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Dual-Band Dual-Sense Circularly Polarized Slot Antenna with an Open-Slot and a Vertical Stub

Bo Chen* and Fu-Shun Zhang

Abstract—A new dual-band dual-sense circularly polarized (CP) slot antenna is designed in this paper. The proposed antenna is composed of a rectangle patch and a modified ground plane. By opening a U-shaped open-slot and loading a vertical stub to the ground plane, a dual-sense CP performance is achieved for two frequency bands. A bevel is cut on the patch to improve the impedance matching. The antenna is fabricated on a low-cost FR4 substrate and fed by a coplanar waveguide (CPW) structure. The antenna has been investigated numerically, and a prototype was experimentally measured. Experimental results show that the measured 10-dB return loss impedance bandwidths are 18.3% (2.72–3.27 GHz) for the lower band and 23.7% (4.65–5.90 GHz) for the upper band, and the measured 3-dB axial ratio (AR) bandwidths for the lower and upper bands can be up to 28.4% (2.48–3.30 GHz) and 26.3% (4.63–6.03 GHz), respectively.

1. INTRODUCTION

In the past few years, the CP antennas have aroused wide attention in current wireless communication systems, such as radar and navigational systems, because the CP antenna can receive the incident waves of any polarization, and its radiating CP wave can be easily received by antenna of any polarization except for its orthogonal polarization wave [1]. Recently, many investigations have been carried out on CP antennas to obtain broadband, multiband operation or omnidirectional radiation performance [2–5]. In some cases, polarization diversity is needed for antennas in order to fulfill the demands of some communication systems. [6, 7] introduce the technique to switch the far-field polarization by implementing shorting pin diodes on the antenna structures. However, these antennas can hardly radiate dual-sense CP waves at the same time. To overcome this difficulty, some compact antennas were designed to achieve dual-band dual-sense CP performance [8–10]. In [8], a single-feed microstrip antenna can obtain dual-band dual-sense CP performance by notching two spiral slots on the ground plane. In [9], a dual-band CPW-fed slot antenna with a C-shaped grounded strip is proposed for dual-sense CP radiation. In [10], another CPW-fed slot antenna can result in different senses of CP radiation in two bands by loading a T-shaped strip and two spiral slots in the ground plane.

In this paper, a CPW-fed slot antenna with a U-shaped open-slot and a vertical grounded stub is designed for the dual-band dual-sense CP radiation. The measured results show that the antenna can achieve good AR bandwidth and impedance matching in both RHCP and LHCP operations. Compared to the antennas in [8–10], the proposed antenna possesses a wider available 3-dB AR bandwidth and a simpler structure. The proposed antenna can be applied to radar, indoor wireless communication and navigational systems.

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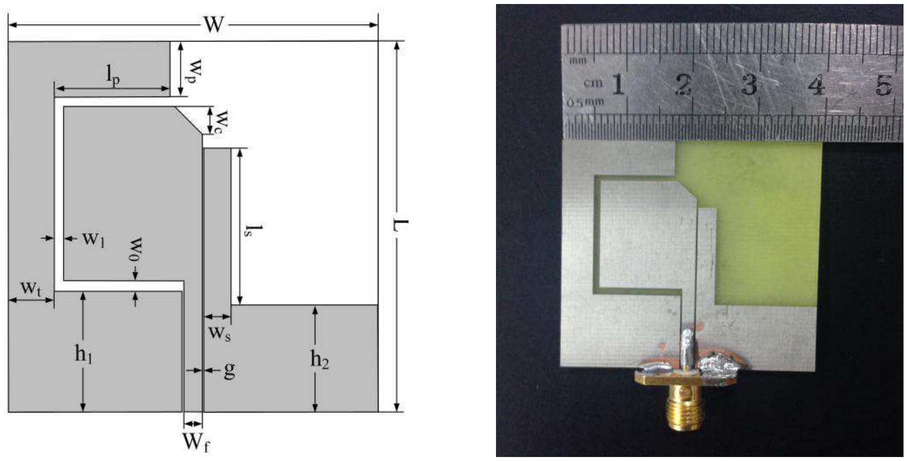


(a) (b)

Figure 1. (a) Geometry of the proposed antenna; (b) Photograph of the prototype.

