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Design and Optimization of CPW-Fed Broadband Circularly Polarized Antenna for Multiple Communication Systems

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Abstract—A novel coplanar waveguide (CPW) fed wide slot antenna for broadband circular polarization (CP) operation is proposed in this letter. Utilizing an asymmetrical ground plane and an open slot, broadband axial ratio and good impedance characteristics can be obtained in the middle and low bands. The perturbation patch on the right side of the wide slot excites the upper-band CP mode. By adjusting the upper-part feedline and the wide slot structure, the axial ratio performance can be optimized to a wideband axial ratio bandwidth (ARBW). Compared with wide slot antennas of similar size, the proposed antenna has a simpler structure while achieving a wider ARBW. The proposed antenna has been fabricated and tested. The measured results show that the -10 dB impedance bandwidth (ZBW) is 2.40–7.55 GHz (103.5%); 3-dB ARBW is 2.47–6.2 GHz (86.0%); and the peak gain is about 4 dBic. Right-hand circular polarization (RHCP) radiation pattern is achieved in $+z$ direction. The proposed antenna can be used in WLAN/WiMAX applications and various wireless communication systems which require broadband ZBW and ARBW.

1. INTRODUCTION

With the rapid update of wireless communication equipment, the traditional single band antenna has been unable to meet the increasing demand of wireless communication, and the broadband antenna that is compatible with multiple bands has attracted a lot of attention [1]. For antenna design, CP is also an important feature. CP antenna can reduce the multipath interference of signal, receive electromagnetic waves in linear polarization (LP) and CP modes, resist the signal attenuation when passing through the ionosphere, and improve the efficiency of wireless communication system [2].

Many researchers have studied new shaped antennas for ideal impedance performance and axial ratio bandwidth (ARBW). Among them, wide slot antennas have attracted much attention due to their advantages of easy circular polarization [3–16]. Papers [3–6] propose several circular-slot antennas. CP waves are generated by a circular radiation patch with an opening on the left side [3]. A metal strip that is orthogonal to the microstrip feedline is protruded on the right side of the slot to generate two equal amplitude orthogonal currents [4]. Slots and radiation patches with special shapes are also utilized to obtain multiple circularly polarized modes and broaden the ARBW [7–18]. In [7], CP characteristic is achieved under the introduction of open slot, but the narrow ARBW limits its application in multi communication systems. An L-shaped radiating patch is a typical structure to get good impedance performance and excite the primary CP mode. It achieves a broadband ARBW under the combined action of the S-shaped slot [8] or the L-shaped ground strips [9]. With L-shaped slot ground and an L-shaped radiating stub with two G-shaped slits [10], ARBW is improved to 42%. The ARBW of 42% is achieved by a parasitically placed quasi-rectangular strip and systematic perturbations in the back [11]. An inverted F-shaped feed-line, a Z-shaped strip, and several slots are utilized as perturbations, which realize the ARBW of 96% in [13] but not fully covered by ZBW of 87.8%. By introducing a nesting-L

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slot and a T-shaped radiator, a broad ARBW (60.9%) is achieved in [15]. For a wider ARBW and excellent gain performance, doubly-fed antennas are proposed in [19, 20], which finally achieve 67% and 110.5% ARBWs. In [21], four CPW feeding ports with equal amplitude and 90° phase difference are utilized to realize wide ARBW (70.8%). However, in a multi-port antenna, a complex feed network increases the size and processing cost of the antenna.

Generally, an asymmetrical ground is utilized to obtain CP characteristics and multiple resonance modes, but the narrow ARBW limits the application of antennas in multi-band communication systems. In this work, multiple CP modes will be excited through different elements. Based on the asymmetric current generated by the ground, each modification brings a great improvement in radiation performance while maintaining the simplicity of antenna design.

A simpler slot antenna for broadband ZBW and ARBW operation is proposed and studied. The asymmetric ground is utilized to excite the primary CP mode. Under the action of open slot, the surface current distribution is optimized, and low-band ARBW and ZBW are expanded. The upper-band ARBW and ZBW are achieved by the perturbation patch on the right side of wide slot. The design process and CP mechanism are analysed in Section 2. The measured results agree well with simulated performance analysed by Ansoft HFSS 15.0.

2. DESIGN AND ANALYSIS OF ANTENNA

In this paper, the proposed antenna is etched on an FR4 dielectric substrate ($\varepsilon r = 4.4$, $\tan\delta = 0.02$, $h = 0.8\,\text{mm}$). The size of the antenna is $50 \times 50\,\text{mm}^2$. The geometrical configuration of proposed antenna is shown in Fig. 1, which is composed of a microstrip feedline with a slanted upper-part, a modified wide slot with an open slot, and a perturbation patch on the left side.

