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A Compact Wideband Circularly Polarized Crossed-Dipole Antenna with Broad Beamwidth

Guang Li* and Fu-Shun Zhang

Abstract—In this paper, a compact wideband circularly polarized (CP) crossed-dipole antenna with wide half-power beamwidth (HPBW) and broad 3 dB axial ratio beamwidth (ARBW) is proposed. The antenna is composed of crossed bowtie dipoles, four pentagonal parasitic elements and eight vertical metallic plates. A double vacant-quarter printed ring with orthogonal bowtie dipoles is designed for CP radiation and broadband characteristics of impedance and 3 dB axial ratio (AR) bandwidths. Parasitic elements and vertical metallic plates are utilized to increase bandwidth and broaden beamwidth further. The total size of the proposed antenna is $0.4\lambda \times 0.4\lambda \times 0.16\lambda$. Simulated results are in good agreement with the measured ones which demonstrate an impedance bandwidth 88.4% and a 3 dB AR bandwidth 73.1% The HPBW of more than 120° is 70.0%. The 3 dB ARBWs of more than 120° in E-plane and H-plane are 63.1% and 37.5%, respectively. With both the excellent CP performance and compact size, the proposed antenna is attractive for modern wireless communications.

1. INTRODUCTION

Circularly polarized (CP) antennas have attracted much research interest in various modern wireless communications, such as wireless local network, satellite communication, radio frequency identification, and the global positioning system due to the reduction in polarization mismatch and the flexibility in the orientation angle between the transmitter and receiver. The basic principle of CP antenna is the radiation of two orthogonal fields that are 90° out of phase but have equal amplitude [1]. Especially, CP antennas with wide impedance bandwidth and broad AR bandwidth are highly preferred.

A dipole antenna with parasitic loop resonators to generate one additional minimum AR point is proposed in [2], and the antenna has a 3 dB AR bandwidth of 28.6% and an impedance bandwidth of 38.2%. The cross dipole with open ends to enhance both impedance and AR bandwidths is proposed in [3]. An impedance bandwidth about 50.2% and a 3-dB AR bandwidth about 27% are achieved. A crossed bowtie dipole antenna with slot-mode radiation to enhance the CP operation bandwidth is proposed in [4]. An impedance bandwidth of approximately 57% and a 3-dB AR bandwidth of approximately 51% are achieved. A dipole antenna with an impedance bandwidth of 66.2% and a 3-dB AR bandwidth of 41.3% is proposed [5]. An antenna with a composite cavity to enhance front-to-back ratio of 30 dB is proposed. The impedance bandwidth of 106.5% and a 3-dB axial ratio (AR) bandwidth of 96.6% are achieved [6]. An antenna using coupled rotated vertical metallic plates to enhance the operating bandwidth from 30% to 106.1% is proposed in [7].

Apart from wide bandwidth, CP antennas with broad HPBW or ARBW are preferred. A single-feed crossed dipole with integrated phase delay line was presented in [8]. The antenna achieves 15.6% 3-dB axial ratio (AR) bandwidth with a simple feeding structure. And the HPBWs of the antenna are 68° (x-z) and 66° (y-z), respectively. A pin-loaded circularly polarized patch antennas with wide 3 dB

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* Corresponding author: Guang Li (liguang0929@foxmail.com).
The authors are with the National Key Laboratory of Antennas and Microwave Technology, Xidian University, Xi'an, Shaanxi 710071, China.

ARBW about 140° is proposed in [9]. Thus far, it is still a challenge that a compact antenna obtains a broad HPBW and ARBW within a wide impedance and AR bandwidths.

In this paper, a compact wideband CP crossed-dipole antenna with wide HPBW and broad 3 dB ARBW is proposed. The performance of the proposed antenna is compared with other reported designs in Table 1. The table shows that the proposed antenna has a wider bandwidth and broader beamwidth while having a compact size among the reported antennas.

Table 1. Comparison of different antennas.

