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Design of a Compact Wideband Circularly Polarized Crossed-Dipole Antenna Using a Modified Cavity

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Abstract—A wideband right-hand circularly polarized (RHCP) crossed-dipole antenna with wide impedance bandwidth (IBW) and axial ratio bandwidth (ARBW) is proposed in this paper. A pair of dipoles with modified arms and a novel back-cavity are introduced to enhance both the IBW and ARBW of a conventional crossed-dipole antenna. Simulated and measured results indicate that the proposed structure can improve the circularly polarized (CP) characteristics significantly. The IBW ($|S_{11}| < -10\,\mathrm{dB}$) and ARBW ($\mathrm{AR} < 3\,\mathrm{dB}$) are 100% and 89.1%, respectively. The total size is $0.4\lambda \times 0.4\lambda \times 0.15\lambda$ (λ being the corresponding free-space wavelength at the frequency of 2.2 GHz). With both the excellent CP operating bandwidth and compact size, the proposed antenna is attractive for broadband wireless communication systems.

1. INTRODUCTION

Due to the capabilities of combating multipath interference or fading, reducing Faraday rotation effect and mitigating polarization mismatch, CP antennas are becoming a key component for various applications such as Satellite Communications Systems, Global Positioning Systems (GPS), mobile communications, and Radio Frequency Identification (RFID). Meanwhile, due to the demand of high-speed transmission in wireless communications, wide impedance bandwidth and wide axial ratio bandwidth are necessary in the systems mentioned above.

Crossed-dipole antennas are attracting more and more attention due to their simple structure, wide bandwidth, and low cost. A simple crossed-dipole CP antenna with an AR bandwidth of 15.6% has been proposed in [1], but the AR bandwidth is still narrow. Many efforts have been made to enhance the bandwidth of CP crossed-dipole antennas, such as adding four parasitic loops in [2], loading with a magneto-electric dipole in [3], adopting open ends in [4], and changing the dipole shape in [5–7]. In [8], a crossed dipole loaded with four slots, four parasitic bowtie patches and four parasitic rectangular strips exhibits a wide IBW of 93.1% and ARBW of 90.9%. In [9], an elliptical cavity-backed crossed-dipole antenna is proposed, and an IBW of 106.5% and an ARBW of 96.6% are achieved. Some works achieving multi-band behavior are very meaningful. In [10], two CP cavity-backed crossed dipoles are proposed, and single-band and dual-band LC resonators are placed along both the dipole arms to realize dual-band and tri-band CP operations. In [11], a rectangular dipole with L-shaped and meandered slots has been presented for triple-band LP operation. However, the structures of the antennas are bulky, hence not suitable for the wireless communication systems.

In this paper, a compact wideband single-feed crossed-dipole CP antenna is presented. A modified cavity is used to broaden the operation bandwidth. The proposed antenna achieves an IBW of 100% and ARBW of 89.1%. The process of antenna design and operating principle are investigated in Section 2.

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Some key parameters of the modified cavity are studied in Section 3. The simulated and experimental results are shown in Section 4.

All the simulation results in this paper are obtained by using the three-dimensional full-wave simulated software Ansys HFSS.

2. ANTENNA DESIGN

Figure 1 shows the geometry of the proposed crossed-dipole antenna. The antenna consists of two crossed dipoles with parasitic square slots and a modified cavity, which is fed by a $50\,\Omega$ coaxial cable. The arms at the top side of the substrate are connected to the inner conductor of the coaxial cable whereas the outer conductor is connected to the arms at the bottom side. The crossed dipoles are connected by two curved-delay lines providing an orthogonal phase difference to realize CP radiation. All of the substrates used in the design are FR4 ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$) with a thickness of 1.5 mm. To obtain wider IBW and ARBW characteristics, a modified cavity is introduced. The cavity is composed of a ground plane loaded with four parasitic rectangular slots and four vertical metal supports which are sequentially placed at