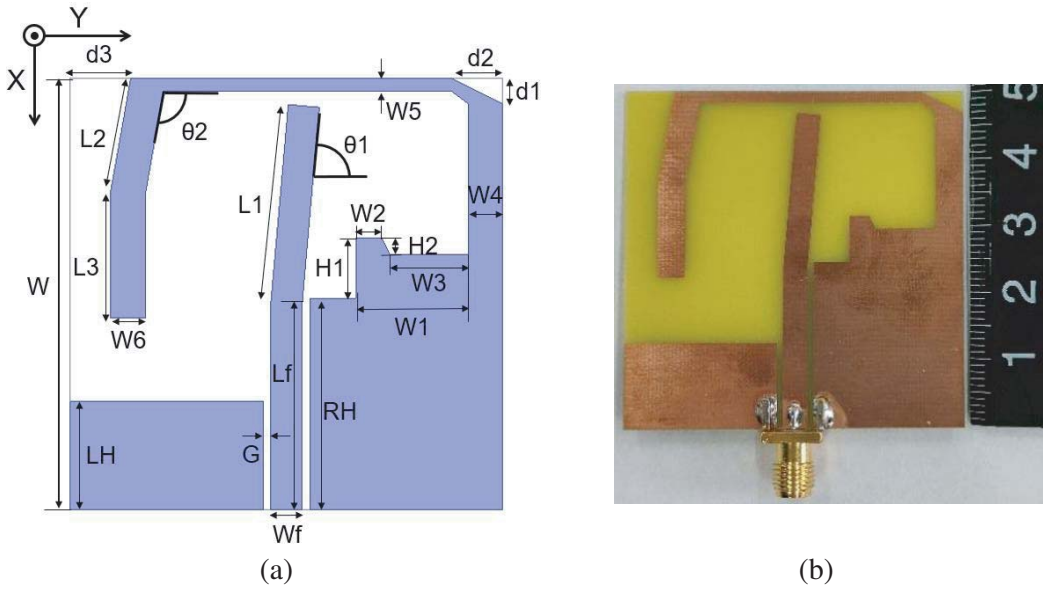


Figure 1. Proposed antenna: (a) geometry and (b) photograph.

2.1. Design Process of Antenna

Figure 2 illustrates five antenna models (Ant. 1–Ant. 5) to show the antenna design process clearly, and the S_{11} and AR of each antenna are shown in Figs. 3(a) and (b). Ant. 1 is considered as a traditional wide slot antenna with a symmetrical structure with respect to the microstrip feedline, which excites the basic resonance frequency at 3.2 GHz and 5.1 GHz. The asymmetrical ground plane in Ant. 2 achieves a narrow ARBW at 2.75 GHz, and the ZBW of Ant. 2 is increased at low frequency band. The open slot of Ant. 3 on the left side of the wide slot is used to expand low-band ARBW and shift ZBW to the

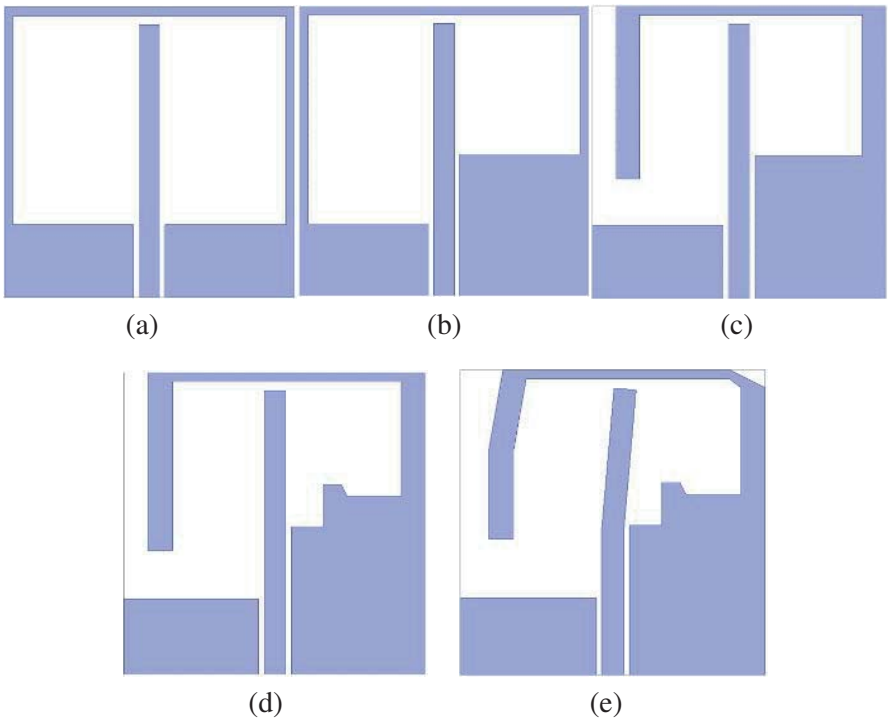


Figure 2. The design process of antenna. (a) Ant. 1. (b) Ant. 2. (c) Ant. 3. (d) Ant. 4. (e) Ant. 5

