Design of a C-band Beam-scanning Reflectarray Antenna for Satellite Communications

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***Abstract*—A beam-scanning reflectarray antenna is designed for C-band (6.7 GHz) satellite communications. The array part of the antenna includes two array planes with one consisting of reflection elements and the other consisting of transmission elements. By horizontally rotating these two planes, we can scan the main beam to cover a large part of hemisphere. A reflectarray prototype with a circular aperture of 580 mm in diameter is fabricated and tested for verification. A high-gain beam with a scan range from 0° to 56.8° off-broadside is achieved. The results confirm the potential of a lightweight and low profile beam-scanning antenna suitable for high-gain satellite communications.**

I. INTRODUCTION

Beam-scanning capability is an important feature of high-gain antennas for applications such as communications between earth stations and MEO or LEO satellites. The most widely used approach in earth stations is a bulky and heavy parabolic reflector alongside with a complex feeding system and an Az/El positioner to control the beam. Utilizing microstrip techniques [1], a beam-scanning lens antenna with two rotatable phase shifting surfaces was demonstrated recently [2]. The idea is to use the nature of a pair of wedge prisms, therefore the feeding and mechanic servo system can be much simpler. Considering the scaling problem, a reflectarray antenna, which puts its array component on the ground, would be more suitable for earth station applications. Moreover, the aperture efficiency is expected to be higher because of the ground plane.

In this paper, a C-band high-gain beam-scanning reflectarray with a circular aperture of 580 mm in diameter is designed, fabricated, and tested. Test results are presented to verify its performance. This proposed prototype can be readily scaled to a larger aperture for earth station applications.

II. BEAM-SCANNING PRINCIPLE OF THE REFLECTARRAY

A. Operation Principle

The structure of the proposed antenna is shown in Fig. 1 (a). From top to bottom are:

- A horn feed;
- A rotatable transmitarray (TA) plane;
- A rotatable reflectarray (RA) plane.

The TA and RA planes can be rotated in the horizontal plane independently, and the two planes together function as a pair of wedge prisms (WPs). The operation principle is briefly illustrated in Fig. 1 (b). The elevation angle is determined by the relative position of the two WPs: when they are aligned in the same direction, the largest inclination beam is achieved; when they are aligned in the opposite direction, a broadside beam is achieved. Meanwhile, the azimuth angle is determined by rotating two WPs together.

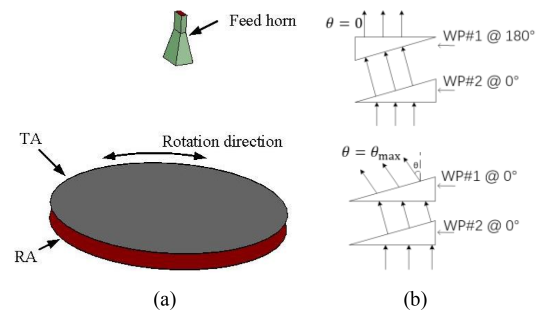

Fig. 1. (a) Configuration of the proposed beam-scanning reflectarray antenna, (b) how WPs control the beam

B. Phase Distribution Design

The overall reflection performance of TA and RA can be derived from scattering matrices of two cascaded sections. Assume that the $[S]$ matrix of a RA element is $[S^A]$ and the $[S]$ matrix of the corresponding TA element is $[S^B]$. According to the theory of linear 2-port network, the overall reflection coefficient S_{11}^C can be written as [3]

$$S_{11}^C = \frac{S_{11}^A S_{12}^B S_{21}^B}{1 - S_{11}^A S_{22}^B} + S_{11}^B \quad (1)$$

If the TA element has a relatively high magnitude of transmission coefficient ($|S_{21}^B| \approx 1$, $|S_{22}^B| \approx 0$), and the element's structure is symmetric ($S_{12}^B = S_{21}^B$), then the phase of S_{11}^C can be simplified as

$$\angle S_{11}^C = \angle S_{11}^A + 2\angle S_{21}^B \quad (2)$$

In order to control the beam direction by rotating two array planes, the overall reflection phase distribution must be divided into two parts: Ψ_0, a parabolic phase distribution to forming a pencil beam; Ψ, a linear progression phase distributions to mimic the nature of a WP. Because the horn feed is placed right above the center of array planes, the Ψ_0 is axial symmetric, so

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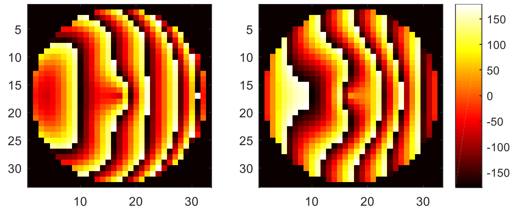
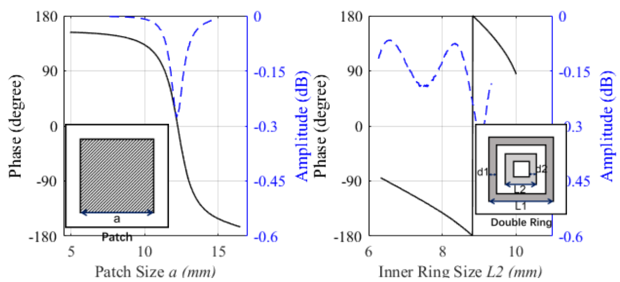