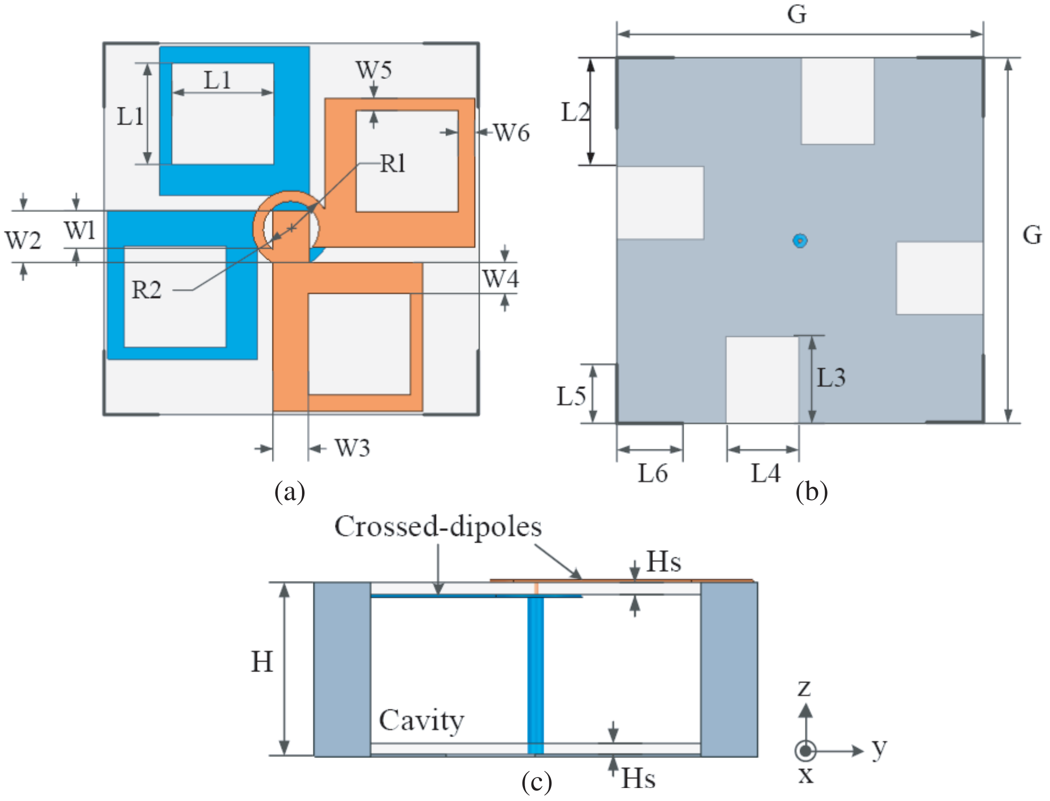


Figure 1. Geometry of the proposed antenna. (a) Top view; (b) Top view of the cavity; (c) Side view.

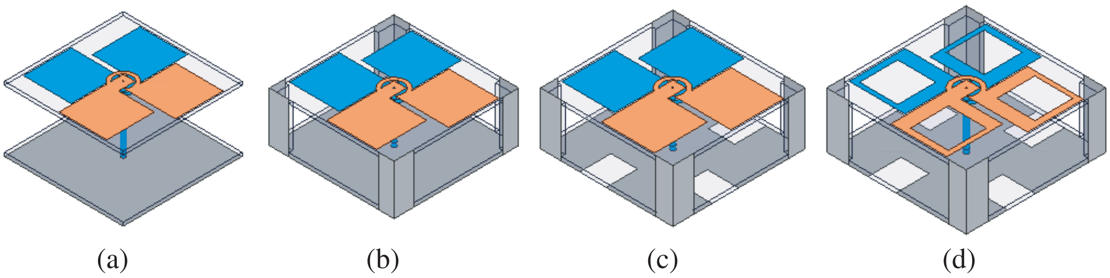
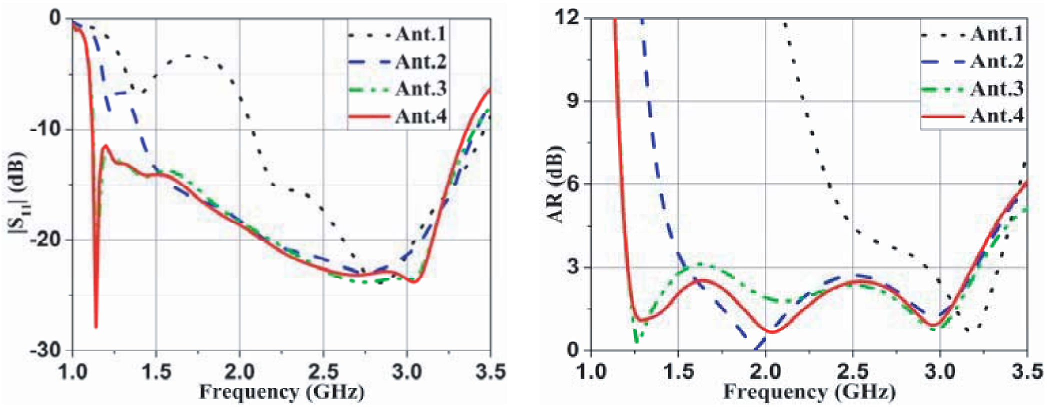