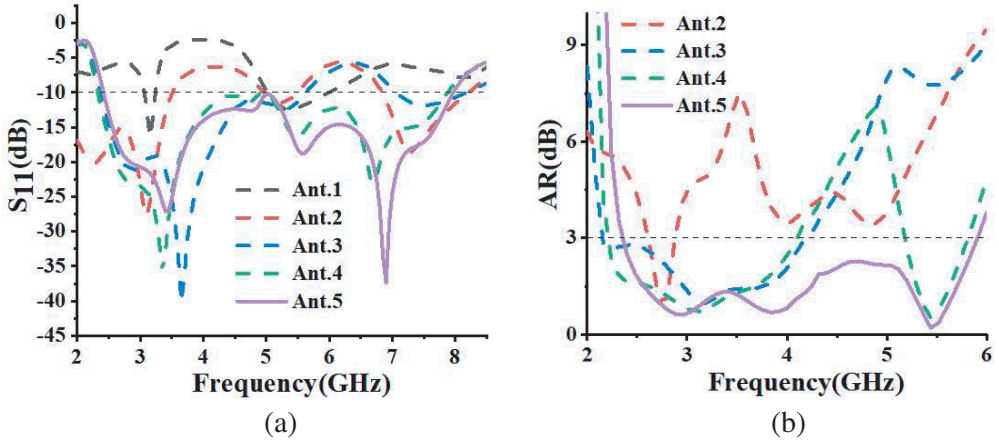


Figure 3. S_{11} and AR of each antenna.

high frequency. As an impact contributor to achieve wideband ARBW, the open slot will be discussed in the following section.

In Ant. 4, the introduction of a perturbation patch excites the high band CP model at 5.5 GHz, and effectively expands the ZBW of the proposed antenna. For broadband CP operation, the top edge of the branch and the upper-part feedline are modified to the inclined patch, as shown in Ant. 5. This result can be considered as the slight revision of current in corresponding directions.

2.2. Analysis of Circular Polarization Mechanism

Generally, two orthogonal electric field components (E_{Hor}, E_{Ver}) with the same amplitude and a phase difference of 90° generate CP. For traditional wide slot antennas, due to the structural symmetry, the

horizontal and vertical currents generated by the ground plane and a long branch around the wide slot are opposite and equal in amplitude.

The vertical electric field (E_{Ver}) component on the feedline leads to LP radiation, as shown in Fig. 4(a). The introduction of the asymmetric ground plane, open slot, and perturbation patch breaks the symmetry of the current distribution on the antenna surface, as shown in Fig. 4(b).

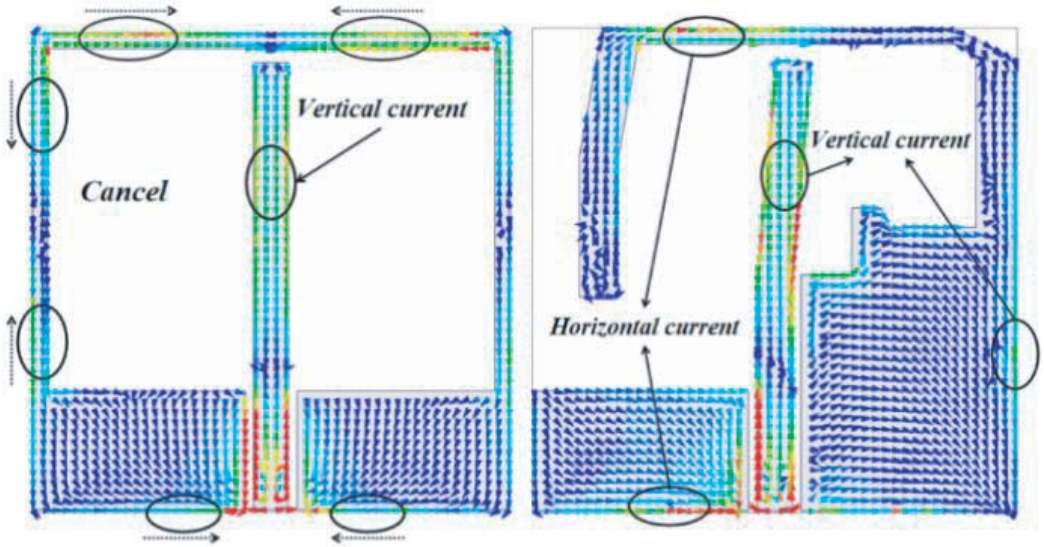


Figure 4. Comparison of current distribution in 2.54 GHz: (a) Ant. 1, (b) Ant. 5.

To clarify the effect of open slot in Ant. 3, the current distributions of Ant. 2 and Ant. 3 at 0° and 90° phases at 3.2 GHz are shown and analysed in Figs. 5(a) and (b). The main current path is marked with $J1$–$J9$, and the vector sum of surface current is marked with J_{sum}. All of them play a dominant role in CP operation. It can be seen from Fig. 5(a) that Ant. 2 fails to produce field components with orthogonal phase and equal amplitude at 3.2 GHz. In Fig. 5(b), the open slot weakens the current intensity ($J1$ at 0° phase, $J9$ at 90° phase). Then, adjust the parameters ($d3$ and $L2 + L3$) to change the currents' length ($J1$ and $J2$ at 90° phase). Ant. 3 excites right-hand CP mode at 3.2 GHz, which expands the low-band ARBW.

