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Design of a Wideband Circularly Polarized Cross-Dipole with Wide Axial-Ratio Beamwidth

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Abstract—A novel wideband circularly polarized (CP) cross-dipole with wide 3 dB axial-ratio (AR) beamwidth is presented. To generate CP radiation, the cross-dipole is fed by a Wilkinson power divider which can provide 90° phase difference. The gain beamwidth and 3 dB AR beamwidth can be widened by the bent arm structures of cross-dipole and four vertical parasitic elements. As a result, the 3 dB AR beamwidth and gain beamwidth of the proposed antenna can achieve over 210° and 105°, respectively. It is observed that the impedance bandwidth ($|S_{11}| \leq -10$ dB) of the proposed antenna is $1.2 \sim 2.0$ GHz, and the AR bandwidth (AR $\leq$ 3 dB) is $1.28 \sim 1.76$ GHz. The simulated and measured results are in good agreement, which shows that the proposed antenna is a good candidate for the application of satellite communications.

1. INTRODUCTION

In recent years, circularly polarized (CP) antennas are widely used in wireless communication systems, such as radio-frequency identification, wireless local area network, and global positioning system [1]. The antenna with wide bandwidth, gain beamwidth, and 3 dB AR beamwidth has been demanded to meet the requirements of wireless communication systems [2–7].

Some techniques have been reported to widen the 3 dB AR beamwidth of basic CP antennas. In [8], two parasitic rings are introduced to broaden 3 dB AR beamwidth, which are laid on the upper and lower layers, respectively, exhibiting a 3 dB AR beamwidth more than 180°. In [9], an inverted, pyramidal, cavity-backed reflector is incorporated with the cross-dipole to produce a unidirectional radiation pattern with a wide 3 dB AR beamwidth of 110°. In [10], four vertical parasitic elements are employed between a simple ±45° dual-polarized radiator and ground to widen the 3 dB AR beamwidth of 195°. In [11], the antenna is backed by a metallic cavity to provide a unidirectional radiation pattern with a wide 3 dB AR beamwidth of over 165°. However, the 3 dB AR beamwidth of these antennas is not wide enough. In [12], circular dipoles, curved ground planes, and corrugated back cavity are used in the design, which has a wide 3 dB AR beamwidth over 230° and a 3 dB gain beamwidth over 150°, but the impedance bandwidth ($|S_{11}| \leq -10$ dB) is given by only 14.8% ($1.470 \sim 1.705$ GHz).

In this paper, a novel wideband and CP cross-dipole with wide 3 dB AR beamwidth is presented. Two pairs of bent arms and four vertical parasitic elements are employed to widen the gain beamwidth and 3 dB AR beamwidth of the cross-dipole, and the bandwidth is broadened by using a microstrip coupled feeding structure. The simulated and measured results show that the impedance bandwidth ($|S_{11}| \leq -10$ dB) of the proposed antenna is about 50% ($1.2 \sim 2.0$ GHz). The AR bandwidth (AR $\leq$ 3 dB) is approximately 32% ($1.28 \sim 1.76$ GHz). The proposed antenna also has a wide 3 dB AR beamwidth over 210° and a gain beamwidth of 105°.

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2. ANTENNA GEOMETRY AND DESIGN

2.1. Antenna Configuration

Figure 1 shows the configuration of the proposed cross-dipole antenna, which consists of two pairs of patch dipoles with four vertical parasitic elements and a feed network. The patch dipoles and Wilkinson power divider are both printed on an FR4 substrate with relative permittivity of $\varepsilon_r = 4.4$ and thickness of $h_{\text{sub}} = 0.8\,\text{mm}$. Figure 2 shows details of the cross-dipole. It can be seen that two bent arms of the patch dipole and two vertical parasitic elements are on the same side of the substrate with the dimensions given by $W1$ and $L1$, respectively, while the feedline is designed on another side of the substrate.

