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Design and realization of tracking feed antenna system

S. H. Mohseni Armaki[1], **F. Hojat Kashani**[1], **J. R. Mohassel**[2], **and M. Naser-Moghadasi**[3a)]

[1] *Electrical engineering faculty, Iran University of science and technology, Tehran, Iran*

[2] *Electrical engineering faculty, University of Tehran, Tehran-Iran*

[3] *Faculty of Eng. Science and Research Branch, Islamic Azad University, Tehran-Iran*

a) *mn.moghaddasi@srbiau.ac.ir*

Abstract: This paper describes the design and realization of a multi-mode tracking feed antenna system, for a circularly polarized wave, which can generate sum and difference patterns suitable for monopulse tracking in remote sensing earth stations. It uses TE_{11} and TE_{21} modes, in a smooth circular waveguide, to obtain the sum and difference patterns. The higher order mode, TE_{21} generated within the feed is separated from the fundamental mode, TE_{11} by using a mode coupler. Circular polarization is converted to linear polarization by pin polarizer septum. The design of the multimode corrugated horn and polarizer are described in some details. The prototyped horn designed here operates in the frequency range of 7.2–8.8 GHz. Sum and delta patterns and polarizer axial ratio are presented. The close agreement between measured and simulated data validates the present design.

Keywords: monopulse tracking feed, corrugated horn, mode coupler, polarizer

Classification: Microwave and millimeter wave devices, circuits, and systems

References

[1] L. Sakr, "The higher order modes in the feeds of the satellite monopulser tracking antenna," *IEEE Melecon 2002*, Cairo, pp. 453–457, 7-9 May 2002.
[2] P. J. B. Clarricoats and A. D. Olver, "Corrugated Horns for Microwave antennas," *IEE Electromagnetic Wave Series 18*, London, 1984.
[3] B. Du, E. K. N. Yung, K. Z. Yang, and W. J. Zhang, "Wide-band linearly or circularly polarized monopulse tracking corrugated horn," *IEEE Trans. Antennas Propag.*, vol. 50, no. 2, pp. 192–197, Feb. 2002.
[4] Ansoft high frequency structure simulation (HFSS), ver. 10, Ansoft Corporation, 2005.
[5] μWave Wizard ver 5.5, [Online] www.mician.com
[6] C. Granet and G. L. James, "Design of corrugated horns: a primer," *IEEE Antennas Propag. Mag.*, vol. 47, no. 2, pp. 76–83, April 2005.

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[7] S. H. M. Armaki, F. H. Kashani, and M. Naser-Moghadasi, "Optimum shape and size of slots for TE_{21} tracking mode coupler," *IEICE Electron. Express* (pending for publication).
[8] S. H. M. Armaki, F. H. Kashani, and M. fallah, "A new profile for metal post circular waveguide polarizer," *Progress In Electromagnetic Research Symp. Proc.*, Cambridge, USA, pp. 703–705, 5-8 July 2010.

1 Introduction

Earth station autotracking systems utilize a monopulse-tracking configuration feed antenna system. In this configuration, a second pattern with a null along boresight is used to provide a "delta" pattern which produces an error signal needed for pointing or tracking. This delta pattern can be produced, for example, by adding four auxiliary horn antennas around the primary antenna. However, the conventional four-horn type monopulse antenna requires four independent horns or four-partitioned horns, which makes the antenna feed systems to be larger in size but on the other hand causes to have a higher cost and complexity.

An alternative more efficient approach is the use of the multi-mode monopulse feed system. This technique uses the fact that when the target is off the boresight of a ground station antenna, higher order modes are excited. These systems often use a single multimode feed horn in conjunction with a tracking mode coupler. The multimode feed horn is designed to support multiple circular waveguide modes. A fundamental circular TE_{11} mode carries a sum radiation pattern are used to generate a sum signal and higher order modes, such as TM_{01} and TE_{21}, which carry a delta radiation pattern used to generate error signals [1]. The tracking mode coupler separates the higher mode from the fundamental mode and thus separates sum and error signals. In this paper we present the design, simulation and realization of a compact tracking feed antenna system for using in cassegrain reflector that works in the receiving band [7.2∼8.8] GHz.

