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A Dual-Band Circularly Polarized Antenna with "X" Parasitic Structures

Weiyun Wang[1] and Ge Sun[2, *]

Abstract—This paper proposes a dual-band circularly polarized antenna with "X" parasitic structures applied in the Beidou satellite navigation system. The innovation of this paper is to introduce the radome with "X" parasitic structures to broaden the beam width of the L-band and to improve the low-elevation gain of the antenna. Furthermore, high dielectric constant materials are used to realize the miniaturization and embedded application of the antenna. The measured results show that the VSWR of the L-band is 1.09 at 1616 MHz, and the VSWR bandwidth (VSWR < 2) is 45 MHz (1589 MHz–1634 MHz). The VSWR of S-band antenna is 1.24 at 2492 MHz, and the VSWR bandwidth (VSWR < 2) is 54 MHz (2471 MHz–2525 MHz). By adding the designed radome, the 20 degree elevation gain of the L-band is increased by 3.755 dBic The measured results show that the gain variation at 20-degree elevations of the antenna at 1616 MHz and 2492 MHz are 4.981 dBic and 3.7 dBic, respectively. Moreover, the beam widths of the antenna at 1616 MHz and 2492 MHz are 130 degrees and 104 degrees, respectively. The antenna has an improved gain and a good roundness at low elevation angles, thus providing a favorable choice for navigation antenna solutions.

1. INTRODUCTION

As an important part of satellite navigation systems, the performance of antennas directly affects the communication quality of a whole navigation system [1–4]. In order to improve signal-to-noise ratio, the antenna of a satellite navigation system needs circularly polarized waves and a wider beam width with a higher low-elevation gain [5]. In order to solve the above problems, researchers have done a lot of work [6–11]. In [12], a compact dual-band and dual-circular polarization stacked patch antenna is designed. By adding two L-shaped stubs on the top patch, its measured impedance bandwidths with $|S_{11}| < -10$ dB are 9.1% and 5.1% for the lower and upper bands, respectively. In [13], a dual-band circularly polarized patch antenna is proposed, which uses an annular metal strip loaded ground plane to enhance the axial ratio bandwidth (AR-BW) for the two operation bands. Experimental results show that its bandwidth for 10-dB return loss is from 1.15 GHz to 1.65 GHz. The 3-dB axial ratio (AR) bandwidths for the lower and upper bands are 9.6% and 7.1%, respectively.

Microstrip antennas are widely used in the field of satellite navigation and communication due to their small size, light weight, and flexibility for fabrication [14]. Circularly polarized waves have strong anti-rain and fog interference and anti-multipath reflection capabilities, which are widely used in aviation communication and navigation systems. Therefore, this paper proposes a dual-band circularly polarized antenna with "X" parasitic structures. By adding a radome with "X" structures, the beam width of the L-band antenna is broadened, and the low-elevation gain of the antenna is improved. Several advanced circularly polarized antennas are listed in Table 1 to compare with this work.

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* Corresponding author: Ge Sun (734834343@qq.com).

[1] ShaanXi Fenghuo Nuoxin Science & Technology Co, China. [2] Key Laboratory of Antennas and Microwave Technology, Xidian University, China.

