{P_{co}(\pi) + P_{xp}(\pi)} \cdot 100\% \tag{3}$$

where,

$$P_{co}(\theta) = \int_0^\theta \int_0^{2\pi} |G_{co}(\theta,\phi)|^2 \cdot \sin\theta \cdot d\theta \cdot d\phi = \text{Co pol. power} \tag{4}$$

$$P_{xp}(\theta) = \int_0^\theta \int_0^{2\pi} |G_{xp}(\theta,\phi)|^2 \cdot \sin\theta \cdot d\theta \cdot d\phi = \text{Cross pol. power} \tag{5}$$

The total power integral is given as,

$$P = P_{co}(\pi) + P_{xp}(\pi) \tag{6}$$

It is apparent from (3), that by reducing the cross polarization, it is possible to improve the beam efficiency.

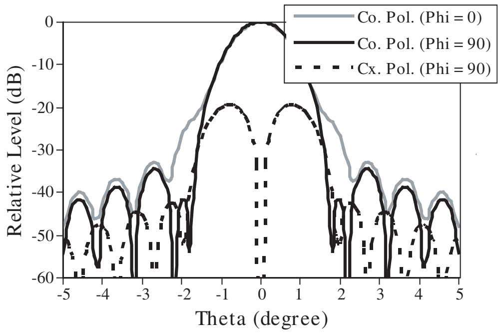

Figure 2. Secondary radiation pattern of an offset reflector fed by a conventional potter horn.

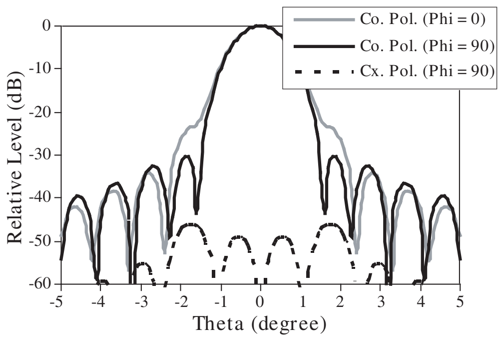

Figure 3. Secondary radiation pattern of an offset reflector fed by a matched feed horn.

3. RESULTS

A MATLAB program has been developed for computation of the secondary radiation pattern of an offset parabolic reflector. The F/D ratio of 0.6 and the offset angle of 50° were selected for the offset geometry under investigation. First, the far field radiation patterns were obtained for an offset reflector illuminated by the two different feeds. The results for the linearly polarized conventional Potter horn illuminated offset reflector are shown in Fig. 2. Fig. 3 shows the co and the cross polar patterns of the proposed matched feed illuminated offset reflector. Comparison of Fig. 2 and Fig. 3 shows that a tri-mode matched feed provides a minimum of 20 dB additional cross polarization suppression as compared to a conventional Potter horn. Next, using the expressions of beam efficiency, described in previous section, the MATLAB codes were developed to calculate the beam efficiency. The simulated results of beam efficiency were obtained as

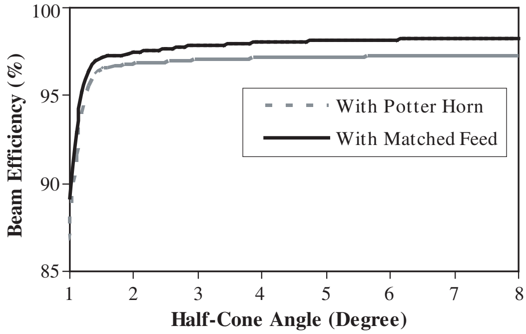

Figure 4. Beam efficiency as a function of half-cone beam angle.

a function of half-cone beam angle (θ_1) and are plotted in Fig. 4. As expected, the improvement in beam efficiency is achieved in case of a matched feed illuminated offset reflector, as compared to a conventional dual-mode Potter horn fed offset reflector.

4. CONCLUSION

In this paper, the improvement in the cross polarization as well as the beam efficiency of an offset parabolic reflector have been discussed. Extensive simulations were carried out and the results for a matched feed illuminated offset reflector were found very encouraging. Thus, it is concluded that the offset reflector antenna in conjunction with a tri-mode matched feed can suppress the unwanted cross-polarization to a significant level and improve the beam efficiency. It is expected that such an antenna system will become the most suitable option for the future microwave radiometers.

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REFERENCES

1. Lo, Y. T. and S. W. Lee, *Antenna Design Handbook*, Van Nostrand, London.
2. Njoku, E. G., "Passive microwave remote sensing of the earth from space — A review," *Proceedings of the IEEE*, Vol. 70, No. 7, 728–750, July 1982.
3. Njoku, E. G., J. M. Stacey, and F. T. Barath, "The seasat scanning multichannel microwave radiometer (SMMR): Instrument description and performance," *IEEE Journal of Oceanic Engineering*, Vol. 5, No. 2, 100–113, April 1980.
4. Hollinger, J. P., J. L. Peirce, and G. A. Poe, "SSM/I instrument evaluation," *IEEE Trans. Geosci. Remote Sensing*, Vol. 28, No. 5, 781–790, September 1990.
5. Contu, S. and F. M. Marinelli, "The antenna system for the multi-Frequency imaging microwave radiometer (MIMR)," *IEEE Antenna and Propagation Society International Symposium*, 2054–2057, June 1994.
6. Sharma, S. B., "The antenna system for the multi-frequency scanning microwave radiometer," *IEEE Antennas and Propagation Magazine*, Vol. 42, No. 3, 21–30, June 2000.
7. Gaiser, P. W., et al., "The windsat spaceborne polarimetric microwave radiometer: Sensor description and early orbit performance," *IEEE Trans. Geosci. Remote Sensing*, Vol. 42, No. 11, 2347–2361, November 2004.
8. Rudge, A. W. and N. A. Adatia, "Offset-parabolic reflector antennas: A review," *Proceedings of the IEEE*, Vol. 66, 1592–1618, December 1978.
9. Balanis, C. A., *Antenna Theory Analysis and Design*, 2nd edition, John Wiley & Sons, 2005.
10. Rudge, A. W. and N. A. Adatia, "New class of primary-feed antennas for use with offset parabolic reflector antennas," *Electronic Letters*, No. 11, 597–599, November 1975.
11. Sharma, S. B., D. A. Pujara, S. B. Chakrabarty, and V. K. Singh, "Removal of beam squinting effects in a circularly polarized offset Parabolic reflector antenna using a matched feed," *Progress In Electromagnetics Research Letters*, Vol. 7, 105–114, 2009.
12. Shee, K. K. and W. T. Smith, "Optimizing multimode horn feed arrays for offset reflector antennas using a constrained minimization algorithm to reduce cross polarization," *IEEE Transactions on Antennas and Propagation*, Vol. 45, 1883–1885, December 1997.

13. Bahadori, K. and Y. Rahmat-Samii, "A tri-mode Horn feed for gravitationally balanced back-to-back reflector antennas," *IEEE Antenna and Propagation Society International Symposium*, 4397–4400, July 2006.
14. Silver, S., *Microwave Antenna Theory and Design*, McGraw-Hill, New York, 1949.
15. Rudge, A. W., "Multiple-beam antennas: Offset reflectors with offset feeds," *IEEE Transactions on Antennas and Propagation*, Vol. 23, 317–322, May 1975.
16. Kildal, P.-S., *Foundations of Antennas*, Indian edition, Overseas Press, 2006.