2. ANTENNA DESIGN

The geometry configuration and photograph of the dual-band dual-sense CP antenna are shown in Figure 1. The antenna is etched on an inexpensive FR-4 substrate with a dielectric constant of $\varepsilon_r = 4.4$, a loss tangent of 0.02 and the thickness of $h = 1$ mm. The overall size of the proposed antenna is $40 \times 40 \times 1\,\text{mm}^3$. The antenna is fed by a 50-Ohm CPW with a strip width of $W_f = 2$ mm and gaps width of $g = 0.2$ mm between the strip and the ground plane. A U-shaped open-slot is cut between the rectangle patch and the left-hand ground plane. The U-shaped open-slot generates a current path for the lower band. The resonant frequency of the lower band is controlled by the length of the U-shaped slot. Meanwhile, this slot configuration can generate the CP operation by exciting two orthogonal modes with equal amplitude but in phase quadrature. A vertical stub is added on the right-hand ground plane close to the rectangle patch. The stub is to break the surface current distributions balanced on the ground plane for CP radiation. This technique can widen the AR bandwidth of the upper band evidently according to [11]. In addition to the impedance matching, there are two resonant modes in the upper band. The lower mode in the upper band is generated by the coupling between the stub and patch. The higher mode is generated by both the U-shaped slot and the vertical stub. The AR characteristic of the upper band can be greatly enhanced by simultaneously optimizing the dimensions of the slot and stub. The final dimensions of the proposed antenna are listed in Table 1. A 50-Ohm SMA connector is used to excite it.

Table 1. Detailed dimensions of the proposed antenna (unit: mm).

W	L	W_f	g	h_1	h_2	l_s
40	40	2	0.2	13	11.5	17
w_s	w_0	w_1	w_t	l_p	w_p	w_c
2.9	1.2	1	5	12.5	6	3

The proposed dual-band dual-sense CP slot antenna is simulated by software Ansoft HFSS ver. 14. To strengthen our understanding of the design rules and working principles, we thoroughly study some key parameters of the proposed antenna. When one parameter is studied, the others are kept constant. The parameter l_p, the length of the end of left-hand ground plane, plays a vital role in the antenna performance for the lower band. l_p is related to the length of U-shaped slot which controls the lower resonant frequency. The current distributions around the slot may generate CP radiation. By properly adjusting l_p, good impedance matching and CP performance can be obtained in the lower band. The simulated return loss and AR are depicted in Figure 2 for different values of l_p. It is shown that the lower and upper bands' center frequencies shift down when increasing l_p, and at the same time, the 3-dB AR bandwidth of the upper band decreases. The vertical stub mainly influence the antenna performance in the upper band due to its coupling with the patch. So we take the dimensions of the stub, l_s and w_s, as key parameters. Figure 3 shows return loss and AR versus frequency with different values of the vertical stub length l_s. By tuning the value of l_s, the antenna can achieve a wide 10-dB return loss bandwidth in the upper band. As l_s increases, the characteristic of AR in the upper band turn worse. Figure 4 displays the influence of the vertical stub width w_s on the impedance matching and the 3-dB AR bandwidth. The best AR characteristic can be achieved in the two bands by properly adjusting the vertical stub width. Comparing with parameters l_p and l_s, parameter w_s has a less effect on the return loss characteristic in both bands.

In order to further study the dual-sense operation property of the proposed antenna, surface current distributions of the whole antenna at the frequencies of 3.0 GHz and 4.8 GHz are given in Figure 5. Note that the current distributions are viewed from the $+z$-direction. It can be clearly seen that the surface current distributions in 0° and 90° are equal in magnitude and opposite in phase with those in 180° and

