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A Design Method of Spaceborne Circularly Polarized Multi-Beam Antenna Array

Yuanyuan Li*, Zhou Zhang, Liang Sun, Guodong Han, and Peisong Dong

Abstract—In this paper, a design method of spaceborne multi-beam antenna array is proposed. Multi-beam is achieved by rotating subarrays. A high efficiency circularly polarized horn antenna array working in Ka band is designed and processed. The antenna array has 16 large axial ratio elliptical beams, which can achieve the beam coverage range of $53^\circ \times 49.1^\circ$. The simulation results are basically consistent with the test results, verifying the effectiveness of the proposed method. The design method of multi-beam antenna proposed in this paper can meet the requirements of multi-beam seamless coverage.

1. INTRODUCTION

With the development of satellite communication technology, satellite communication systems require antennas to have the characteristics of miniaturization and low cost, as well as characteristics of broadband, high gain, and high efficiency. Spaceborne antenna is an important part of satellite payload, and satellite mobile communications require effective frequency reuse methods to expand the number of users [1]. Multi-beam antenna can use the same aperture surface to generate multiple different pointing beams at the same time and cover a specific area, which can meet the requirements of high-quality, large-capacity, and high-coverage satellite communication. Multi-beam antennas provide the possibility for frequency reuse. Frequency reuse means that the same frequency is used multiple times, and the same frequency is allocated according to beams of different directions, which improves the utilization rate of the frequency. At the same time, the communication capacity of the entire network can be increased without increasing the bandwidth. Multi-beam antenna technology can cover the target coverage area with high effective isotropic radiated power (EIRP) and antenna gain-to-noise-temperature (G/T) value and can effectively improve the communication capacity of satellite through frequency reuse technology. The configuration of multi-beam antennas on communication satellites can realize polarization isolation, spatial isolation, spectrum reuse, and double the communication capacity. Some designs have been presented to realize multi-beams [2–6]. The size of the reflective surface and lens multi-beam antenna is often larger. In 2000, folded reflector antennas proposed by Wolfgang Menzel used two reflections of electromagnetic waves to reduce the profile of the reflector antenna by half, greatly reducing the size of the antenna [7]. Ref. [8] proposed a new method for beam scanning using a folded reflector array structure. The authors used a coded active phased-shifted reflector unit to realize a folded reflector array antenna with high gain and wide-angle beam scanning performance. However, the implementation scheme is expensive and can only achieve single-beam angle scanning. The design of spaceborne multi-beam antennas and the method of multi-beam implementation are at the core of implementation difficulties.

A Ka-band circularly polarized multi-beam antenna array is proposed in this paper. The radiation element of the antenna array is a rectangular horn antenna, and a baffle polarizer is used to achieve circular polarization. The radiating unit in the form of a horn has the advantages of simple design,

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high radiation efficiency, excellent circular polarization performance, simple and reliable structure, and easy realization [9]. It also has the characteristics of radiation resistance. The 16 circularly polarized horn antenna cells are arranged in a subarray, and the beam coverage of each subarray is 53° × 3.07°. In this paper, the method of rotating adjacent sub-arrays is used to realize the seamless and uncovered multi-beams of the elevation plane. It can improve the coverage gain of the satellite antenna and has the advantages of high antenna efficiency and flexible design of a single beam. The design method realizes different directions through space diversity characteristics and can be used for frequency reuse to improve channel capacity.

2. DESIGN OF KA-BAND CIRCULARLY POLARIZED HORN ANTENNA

The topology of the Ka-band circularly polarized antenna is shown in Figure 1. The antenna is composed of a square horn, a square waveguide, and a baffle circular polarizer. The working principle of the antenna is to use a square waveguide to feed the horn pair and to radiate electromagnetic waves into free space through the horn.

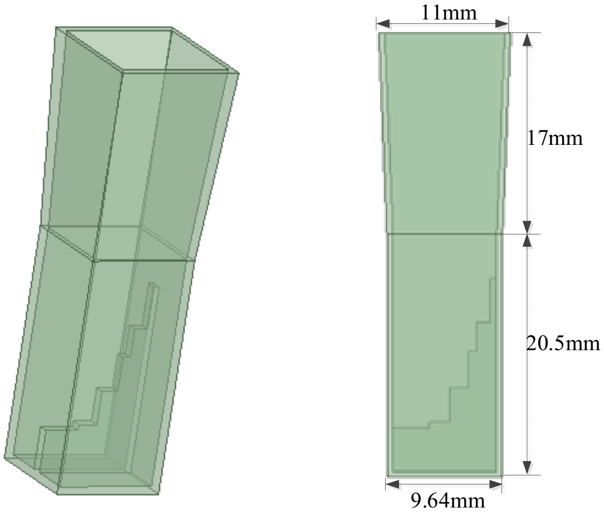

Figure 1. Topology of Ka-band circularly polarized antenna.