Figure 2. The process of antenna design. (a) Ant.1; (b) Ant.2; (c) Ant.3; (d) Ant.4.

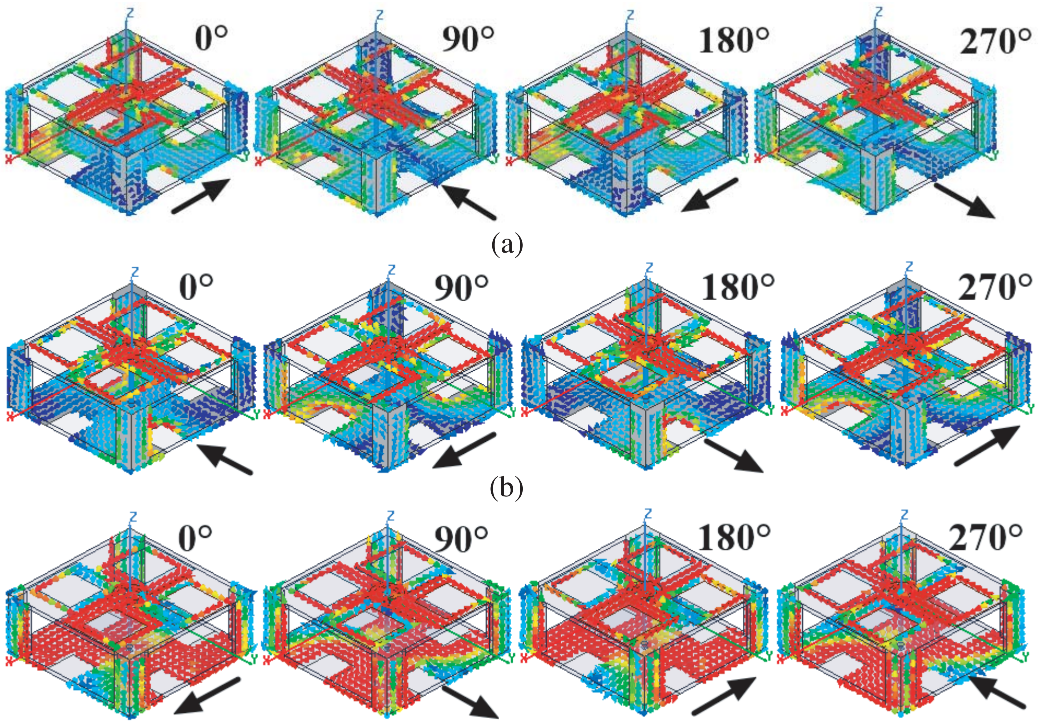
the corners of the ground plane. The optimized parameters are as follows: $R1 = 4.1\,\mathrm{mm}$; $R2 = 5.7\,\mathrm{mm}$; $W1 = 5.8\,\mathrm{mm}$; $W2 = 7.7\,\mathrm{mm}$; $W3 = 5.3\,\mathrm{mm}$; $W4 = 4.6\,\mathrm{mm}$; $W5 = 1.8\,\mathrm{mm}$; $W6 = 2.4\,\mathrm{mm}$; $L1 = 15\,\mathrm{mm}$; $L2 = 16.3\,\mathrm{mm}$; $L3 = 13\,\mathrm{mm}$; $L4 = 11\,\mathrm{mm}$; $L5 = 7\,\mathrm{mm}$; $L6 = 8\,\mathrm{mm}$; $G = 55\,\mathrm{mm}$; $H = 20\,\mathrm{mm}$; $Hs = 1.5\,\mathrm{mm}$. The size of the antenna is only $55\,\mathrm{mm} \times 55\,\mathrm{mm} \times 20\,\mathrm{mm}$.