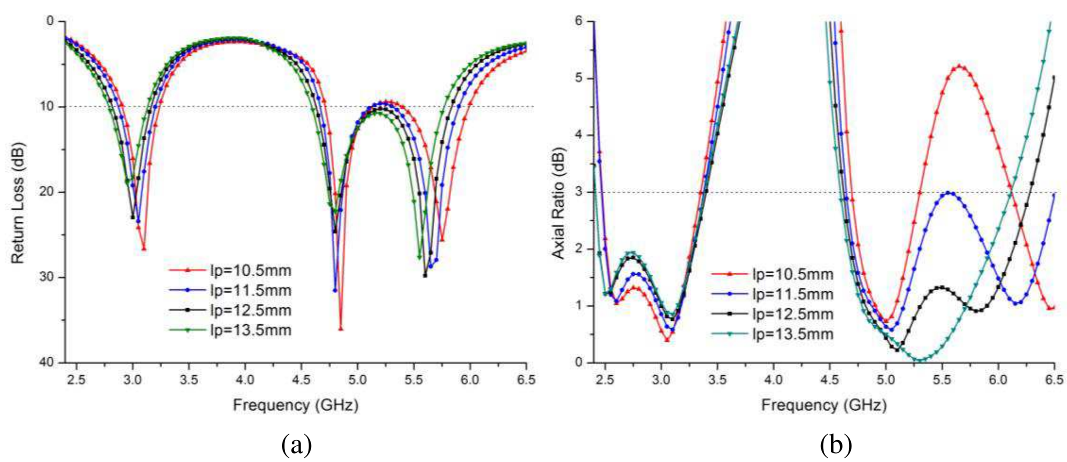


Figure 2. Simulated return loss and AR versus frequency for different values of l_p. (a) Return loss, (b) AR