The circular polarization antenna adopts a baffle circular polarizer to realize circular polarization. The partition determines the performance of the circular polarizer. The baffle circular polarizer is a three-port microwave device. The common end has two modes, TE01 and TE10. At the same time, there are two modes at the two rectangular ports. For the two orthogonal polarization modes TE01 and TE10 modes, during the transmission process, due to the effect of the stepped partition, when the waves of the two mutually perpendicular modes reach the two rectangular waveguide ports through the stepped partition, the power of the TE10 mode is equally divided, and the power of TE01 mode is not only equally divided, but also the direction of the electric field will undergo a 90° transition. Therefore, left-hand and right-hand circularly polarized waves can be obtained at the rectangular waveguide port.

Baffle circular polarizers are widely used in waveguide network systems. Compared with traditional polarizers, their characteristics are that they can achieve simultaneous left and right circular polarizations without the need for an orthogonalizer, and the ports are isolated, phase consistent, and stationary. Indexes such as spreading insertion loss can easily meet the requirements. The external structure of the separator polarizer is shown in Figure 2. A zigzag separator is inserted into the square waveguide. One end of the waveguide is the entrance of the dual-polarized wave, and the other end is divided into two polarization ports in the direction of rotation. The size of each part of the diaphragm circular polarizer can be determined according to [10]. Establish an integrated model of circular polarizer and radiation unit in high-frequency structure simulator (HFSS), as shown in the Figure 1. By adjusting

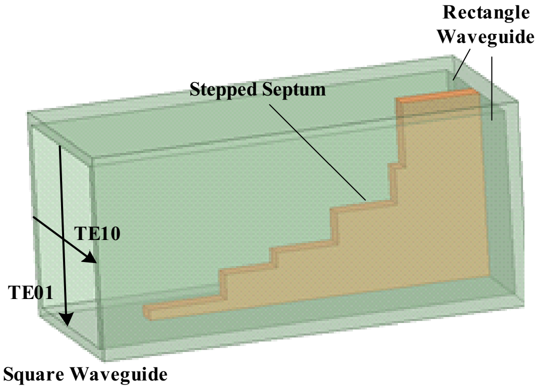

Figure 2. Topology of baffle circular polarizer.

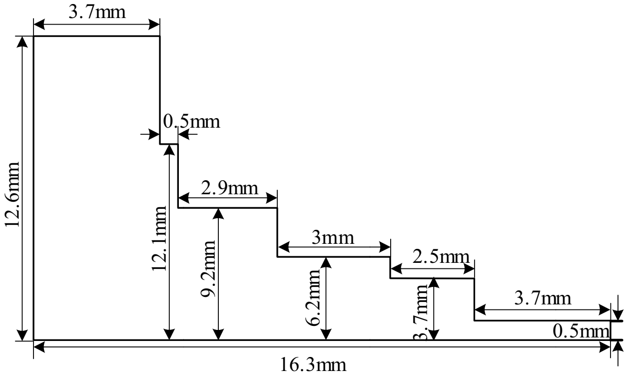

Figure 3. The size of baffle circular polarizer.

the geometric parameters of the baffle, the standing wave and axial ratio are optimized. The optimized size of the HFSS design is shown in Figure 3.

Figure 4 shows the simulation results of the antenna unit. It can be seen from the figure that the axial ratio of the antenna from 19.5 GHz to 31.6 GHz is less than 3, and the voltage standing wave ratio (VSWR) is less than 2. The percentage bandwidth is about 52.8%, and the gain is 10.2 dBi, as shown in Figure 5.

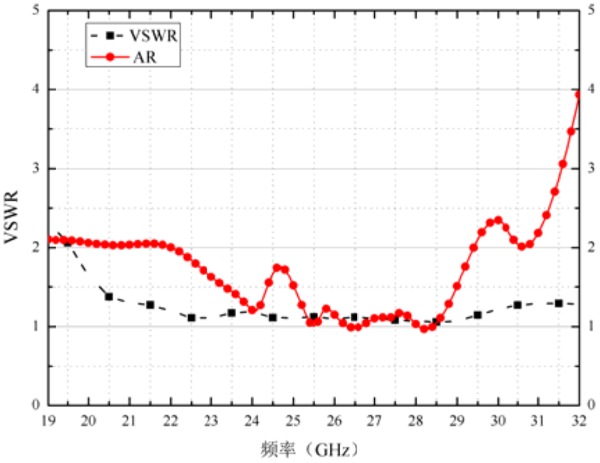

Figure 4. Simulate results of the Ka-band circularly polarized antenna.