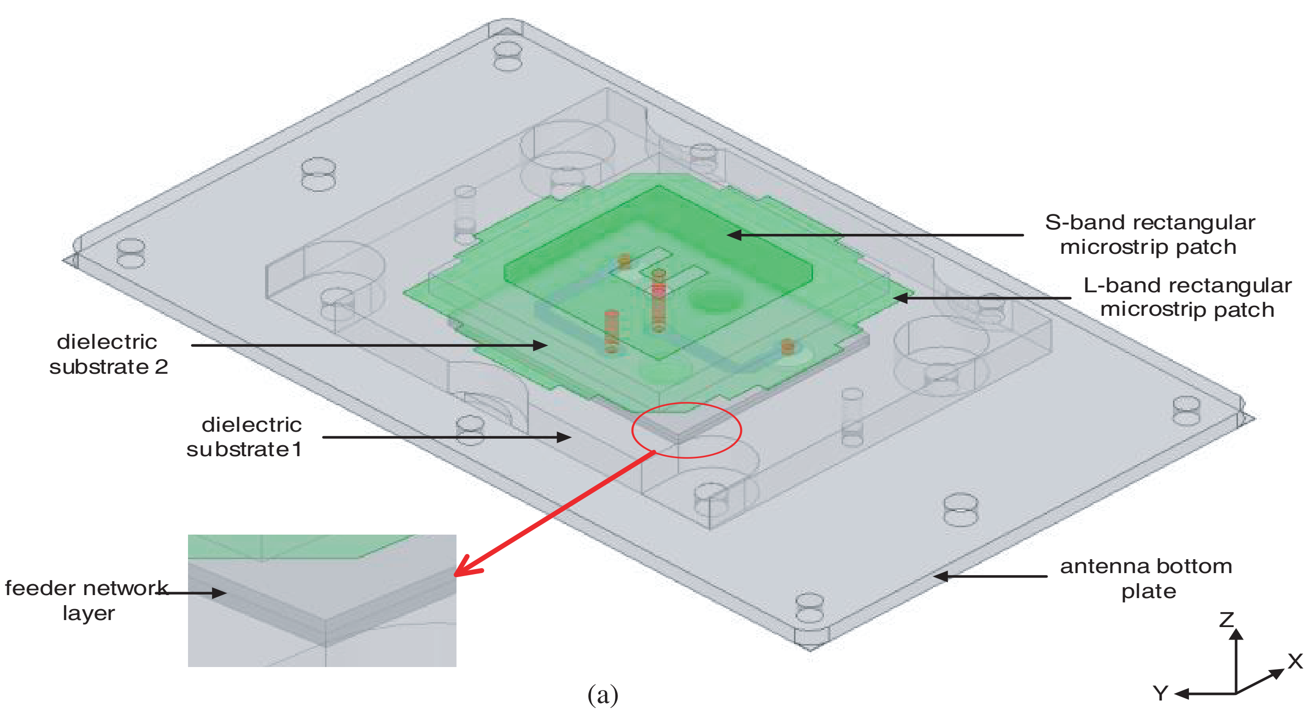
Table 1. Comparison of circularly polarized antennas.

Ref.	Center Frequency (MHz)	Impedance bandwidth	relative AR-BW	Gain (dBic)	Dualband or not	Beam width (deg)	Size (mm)
[1]	1268	11.8%	–	–	No	140	$18 * 18 * 23.5$
[3]	1268	5.9%	2.4% (3 dB)	4.0	No	170	$30 * 30 * 3.18$
[9]	193	–	1.3% (6 dB)	5.7	No	–	$40 * 40 * 1.57$
[11]	2400, 5800	7%, 18.8%	–	7.54, 6.8	Yes	–	$40 * 40 * 1.6$
This work	1616, 2492	2.7%, 2%	0.52% (3 dB) 0.62% (3 dB)	2.48, 3.67	Yes	130 104	$80 * 48.5 * 5.27$

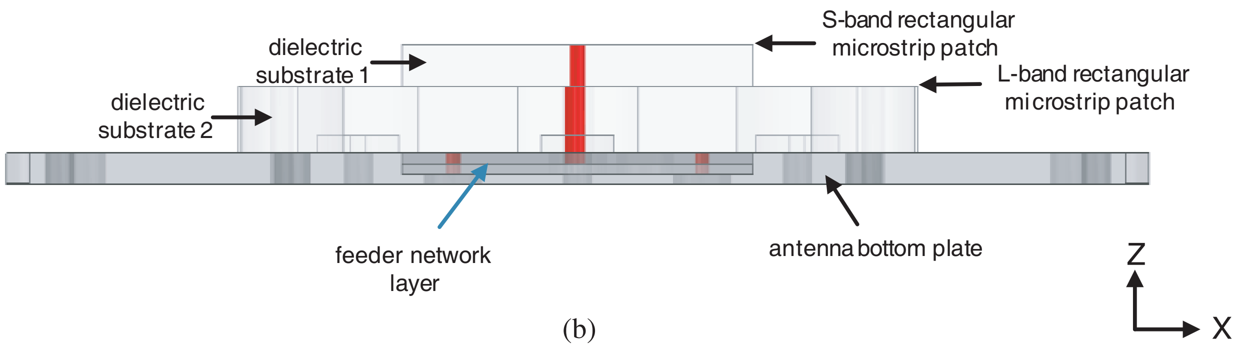
2. ANTENNA DESIGN AND SIMULATION

2.1. Structure of the Proposed Antenna

Figure 1(a) shows the geometry of the antenna proposed in this paper. Fig. 1(b) shows the cross-section of the dual-band circularly polarized antenna. The antenna consists of six parts: an antenna bottom plate, a feed network, an L-band dielectric substrate, an L-band square microstrip patch, an S-band dielectric substrate, and an S-band square microstrip patch. The antenna ground is located at the bottom layer which is a 1.45 mm thick (78 mm $*$ 46.4 mm) aluminum plate. The antenna dielectric substrates are all made of high dielectric constant material Taconic CER-10 (relative dielectric constant



(a)



