

Design of an L-Band Reflectarray Antenna for BeiDou Satellite Applications

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Abstract— A 2.88-m L-band circularly polarized reflectarray antenna is designed and implemented for satellite applications. Variable-sized microstrip patch elements with a double-layer substrate are used to minimize dielectric loss, antenna weight, and system cost. Instead of traditional horns, a simple circularly polarized microstrip array is designed as the feeding antenna. An unconventional main beam direction of 45.5° is achieved for monitoring navigation signals from a geostationary satellite. Simulation results show the co-polarization gain reaches 31.3 dB at 1.56 GHz, which validates the effectiveness of reflectarrays in this type of applications.

Index Terms — Antenna, circular polarization, L-band, navigation, reflectarray.

I. INTRODUCTION

To improve the positioning accuracy of navigation satellites, its signal needs to be constantly monitored. High-gain antennas with beam scanning capabilities are usually employed to track the satellites along various orbits. Traditionally, large aperture parabolic reflector antennas are extensively used mainly because of their excellent radiation performance. They, however, have distinct disadvantages, such as large size, heavy weight, and demanding requirements for the servo system for beam scanning.

The reflectarray antenna has become an attractive alternative to a reflector antenna in various applications since its inception due to its favorable electrical and mechanical features [1, 2]. Although reflectarray antennas covering different frequencies have been designed in literature, only a few L-band reflectarray antennas have been proposed [3, 4] for low-gain applications.

In this paper, the concept of employing high-gain L-band reflectarray antennas for navigation signal monitoring is explored. A prototype with a large tilted angle of the main beam is designed for geostationary communications. The detailed design procedure is presented in Section II, with an emphasis on practical considerations to reduce the fabrication cost and to improve its assembly capability. Some preliminary simulation results are presented in Section III to validate the proposed concept. And Section IV concludes this paper.

II. DESIGN PROCEDURE

The target is a geostationary navigation satellite and the operating frequency is 1.56 GHz. Because of the high orbiting altitude, the required gain of the reflectarray is 30

dBc so that the monitored signal level is adequate for direct demodulation process. Therefore, a square aperture with side length of 2.88 m is needed for this design. Although the design procedure for conventional reflectarrays at high frequencies is quite mature and various examples have been reported in literature, the large reflectarray aperture required for high-gain reflectarray antennas operating at L-band does impose certain challenges, especially when the fabrication cost, assembly accuracy and portability are considered.

The reflectarray is placed on a flat rooftop to ease the requirements on assembly and maintenance. Therefore, the main beam is tilted 45.5° off the zenith direction. The unconventional large main beam angle also causes a challenge and must be taken into account in the design.

A. Reflectarray System Design

A schematic view of the reflectarray system is shown in Fig. 1. The reflectarray aperture is divided into four 1.44-m square panels so that it can be easily assembled and transported if necessary. Each panel consists of 9 pieces of subarrays with side length of 0.48 m for the ease of fabrication. The feeding antenna is supported by an aluminum frame with height of 2 m, tilted 15° off the normal direction. The main beam direction is tilted 45.5° opposite to the feed.

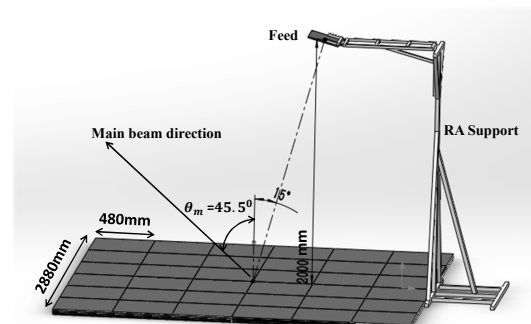


Fig. 1. Schematic view of the proposed reflectarray antenna.

B. Reflectarray Element Design

Microstrip patches with variable sizes are used for their well-known element performances and suitability for circularly polarized signals. A thick substrate is usually required at L band for smooth phase shift and bandwidth consideration, which would make the fabrication cost and weight unacceptable. Instead, the patches are etched on a thin ungrounded FR4 substrate ($\epsilon_r = 4.4$, $\tan\delta = 0.025$) with thickness of 2 mm, and polymer cylindrical spacers with height of 8 mm are placed between the FR4 substrate

and the aluminum ground plate. The FR4 substrate can significantly reduce the fabrication cost, and the air layer can reduce the equivalent substrate permittivity, mass and dielectric loss, resulting in better phase and magnitude performances of the element.

The compensation phases, which are required to collimate the main beam in a large tilted angle, change rapidly and the patch sizes of adjacent elements can be very different. This would destroy the periodic boundary assumption in element simulation and cause unexpected phase errors. Therefore, a sub-wavelength element spacing is needed to smooth the compensation phase distribution. The reflection coefficients with different element spacings are shown in Fig. 2, and 60-mm spacing is chosen for its smoother phase curve.