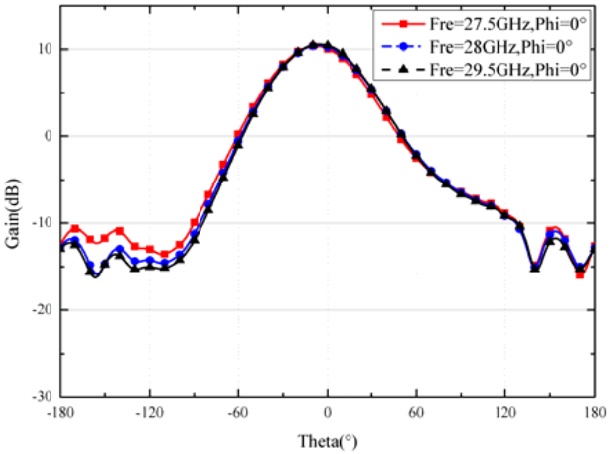

Figure 5. Radiation pattern of the Ka-band circularly polarized antenna.

3. DESIGN OF MULTI-BEAM ANTENNA ARRAY

In order to achieve high-gain radiation of the antenna, the antenna is designed as an array, and the power is synthesized by using a one-to-sixteen waveguide power division network.

The whole structure of the proposed multi-beam antenna array is composed of three parts: radiation layer, power division network layer, and the structural skeleton. The radiating layer is formed by linearly arranged circularly polarized horn antennas. Each column is a subarray, and there are 16 subarrays in total. The 16 subarrays are rotated in turn by a certain angle to achieve spatial diversity, and a 16-beam antenna array can be formed. Each antenna array can achieve a beam coverage of $53° \times 3.07°$, and 16 subarrays can form 16 beams pointing at different points to achieve a beam coverage of $53° \times 49.12°$. The power division network is connected to the radiating layer. They are processed in an integrated manner.

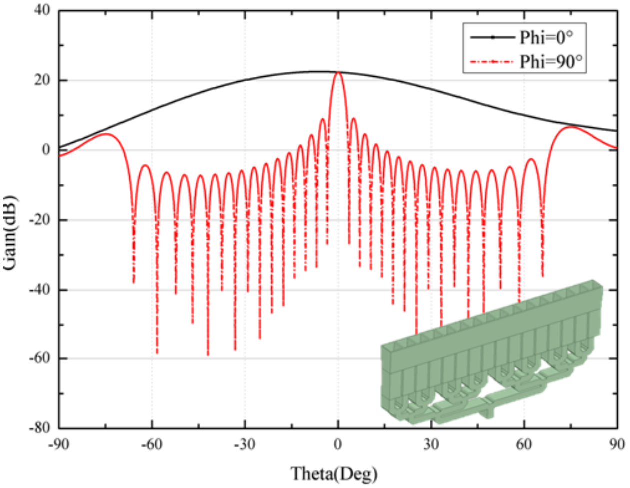

Figure 6. Simulation results of one antenna subarray.

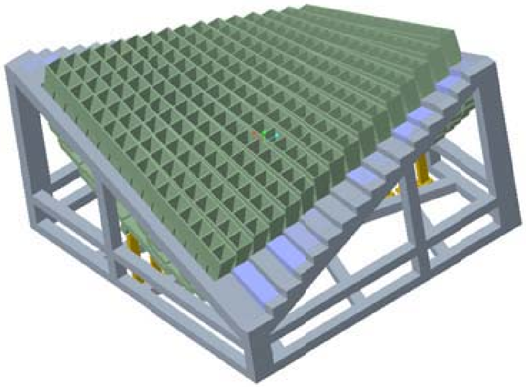

Figure 7. Structure of multi-beam antenna array.

Figure 6 shows the structure of the antenna subarray and the simulation results of one subarray. The structure diagram of the multi-beam antenna array composed of 16 subarrays is shown in Figure 7.