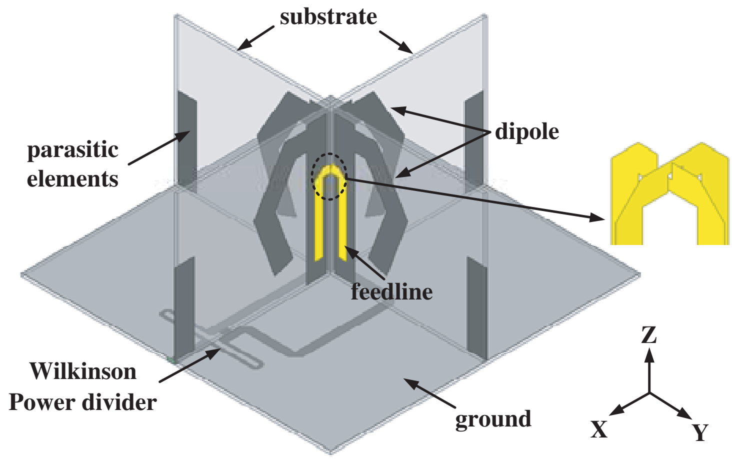


Figure 1. Configuration of the proposed cross-dipole antenna.

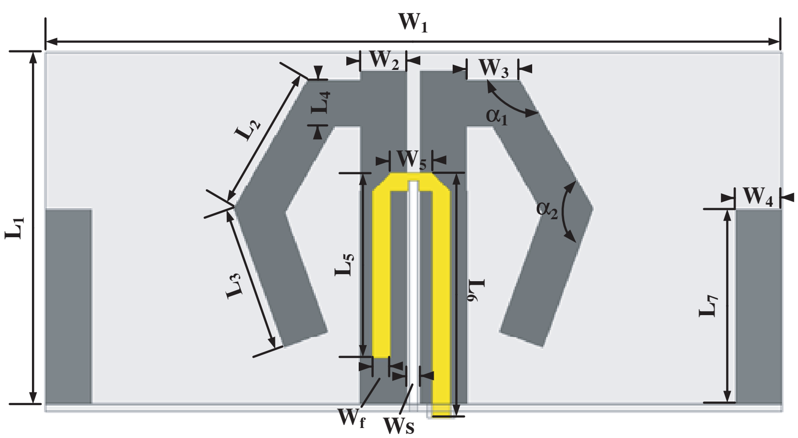


Figure 2. Configuration of the proposed cross-dipole antenna. The details of the cross-dipole antenna. $W1 = 80\,\text{mm}$, $W2 = 5\,\text{mm}$, $W3 = 5.75\,\text{mm}$, $W4 = 5\,\text{mm}$, $W5 = 4.5\,\text{mm}$, $Ws = 1.5\,\text{mm}$, $Wf = 2\,\text{mm}$, $L1 = 38\,\text{mm}$, $L2 = 16\,\text{mm}$, $L3 = 16\,\text{mm}$, $L4 = 5\,\text{mm}$, $L5 = 20\,\text{mm}$, $L6 = 26.5\,\text{mm}$, $L7 = 21\,\text{mm}$, $\alpha_1 = 120°$, $\alpha_2 = 130°$.

2.2. Antenna Mechanism

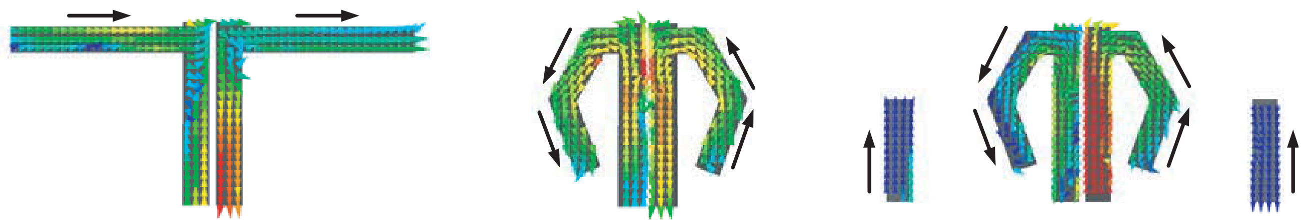
To demonstrate the effect of bent arms and parasitic elements for the cross-dipole, three reference antennas are simulated by using HFSS 18. Figure 3 shows configurations of the reference antennas, including Antenna A with straight arms, Antenna B with bent arms, and Antenna C with bent arms and parasitic elements.