2 Feed system structure

The block diagram of feed antenna system is shown in Fig. 1.a. It consists of conical corrugated horn, TE_{21} mode coupler, and metal post circular waveguide polarizer. The conical corrugated horn is precisely matched for both TE_{11} and TE_{21} modes. For most applications as depicted in Fig. 1.a, the horn is fed from smooth-wall waveguide supporting the TE_{11} and TE_{21} modes. We therefore used a mode converter, which transforms TE_{11} and TE_{21} modes launched by the monopulse TE_{21} coupler into HE_{11} and HE_{21} modes respectively. The zero-impedance smooth-wall circular waveguide is transformed into a high-impedance corrugated waveguide by using a series of grooves that taper in depth or width. This conversion must be carried out with minimum mismatch and excitation of higher order modes. A small flare

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conical corrugated horn structure is designed and simulated using Mician Microwave Wizard software [5].

The mode coupler detects the signal of higher order mode that is used to create the difference pattern which will be applied for the monopulse tracking. The mode detection is done by resonant coupling slots cut in a longitudinal waveguide wall [7]. A mode coupler for the TE_{21} mode consists of 4 longitudinal slots. Finally the septum polarizer provides the circular polarization for the sum signal.

3 Corrugated Horn

Corrugated conical horn plays a key role in feed horn system. The design of a tracking corrugated feed horn requires the simultaneous achievement of dual mode operation (sum and delta) and low return loss impedance matching.

The horn designed in this paper has been obtained by means of simple procedure which extends the ideas presented in [2, 3] and [6]. Therefore the horn can be considered as composed of two regions: the first part called "throat" region which provides the modal conversion and the matching of the antenna; the second part, called "radiating" region which is mainly responsible for the radiation pattern characteristics of the feed horn system.

3.1 Throat region

The definition of the throat region geometry can be regarded as the design of a loaded impedance transition which has to guarantee good input matching and correct modes conversion at the same time. The load corresponds to the radiating region of the horn. To ensure good propagation conditions for HE_{11} & HE_{21} modes, the radius at the input to the mode converter should be chosen such that $k_l a_l \geq 3.054$ where k_l is free space wave number corresponding to the lowest frequency, $f_l = 7.2\,GHz$. Here, we choose $a_m = 21\,mm$.

As pointed out in [6], the choice of mode converter structure depends on the bandwidth. Since the operative frequency bandwidth is not very broadband, the variable-depth-slot mode converter has been chosen. Since the first slot admittance S_1 at center frequency $f_0 = 8.2\,GHz$, should be infinite, we choose $s_1 = \lambda_0/2 = 18.3\,mm$. The other parameters according to [6] are: numbers of slots, $N_{mc} = 5$, slot pitch, $p = 7\,mm$, $s_2 = 16.5\,mm$, $s_3 = 14.8\,mm$, $s_4 = 13\,mm$, and $s_5 = 11\,mm$.

Evaluation of the converter can be accomplished by approximating the mode converter as a series of constant diameter corrugated waveguides. The results from field matching studies support a perfect match when the guide wavelengths in the two waveguides have the same value [2]. Sharp changes in guide wavelength along the mode converter are indicative of a change in impedance and can cause higher order modes to be exited.

Curves of Fig. 2.a and Fig. 2.b show the normalized guide wavelength against normalized slot depth for various normalized inner radii for HE_{11} and HE_{21} modes respectively [2]. These curves corresponds to the fields