4. SIMULATION AND MEASUREMENT RESULTS

The effectiveness of the proposed multi-beam antenna design method is experimentally verified by fabricating the prototype with 3 antenna subarrays and measuring with the comparison method, as shown in Figure 8. The comparison method to measure the antenna gain is essentially to compare the gain of the antenna under test with the standard gain of a known antenna to obtain the gain of the antenna under test. The comparison method is basically the same as the antenna pattern measurement system, except that when the antenna gain is measured, a standard gain antenna is placed next to the antenna to be tested, as shown in Figure 9. Figure 10 shows the measured pattern of the antenna subarray. The measured gain of the antenna subarray is 22.21 dB, which is 0.42 dB less than the simulated gain. The 3 dB beamwidth is 59.48° × 2.99°. The simulation results are in good agreement with the measurement ones. The discrepancy between the simulated and measured results is mainly attributed to processing and cable loss.

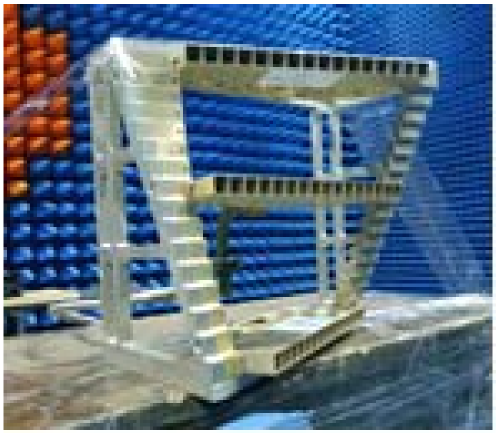

Figure 8. Photograph of measurement setup and the fabricated subarrays.

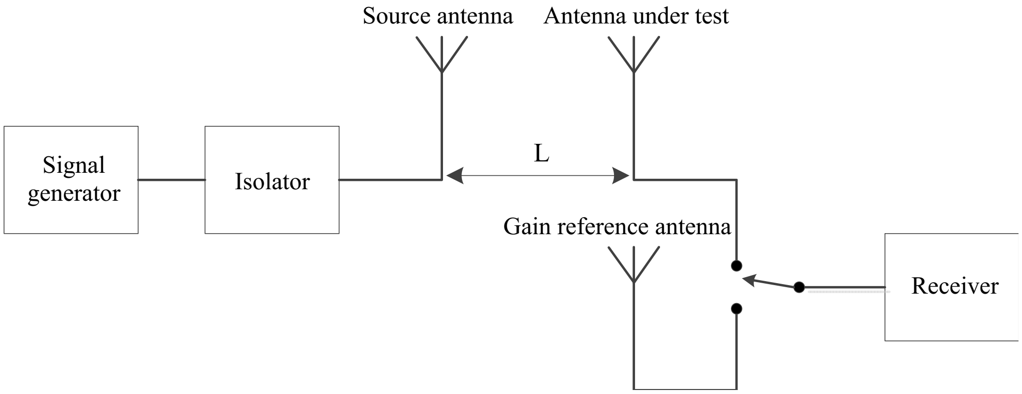

Figure 9. Schematic diagram of gain measurement by comparison method.

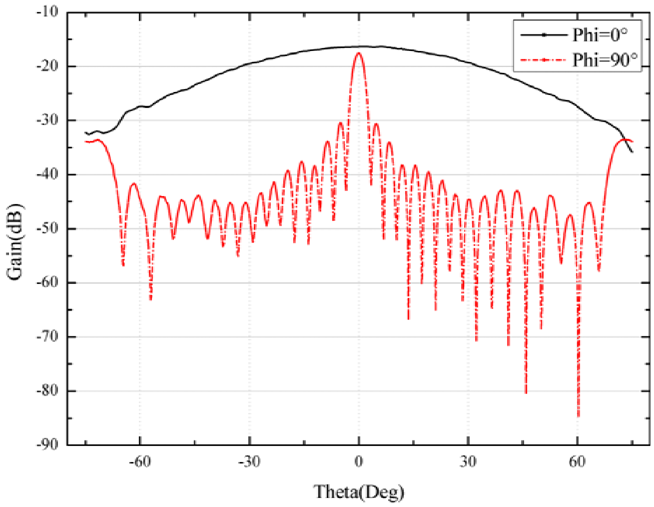

Figure 10. Measurement result of one fabricated subarray.

5. CONCLUSIONS

In this paper, a spaceborne multi-beam antenna array design method is proposed to realize multi-beam coverage by using the spatial diversity technology of antenna array physical rotation. A Ka-band ultra-wideband circular polarization antenna array suitable for spaceborne environment is designed and processed. The simulation and test results are basically the same. The design method of multi-beam antenna proposed in this paper can meet the requirement of seamless coverage of satellite to the ground.

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