In order to understand the effect of the bent arms and parasitic elements in depth, Figure 4 plots the current distributions of the reference antennas at 1.575 GHz, where the current path is clearly marked. The current path is bent with the bent arms when the configuration of the antenna varies from (a) to (b). Therefore, there is a vertical component of current, which can produce horizontal radiation to widen the 3 dB AR beamwidth. For the same reason, the parasitic elements can also widen the 3 dB AR beamwidth due to the addition of vertical current distribution as shown in (c).

Figure 5 shows reflection coefficients and 3 dB AR beamwidths of the reference antennas. It can be seen that there is almost no difference in reflection coefficients of the reference antennas, which means that the bending structure of the arms and parasitic elements rarely influence impedance matching of

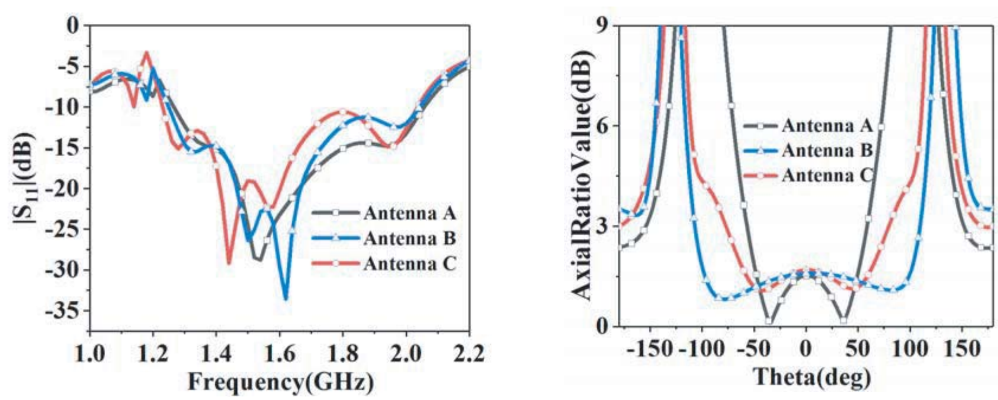
(a) (b) (c)

Figure 3. Configurations of the reference antennas. (a) Antenna A with straight arms. (b) Antenna B with bent arms. (c) Antenna C with bent arms and parasitic elements.



(a) (b) (c)

Figure 4. Current distributions of the reference antennas. (a) Antenna A with straight arms. (b) Antenna B with bent arms. (c) Antenna C with bent arms and parasitic elements.



(a) (b)

Figure 5. Reflection coefficients and 3 dB AR beamwidths of reference antennas. (a) Reflection coefficients of reference antennas. (b) 3 dB AR beamwidths of reference antennas.

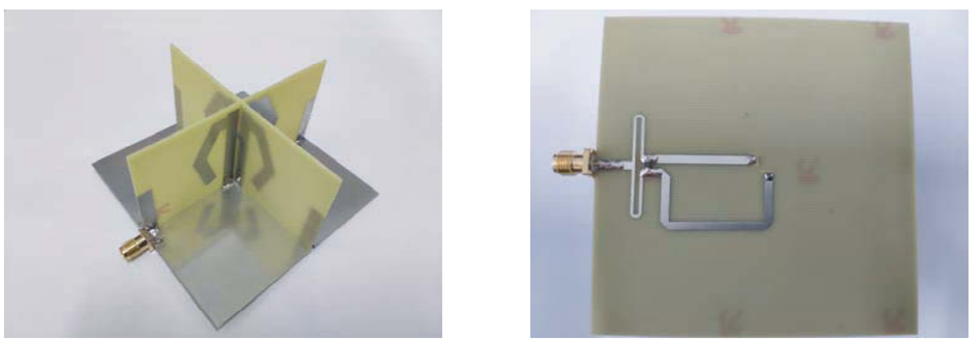
the cross-dipole in Figure 5(a). However, significant changes have happened in the 3 dB AR beamwidth as shown in Figure 5(b). As can be seen from Figure 5(b), the 3 dB AR beamwidth of Antenna A with straight arms is approximately 105°; the 3 dB AR beamwidth of Antenna B with bent arms can be widened to 146°; and 3 dB AR beamwidth of Antenna C with bent arms and parasitic elements can be further widened to 216°. It is obvious that the bending structure of the arms and the parasitic elements can effectively widen the 3 dB AR beamwidth of the cross-dipole.