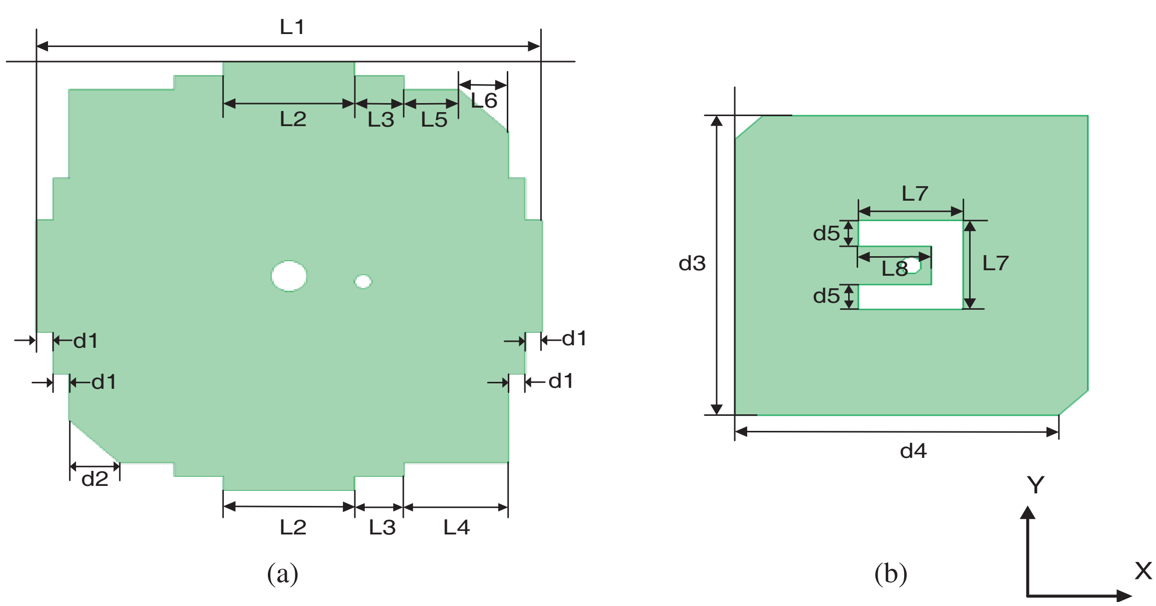
(b)

Figure 1. (a) Geometry of the dual-band circularly polarized antenna. (b) Cross-section of the dual-band circularly polarized antenna.

of 10, loss tangent value of 0.0035) to achieve the miniaturization of the antenna. The dual-band antenna adopts a microstrip laminated structure design, in which the receiving antenna working in the S frequency band is stacked on the L-band transmitting antenna. Fig. 2 shows the structure of two microstrip patches. The square patch in Fig. 2(a) is symmetrical along two diagonals. The two cut corners of the square slice in Fig. 2(b) are of the same size. Table 2 shows the dimensions of the dual-band microstrip antenna.

Table 2. Dimensions of the dual-band microstrip antenna.

Name	$L1$	$L2$	$L3$	$L4$	$L5$	$L6$	$L7$
Length	30.7 mm	8 mm	3 mm	6.35 mm	3.35 mm	3 mm	5.2 mm
Name	$L8$	$d1$	$d2$	$d3$	$d4$	$d5$	
Length	3.6 mm	1 mm	3 mm	17.48 mm	16.08 mm	1.5 mm	



(a) (b)

Figure 2. Structure of the microstrip patches. (a) L-band. (b) S-band.

2.2. Realization of Dual-Band Circular Polarization

There are two propagation modes TE_{10} and TE_{10} in the rectangular microstrip patch, which are a set of orthogonal working modes in space, providing conditions for generating circularly polarized waves. By performing reasonable perturbation of the rectangular microstrip patch angle and opening the U-shaped groove, the above two working modes are separated, and the antenna generates a dual-band circularly polarized wave through the excitation of the feed network and the coaxial line.

HFSS 15.0 electromagnetic simulation software was used for modeling and simulation. The voltage standing wave ratio (VSWR) of the dual-band circularly polarized antenna is shown in Fig. 3(a), and the AR is shown in Fig. 3(b). The L band antenna is a transmitting antenna, whose center frequency is at 1616 MHz, and VSWR bandwidth and AR bandwidth are 65 MHz (1577–1642 MHz) and 10 MHz (1609–1619 MHz), respectively. The S band antenna is a receiving antenna with a center frequency of 2492 MHz, a VSWR bandwidth of 5 MHz (2472–2522 MHz), and an AR bandwidth of 13 MHz (2481–2494 MHz).