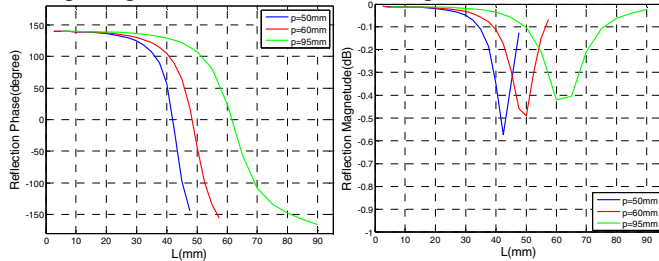


Fig. 2. Element reflection coefficients with different spacings.

C. Feeding Antenna Design

A horn antenna is usually used as the feed in reflectarrays. At L-band, however, it is bulky and expensive. Therefore, a microstrip array antenna is designed as an alternative. To provide an optimized illumination on the reflectarray, an approximately -8.5 dB feed taper is required and the 10-dB beamwidth is about 70° . Its polarization is left-handed circularly polarization (LHCP).

The detailed structure of the microstrip array feed antenna is illustrated in Fig. 3. The same double-layer structure with FR4 and air is utilized. A probe-fed 2×2 array with side length of 255 mm is excited with equal amplitudes but with different phases (0° , 90° , 180° , 270°) [5] so that an LHCP wave can be produced. Three Wilkinson power dividers are placed on the back layer to provide the required excitations and good port isolations.

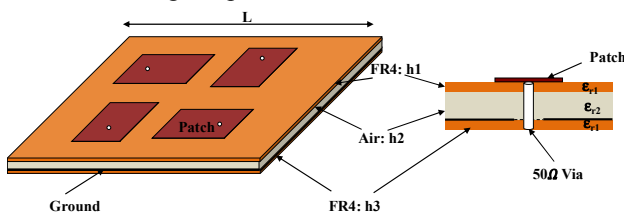


Fig. 3. Detailed structure of the microstrip array feed antenna.

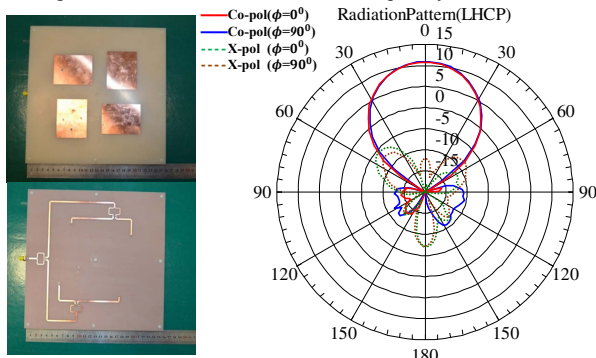


Fig. 4. Feed antenna prototype and measured radiation patterns.

The prototype of the feed antenna and its measured radiation patterns at 1.56 GHz are shown in Fig. 4. The measured gain is 10.9 dBi with satisfactory feed taper and 10-dB beamwidth. It thus validates that a simple microstrip array can be used as an effective and inexpensive feed solution in reflectarrays.

III. RADIATION PATTERN OF THE REFLECTARRAY

Based on the element performance and the feed radiation parameters, the 2.88-m reflectarray prototype, as illustrated in Fig. 1, has been designed and simulated. Its radiation patterns obtained using the array theory [6] is plotted in Fig. 5. The calculated gain is 31.3 dB and the sidelobe levels are below -20 dB. The radiation characteristics meet the requirements of the design.

The fabrication and measurement of the prototype reflectarray are being performed. More experimental results will be presented during the conference.

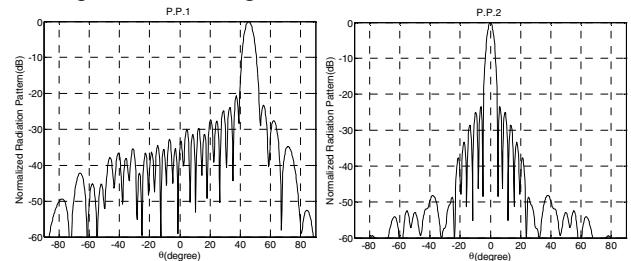


Fig. 5. Simulated radiation patterns of the reflectarray: offset plane (left) and orthogonal plane (right).

IV. CONCLUSION

The design of an L-band circularly polarized reflectarray antenna for BeiDou navigation satellite system is presented. In order to satisfy the design requirements on gain, cost, assembly accuracy, maintenance and portability, a segmented double-layer structure with FR4 and air substrates is adopted. Variable-sized microstrip patch elements with sub-wavelength spacing are chosen, and a simple microstrip array is designed and measured as an alternative solution of the feeding antenna in reflectarrays.

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