Progress In Electromagnetics Research Letters, Vol. 46, 31–36, 2014

Dual-band CPW-Fed Circularly Polarized Slot Antenna with Improved Ground Plane Structure

Bo Chen* and Fushun Zhang

Abstract—In this letter, a new design of dual-band circularly polarized (CP) slot antenna is proposed. By embedding a vertical stub, a T-shaped strip and a slit to the ground plane, the CPW-fed slot antenna can radiate right-handed circularly polarized (RHCP) wave in two bands 3.0 GHz and 5.0 GHz. The designed antenna with a size of $33 \times 27 \times 1\,\mathrm{mm}^3$ is fed by a 50-Ohm SMA connector and fabricated on a low-cost FR-4 substrate. Experimental results show that the measured 10-dB return loss impedance bandwidths are 20.4% for the lower band and 23% for the upper band, and the measured 3-dB axial-ratio (AR) bandwidths are 14.1% and 15.8%, with respect to 3 GHz and 5 GHz, respectively.

1. INTRODUCTION

In the past few years, CP antennas have been widely utilized in wireless communication systems since they are more resistant to bad weather conditions and less sensitive to the orientation of the corresponding mobile device [1]. Recently, as the need of dual-band antenna is increasing, various designs of printed antennas have been presented to achieve dual-band CP operation [2–7]. In [2], a microstrip antenna with an S-shaped slot cut in the patch can achieve dual-band CP radiation. In [4], a monopole antenna with dual-band circular polarization is proposed, which is composed of a ground plane embedded with an L-shaped slit and a rectangular patch. In [7], a hexagonal-shaped slot antenna using microstrip feed with L-shaped stub is proposed to achieve dual-band CP performance. However, these designs have narrow AR bandwidths or impedance bandwidths which are lower than 10%. To overcome this difficulty, coplanar waveguide (CPW) structure has been more and more popular with antenna designers since this kind of feeding structure can widen impedance bandwidth evidently. In a recent study, a symmetric-aperture antenna using CPW feed is proposed, whose 10-dB return loss impedance bandwidth and 3-dB AR bandwidth can reach as large as 107% and 68%, respectively [8]. Also, several dual-band CP antennas fed by CPW structure have been reported recently [9–11].

In order to achieve dual-band CP performance, a new design of CPW-fed slot antenna with a T-shaped strip, a vertical stub and a slit embedded in the ground plane is proposed and experimentally investigated in this paper. Compared to [9–11], the proposed antenna has a simpler structure and a improved dual-band CP characteristic. The achieved 3-dB AR bandwidths are 14.1% (from 2.64 GHz to 3.24 GHz) for the lower band and 15.8% (from 4.56 GHz to 5.34 GHz) for the upper band. The details of the antenna design are given in the next section, and the simulated and experiment results will be discussed to demonstrate the performance of the proposed antenna.

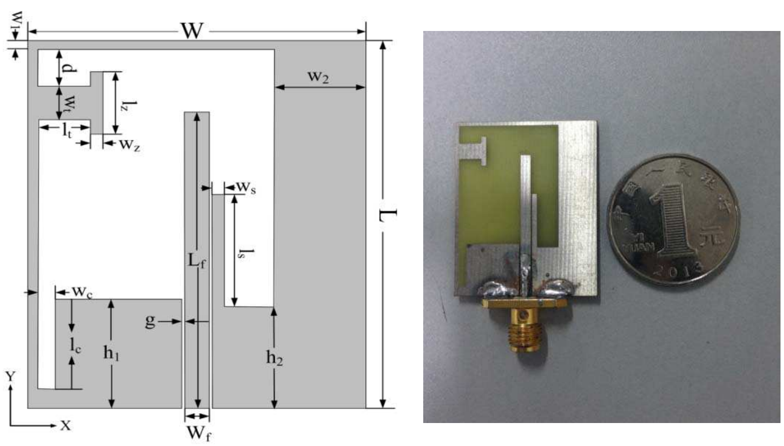
2. ANTENNA DESIGN

The geometry of the proposed dual-band CP antenna and a photograph of the manufactured antenna are shown in Figure 1. The ground plane is modified by loading a vertical stub, a T-shaped strip and