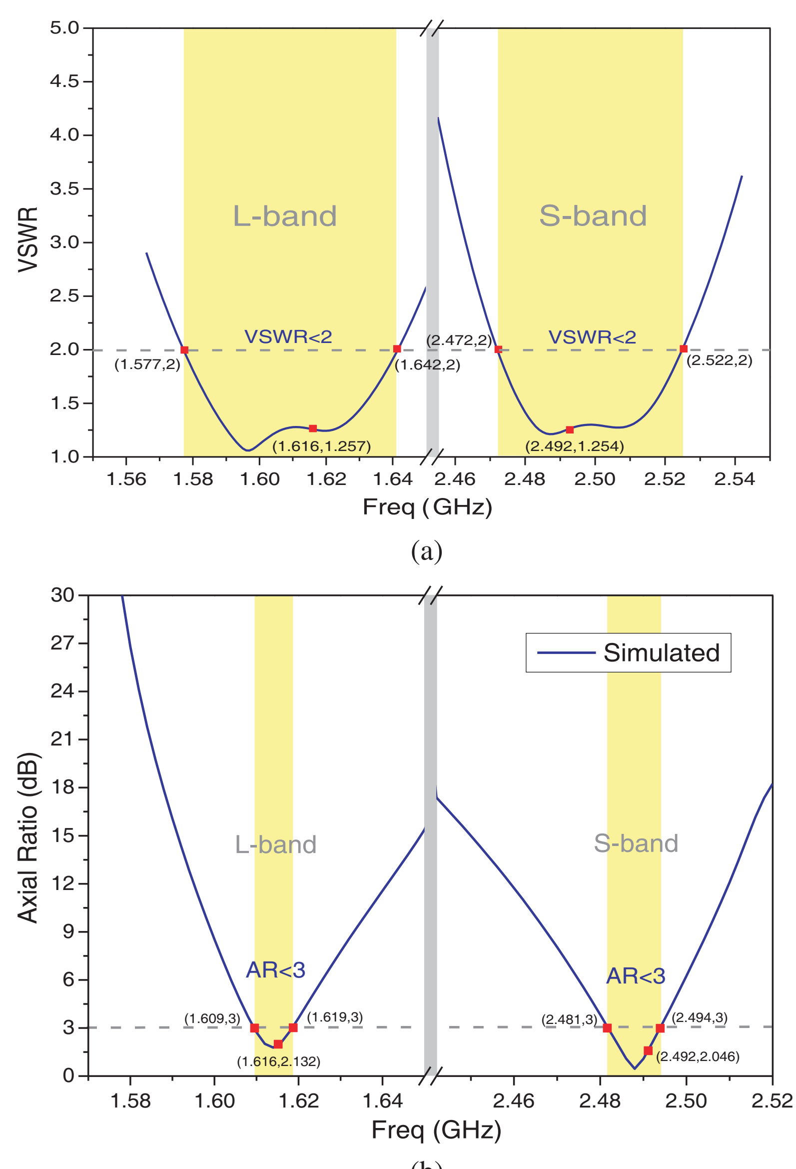


Figure 3. (a) VSWR of the dual-band circularly polarized antenna (simulated results). (b) AR of the dual-band circularly polarized antenna (simulated results).

2.3. Improvement of the Low Elevation Angles Gain

In order to broaden the beam width of the L-band antenna and increase the low-elevation gain of the antenna, a radome with "X"-shaped parasitic structures is added above the antenna. The radome with "X" parasitic structures adopts a parasitic cross-element structure, and the parasitic elements of a specific size are placed on the left and right ends of the radome. The number of elements is asymmetrical, with two parasitic elements on one side and three parasitic elements on the other side. The radome is made of non-metallic materials, and then the metal layer is parasitic on the surface through LDS process. Fig. 4 is the radome model with "X" structures. Four cross parasitic dipoles are located outside the radome, as shown in Fig. 4(a); another is located inside the radome, as shown in Fig. 4(b). The specific parameters of radome are given in Table 3.

Table 3. Radome parameter table.

Name	H1	H2	H3	H4	H5
Length	22 mm	15 mm	10 mm	24 mm	26 mm
Name	A	B	L	W	
Length	30 deg	45 deg	80 mm	48.5 mm	