To clarify the operation mechanism, the process of antenna design is shown in Figure 2. The initial design (Ant.1) is a conventional crossed-dipole antenna with open ends and a flat reflector. Due to both the low antenna height and small reflector size, it exhibits a narrow ARBW (2.92–3.33 GHz) as shown in Figure 3(b). To achieve a broadband CP operation, four vertical metal supports are introduced in Ant.2. As a result, the IBW is extended to 83.6% from 1.40 to 3.41 GHz in Figure 3(a) while the ARBW is extended to 70.0% from 1.54 to 3.20 GHz in Figure 3(b). Then four rectangular slots are



(a) (b)

Figure 3. Simulation results of four antenna designs. (a) $|S_{11}|$; (b) AR.



(a)

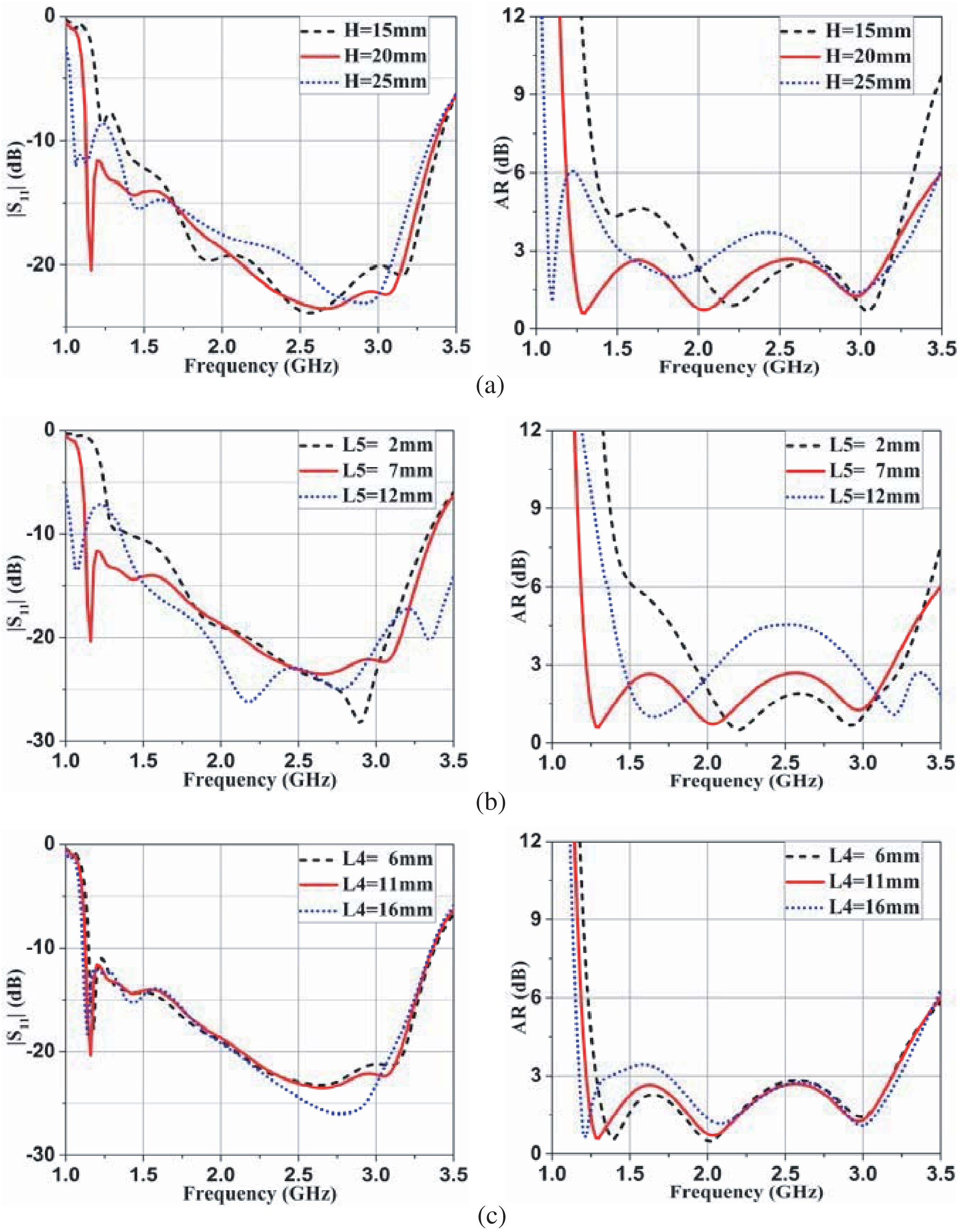
(b)