Received 6 April 2014, Accepted 2 May 2014, Scheduled 5 May 2014

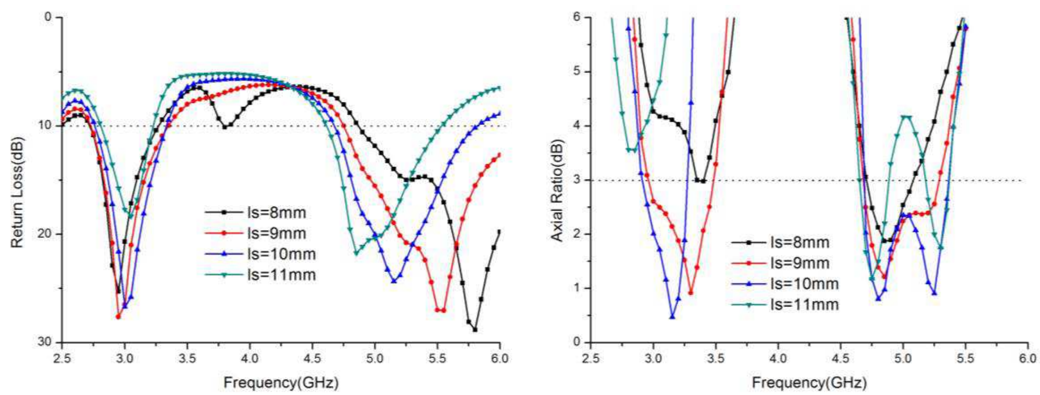
* Corresponding author: Bo Chen (cb199021@126.com).

The authors are with the National Laboratory of Science and Technology on Antennas and Microwaves, Xidian University, Xi'an, Shaanxi 710071, China.



(a) (b)

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



(a) (b)

Figure 2. Simulated return loss and AR with different vertical stub length (l_s). (a) Return loss. (b) AR in the $+z$ direction.

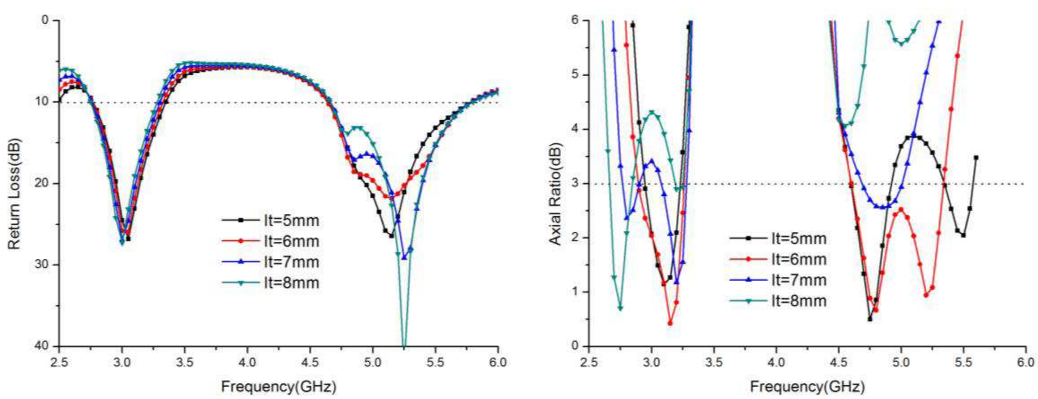
Table 1. Detailed dimensions of the proposed antenna (unit: mm).

W	L	W_f	g	L_f	h_1	h_2	w_s	l_s
27	33	2	0.2	23.6	9.8	9	1	10
w_c	l_c	w_t	l_t	w_z	l_z	d	w_1	w_2
8	8.2	3	4.2	1	5.6	3.3	0.8	7.3

a slit in order to obtain a dual-band CP performance. The stub added on the ground plane is to break the surface current distributions balanced on the ground for CP radiation. This technique has been introduced in [12]. The T-shaped strip loaded in the top left corner can offer a current path for the lower band, resulting in dual-band operation. By tuning the length of the stub and the shape of the strip, two orthogonal electrical fields with an equal magnitude and 90° phase difference are generated in two bands. The slit cutting in the bottom left corner is used for making the CP center frequency coincide with the impedance center frequency. Besides, the ground plane is designed to be an asymmetrical structure which helps to achieve good impedance matching. FR4 is used as a substrate with the relative permittivity $\varepsilon_r = 4.4$ and thickness $h = 1$ mm. The final dimensions of the proposed antenna are listed in Table 1. The 50-Ohm CPW feed-line is excited with a SMA-KFD connector.