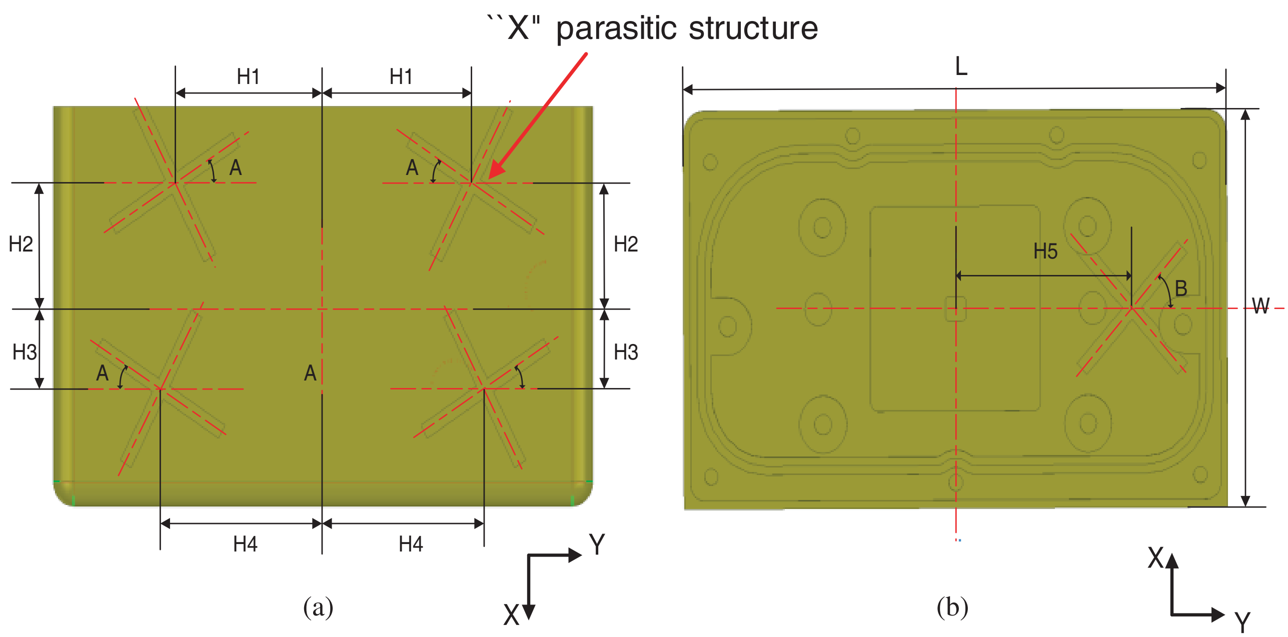


Figure 4. Radome model with "X" structures. (a) Top view. (b) Bottom view.

Figure 5 shows the roundness simulation results of the L-band antenna at 1616 MHz with or without radome at 20 degree elevation. The minimum gain at 20 degree elevation is increased from −7.273 dBic to −3.518 dBic.

3. EXPERIMENTAL RESULTS AND ANALYSIS

3.1. Test Environment

In order to verify the performance of the antenna, the dual-band circular polarization antenna proposed in this article was measured. Fig. 6 shows a photo of the dual-band circularly polarized antenna proposed in this paper. Fig. 7 shows photos of the radome with "X" parasitic structures.

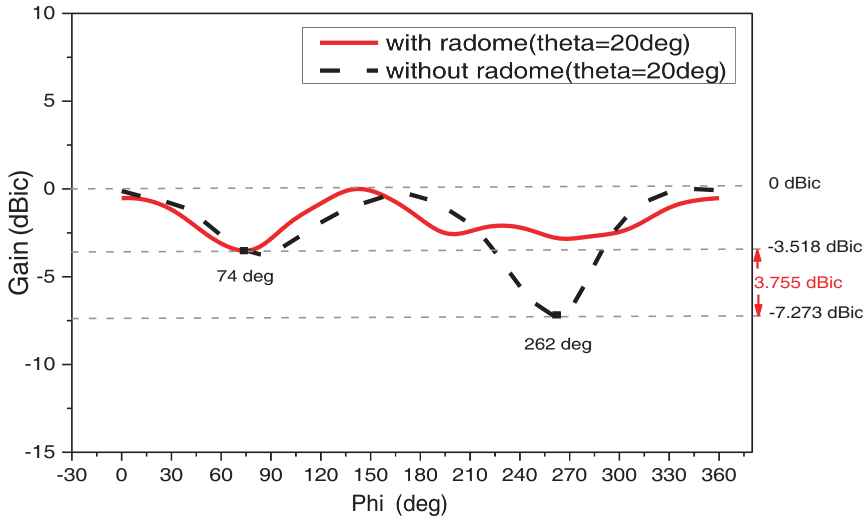


Figure 5. Roundness simulated results of the L-band antenna.