(c)

Figure 4. Simulated surface current distributions at different time phase of 0°, 90°, 180° and 270°. (a) At 3 GHz; (b) At 2 GHz; (c) At 1.28 GHz.

loaded on the bottom of the cavity (Ant.3), because of which a wider IBW of 98.9% (1.12–3.41 GHz) and ARBW of nearly 90.7% (1.21–3.22 GHz) are achieved. As can be seen in Figure 3(b), the AR value of Ant.3 around 1.6 GHz is slightly beyond 3 dB. As such, to balance the current amplitudes of the two crossed dipoles, four parasitic square slots are etched on the crossed-dipole arms. Thus, an ARBW of 90% (1.21–3.19 GHz) can be obtained while the impedance bandwidth (1.12–3.36 GHz) remains almost unchanged.

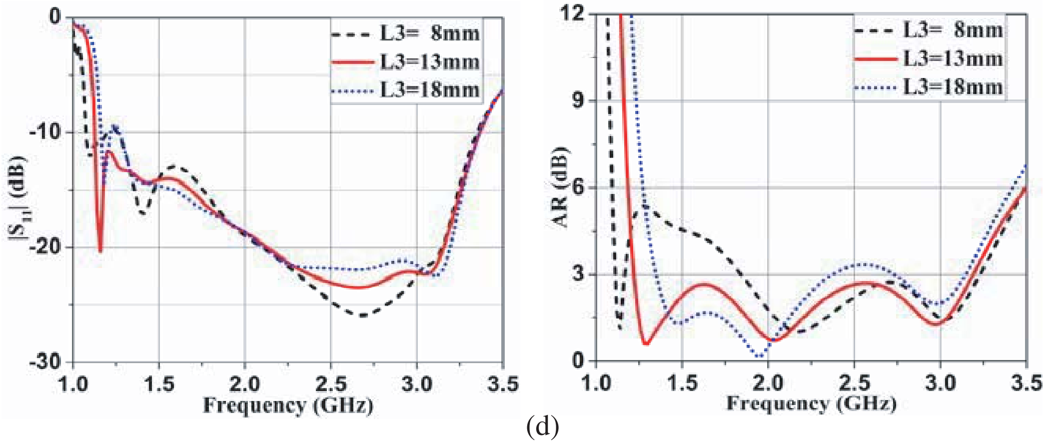
To better understand the operating mechanism of the proposed antenna, the surface current distributions of Ant.4 for different time phases of 0°, 90°, 180° and 270° at 3.0 GHz, 2.0 GHz, and 1.28 GHz are shown in Figure 4. Surface currents on the crossed dipoles rotate in anti-clockwise direction at all frequencies, so the resulting polarization is RHCP. It can be seen from Figure 4(a) that most of the surface currents are concentrated on the crossed-dipole while the currents on the cavity are very



(a)

(b)

(c)



(d)

Figure 5. $|S_{11}|$ and AR of the proposed antenna with different parameters. (a) H; (b) $L5$; (c) $L4$; (d) $L3$.