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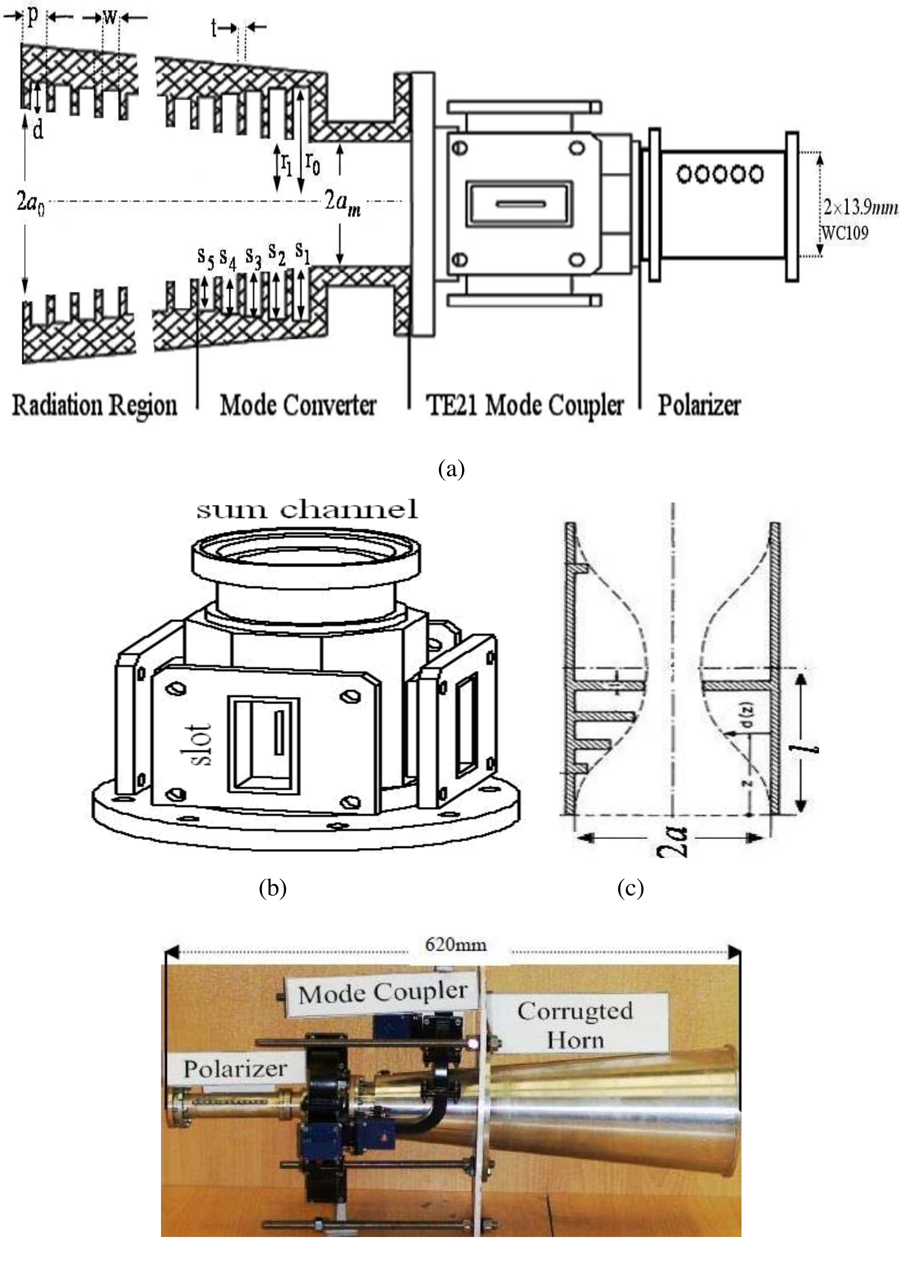

Fig. 1. (a) Tracking feed antenna system (b) Photograph of TE_{21} mode extractor [7] (c) Profile of metal post polarizer (d) Photograph of feed antenna system

with a slot width of 0.1λ and ridge width of 0.05λ. Matching trajectory for corrugated mode converter is obtained by plotting the inner radius and slot depth for each corrugation. For an assessment of good matching, the trajectory at the upper, center, and lower frequencies for HE_{11} and HE_{21} modes must be placed on the guide wavelength curves.

3.2 Radiation region

As it has been pointed out in [2], the corrugation geometry of the radiating region depends on the radiation pattern specifications. The groove dimen-

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sions for the radiation region were chosen to achieve the desired crosspolar radiation characteristic. The groove depth d = 9.3 mm is chosen such that it is quarter-wavelength at 8.2 GHz. The choice of the pitch of the grooves, p = 7 mm corresponds to 5 grooves /wavelength at 8.2 GHz. The ratio of the ridge, t, to groove spacing, w, should be made as small as possible to reduce the frequency sensitivity of the crosspolar radiation characteristics. Mechanical constraints have been easily taken into account by enforcing that ridge width and pitch are larger than a minimum value. As a compromise, a value of t/p = 0.3 has been used.

The semi flare angle θ_o and radius of aperture a_o are determined by the required beamwidth and the operating frequency. The flare angle of the horn has been chosen 14.6 degrees to place it within the category of small flared-angled horn [6]. The conical horn flares to an aperture size of $a_o = 77$ mm determined by optic considerations. The length of the horn has an impact on the sidelobes and the stability of phase center of the horn. We set it to be $10\lambda_l$ and as a result 57 slots are used in this horn.