in the $+z$ direction.

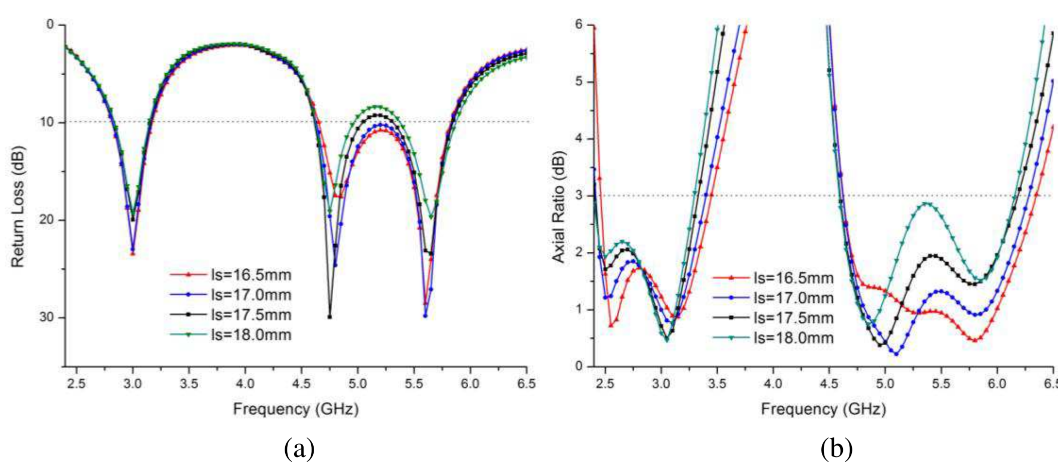
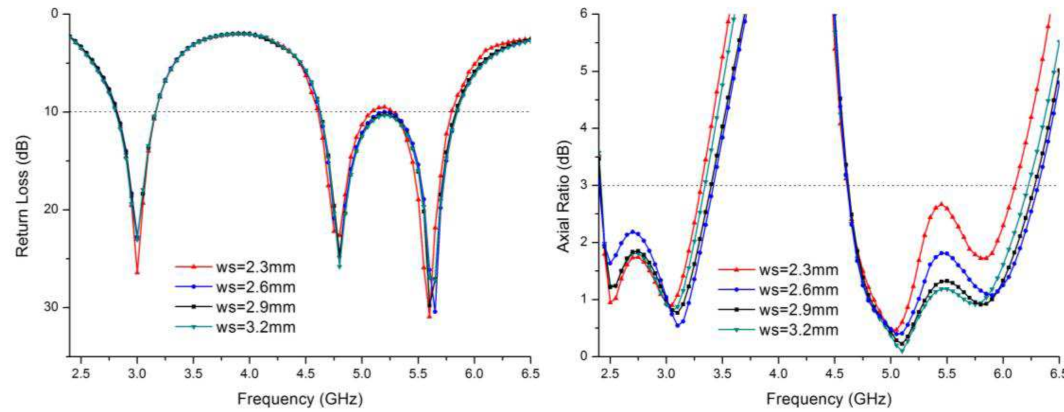
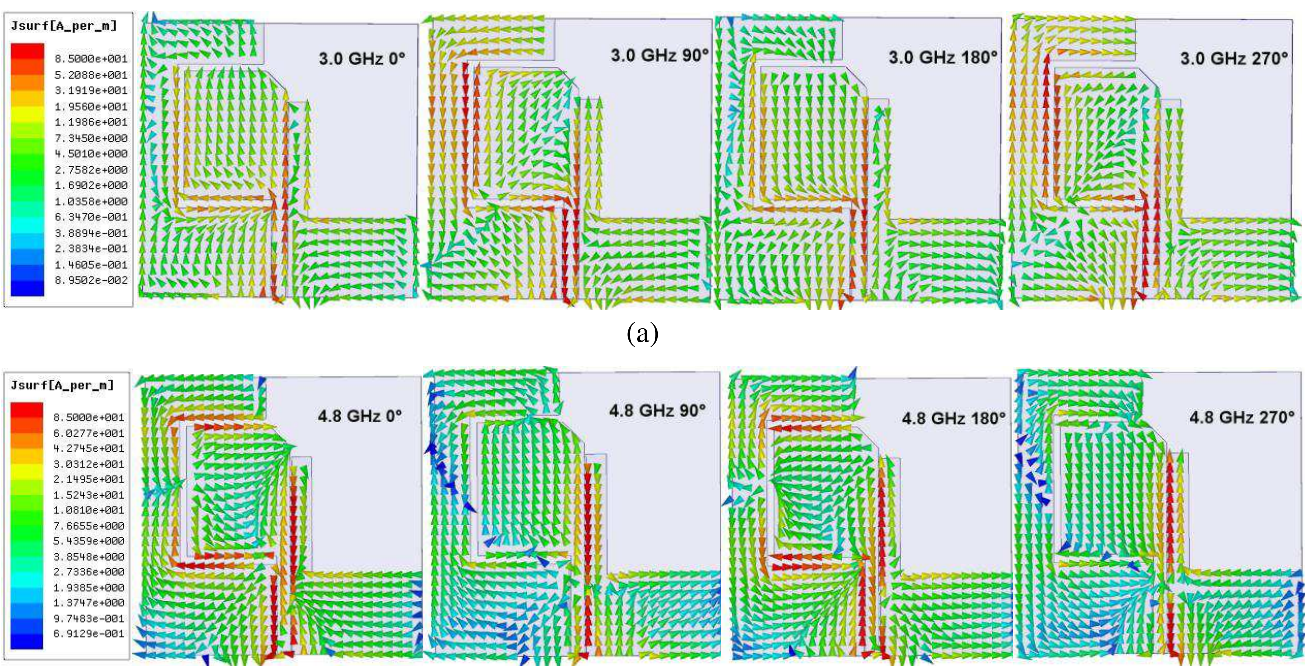