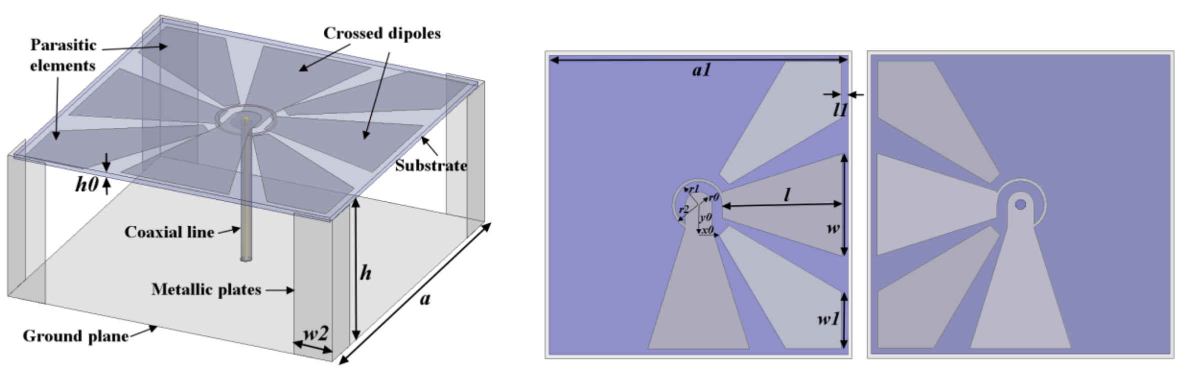
Ref.	**Size (λ^3)**	**Impedance Bandwidth**	**AR Bandwidth**	**HPBW Bandwidth**	**ARBW Bandwidth**
[6]	$1.52 \times 1.52 \times 0.31$	106.5% (0.9–2.95 GHz)	96.6% (1–2.87 GHz)	-	-
[7]	$0.59 \times 0.59 \times 0.24$	115.2% (0.84–3.12 GHz)	106.1% (0.92–3 GHz)	$> 120°$ 25.8%	$> 110°$ 64.3%
[8]	$0.92 \times 0.92 \times 0.21$	30.7% (2.01–2.74 GHz)	15.6% (2.13–2.49 GHz)	66° -	-
[9]	$0.4 \times 0.4 \times 0.02$	2.7% (2.418–2.483 GHz)	0.6% (2.444–2.46 GHz)	-	140° 0.6%
Prop.	$0.4 \times 0.4 \times 0.16$	88.4% (1.2–3.1 GHz)	73.1% (1.3–2.8 GHz)	$> 120°$ 70%	$> 120°$ 63.1%(E); 37.5%(H)

This paper is organized as follows. The previous researches on CP crossed dipole antennas are introduced in Section 1. The structure of the compact antenna is proposed, and some key parameters are discussed in Section 2. In Section 3, the measured results are presented. A conclusion is provided in Section 4.

2. ANRENNA DESIGN AND PARAMETERS STUDIES

2.1. Antenna Design

Figure 1 shows the configuration of the proposed antenna, which consists of two asymmetric bowtie dipoles, four pentagonal parasitic elements, eight vertical metallic plates, and a square ground plane. The bowtie dipoles are crossed perpendicularly to each other, and each dipole consists of two identical patch arms, which are double-sided printed on the top and bottom surfaces of a dielectric substrate with a dielectric constant of 3.38 and thickness of 0.8 mm. Double vacant-quarter printed rings provide



(a) (b)

Figure 1. Configuration of the proposed antenna. (a) Perspective view. (b) Top and bottom view. $a = 60$ mm, $h = 26$ mm, $h = 0.8$ mm, $l = 23.5$ mm, $w = 20$ mm. $a_1 = 58.4$ mm, $l_1 = 1.2$ mm, $w_1 = 11$ mm, $w_2 = 7$ mm, $r = 2.6$ mm, $r_1 = 4.6$ mm, $r_2 = 5.2$ mm, $x = 4$ mm, $y = 6$ mm.

a 90° phase difference to the dipole arms such that the CP radiation is generated, and the antenna is fed by a single $50\,\Omega$ coaxial cable, of which negative part is connected to the ground plane. The proposed antenna was optimized using ANSYS HFSS, and the optimized geometric parameters are listed as follows: $a = 60\,\text{mm}$, $h = 26\,\text{mm}$, $h = 0.8\,\text{mm}$, $l = 23.5\,\text{mm}$, $w = 20\,\text{mm}$. $a_1 = 58.4\,\text{mm}$, $l_1 = 1.2\,\text{mm}$, $w_1 = 11\,\text{mm}$, $w_2 = 7\,\text{mm}$, $r = 2.6\,\text{mm}$, $r_1 = 4.6\,\text{mm}$, $r_2 = 5.2\,\text{mm}$, $x = 4\,\text{mm}$, $y = 6\,\text{mm}$.