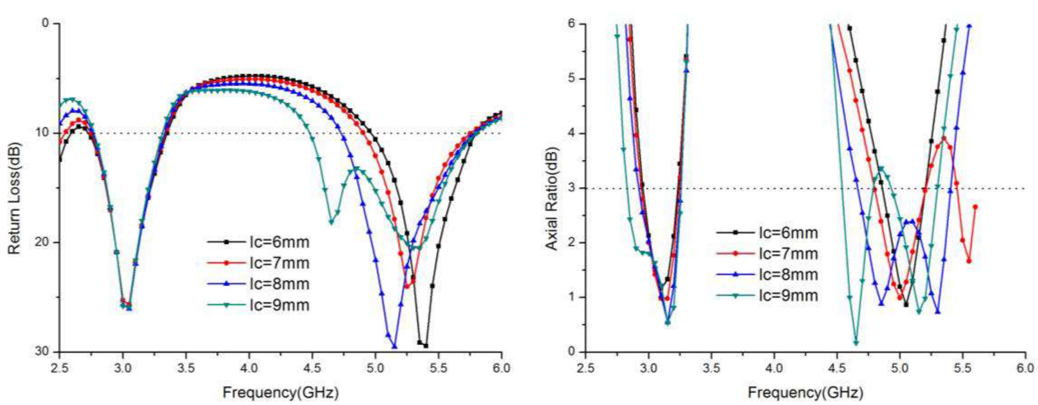
To strengthen our understanding of the working principles and design rules, we thoroughly studied the key parameters of the proposed antenna using Ansoft HFSS, a commercially available software. Through out the studies presents in this section. All other parameters that have not been mentioned are fixed to the values shown in Table 1. The simulated return loss and AR are shown in Figure 2 for different values of the length of the vertical stub, l_s. As l_s increases, the upper band's center frequency shifts down quickly, while that of the lower band moves up slowly. l_s has a great effect on AR of the two bands. When l_s deviates from its optimized value, the AR performance of two bands becomes worse. Figure 3 shows the effects of the T-shaped strip length (l_t) on the return losses and ARs of two bands. It can be seen that l_t can significantly affect the impedance matching in the upper band, while it has little influence on the $|S_{11}|$ of the lower band. By tuning l_t, both of two bands can achieve good AR characteristic. The effect of the slit cut in the ground plane is also studied. As can be observed from Figure 4, l_c mainly influences the performance of the upper band. When the length of the slit $l_c = 6$ mm, the center frequency of the $|S_{11}|$ is beyond the center frequency of the AR in the upper band. By increasing l_c, the coincidence between return loss and AR can be obtained in the upper band.

In order to perceive why the CP can be generated by the proposed antenna, we simulate the time-varying surface current distributions. The simulation results of surface current distributions at 3 GHz and 5 GHz are shown in Figure 5. The current distributions in the figure are viewed from the $+z$-direction. It can be observed that the surface current distributions in 0° and 90° are equal in magnitude and opposite in phase of 180° and 270°, which satisfies the requirement of the spatial and temporal quadrature for CP [13]. Also, it can be seen that the currents distributed around the T-shaped strip



(a) (b)

Figure 3. Simulated return loss and AR with different T-shaped strip length (l_t). (a) Return loss. (b) AR in the $+z$ direction.



(a) (b)

Figure 4. Simulated return loss and AR with different slit length (l_c). (a) Return loss. (b) AR in the $+z$ direction.