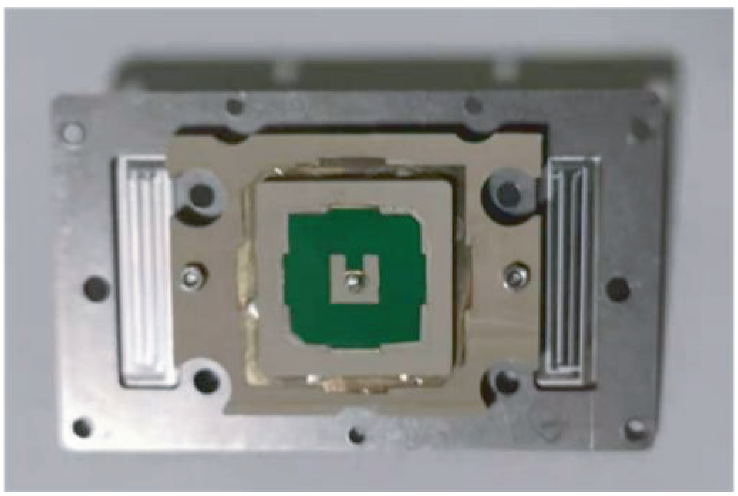
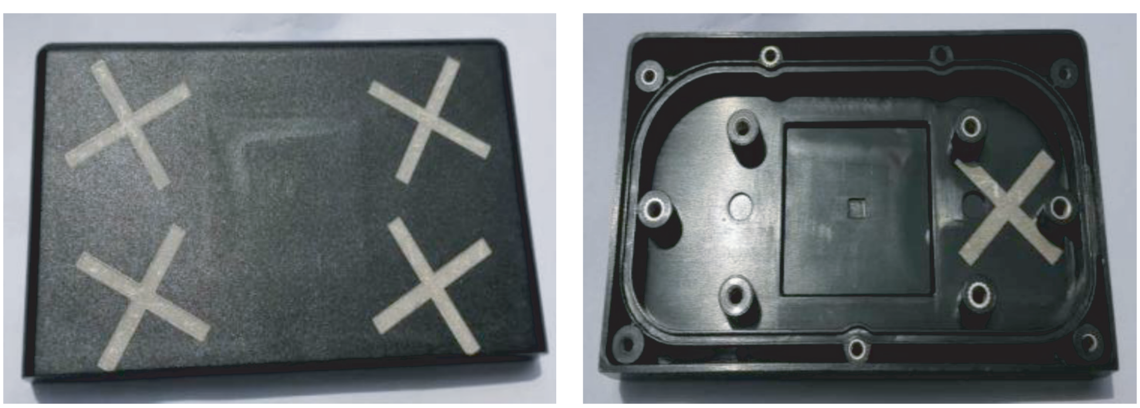


Figure 6. Photo of the proposed dual-band circularly polarized antenna.



(a) (b)

Figure 7. Photo of the radome with “X” parasitic structures. (a) Top view. (b) Bottom view.

3.2. Measured Results and Analysis

Figure 8 shows the comparison between the measured and simulated results of the VSWR of the antenna. The measured results in the working frequency band are basically consistent with the simulation results. It can be seen from Fig. 8 that the working bandwidth L-band antenna is 45 MHz (1589 MHz–1634 MHz), and the S-band has a bandwidth of 54 MHz (2471 MHz–2525 MHz). The measured results agree well with the engineering needs.