A double vacant-quarter printed ring with orthogonal bowties is employed for CP radiation and broadband characteristics of impedance and 3 dB AR bandwidths. The bowtie dipoles radiate bidirectionally and thus produce a low broadside gain without a ground plane in free space. The unidirectional radiation is generated by a ground plane and consequently improves the antenna gain. The parasitic resonators and vertical metallic plates increase the length of the current path on the crossed dipoles, hence broader CP bandwidth is achieved. A horizontal current of the bowtie dipoles is produced on the radiating patch. A vertical current is induced on the vertical metallic plates by the E-field of the radiating patches, hence the beamwidth of the antenna is broadened.

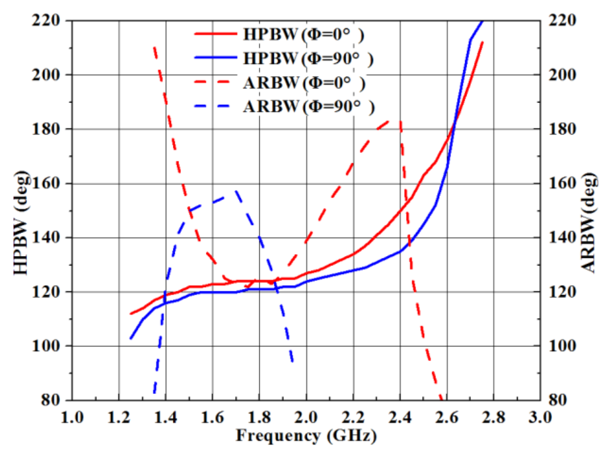


Figure 2. Simulated HPBW and 3 dB ARBW of the proposed antenna.

Figure 2 shows the simulated HPBW and 3 dB ARBW of the proposed antenna. The red and blue solid (dashed) lines represent the HPBW (ARBW) of the proposed antenna in the E- and H-planes. The plane of $\Phi = 0^\circ$ is E-plane, and the plane of $\Phi = 90^\circ$ is H-plane. To investigate the mechanism of the proposed antenna, the surface current distributions at 1.3 GHz at four phase angles: 0°, 90°, 180°, 270° are shown in Fig. 3. The surface currents on the orthogonal dipoles are perpendicular such that the CP is generated. Owing to the coupling with the dipoles, orthogonal currents can be induced on the parasitic elements and vertical metallic plates. Additional impedance and AR passbands can, therefore, be generated beside the original operating band, enhancing its bandwidth substantially. Meanwhile, the beamwidth performance of the proposed antenna can be enhanced by the vertical coupling surface current on the metallic plates. With the increase of the phase angles from 0° to 270°, the surface currents are changed anticlockwise such that the righthand CP is generated.

2.2. Parameters Studies

To describe the performance of the antenna, some key parameters of the proposed antenna are discussed. Important parameters of the presented antenna include the length l and width w of the dipole arms and the distance h from the substrate to the ground plane. All the parameters stay the same as in Fig. 1 unless stated.

Figure 4(a) shows the S_{11} and AR for different dipole lengths l from 22.5 to 24.5 mm. A broader matching and AR bands are achieved with 23.5 mm. Fig. 4(b) shows results for different dipole widths w from 18 to 22 mm. The impedance and AR band is extremely invariant without regard for the beam performance. Fig. 4(c) shows results for different distances h from 25 to 27 mm. The performance of the impedance and AR bands is superior with 26 mm.