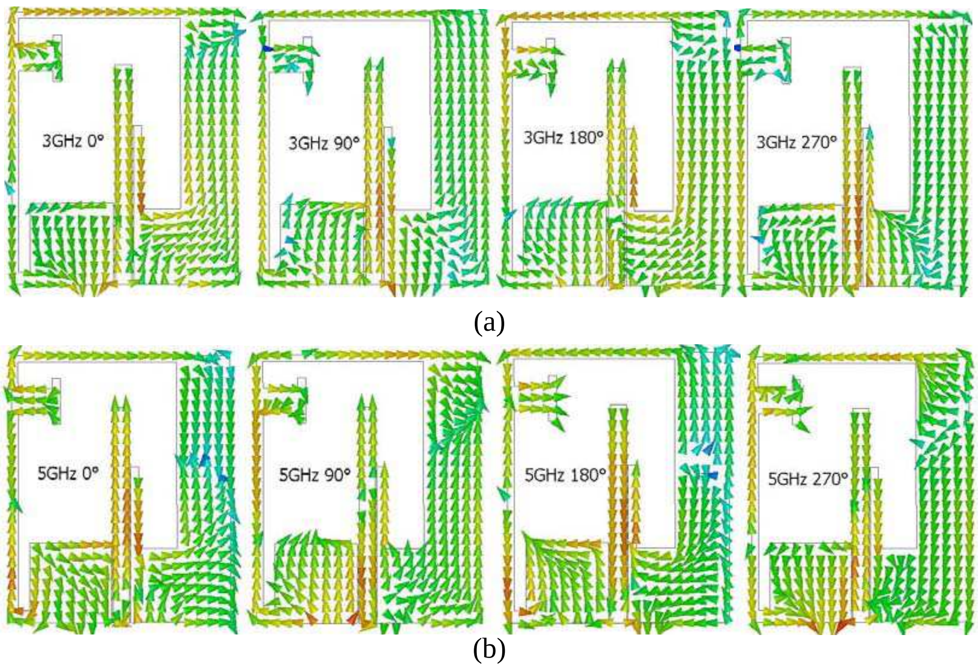


Figure 5. Surface current distributions of the proposed antenna in 0°, 90°, 180° and 270° phase. (a) 3 GHz. (b) 5 GHz.

and the vertical stub are stronger than other areas at 3 GHz, and the area around the slit can also offer strong current at 5 GHz. These strong currents play the role of the dominant current. If the dominant current rotates in the anti-clockwise direction, the antenna can radiate the RHCP wave in the $+z$-direction.

3. ANTENNA PERFORMANCE

The proposed antenna has been fabricated and measured. Figure 6 shows the measured return loss. It can be observed that the measured impedance bandwidths are 20.4% (from 2.64 GHz to 3.24 GHz) for 3 GHz-band and 23% (from 4.54 GHz to 5.72 GHz) for 5 GHz-band. Figure 7 shows that the measured AR bandwidths are 14.1% (from 2.76 GHz to 3.18 GHz) for 3 GHz-band, and 15.8% (from 4.56 GHz to 5.34 GHz) for 5 GHz-band. Reasonable agreement is achieved between measurement and simulation. The discrepancy between the simulated and measured results is mainly due to the tolerances in the manufacturing progress and the dielectric constant.

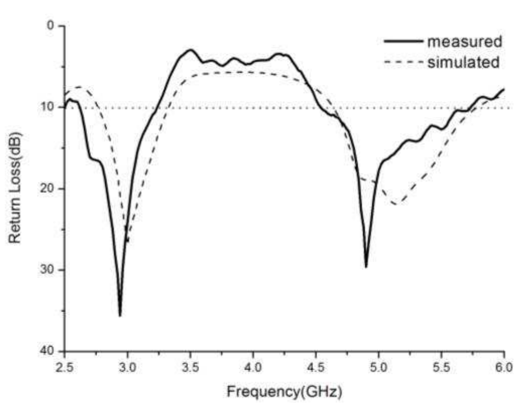


Figure 6. Simulated and measured return loss of the proposed antenna.

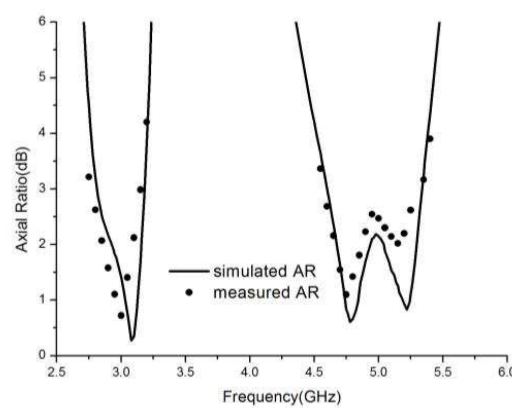


Figure 7. Simulated and measured axial ratio of the proposed antenna.

