A Sequential-Phase Fed Dual-Band Dual-Circular-Polarized Patch Antenna for Ka-BandSatellite Communications

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ABSTRACT

In this paper, a dual-band dual-circular-polarized patch antenna for Ka-band satellite communications is presented. It integrates 2 2 aperture-coupled corner-truncated microstrip patch antenna elements and the microstrip feeding network provides a good amplitude and phase for the subarrays. By using sequential rotation technique, it achieves good impedance bandwidth and axial ratio bandwidth, which covers the uplink frequencies (30-31 GHz) and downlink frequencies (20-21 GHz) of Ka-band satellite communications. Since the elements are placed within an appropriate range, the two ports are well isolated. The detailed design process is given in this paper, and good simulation and measured results are obtained.

Index Terms—Ka-band satellite communications, dual-band, dual-circular-polarization, patch antenna, sequential rotationtechnique.

INTRODUCTION

With the continuous development of wireless communica- tion technology, satellite navigation and positioning technolo- gy, as an important direction in the field of communication, is changing constantly. Early satellite communications were generally concentrated in C band and Ku band, while Ka- band satellite communications were relatively seldom used. On the one hand, the higher the frequency, the greater the loss; on the other hand, the cost of small satellite communication system is relatively higher, and the design is more difficult. Due to the situation that the C-band and Ku-band will be congested in the future, satellite communications for the Ka band have been developed. In recent years, the development and industrialization of small and high-performance Ka-band mobile antennas are emerging in the satellite communication market [Marcellini et al., 2011]. High data rate links and small planar antennas for Ka-band satellite communications have been paid more and more attention.

In order to reduce the influence of weather and multipath reflection during satellite communication, circular polarization is more preferable than linear polarization in polarization selection. There are many ways to realize circular polarization, and sequential rotation technique is an effective one which can improve the impedance bandwidth and axial ratio bandwidth of the antenna. Ka-band satellite communications are required to have right-hand circular polarization with uplink frequencies between 30-31 GHz and left-hand circular polarization with downlink frequencies between 20-21 GHz. For some planar antennas, microstrip antennas and slot antennas are widely used, and microstrip antennas become the first choice in this aspect because of their compactness and easy realization of circular polarization. In [Rohrdantz, et al., 2015], a dual-polarized microstrip antenna operating in Ka band is introduced. This design adopts a tuning fork shaped microstrip line structure which is well coupled to a cross slot and can stimulate circular polarization characteristics when both ports are fed at the same time. In [Mener, et al., 2017], a Ka band dual-frequency dual-circular-polarized annular slot antenna is proposed. The design adopts the sequential- phase fed, the large ring slot radiates lower frequencies, the small ring slot radiates higher frequencies, and the interleave arrangement between the large ring slot and the small ring slot, which solves the dual-frequency coplanar problem well. In [Xu, et al., 2019], a Ka band dual-frequency dual-circular-polarized microstrip antenna is designed, which adopts stacking patch structure and coaxial probe feed. In order to enhance the isolation of the two patches, a metal layer is used between the two patches as the ground structure of the upper patch.

There are also some innovative designs that realize coplanar dual- band dual-circular-polarization [Zhang, et al., 2016, Smolders, et al., 2013], single-band dual-circular- polarization [Luo et al., 2016] and dual-linear-polarization at S-band and dual- circular-polarization at C-band [Chakrabarti et al., 2018].

There are three main contributions in this paper. 1) A dual-band dual-circular-polarized coplanar microstrip antenna operating in Ka band is designed, and good results are obtained in simulations and measurements. 2) The two orthogonal modes of the patch antenna are excited by truncating corner of the elements, where the two different elements show left- hand circular polarization and right-hand circular polarization characteristics respectively. 3) The aperture coupling feeding increases the impedance bandwidth of the patch antennaa and the proper feeding network is constructed by using the T- junctions power divider. The impedance bandwidth and axial ratio bandwidth of the patch antenna are increased by using the sequential rotation technique.