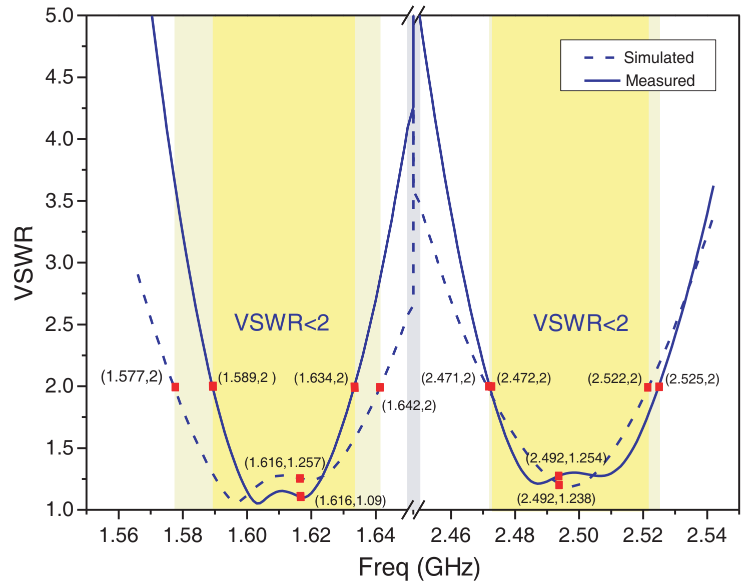
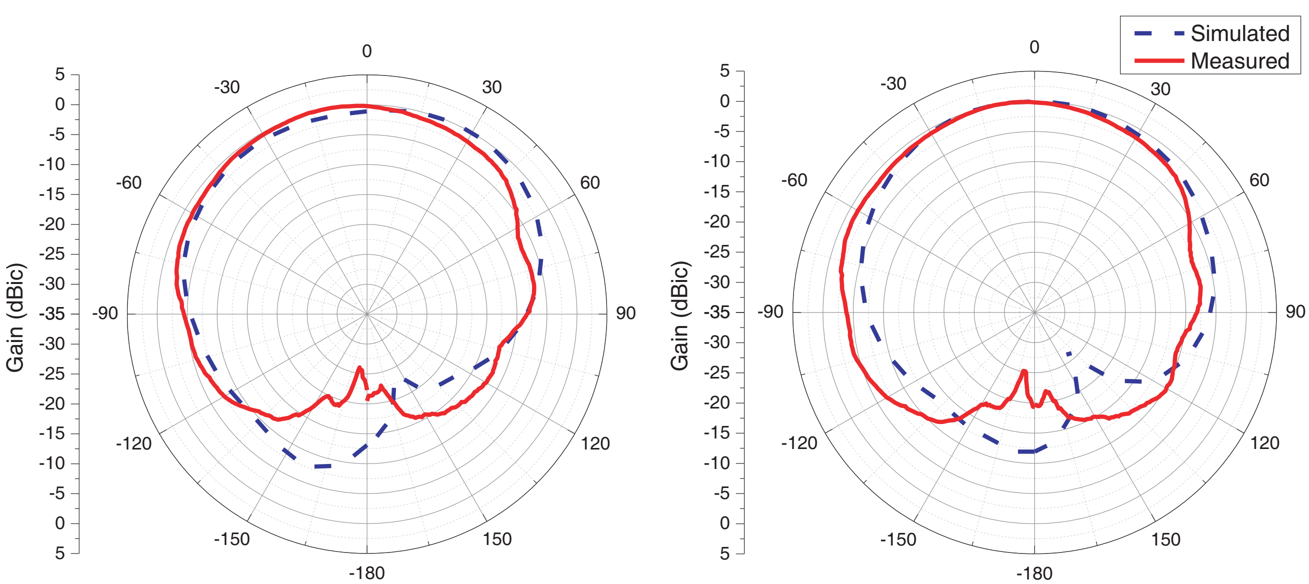
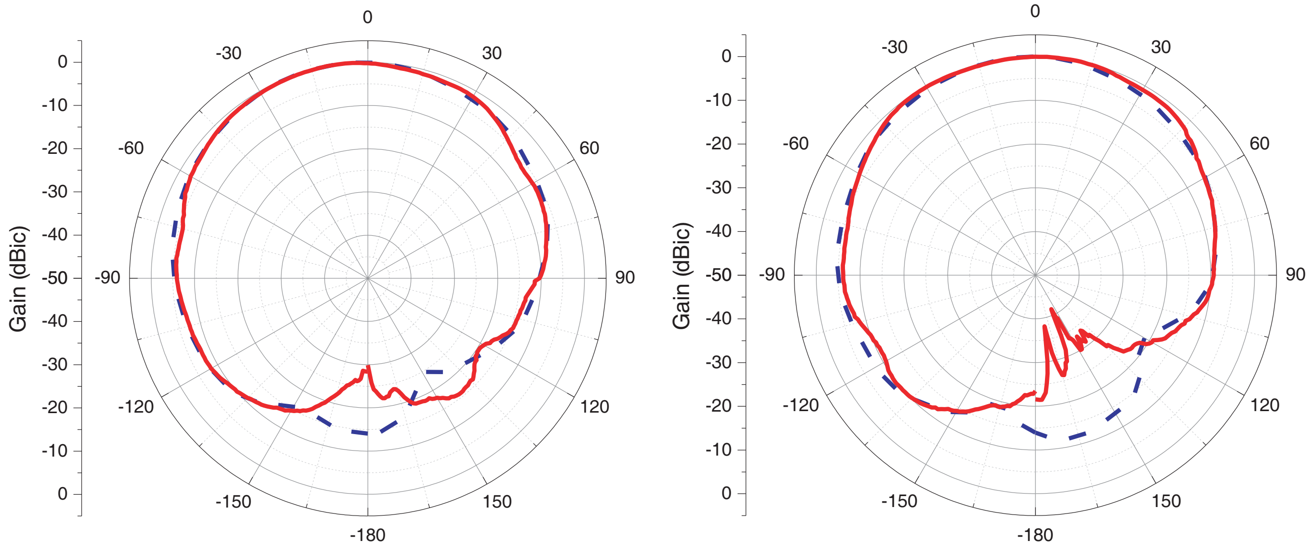


Figure 8. Measured and simulated results of the VSWR of the antenna.