The measured radiation patterns for RHCP and LHCP in XOZ-plane and YOZ-plane at 3 GHz and 5 GHz are presented in Figure 8. It shows that the antenna can generate RHCP wave in the $+z$-direction and LHCP wave in the $-z$-direction in both two bands. In the boresight direction, cross-polarization is 20 dB lower than the co-polarization. As can be seen from Figure 9, the peak gain is 3.5 dBic in the lower band and 3.2 dBic in the upper band.

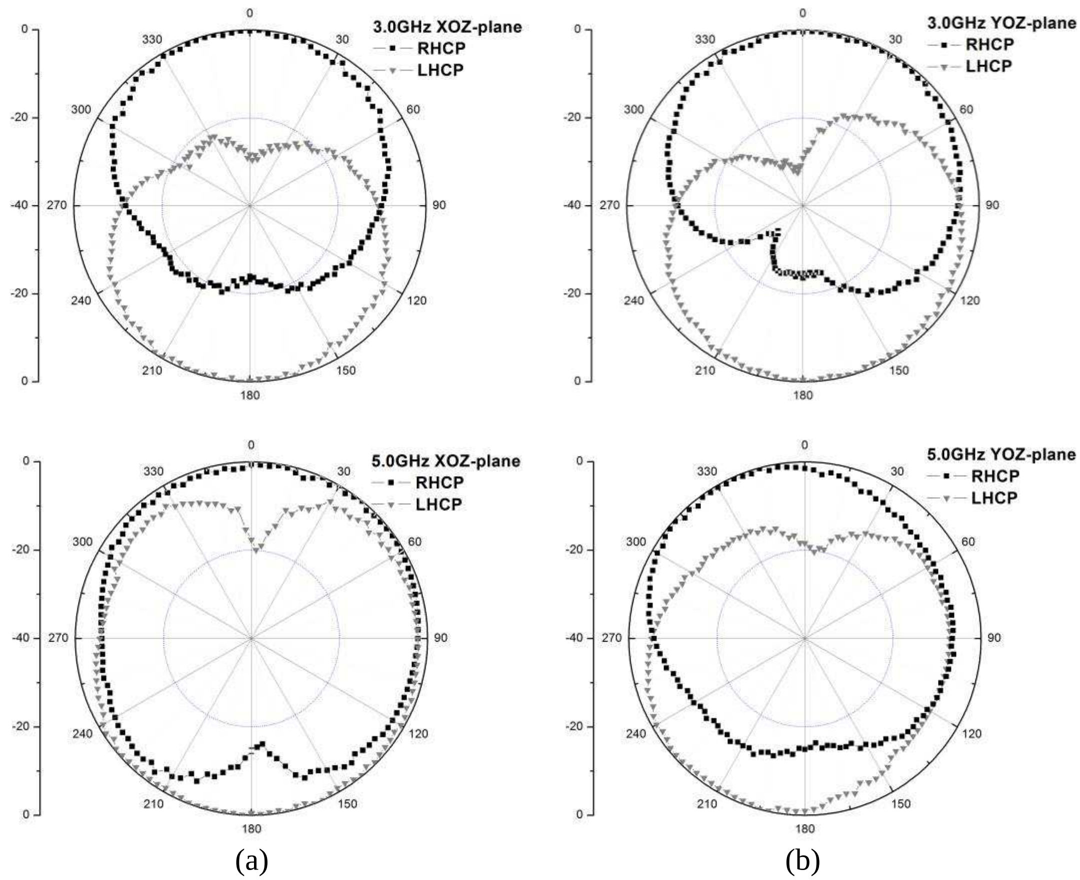


Figure 8. Measured radiation patterns of the proposed antenna at 3 GHz and 5 GHz. (a) XOZ-plane. (b) YOZ-plane.