3. SIMULATED AND MEASURED RESULTS

For demonstration, a prototype of the proposed crossed dipole antenna is designed, fabricated, and tested. Photographs of the fabricated antenna are shown in Figure 6.

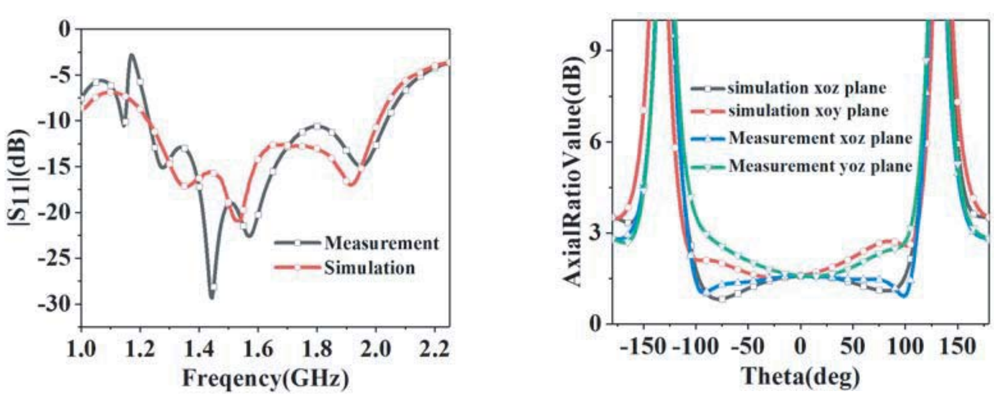
Figure 7 shows the simulated and measured reflection coefficients and 3 dB AR beamwidths (1.575 GHz) of the proposed antenna. With the reference to Figure 7(a), the simulated and measured impedance bandwidths ($|S_{11}| \leq -10$ dB) are 1.2 $\sim$ 2.0 GHz and 1.23 $\sim$ 2.03 GHz, respectively. With the reference to Figure 7(b), the simulated and measured 3 dB AR beamwidths are 216°, 210° (*xoz* plane), and 214°, 200° (*yoz* plane), respectively.

The simulated and measured AR bandwidths and gains of the proposed antenna are presented in Figure 8. As can be seen from Figure 8(a), the simulated and measured AR bandwidths are 1.28 $\sim$ 1.76 GHz and 1.3 $\sim$ 1.85 GHz. Figure 8(b) shows that the measured gain of the proposed antenna is more than 0 dB from 1.4 GHz to 2.0 GHz and less than 0 dB from 1.2 GHz to 1.4 GHz, and



(a) (b)

Figure 6. The photographs of the fabricated antenna. (a) Stereoscopic photograph of the antenna. (b) Photograph of Wilkinson power divider.

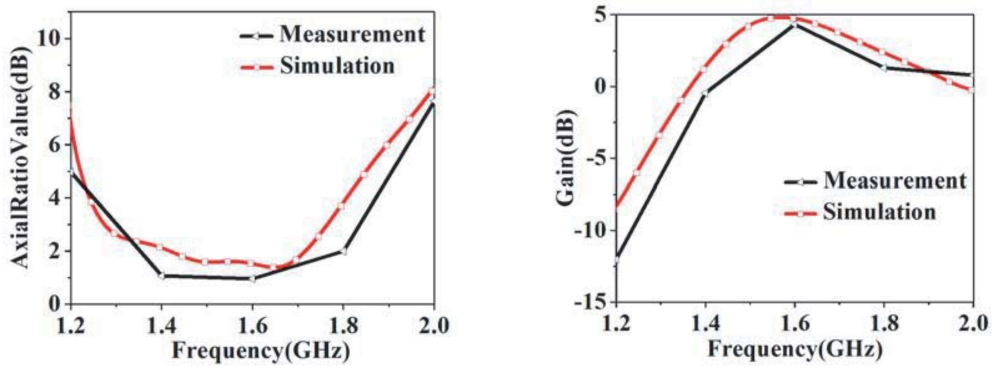


(a) (b)

Figure 7. The simulated and measured reflection coefficients and 3 dB AR beamwidths (1.575 GHz) of the proposed antenna. (a) Reflection coefficients. (b) 3 dB AR beamwidths (1.575 GHz).