Figure 3. Simulated return loss and AR versus frequency for different values of l_s. (a) Return loss, (b) AR in the $+z$ direction.



(a) (b)

Figure 4. Simulated return loss and AR versus frequency for different values of w_s. (a) Return loss, (b) AR in the $+z$ direction.



(a)

(b)

Figure 5. Surface current distributions of the proposed antenna in 0°, 90°, 180° and 270° phase. (a) 3.0 GHz, (b) 4.8 GHz.

270° at 3.0 GHz and 4.8 GHz, which satisfies the requirement of the spatial and temporal quadrature for CP. It also can be observed that the currents distributed around the U-shaped slot are stronger than other areas in the lower band, and the vertical stub can offer strong currents in the upper band. These strong currents act as the dominant current which relates to the kind of CP the antenna radiates. The different rotating orientation of the dominant current determines that the proposed antenna can radiate opposite-sense CP waves in the lower and upper bands, respectively.

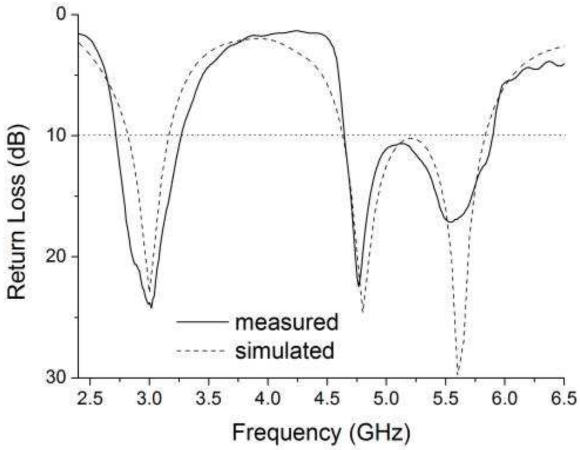


Figure 6. Simulated and measured return loss of the proposed antenna.

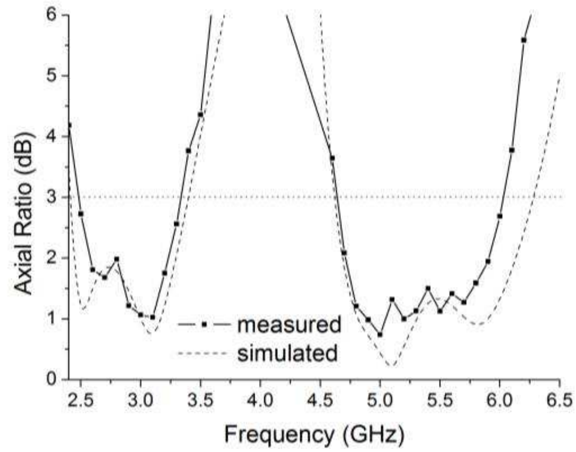


Figure 7. Simulated and measured axial ratio of the proposed antenna.