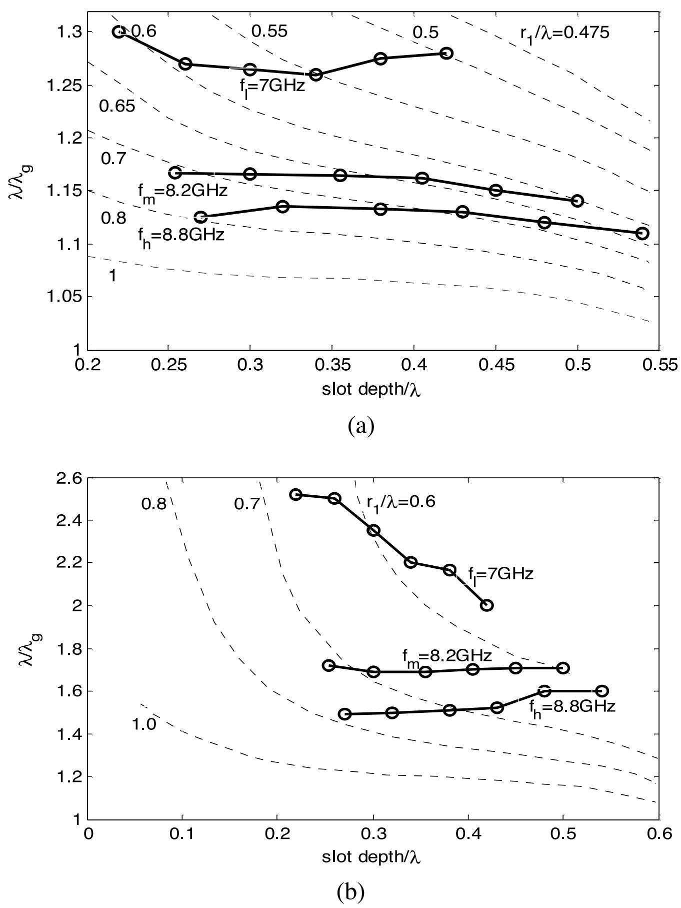

Fig. 2. (a) Trajectories of three frequencies for HE_{11} mode (b) Trajectories of three frequencies for HE_{21} mode

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4 TE_{21} Mode Coupler

The structure of the TE_{21} mode coupler is shown in Fig. 1.b [7]. It is formed by an overmoded circular waveguide as the coupling line, and dominant mode rectangular waveguide as the coupled line. Since the mode coupler should extract azimuth and elevation errors, there are four arms, two for azimuth delta port and two for elevation delta port. Converting TE_{10} to TE_{21} between the guides is controlled by the size and shape of coupling slots located in a common wall [7].

Although the analytic method is very useful in understanding coupling mechanism, it is unable to analyze the effect of frequency response for various shapes of slots [7]. Therefore we have used HFSS for simulating the mode coupler [4]. The radius of overmoded circular waveguide is 21 mm with TE_{21} cut off frequency of 6.94 GHz.

5 Polarizer

A circularly polarized wave is represented by the superposition of two orthogonal linearly polarized waves that possess identical magnitude and a phase difference of 90 degrees. In conventional polarizers such as metal post (pin) polarizes apart from good matching properties at each port, there are two basic demands on the design of these polarizer type. Firstly, the signals of the linearly polarized modes must be exactly divided (combined) into orthogonal components with identical magnitudes. Secondly a 90 degrees differential phase shift between these semi signals has to be accomplished.

Fig. 1.c depicts the structure of proposed polarizer with metal posts [8]. The polarizer is composed of a circular waveguide and 13 symmetrical metal posts arranged in a single line and aligned diagonally with regard to the E vector. To obtain good VSWR and AR characteristics, the post depth in the matching sections follows the tangential function profile that is predefined as:

$$d(z) = (a/2)\left[(1-A)\,z/l + A\tan^2(\pi z/4l)\right] \quad \text{where} \quad A = 0.7 \qquad (1)$$

The separation between metal posts and the diameter of posts are $a/2$, $0.04\lambda_g$ respectively and length of the waveguide polarizer is about $2\lambda_g$. Desired response is then obtained by fine tuning of the depth using HFSS.

6 Measurement Result of feed system

The tracking feed horn system was realized and simulated for the frequency range of 7.2–8.8 GHz. The feed horn system photograph is shown in Fig. 1.d. Simulation is carried out using Mician Microwave Wizard software. Fig. 3.a. shows the simulated AR (Axial Ratio) in different frequencies. Fig. 3.b shows the measured return loss of feed antenna system (including TE_{21} mode coupler and polarizer). As we can see in this figure, the return loss in the sum mode is better than 18 dB.