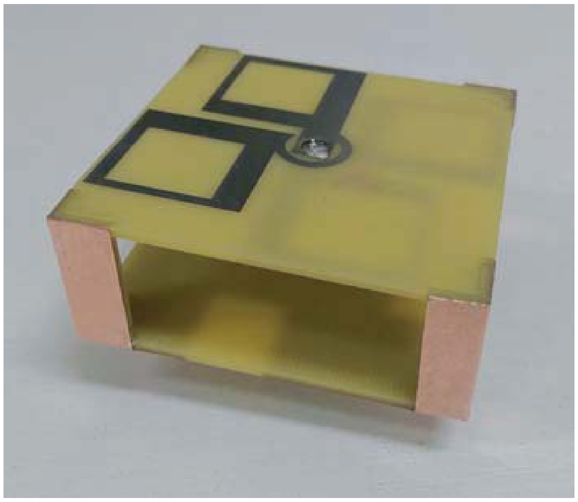


Figure 6. Photograph of the proposed antenna.

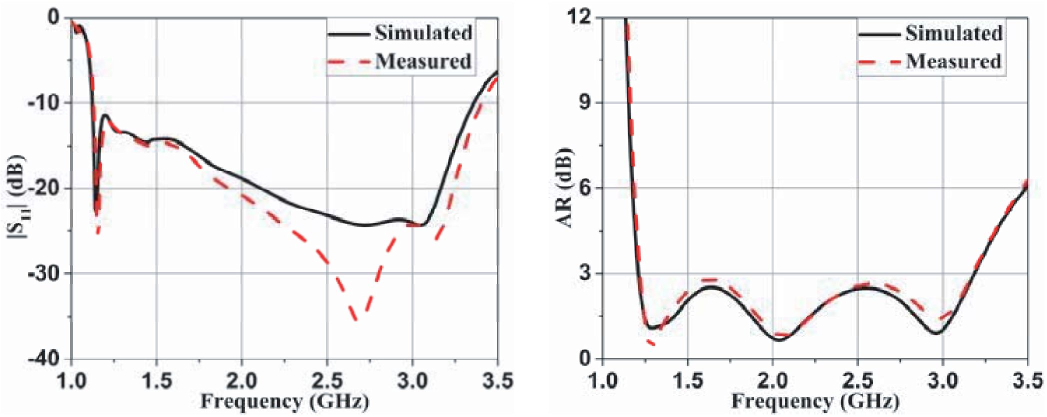
weak at 3 GHz. It indicates that the initial CP resonance frequency of the crossed-dipole is at 3 GHz. In Figure 4(b), the coupling between the crossed-dipole and the cavity provides a new CP resonant frequency at 2 GHz due to the introduction of four vertical metal supports. When the antenna is operating at 1.28 GHz as observed in Figure 4(c), the surface currents on the cavity get stronger than the currents at 2 GHz. With the increase of the surface current path, another CP resonance frequency (1.28 GHz) is generated owing to the effect of four rectangular slots on the bottom of the cavity.

3. PARAMETRIC STUDY

A parametric study is developed to investigate the influence of the modified cavity on the IBW and ARBW. Figure 5(a) shows the $|S_{11}|$ and AR for different cavity heights of H. It can be observed that both the IBW and ARBW are greatly influenced, especially in the lower frequency band. The second CP resonance frequency is introduced with the addition of four vertical metal supports, which makes it possible to adjust the second CP resonance frequency by choosing H properly. The width of the vertical supports also influences the operation bandwidth significantly. As shown in Figure 5(b), a CP resonance frequency (around 1.3 GHz) disappears with $L5 = 2$ mm for the weak coupling. When $L5 = 12$ mm, the coupling between cavity and crossed dipoles is enhanced, and the CP characteristics at the center frequencies are degraded greatly. Then the effects of the four rectangular slots in the bottom of the cavity are studied. Figure 5(c) and Figure 5(d) show the simulated results for different slot side lengths of $L3$ and $L4$. It can be seen that the IBW is almost unchanged while the lowest CP resonance frequency can be easily tuned by changing $L3$ and $L4$.

