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A Printed Circularly Polarized Loop Antenna with Beam Parallel with Its Plane

Ya-Li Yao*, Fu-Shun Zhang, and Fan Zhang

Abstract—A printed loop antenna with a circularly polarized beam parallel with its plane is proposed. The proposed quadrangle loop antenna is fed with microstrip line at one of its corners. The microstrip line part and loop part provide vertical polarization and horizontal polarization, respectively. The proposed antenna is simple in structure and can be easily integrated with other microwave components on the same substrate. Simulated results show that the proposed antenna has a wide impedance bandwidth ($|S_{11}| < -10\,\mathrm{dB}$) and wide 3-dB AR bandwidth ranging from 8.0 to 10.5 GHz (27%). A prototype of the proposed antenna is fabricated and tested. The measured and simulated results have good agreement.

1. INTRODUCTION

Due to the features of circular polarization, circularly polarized (CP) antennas have several important advantages compared to antennas using linear polarizations [1]. CP antenna is very effective in combating multi-path interferences or fading [1]. The second advantage is that CP antenna is able to reduce the 'Faraday rotation' effect due to the ionosphere [1]. Another advantage of using CP antennas is that no strict orientation between transmitting and receiving antennas is required [1]. Therefore, CP antennas are very useful for various wireless systems. As a result, the research on CP antennas has always been a hot issue in recent decades.

Loop antenna is one of the most basic antenna structures and has been studied for a long time. Loop antenna is popular due to its simplicity for fabrication, low cost and multifunction. A loop antenna can be in the form of square, triangle, ellipse, circle, and many other configurations [2]. However, these loop antennas usually radiate linearly polarized (LP) beams [3–5].

To take full advantage of both circular polarization and loop antenna, many CP loop antennas have been proposed in recent years. There are three kinds of CP loop antenna structures. First, circular polarization can be generated by impedance loading on a one-wavelength loop antenna [6, 7]. Because when the loop antenna is loaded with an impedance, its various characteristics, such as current distribution and input impedance, can be improved. Generation of circular polarization is possible if current distribution on the loop has a constant amplitude and progressive phase [6]. Second, a loop antenna fed by a single source can radiate an axial beam of circular polarization when perturbation elements are added to the loop [8]. This is because a traveling wave type current distribution is generated by the added perturbation elements. Third, circular polarization can be obtained by introducing a gap at the loop antenna [9–12]. The characteristics of a CP loop antenna can be controlled by the position of the gap. However, each of these CP loop antennas mentioned above radiates a beam vertical to its own plane.

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* Corresponding author: Ya-Li Yao (yylxidian@163.com).
The authors are with the Science and Technology on Antenna and Microwave Laboratory, Xidian University, Xi'an, Shaanxi 710071, China.

This paper proposes a printed CP loop antenna with a beam parallel with its plane. Comparison between the published loop antennas mentioned above and this work is listed in Table 1. It is shown in Table 1 that most of the loop antennas proposed in previous works radiate LP/CP beams vertical to the planes. LP beam parallel with the plane is achieved in [4]. To the authors' knowledge, no CP loop antennas with a beam parallel with their planes are proposed in previous works. The proposed antenna is a quadrangle loop fed with microstrip line at one of its corners. The microstrip line part mainly provides the vertical polarization, and the horizontal polarization is generated by the loop part. Simulated results show that the proposed antenna radiates a beam in parallel with its plane. The proposed antenna achieves wide impedance bandwidth ($|S_{11}| < -10\,\text{dB}$) and wide 3-dB AR bandwidth, both of which can cover a frequency range from 8.0 to 10.5 GHz (27%). A prototype of the proposed antenna is fabricated and tested. Measured results agree well with simulated ones. The proposed antenna is simple in structure and can be easily integrated with other microwave components on the same substrate.

Table 1. Published loop antennas and this work.