The surface current distributions of the proposed antenna at 5.5 GHz are shown in Fig. 5(c). Under the influence of perturbation patch, at 0° phase, J_{sum} is oriented to $-x$ direction approximately. After a quarter of a period, J_{sum} faces the $-y$ direction approximately. Hence, J_{sum} rotates counterclockwise, which indicates that the proposed antenna radiates right-hand waves in the $+z$ direction.

3. PARAMETRIC STUDY

To obtain the best axial ratio and return loss performance, the antenna parameters are studied. The height of the perturbation patch H1, the height of left ground plane LH, and the inclination angle of the upper-part feedline are especially analyzed to find their influences on antenna performance. In parameter analysis, all other antenna parameters keep optimized values.

In Section 2, we can see that the perturbation patches can optimize the high-band impedance matching and excite the high-band CP mode. This effect is also shown in Figs. 6(a) and (b). H1 controls the current amplitude around the perturbation patch at 5.5 GHz, hence, the ARBW in the upper band is sensitive to the variation of H1. For the best ZBW and ARBW, H1 is selected as 7 mm.

The following studied parameter is the height of left ground plane LH. S_{11} and AR curves corresponding to LH values are shown in Figs. 6(c) and (d). In the analysis of circular polarization mechanism, we can see that the current at the edge of left ground plays an important role to achieve