4. SIMULATED AND EXPERIMENTAL RESULTS

A prototype of the proposed antenna is fabricated and measured as shown in Figure 6. The simulated and measured $|S_{11}|$ of the proposed antenna are shown in Figure 7(a). It can be seen that the measured IBW is 100% from 1.13 GHz to 3.41 GHz, and a good agreement is observed between them. Figure 7(b) shows the simulated and measured ARs. It can be observed that the simulated and measured ARBWs are 90% (1.21–3.19 GHz) and 89.1% (1.22–3.18 GHz), respectively. Figure 8 shows the simulated and measured radiation patterns of the proposed antenna at 1.28 GHz, 2 GHz, and 3 GHz in XOZ and YOZ planes. The frequencies of 1.28 GHz, 2.0 GHz and 3.0 GHz correspond to the minima of Figure 7(b) of AR versus frequency. It can be seen that stable broadside radiation patterns are obtained across the whole operating band. Because most of the surface currents are concentrated on the crossed-dipole at 3 GHz and the crossed dipoles asymmetrical due to the two curved-delay lines, the radiation patterns are not symmetrical at 3 GHz. The front-to-back ratios of the proposed antenna are 6.4 dB, 6.0 dB and 0.3 dB at 1.28 GHz, 2 GHz, and 3 GHz. The measured and simulated gains are shown in Figure 9,