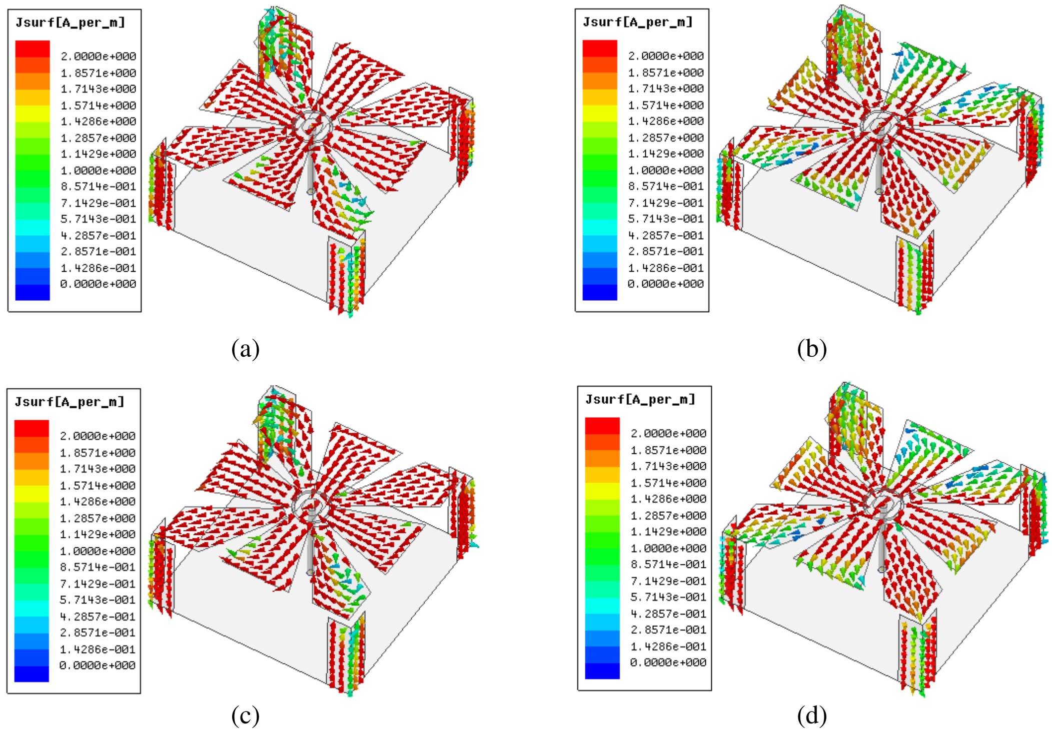
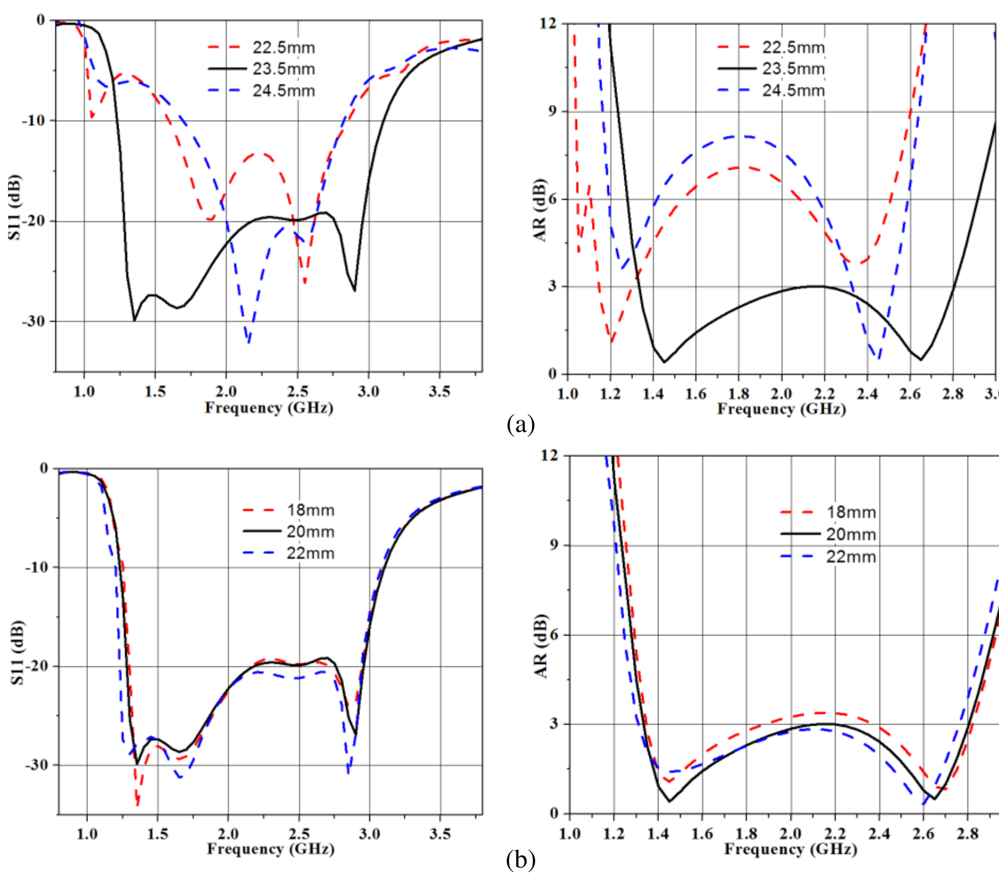
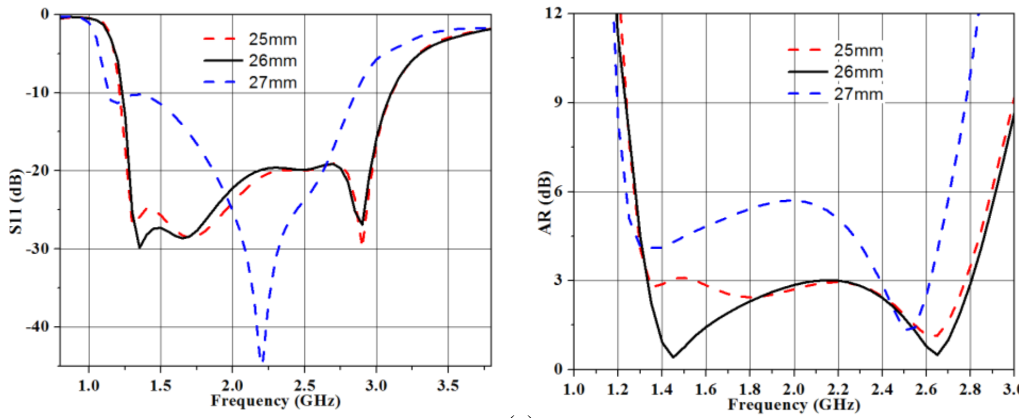