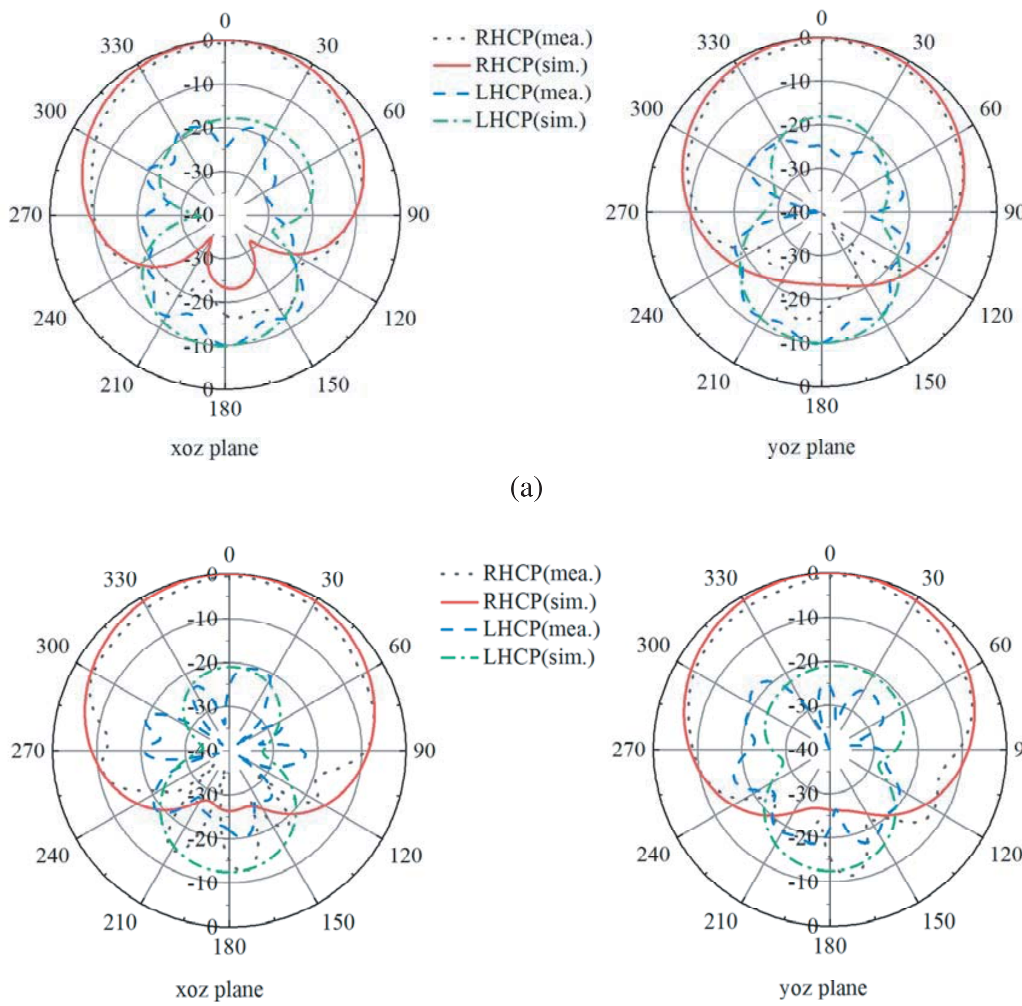
the reason is that the antenna has such a wide beamwidth that makes the directivity become poor and the gain of the antenna become relatively low.

Figure 9 shows the simulated and measured 2D radiation patterns at 1.4 GHz, 1.575 GHz, and 1.7 GHz, respectively, with the results normalized by their respective boresight antenna gains. As shown in Figure 9, the measured gain beamwidths of the proposed antenna are 106°, 105°, and 108° at