Figure 9 is a comparison diagram of the measured and simulated radiation patterns of the dual-band circularly polarized antenna with "X" parasitic structure radome. It can be seen from Fig. 9 that the measured results are consistent with the simulated ones, and the antenna has good low elevation angles radiation characteristics. According to the measured results, the beam width of the antenna at 1616 MHz and 2492 MHz is 130 degrees and 104 degrees, respectively, and the gain of the antenna at 1616 MHz and 2492 MHz is 2.48 dB and 3.67 dB, respectively.



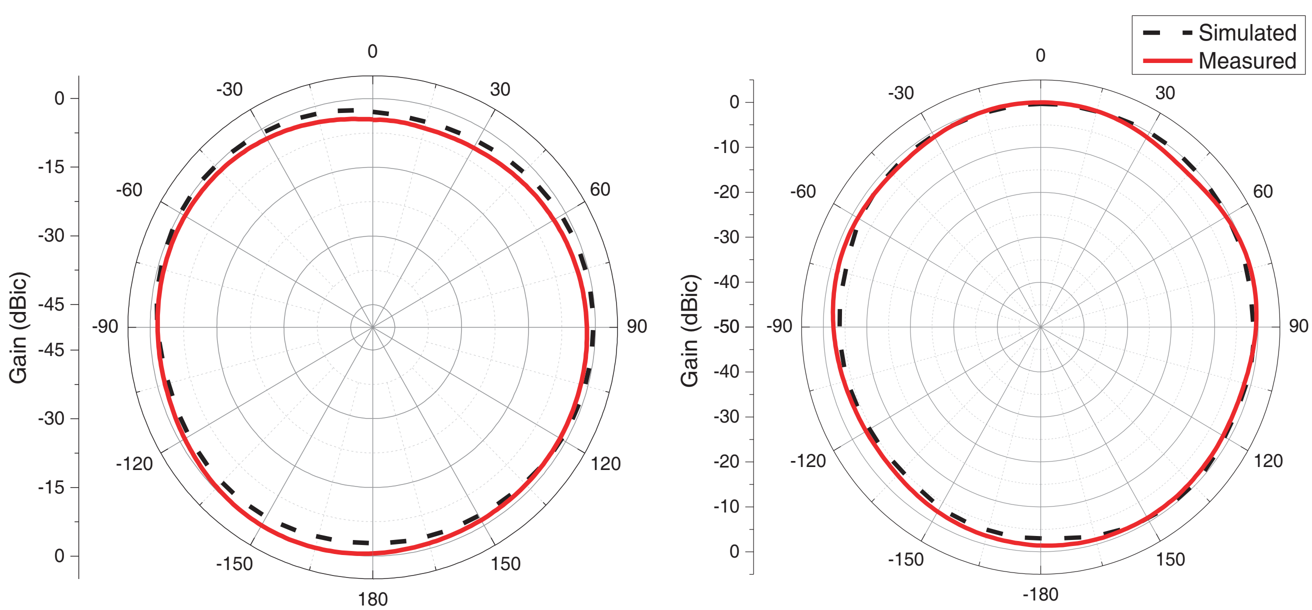
(a) (b)



(c) (d)

Figure 9. Measured and simulated radiation pattern of the proposed antenna. (a) 1616 MHz, phi = 0 deg. (b) 1616 MHz, phi = 90 deg. (c) 2492 MHz, phi = 0 deg. (d) 2492 MHz, phi = 90 deg.

Figure 10 is the roundness of the measured and simulated patterns in the direction of 20 degree elevation. Fig. 10(a) and Fig. 10(b) show the results with frequencies of 1616 MHz and 2492 MHz, respectively. It can be seen from Fig. 10 that the antenna measured results are consistent with the simulation ones. According to the measured results, when the frequency of the antenna is 1616 MHz and 2492 MHz, the 20 degree elevation gain variation is 4.981 dBic and 3.7 dBic, respectively.



(a) (b)

Figure 10. Roundness of the measured and simulated patterns. (a) 1616 MHz. (b) 2492 MHz.

4. CONCLUSION

The antenna proposed in this paper has improved gain and a good roundness at low-elevation by adding the radome with "X" parasitic structures. The measured results show that the L-band antenna at the center frequency of 1616 MHz has a bandwidth of 45 MHz (1589 MHz–1634 MHz). The S-band antenna has a bandwidth of 54 MHz (2471 MHz–2525 MHz), which meets the engineering requirements. By adding the X-shaped parasitic radome, the roundness of 20 degree elevation of L-band antenna is increased by 3.755 dBic The measured results show that the roundness of the 20 degree elevation of the antenna at 1616 MHz and 2492 MHz is 4.981 dBic and 3.7 dBic, respectively. The antenna has the characteristics of low profile, high low-elevation gain, and good roundness, and can be a good candidate for navigation antenna applications.

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