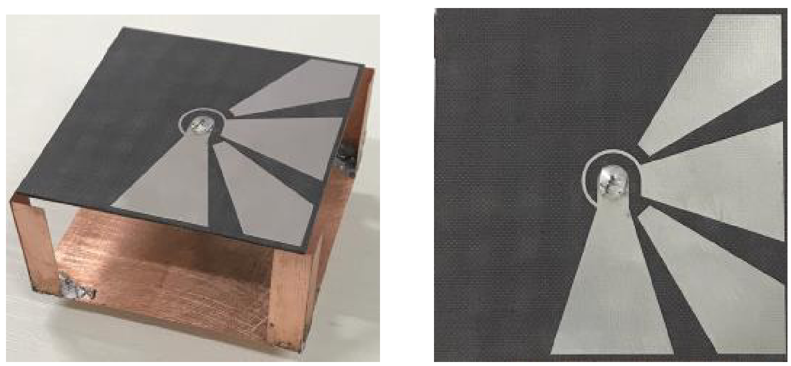
Figure 3. Surface current distributions of the proposed antenna at 1.3 GHz at four phase angles. (a) 0°, (b) 90°, (c) 180°, (d) 270°.





(c)

Figure 4. Simulated S_{11} and AR for different (a) dipole arm length l, (b) dipole arm width w and (c) distance h from the substrate to the ground plane.



(a) (b)

Figure 5. Prototype of the proposed antenna. (a) Perspective view. (b) Top view.