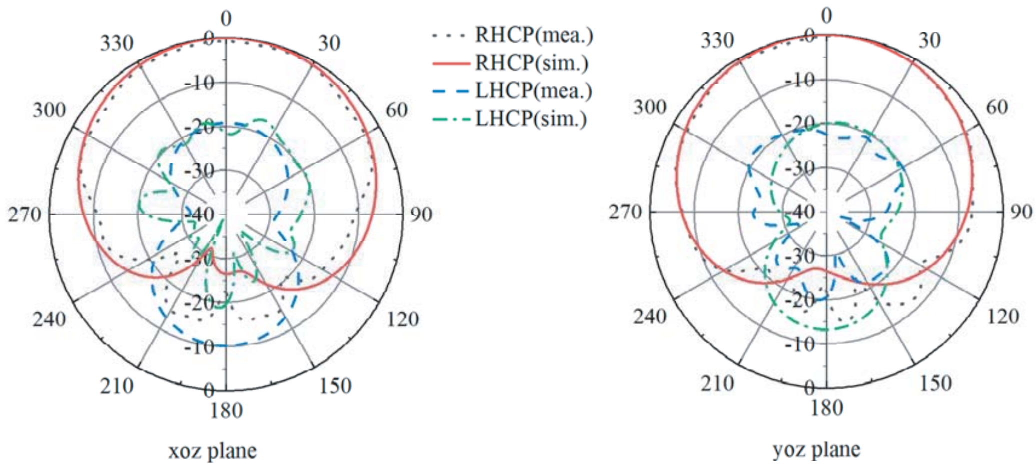
(a) (b)

Figure 8. The simulated and measured AR bandwidths and gains of the proposed antenna. (a) AR bandwidths. (b) Gains.



(a)

(b)



(c)

Figure 9. The simulated and measured normalized radiation patterns of the proposed antenna. (a) 1.4 GHz. (b) 1.575 GHz. (c) 1.7 GHz.

Table 1. Comparison between the proposed antenna and other CP antennas.

Ref.	Relative Dimension (λ^3)	Impedance bandwidth (GHz)	AR bandwidth (GHz)	Overlapping Bandwidth	Gain beamwidth	3 dB AR beamwidth
[8]	$0.57 \times 0.57 \times 0.15$	$2.452 \sim 2.549$(3.9%)	-	-		180°
[9]	$0.63 \times 0.63 \times 0.16$	14.8%	2.1%	2.1%	120°	110°
[10]	$0.86 \times 0.86 \times 0.26$	$1.71 \sim 2.17$(23.7%)	$1.71 \sim 2.17$(23.7%)	23.7%	-	195°
[11]	$0.51 \times 0.51 \times 0.13$	$1.274 \sim 2.360$(59.8%)	$1.39 \sim 1.82$(26.8%)	26.8%	-	165°
[12]	$0.44 \times 0.44 \times 0.35$	$1.47 \sim 1.75$(17.3%)	$1.535 \sim 1.635$(6.3%)	6.3%	140°	230°
proposed	$0.35 \times 0.35 \times 0.15$	$1.2 \sim 2.0$(50%)	$1.28 \sim 1.76$(31.5%)	31.5%	155°	210°

λ: wavelength at the low frequency of passband.

1.4 GHz, 1.575 GHz, and 1.7 GHz. Meanwhile, it can be seen that the proposed antenna can generate RHCP field within wide beamwidth, and the measured 3 dB AR beamwidths are 190°, 216°, and 220° at 1.4 GHz, 1.575 GHz, and 1.7 GHz. All the comparisons mentioned above show that the measured results are in good agreement with the simulated ones.

Part of the performance parameters of the current and other CP antennas are listed in Table 1 for comparison. With reference to the table, the 3 dB AR beamwidth of the proposed antenna is 210°, which is the widest among these antennas except [12], but other performance parameters, like relative dimension, impedance bandwidth, and AR bandwidth, are superior to the antenna in [12].

4. CONCLUSION

In this paper, a novel wideband circularly polarized (CP) cross-dipole with wide 3 dB axial-ratio (AR) beamwidth is presented. The cross-dipole, fed by a Wilkinson power divider which can provide 90° phase difference to generate CP radiation, consists of two pairs of orthogonal patch dipoles. Meanwhile, the bent arm structure of cross-dipole and four vertical parasitic elements are introduced to widen the gain beamwidth and 3 dB AR beamwidth. The simulated results indicate that the 3 dB AR beamwidth and gain beamwidth of the proposed antenna can achieve over 210° and 155°, respectively. It is observed that the frequency range ($|S_{11}| \leq -10$ dB) of the proposed antenna is $1.2 \sim 2.0$ GHz, and the AR bandwidth (AR ≤ 3 dB) is $1.28 \sim 1.76$ GHz. The agreement between the measured and simulated results indicates that the proposed antenna is a good candidate for the application of satellite communications.

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