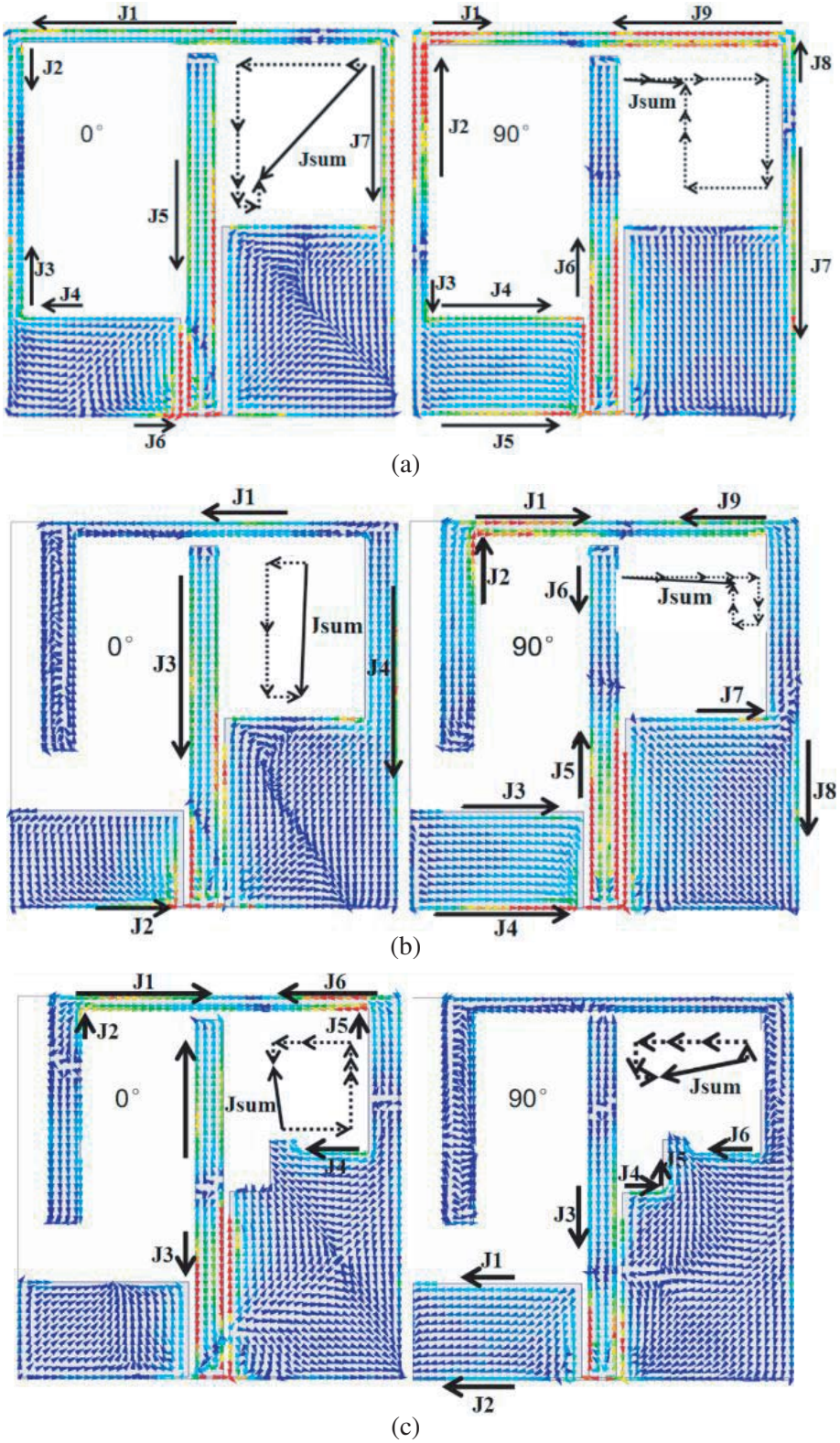


Figure 5. Analysis of surface current distribution: (a) current distribution of Ant. 2 at 3.2 GHz, (b) current distribution of Ant. 3 at 3.2 GHz, (c) current distribution of proposed antenna at 5.5 GHz.

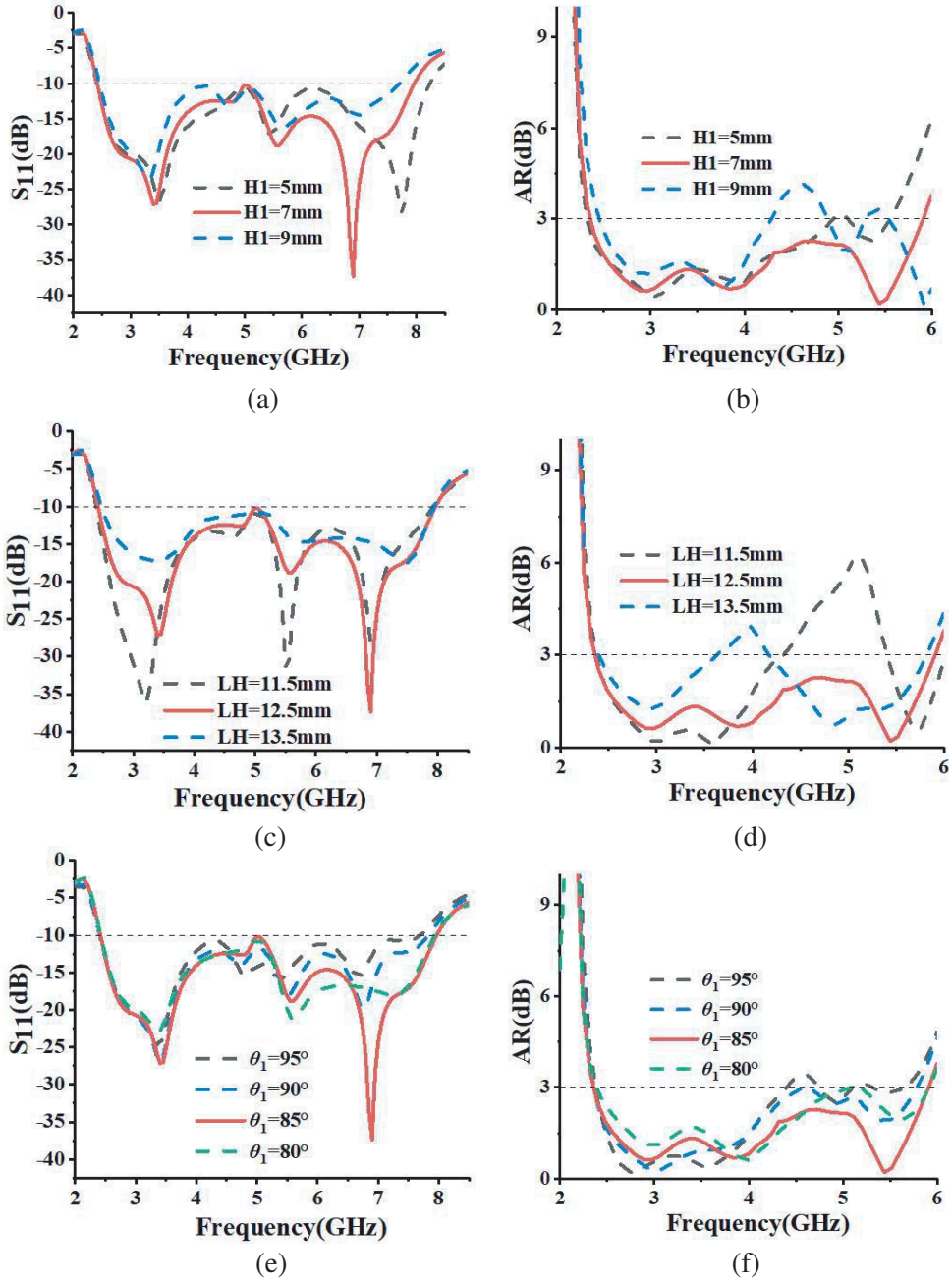


Figure 6. Simulated results with different parameters: (a) H1_S_{11}, (b) H1_AR, (c) LH_S_{11}, (d) LH_AR, (e) θ1_S_{11}, (f) θ1_AR.

all of the CP modes. However, the variation of LH leads to the change of current intensity. With the increase of LH, the curve fluctuates violently in the entire ARBW, but the ZBW changes slightly. Finally, choose LH as 12.5 mm for getting the widest ARBW.