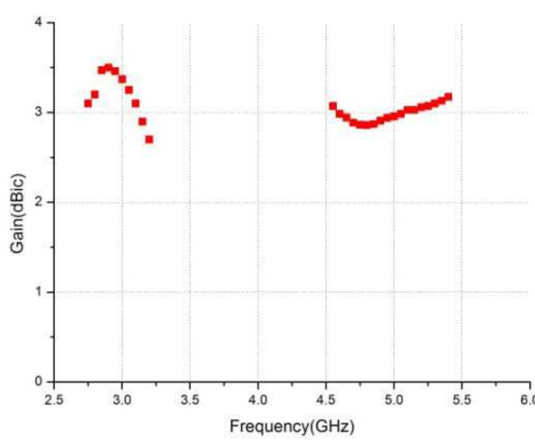


Figure 9. The measured peak gain versus frequency.

4. CONCLUSION

A novel dual-band CP slot antenna has been designed, fabricated and measured. By introducing a T-shaped strip, a vertical stub and a slit in the ground plane, dual-band circular polarization can be achieved. The measured impedance and axial ratio bandwidths are 20.4%, 14.1% for the lower band and 23%, 15.8% for the upper band. The antenna can obtain good circularly polarized characteristics.

REFERENCES

1. Mousavi, P., B. Miners, and O. Basir, "Wideband L-shaped circular polarized monopole slot antenna," *IEEE Antennas Wireless Propag. Lett.*, Vol. 9, 822–825, 2010.
2. Nasimuddin, Z. N. Chen, and X. Qing, "Dual-band circularly polarized-shaped slotted patch antenna with a small frequency-ratio," *IEEE Trans. on Antennas and Propag.*, Vol. 58, No. 6, 2112–2115, Jun. 2010.
3. Liao, W. and Q.-X. Chu, "Dual-band circularly polarized microstrip antenna with small frequency ratio," *Progress In Electromagnetics Research*, Vol. 15, 145–152, 2010.
4. Jou, C. F., J.-W. Wu, and C.-J. Wang, "Novel broadband monopole antennas with dual-band circular polarization," *IEEE Trans. on Antennas and Propag.*, Vol. 57, No. 4, 1027–1034, Apr. 2009.
5. Bao, X. and M. J. Ammann, "Dual-frequency dual-sense circularly-polarized slot antenna fed by microstrip line," *IEEE Trans. on Antennas and Propag.*, Vol. 56, No. 3, 645–649, Mar. 2010.
6. Hsieh, G.-B., M.-H. Chen, and K.-L. Wong, "Single-feed dual-band circularly polarised microstrip antenna," *Electron. Lett.*, Vol. 34, No. 12, 1170–1171, Jun. 1998.
7. Jeevanandham, N., Nasimuddin, K. Agarwal, and A. Alphones, "Dual-band circularly polarized hexagonal-slot antenna," *European Microwave Conference (EuMC 2012)*, 508–511, Amsterdam RAI, The Netherlands, Oct. 29–Nov. 2, 2012.
8. Nasimuddin, Z. N. Chen, and X. Qing, "Symmetric-aperture antenna for broadband circular polarization," *IEEE Trans. on Antennas and Propag.*, Vol. 59, No. 10, 3932–3936, Oct. 2011.
9. Li, W.-M., B. Liu, and H.-W. Zhao, "The U-shaped structure in dual-band circularly polarized slot antenna design," *IEEE Antennas Wireless Propag. Lett.*, Vol. 13, 447–450, 2014.
10. Chen, J.-S., "Dual-frequency annular-ring slot antennas fed by CPW feed and microstrip line feed," *IEEE Trans. on Antennas and Propag.*, Vol. 53, No. 1, 569–571, Jan. 2010.
11. Chen, C. and E. K. N. Yung, "Dual-band dual-sense circularly-polarized CPW-fed slot antenna with two spiral slots loaded," *IEEE Trans. on Antennas and Propag.*, Vol. 57, No. 6, 1829–1833, Jun. 2009.
12. Zhang, L., Y.-C. Jiao, Y. Ding, B. Chen, and Z.-B. Weng, "CPW-fed broadband circularly polarized planar monopole antenna with improved ground-plane structure," *IEEE Trans. on Antennas and Propag.*, Vol. 61, No. 9, 4824–4828, Sep. 2013.
13. Stutzman, W. L., *Polarization in Electromagnetic Systems*, Artech House, Norwood, MA, 1993.