(a) (b)

Fig. 2. Phase distributions of (a) RA plane, and (b) TA plane



(a) (b)

Fig. 3. (a) RA element, (b) TA element

that it will not change while being rotated. A common phase allocation of these three phase distributions can be like following

$$\angle S_{11}^{A} = \Psi_0 + \Psi,\ \angle S_{21}^{B} = \frac{1}{2}\Psi \tag{3}$$

It is worthwhile to point out that Ψ_0 can be separated in any portion and the phase allocation is still valid as long as $\angle S_{11}^{C}$ remains the same. A general form of phase distributions of TA and RA are like following

$$\angle S_{11}^{A} = \alpha\Psi_0 + \Psi,\ \angle S_{21}^{B} = \frac{1}{2}\left((1-\alpha)\Psi_0 + \Psi\right) \tag{4}$$

where α can be any real number. An example phase distribution is show in Fig. 2.

III. Design, Simulation, and Test of The Reflectarray

Following the above operation principle, a beam-scanning reflectarray is designed. Some parameters of three components of the antenna are listed:

- A circularly polarized horn feed at normal incidence: f = 6.7 GHz, height = 348 mm, edge taper = −11 dB;
- RA element in Fig. 3 (a): element size = 17.2 mm, substrate: ε_r =2.55, thickness =1.58 mm.
- TA element in Fig. 3 (b): element size = 17.2 mm, substrate: ε_r = 2.55, thickness = 0.79 mm, layer separation = 10 mm.

Because the TA's contribution to overall phase is twice of its transmission phase, a phase range of 180° is enough for TA plane. Here we used a 3-layer double ring as TA element, where the parameters are as follows: L1=16.6 mm, d1 = d2 = 1 mm. We used 10 mm height plastic spacers to separate three layers.

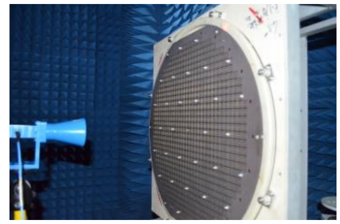
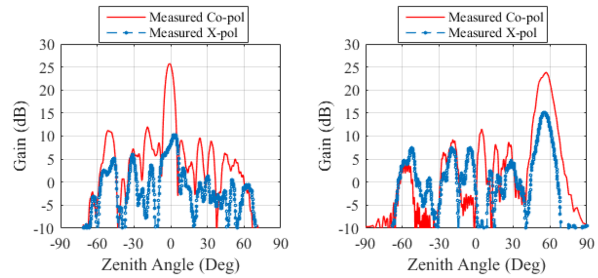


Fig.4. Reflectarray prototype measured in a near-field acustic cahmber



(a) (b)

Fig. 5. Measured radiation pattern(a) θ = 0° (b) θ = 58°

Results of unit cell simulation showed a phase range slightly over 180° with transmission magnitude better than −0.35 dB.

A beam-scanning reflectarray prototype with a cicular aperture is fabricated as shown in Fig. 4. The simulated and measured radiation patterns are presented in Fig. 5 with one beam at broadside and the other beam scan to 58°. The measured results demonstrate the beam-scanning capability of the proposed reflectarray. A summary of simulated and measured results are tabulated in Table I. Both TA element and RA element are symmetric thus the proposed design is suitable for both linear and circular polarizations. When the main beam pointing at 56.8° the cross polarization was −9.2 dB.

TABLE I. Simulated and Tested Gains and Beam Width

	Simulated	**Measured**	**Simulated**	**Measured**
Beam direction	0°	0.8°	58°	56.8°
Gain	27.6 dB	25.8 dB	24.5 dB	24.3 dB
3dB beam width off axis	5.5°	4.2°	6.4°	8.7°

IV. Conclution

In this paper, a high-gain beam-scanning reflectarray antenna has been designed, fabricated, and measured. By horizontally rotating two array planes, it achieves a high gain around 25 dB and a scan range from around $-60°$ to $+60°$. The lightweight and low profile antenna has a simple feeding and mechanic system. It shows great potentials in high-gain beam-scanning applications for satellites communications due to its ease of installation, deployment, and its high scalability.

References

[1] Huang J. Reflectarray antenna. John Wiley & Sons, Inc., 2005.

[2] Gagnon N, Petosa A. Using rotatable planar phase shifting surfaces to steer a high-gain beam. IEEE Transactions on Antennas and Propagation, 2013, 61(6): 3086-3092.

[3] Pozar D M. Microwave engineering. John Wiley & Sons, 2009.