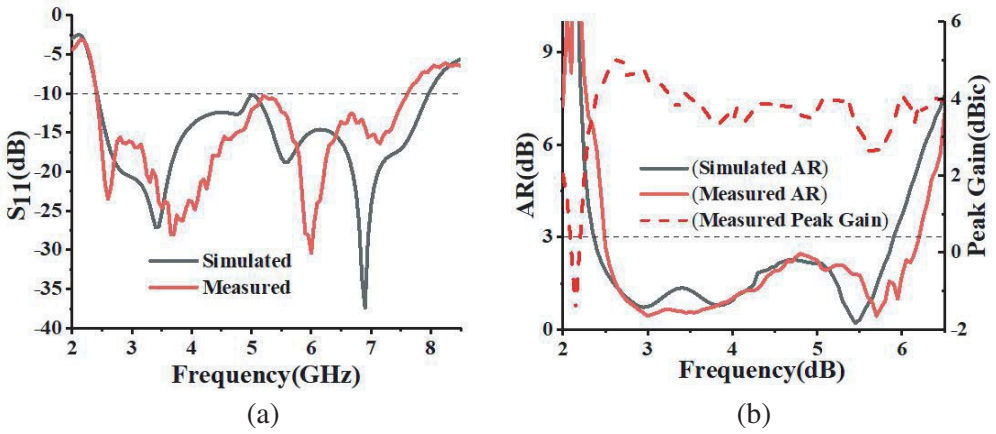
Figures 6(e) and (f) illustrate the effect of different θ1 values on the S_{11} and AR curves, respectively. Both ARBW and ZBW are easily affected by θ1 at upper band. When θ1 decreases, the distance between the inclined part of the feedline and perturbation patch gradually decreases, and the coupling effect is enhanced, thereby optimizing the impedance matching at high frequency. Meanwhile, the direction of the current at the upper-part feedline changes, which impacts the entire ARBW. θ1 is chosen as 85° to achieve the best impedance and AR performance.

4. EXPERIMENTAL VERIFICATION

To verify simulated results, the proposed antenna with optimized parameters has been fabricated, as shown in Fig. 1(b). The optimized dimensions are listed in Table 1. Fig. 7(a) illustrates the comparison of measured and simulated S_{11}. The fabricated antenna covers a ZBW of 103.5% (2.40–7.55 GHz), which is slightly narrower than the simulated result (2.39–7.96 GHz) due to the degradation of upper-band impedance performance. Fig. 7(b) illustrates that the measured ARBW is 86.0% (2.47–6.2 GHz), which is in good agreement with the simulated result. The peak gain of average 4 dBic is also demonstrated in Fig. 7(b). The radiation patterns of the optimized antenna at 2.5 GHz, 3.6 GHz, and 5.8 GHz in xz-plane and yz-plane are shown in Fig. 8. We can see that the proposed antenna radiates RHCP waves in the $+z$ direction with a reasonable agreement between measured and simulated results. Although there are discrepancies that can be mostly attributed to the SubMiniature version A (SMA) connector and fabrication tolerances between the measured and simulated results, these changes are still acceptable.

Table 1. Dimensions of the proposed antenna (mm).

Parameters	Value	Parameters	Value
W	50	$W4$	4
WF	3.6	$W5$	1.5
$W1$	13	$W6$	4
$H1$	7	LH	24
$W2$	3	$d1$	3
$H2$	2	$d2$	6
$W3$	9	G	0.9
$L1$	23	LH	12.5
$L2$	13.5	RH	24.5
$L3$	14.5	$O1$	85°
$O2$	100°		



(a) (b)

Figure 7. Measured and simulated characteristics of proposed antenna: (a) S_{11}, (b) AR and measured Peak Gain.

Table 2 illustrates the comparisons of the proposed antenna and several referred antennas, which means that the proposed antenna has the widest ARBW with a wide ZBW and simple structure.