This paper is organized as follows. Section II describes the basic geometry of antenna elements and array, and feed network, while Section III reports experimental results from a fabricated prototype operating at 20.5 GHz and 30.5 GHz. Finally, the conclusions are provided in Section IV.

ANTENNA DESIGN

A. The design of elements

A left-hand circular polarized rectangular patch element operating at 20.5 GHz and a right-hand circular polarized rectangular patch element operating at 30.5 GHz are designed respectively. Each element has two corners truncated for cir- cular polarization. The coupling feeding is adopted to achieve good impedance matching by adjusting the size of the slot and the length of the branches. The size of two elements is shown in Fig. 1.

B. Array design

The sequential rotation technique is applied to improve the impedance bandwidth and the axial ratio bandwidth of the antenna. By adjusting the space of the elements, better gain characteristics can be obtained and the influence of coupling between the elements can be reduced. Because of the cross arrangement between the two frequencies bands, it is necessary to select a reasonable arrangement and distribution to enhance isolation between two ports. The selected substrates are RO4003 of 0.2 mm and RO4450 of 0.2 mm. Their relative dielectric constants are 3.55 and 3.52 respectively. Fig.2 shows the perspective, side and top views of the array respectively.

C. Feed network

The design of feed network is an important part of array design. Since this antenna works in dual band, two indepen- dent feeding networks need to be designed respectively. The central frequencies of the feed network are 20.5 GHz and
30.5 GHz respectively. The feeding network is based on the microstrip quarter-wave matched T-junctions, which excites the neighboring patch antenna elements of different subarrays with increasing or decreasing phase of 90° to produce left- hand circular polarization or right-hand circular polarization. The required phase variation is achieved by the microstrip of different lengths. Figure 3 shows the feed network.

SIMULATION AND MEASUREMENT RESULTS

A prototype of the proposed antenna is shown in Fig.4. To facilitate the installation of SMA connector, the overall size of the antenna is designed as 40 mm 40 mm. As the antenna ground is in the middle layer between the antennas in this design, some grounded metal columns are added for the transition from GCPW to the microstrip line. Due to the errors in the machining process and the measurements, the operating frequency band is shifted to the lower frequency slightly.

For the elements, its simulated matching bandwidths(-10 dB) are 29.03-31.89 GHz at the uplink frequencies and 19.9- GHz at the downlink frequencies, and its axial ratio bandwidths(3 dB) of the downlink frequencies and uplink frequencies are 30.18-30.78 GHz and 20.39-20.62 GHz, re- spectively. The simulated and measured scattering parameters of the downlink and uplink frequencies of the antenna sub- arrays are shown in Fig.5. It can be seen that the impedance bandwidth of the antenna is greatly improved compared with the elememts', its -10 dB simulated impedance bandwidth is 19.53-21.87 GHz and 27.7-33.39 GHz, respectively, and the measured impedance bandwidth is 19.1-22 GHz and 27.1-33.1 GHz. The isolation is below -25 dB at downlink frequencies and -30 dB at uplink frequencies, which fully meets the practical application requirements. In Fig. 6, the simulated 3 dB axial ratio covers 19.9- 21.13 GHz and 28.77-31.66 GHz bands for the downlink and uplink antenna, respectively, and the measured 3dB axial ratio band is 19.4-20.7 GHz and 28-31.2 GHz. The simulated gain curve reaches the peak value in the required frequency band, but the measured results are slightly different.

The co-polar and cross-polar patterns for the downlink frequencies and uplink frequencies are shown in Fig. 7. For the downlink (20 GHz), the simulated half-power beamwidths are about 43° at phi = 0° , the side lobe levels (SLLs) are about 13 dB lower than the main beam peak, and the gain of the antenna is 9.6 dBi. There is no significant change between the measured result and the simulated result, except that the gain is slightly increased to 11.1 dBi. For the uplink (30 GHz), the simulated 3 dB beamwidths are about 45° at phi = 0° , the side lobe levels (SLLs) are about 13 dB lower than the main beam peak, the gain of the antenna is 10.9 dBi. Due to the sensitivity of measuring devices to high frequencies, the measured results fluctuated greatly, and the half-power beamwidths and side lobe levels deteriorated slightly.