Fig. 3. (c,d,e,f) show the measured and simulated sum (copolar and 45 degrees crosspolar) and difference radiation patterns of feed antenna system

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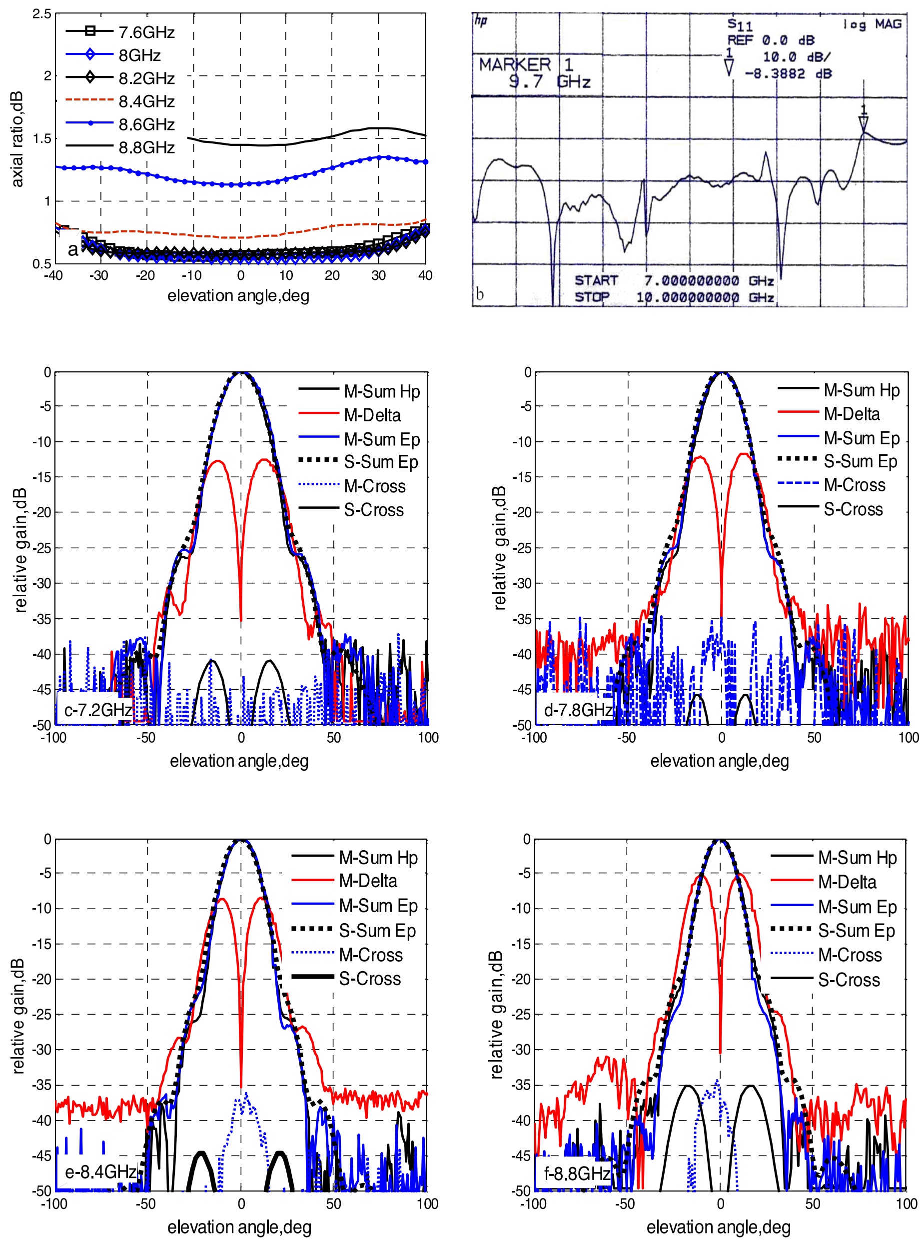

Fig. 3. (a) Simulated AR of polarizer at various frequencies (b) Measured return loss of feed horn system (c,d,e,f,) Simulated (S) and measured (M) radiation patterns of feed horn system at different frequencies (Hp: H plane, Ep: E plane)

at four frequencies within the band. All radiation patterns are made without polarizer. It is observed that the sum copolar patterns demonstrate a high degree of circular symmetry. The difference patterns also indicate good symmetry with a less than −30 dB deep null on-axis. Since we have been forced to use a pyramidal horn antenna as a source, and its crosspolarization performance was not good enough to permit meaningful crosspolariztion measurements, the comparison between simulated and measured results is not justified in crosspolar radiation patterns. The simulated crosspolarization levels at the four frequencies are less than −35 dB.

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7 Conclusion

This paper presents the realization design and simulation of monopulse tracking circularly feed horn system. The design presented in this paper has been efficiently applied to define the architecture of tracking feed antenna system for remote sensing earth stations. The feed design and simulation given here, has been validated experimentally. Good agreement between simulation and experimental data is observed. A configuration, design and simulation of metal post circular polarizer with tangential profile for depths of posts have been introduced. The presented polarizer does not need experimental tuning depths of posts.

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