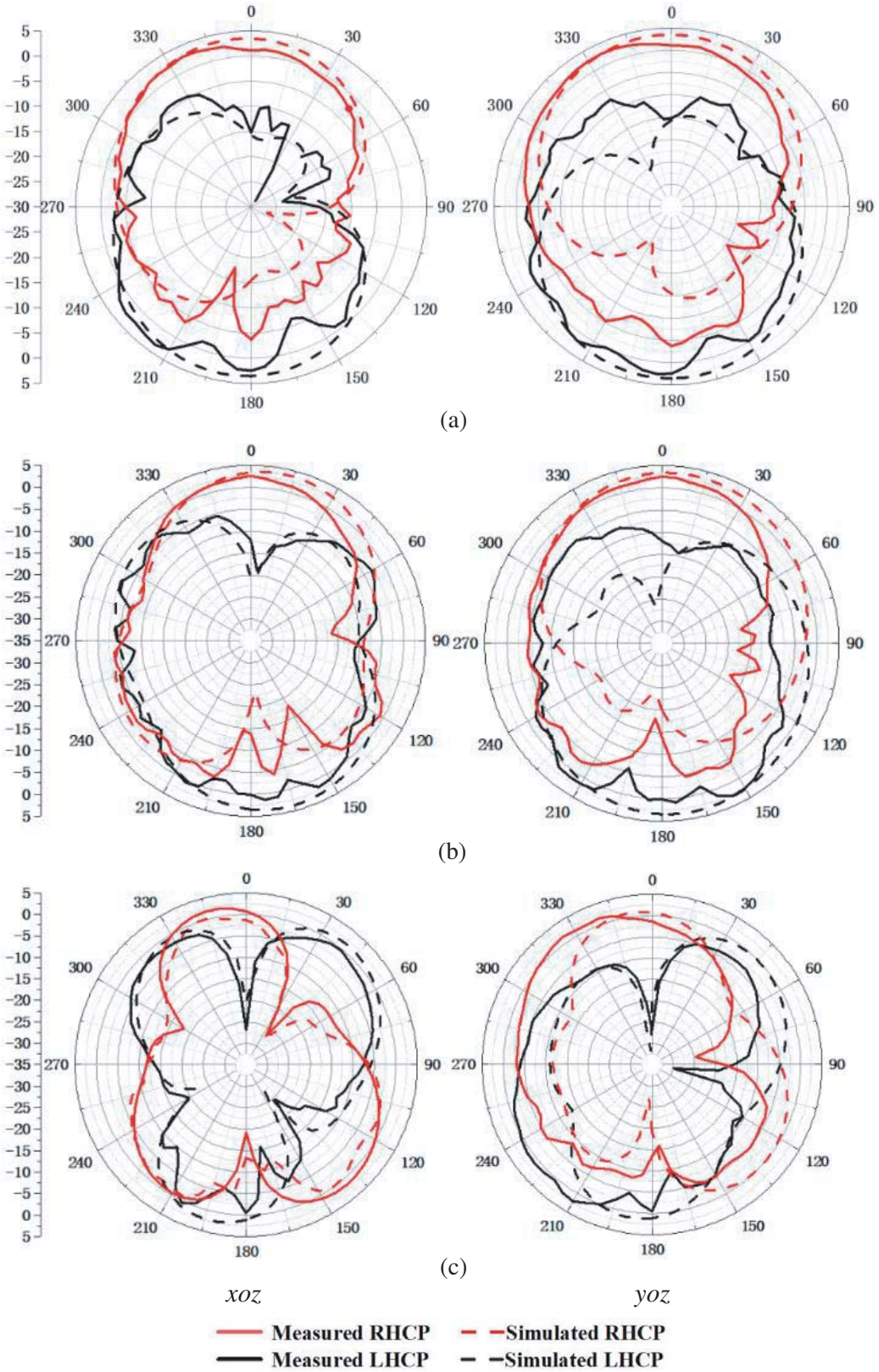


Figure 8. Simulated and measured radiation patterns: (a) 2.5 GHz, (b) 3.6 GHz and (c) 5.8 GHz.

Table 2. Comparison of broadband CP antennas.

Ref.	Size (mm^3)	-10 dB IBW	3 dB ARBW
[11]	$25 \times 24.7 \times 0.813$	42.6%	42%
[12]	$28 \times 28 \times 1.4$	60.1%	54.5%
[13]	$38.8 \times 38.8 \times 0.8$	87.8%	96%
[17]	$45 \times 45 \times 1.575$	100.5%	61.5%
[18]	$37.6 \times 33.5 \times 0.813$	82%	80%
[19]	$60 \times 60 \times 1.6$	76%	67%
Proposed	$50 \times 50 \times 0.8$	103.5%	86.0%

5. CONCLUSION

A broadband CP slot antenna is proposed and fabricated in this article. With an asymmetrical ground plane, an open slot on the left of the wide slot, and perturbation patch embedded in the wide slot, finally, the proposed antenna achieves broadband ZBW and ARBW. The proposed antenna has been measured. Experimental results show that the ARBW of 86.0% and the ZBW of 103.5% are obtained. The antenna is particularly suitable for WLAN (2.4–2.484 GHz, 5.15–5.35 GHz, 5.725–5.825 GHz) and WiMAX (2.5–2.69 GHz, 3.4–3.69 GHz, 5.25–5.85 GHz) applications.