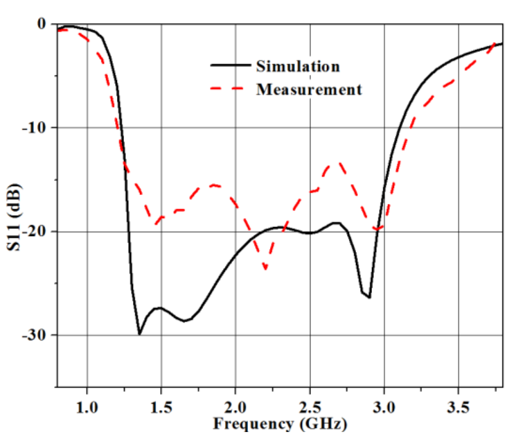


Figure 6. Simulated and measured S_{11} of the proposed antenna.

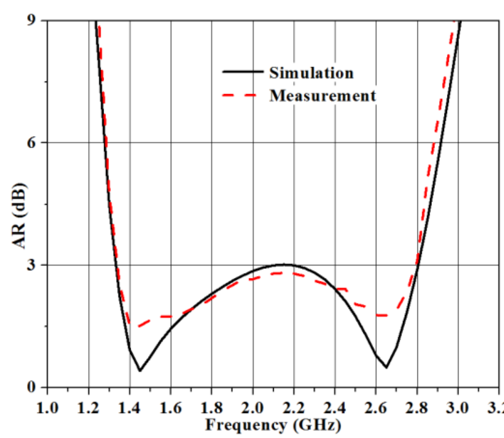


Figure 7. Simulated and measured AR of the proposed antenna.

3. SIMULATION AND MEASUREMENT RESULTS

In order to verify the proposed design, the prototype of the proposed antenna which is shown in Fig. 5 was fabricated and measured. The measured and simulated S_{11} are depicted in Fig. 6. As shown in the figure, the measured -10 dB S_{11} is around 88.4% (1.2–3.1 GHz). The measured values are smaller than the simulated results which may be attributed to fabrication errors. In addition, the simulated and measured ARs are also illustrated in Fig. 7. The measured 3-dB AR bandwidth is about 73.1% from 1.3 to 2.8 GHz, which is in good agreement with the simulated results. Fig. 8 shows the gains of the antenna. A flat gain with the variation less than 3 dB is achieved within the whole band. Fig. 9 shows the simulated and measured radiation patterns at 1.3, 2.0 and 2.7 GHz in both E-plane ($\Phi = 0°$) and H-plane ($\Phi = 90°$). All the measured cross polarization at all frequencies is below -1 dB in the main beam.