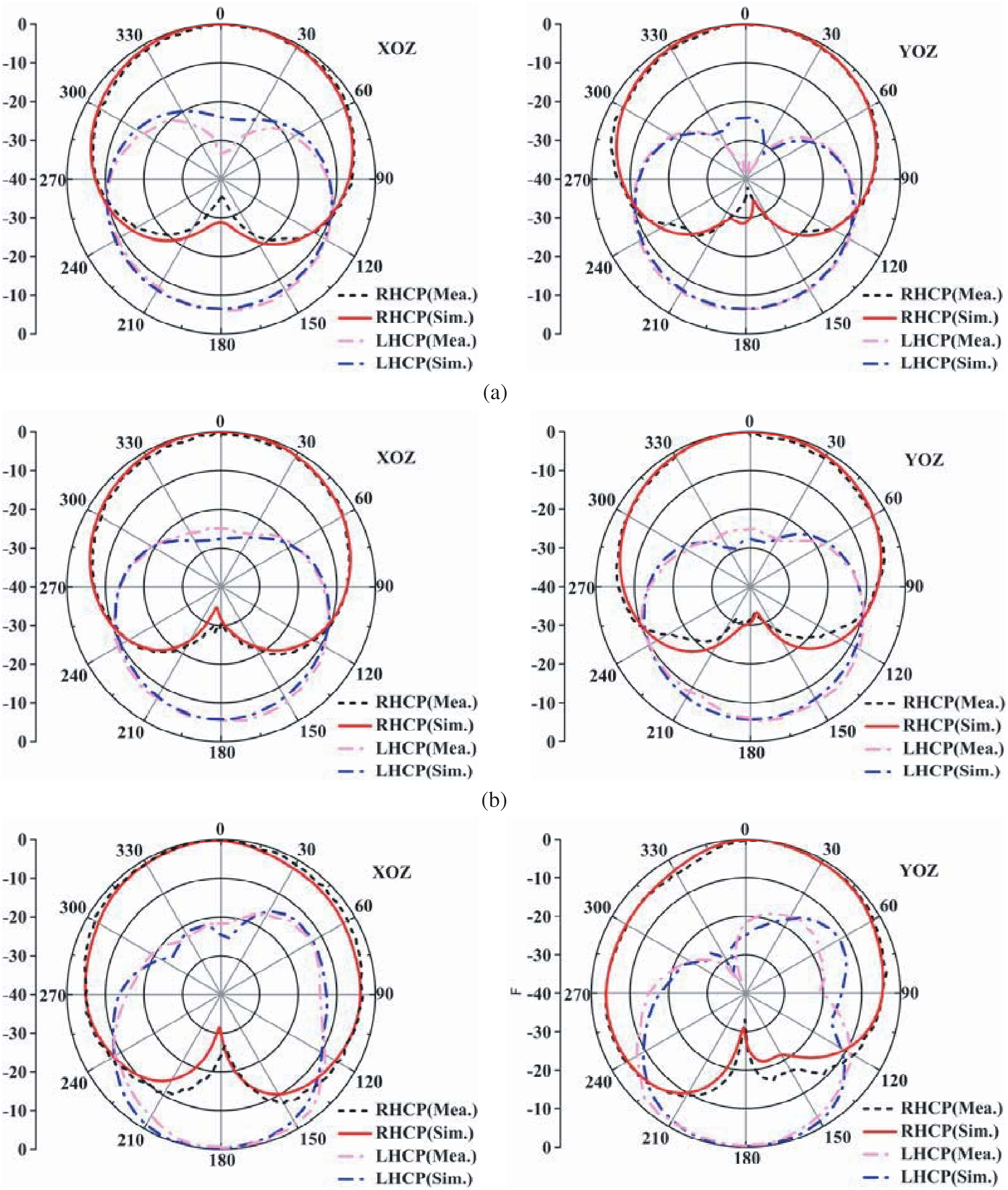


(a) (b)

Figure 7. Simulated and measured results of the proposed antenna. (a) $|S_{11}|$; (b) AR.

Table 1. Performance comparison between the proposed antenna and the previous works.

Antenna Structure	Electrical Size (λ^3)	IBW	ARBW
Proposed	$0.4 \times 0.4 \times 0.15$	100%	89.1%
Ref. [1]	$0.92 \times 0.92 \times 0.22$	30.7%	15.6%
Ref. [2]	$1.05 \times 1.05 \times 0.25$	38.2%	28.6%
Ref. [3]	$0.64 \times 0.64 \times 0.16$	59.8%	26.8%
Ref. [4]	$0.45 \times 0.45 \times 0.24$	50.2%	27%
Ref. [5]	$0.88 \times 0.88 \times 0.23$	57%	51%
Ref. [6]	$2.06 \times 2.06 \times 0.13$	66.9%	55.1%
Ref. [7]	$0.4 \times 0.4 \times 0.17$	66.2%	41.3%
Ref. [8]	$1.1 \times 1.1 \times 0.4$	93.1%	90.9%
Ref. [9]	$1.68 \times 1.68 \times 0.35$	106.5%	96.6%



(a)

(b)

(c)

Figure 8. Simulated and measured radiation pattern of the proposed antenna. (a) 1.28 GHz; (b) 2 GHz; (c) 3 GHz.

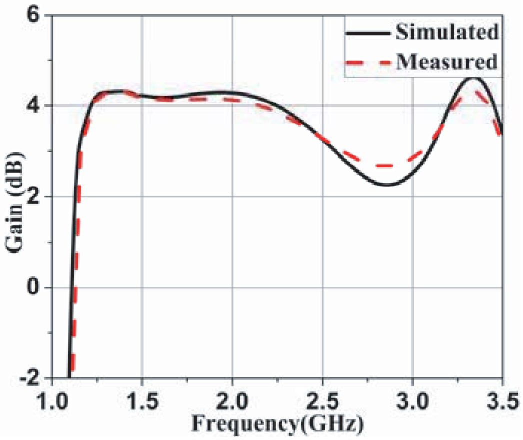


Figure 9. Simulated and measured gain of the proposed antenna.

which shows that the measurement agrees reasonably with the simulation. The peak gain is 4.4 dB at 3.3 GHz. Discrepancies between the simulated and measured results are likely due to the substrate and measurement errors.

To illustrate the advantages of compact antenna size and wide CP operating bandwidth, a comparison between the proposed antenna and previous works is summarized in Table 1. As shown in Table 1, the proposed antenna exhibits a more compact size with wider CP operation bandwidth than other antennas.

5. CONCLUSION

A compact wideband CP crossed-dipole antenna is proposed in this paper. The experimental results show that the antenna size is reduced while the IBW and ARBW are enhanced due to the introduction of a modified cavity. The proposed antenna achieves a wide IBW of 100% (1.13–3.41 GHz) and ARBW of 89.1% (1.22–3.18 GHz). Good CP characteristics are achieved in the entire operation band while the size is only $0.4\lambda \times 0.4\lambda \times 0.15\lambda$. With excellent CP operating bandwidth, the proposed antenna can be a good candidate for broadband wireless communication systems.

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