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REFERENCES

1. Sze, J. and C. Chang, "Circularly polarized square slot antenna with a pair of inverted-L grounded strips," *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, 149–151, 2008.
2. Ghobadi, A. and M. Dehmollaian, "A printed circularly polarized Y-shaped monopole antenna," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 22–25, 2012.
3. Deng, I.-C., Q.-X. Ke, R.-J. Lin, and Y.-T. King, "A circular CPW-fed slot antenna resonated by the circular loop for broadband circularly polarized radiation," *Microwave and Optical Technology Letters*, Vol. 50, No. 5, 1423–1426, 2008.
4. Deng, I.-C., J.-B. Chen, Q.-X. Ke, J.-R. Chang, W.-F. Chang, and Y.-T. King, "A circular CPW-fed slot antenna for broadband circularly polarized radiation," *Microwave and Optical Technology Letters*, Vol. 49, No. 11, 2728–2733, 2007.
5. Cao, R. and S. Yu, "Wideband compact CPW-fed circularly polarized antenna for universal UHF RFID reader," *IEEE Transactions on Antennas and Propagation*, Vol. 63, No. 9, 4148–4151, Sept. 2015.
6. Majidzadeh, M., J. Nourinia, and Ch. Ghobadi, "Compact CPW-fed antenna with circular polarization characteristics in WLAN frequency band," *ACES Journal*, Vol. 28, No. 10, Oct. 2013.
7. Jan, J., C. Pan, K. Chiu, and H. Chen, "Broadband CPW-fed circularly-polarized slot antenna with an open slot," *IEEE Transactions on Antennas and Propagation*, Vol. 61, No. 3, 1418–1422, Mar. 2013.
8. Zhou, S., P. Li, Y. Wang, W. Feng, and Z. Liu, "A CPW-fed broadband circularly polarized regular-hexagonal slot antenna with L-shape monopole," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 1182–1185, 2011.

9. Li, G., H. Zhai, T. Li, L. Li, and C. Liang, "CPW-fed S-shaped slot antenna for broadband circular polarization," *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, 619–622, 2013.
10. Ojaroudi, M., N. Ojaroudi, and N. Ghadimi, "Enhanced bandwidth small square slot antenna with circular polarization characteristics for WLAN/WIMAX and C-bnad applications," *ACES Journal*, Vol. 28, No. 2, 156–161, 2013.
11. Ullah, U. and S. Koziel, "Design and optimization of a novel miniaturized low-profile circularly polarized wide-slot antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 32, No. 16, 2099–2109, 2018.
12. Rasool, N., K. Huang, A. B. Muhammad, and Y. Liu, "A wideband circularly polarized slot antenna with antipodal strips for WLAN and C-band applications," *Int. J. RF Microw. Comput. Aided Eng.*, Vol. 29, e21945, 2019.
13. Liu, W.-W., Z.-H. Cao, and Z. Wang, "New broadband circularly polarized antenna with an inverted F-shaped feedline," *Int. J. RF Microw. Comput. Aided Eng.*, Vol. 30, e22313, 2020.
14. Sze, J., C. G. Hsu, Z. Chen, and C. Chang, "Broadband CPW-fed circularly polarized square slot antenna with lightening-shaped feedline and inverted-L grounded strips," *IEEE Transactions on Antennas and Propagation*, Vol. 58, No. 3, 973–977, Mar. 2010.
15. Li, G., H. Zhai, L. Li, and C. Liang, "A nesting-L slot antenna with enhanced circularly polarized bandwidth and radiation," *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, 225–228, 2014.
16. Mousazedeh, A., M. Naser-Moghaddasi, F. Geran, S. Mohammadi, and P. Zibadoost, "Broadband CPW-fed circularly polarized square slot antenna with arc-shaped and inverted-L grounded strips," *ACES Journal*, Vol. 28, No. 4, 314–320, 2013.
17. Arshad, S., F. A. Tahir, A. Rashid, M. M. S. Missen, and J. A. Flint, "Co-planar-waveguide fed circularly polarized antenna for wireless WLAN/LTE applications," *Electromagnetics*, Vol. 40, No. 5, 354–363, Jul. 3, 2020.
18. Ullah, U., S. Koziel, and I. B. Mabrouk, "A simple-topology compact broadband circularly polarized antenna with unidirectional radiation pattern," *IEEE Antennas and Wireless Propagation Letters*, Vol. 18, No. 12, 2612–2616, Dec. 2019.
19. Jiang, L., C. Lu, W. Cao, and L. Sun, "A broadband CPW-fed dual circularly polarized slot antenna with modified L-shaped monopoles," *IEICE Electronics Express*, Vol. 15, No. 16, art. No. 20180645, 2018.
20. Xu, R., J. Li, J. Yang, K. Wei, and Y. Qi, "A design of U-shaped slot antenna with broadband dual circularly polarized radiation," *IEEE Transactions on Antennas and Propagation*, Vol. 65, No. 6, 3217–3220, Jun. 2017
21. Liu, H., Y. Liu, and S. Gong, "Broadband microstrip-CPW fed circularly polarised slot antenna with inverted configuration for L-band applications," *IET Microwaves, Antennas and Propagation*, Vol. 11, No. 6, 880–885, 2017.