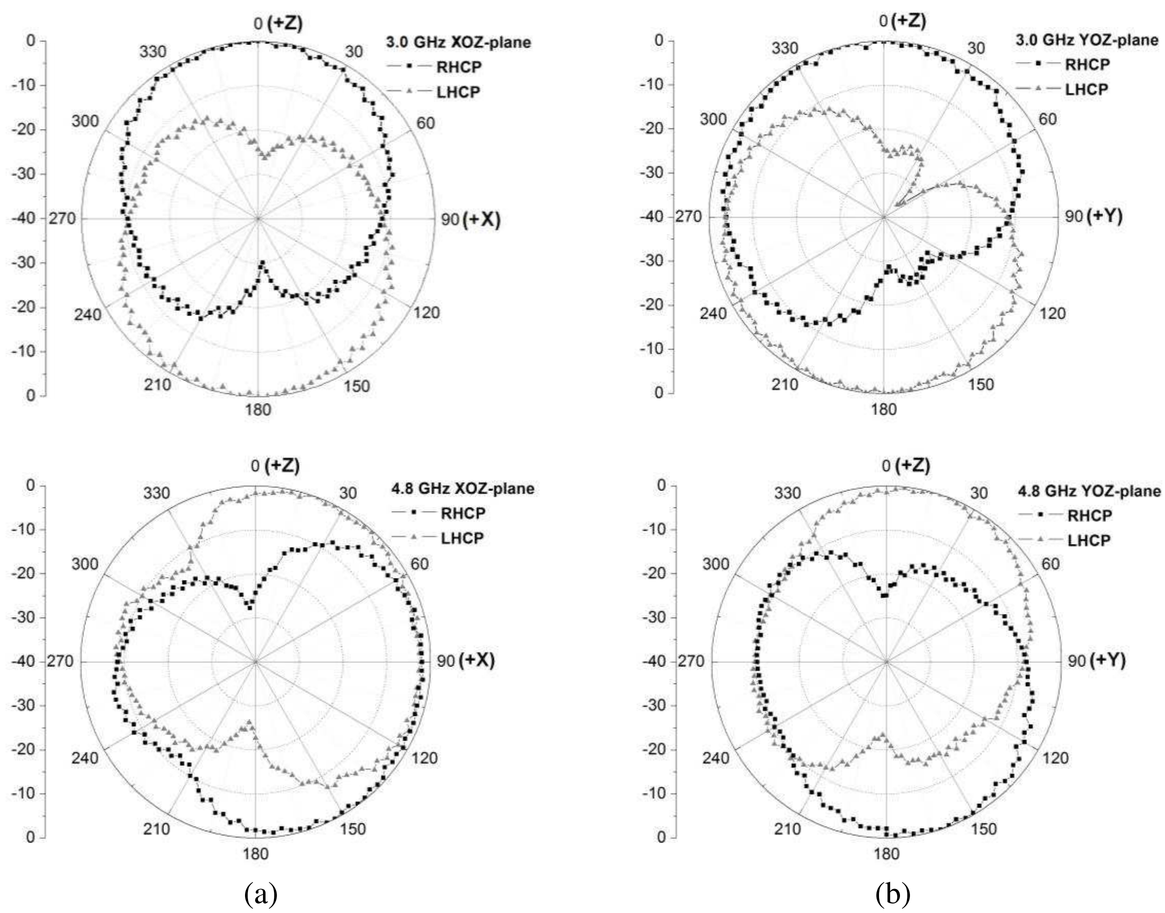


Figure 8. Measured radiation patterns of the proposed antenna at 3.0 GHz and 4.8 GHz. (a) XOZ-plane; (b) YOZ-plane.

3. ANTENNA PERFORMANCE

A prototype of the proposed antenna is fabricated and measured by a Wiltron 37269A vector network analyzer. Figure 6 shows simulated and measured return loss versus frequency of the proposed antenna. It can be observed that the measured 10-dB return loss bandwidths are 18.3% (2.72–3.27 GHz) for the lower band and 23.7% (4.65–5.90 GHz) for the upper band. Figure 7 plots the measured and simulated AR curves for the proposed antenna. The measured 3-dB AR bandwidths can reach 28.4% (2.48–3.30 GHz) for the lower band (RHCP) and 26.3% (4.63–6.03 GHz) for the upper band (LHCP), respectively. The measured 3-dB AR bandwidths can completely cover the 10-dB return loss bandwidths. Reasonable agreement between the simulated and measured results is obtained.

Figure 8 shows the measured far-field radiation patterns of the prototype in XOZ-plane and YOZ-plane at 3.0 GHz and 4.8 GHz. It can be seen that in the boresight direction, the proposed antenna is able to radiate RHCP and LHCP waves, and cross-polarizations are 24.0 dB and 25.0 dB lower than co-polarizations for 3.0 GHz and 4.8 GHz, respectively. The RHCP radiation pattern at 3.0 GHz is symmetrical for the XOZ-plane with a 3 dB beamwidth of 78° and offset by 30° for the YOZ-plane with a beamwidth of 120°. For 4.8 GHz, the LHCP pattern is almost symmetrical with a beamwidth of 66° for the YOZ-plane and offset by 60° with beamwidth of 135° for the XOZ-plane. Figure 9 illustrates the gain of the antenna versus frequency. The peak gains of the lower band and upper band are 3.0 and 1.4 dBic. As can be seen in Figure 8, the 3 dB AR beamwidth narrows down in the upper band, and the cross-polarization takes more energy than that in the lower band. So the peak gains become negative in the upper band.

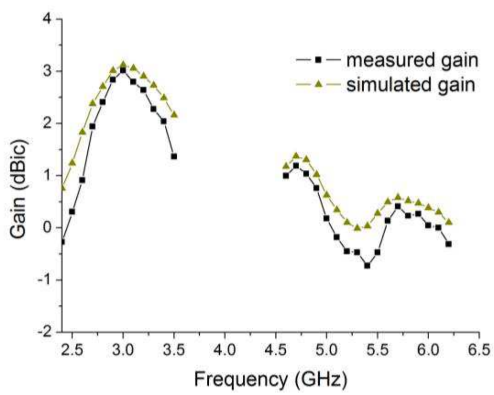


Figure 9. The simulated and measured peak gain versus frequency.

4. CONCLUSION

A new dual-band dual-sense CPW-fed CP slot antenna has been designed. By using a U-shaped open-slot and a vertical stub, dual-sense circular polarization can be achieved. The proposed antenna can achieve RHCP and LHCP performance for the lower and upper frequency bands, respectively. The obtained results show that the measured 10-dB return loss bandwidth can reach as high as 18.3% (2.72–3.27 GHz) for the lower band and 23.7% (4.65–5.90 GHz) for the upper band in which the measured ARs are lower than 3 dB. The proposed antenna with a simple structure and good dual-sense CP performance is suitable for the modern wireless communication systems.

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