CONCLUSION

A dual-band dual-circular-polarized coplanar microstrip an- tenna operating in Ka band is designed and fabricated. The simulation and measured results show that the antenna per- forms well in both uplink and downlink frequencies. The patch units of the two frequency bands are cross-arranged by using sequential rotation technology, which achieved wider impedance bandwidth and axial ratio bandwidth, the isolation and gain of the antenna basically meet the application require-ments.

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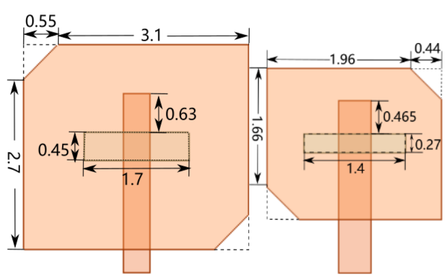

Fig. 1. The dimensions of two elememts.(a)downlink.(b)uplink.(unit: mm)

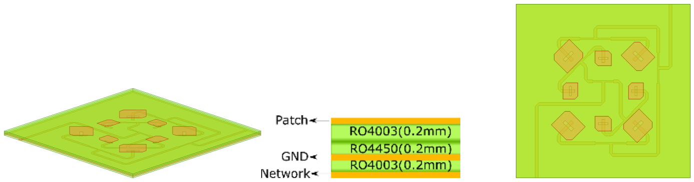

Fig. 2. (a) Perspective view. (b) side view. (c) top view. (Not in proportion)

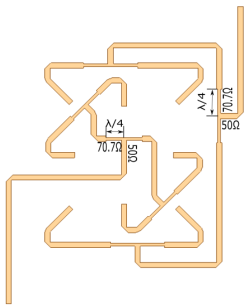

Fig. 3. Layout of feed network

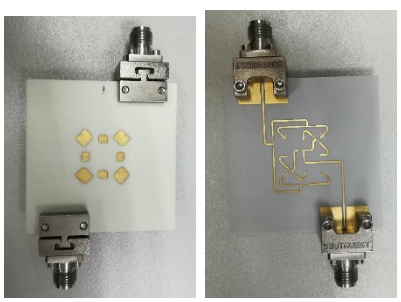

Fig. 4. A prototype of the designed antenna. (a) front side. (b) back side.

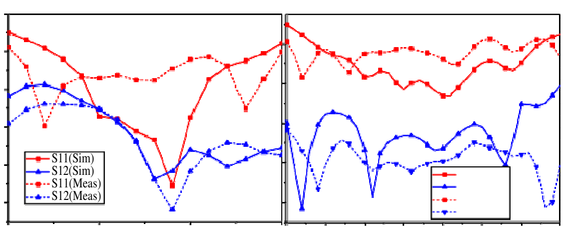

Fig. 5. Simulated and measured Scattering parameters of two subarrays. (a) downlink frequencies. (b) uplink frequencies

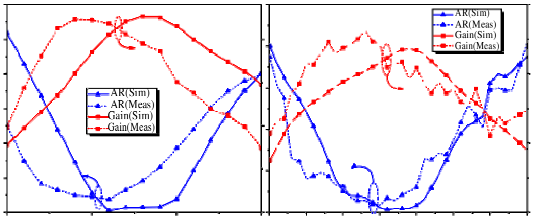

Fig. 6. Simulated and measured axial ratio and gain for a broadside direction(Theta = 0°, phi= 0°.) against frequency. (a) downlink frequencies. (b) uplink frequencies

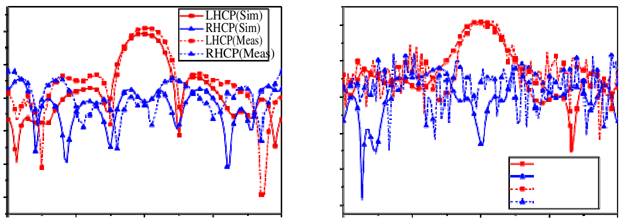

Fig. 7. Simulated and measured gain of two subarrays. (a) 20 GHz , phi = 0°. (b) 30 GHz ,phi = 0°.