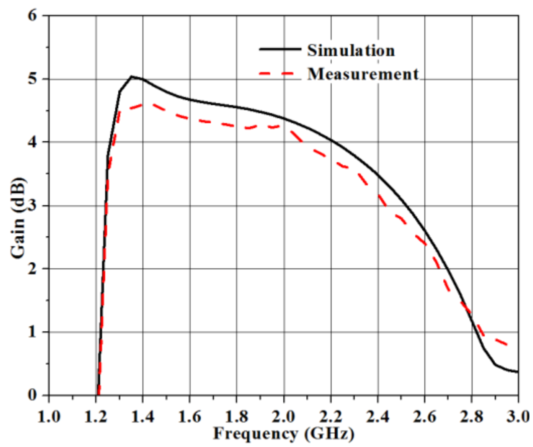
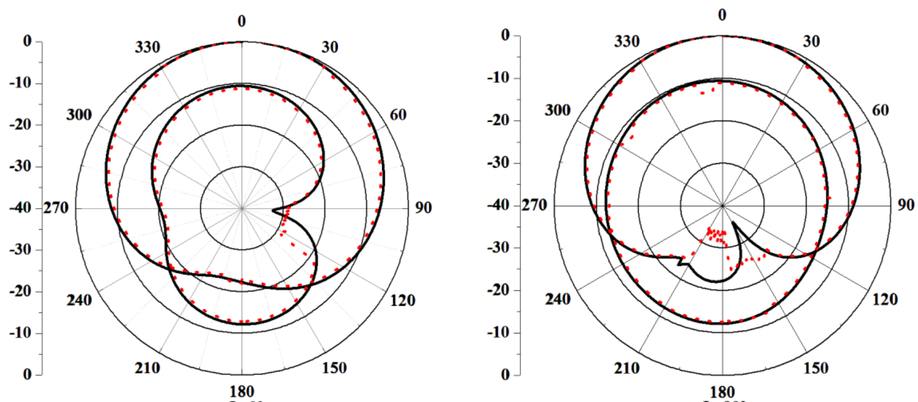
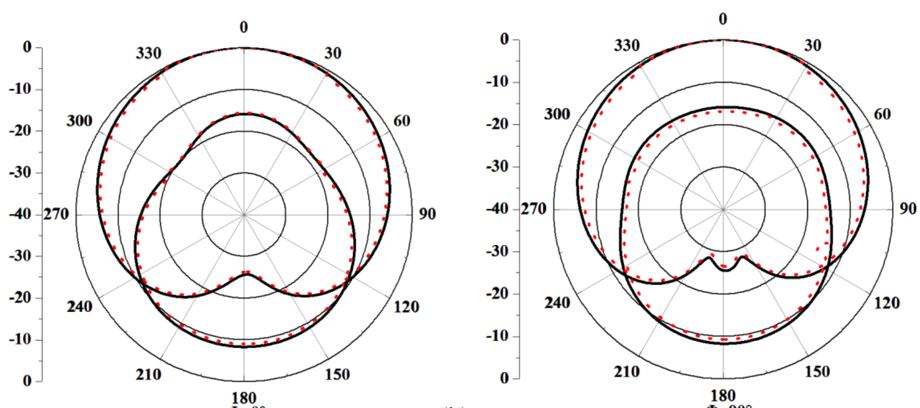


Figure 8. Simulated and measured gain of the proposed antenna.



(a)



(b)

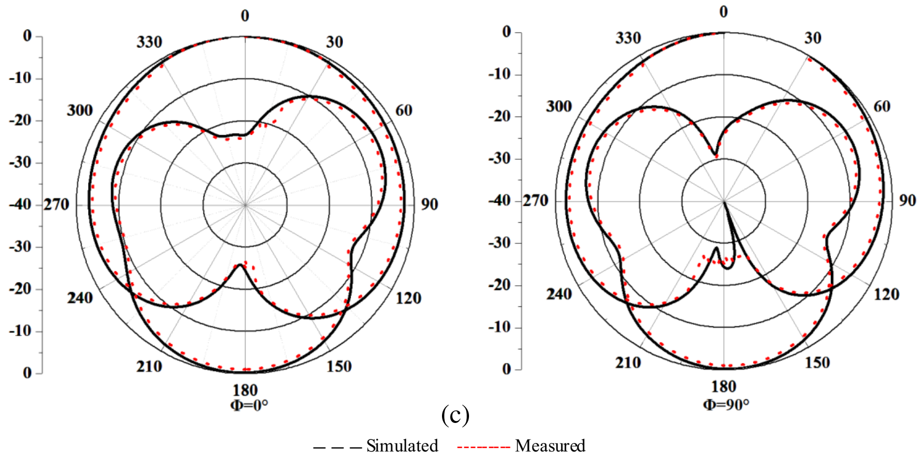


Figure 9. Simulated and measured radiation patterns of the prototype. (a) 1.3 GHz. (b) 2.0 GHz. (c) 2.7 GHz.

4. CONCLUSION

A compact wideband CP crossed-dipole antenna with wide HPBW and broad 3 dB ARBW is proposed in this paper. The total size of the antenna is $0.4\lambda \times 0.4\lambda \times 0.16\lambda$. The impedance bandwidth is 88.4%, and 3 dB AR bandwidth is 73.1%. The HPBW of more than 120° is 70.0%. The 3 dB ARBWs of more than 120° in *E*-plane and *H*-plane are 63.1% and 37.5%, respectively. With both the excellent CP performance and compact structure, the proposed antenna is attractive for modern wireless communications.

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