Reference	Polarization	Beam vertical/ parallel to/ with the plane	Structure
[4]	LP	vertical/parallel	square loop CPW-fed
[5]	LP	vertical	square loop fed at one corner
[6]	CP	vertical	reactively loaded one-wavelength circular loop
[7]	CP	vertical	reactively loaded one-wavelength circular loop
[8]	CP	vertical	square loop added with perturbation elements
[9]	CP	vertical	quadrangle loop with one point opened
[10]	CP	vertical	circular loop with one point opened
[11]	CP	vertical	probe-fed open circular loop with parasitic loop
[12]	CP	vertical	open circular loop with parasitic loop
This work	**CP**	**parallel**	microstrip-fed printed quadrangle loop

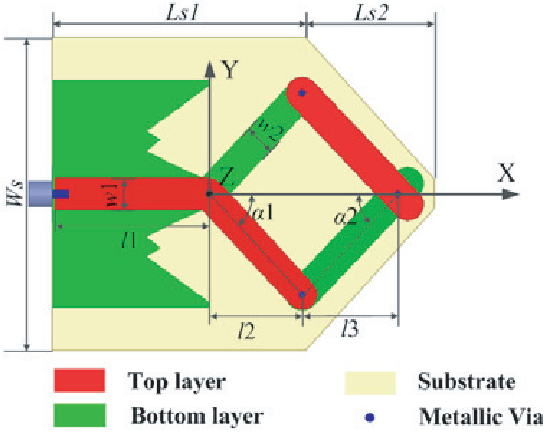


Figure 1. Geometry of the proposed antenna.

2. PRINCIPLE AND DESIGN

The geometry of the proposed antenna is shown in Fig. 1. It is shown that the printed quadrangle loop is formed by four printed strips connected by three metallic via holes. Two strips are printed on the top layer of the substrate, and the other two strips are printed on the bottom layer of the substrate. The printed quadrangle loop is fed by a microstrip line at one of its corners with a novel ground. An Arlon AD260A substrate with a thickness of 3 mm and dielectric permittivity of 2.6 is used as the substrate of the proposed antenna. As shown in Fig. 1, the length and width of the antenna are represented by $Ls1 + Ls2$ and W, respectively. The width of the microstrip line is denoted by $w1$. The printed quadrangle loop is symmetric with respect to X-axis from the $+Z$-axis view. The width $w2$ of each printed strip is uniform.

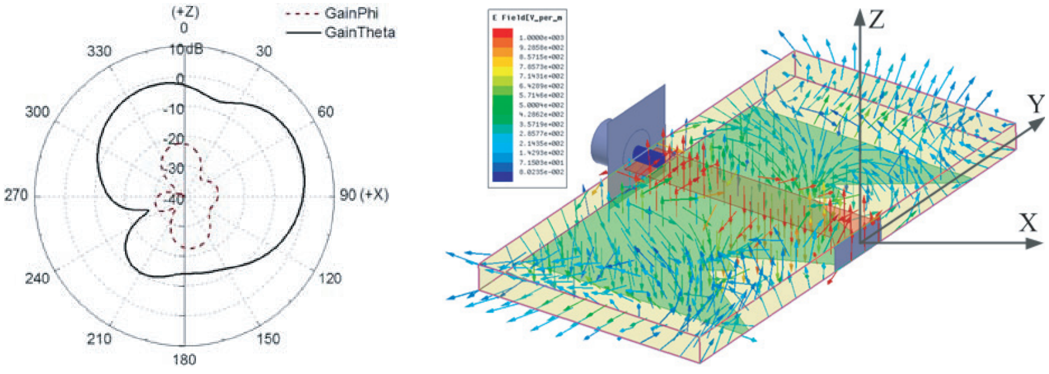
The microstrip line part provides vertical polarization, and the printed loop provides horizontal polarization. In addition, the $+Y$-axis ($\theta = 90°$, $\varphi = 90°$) is the maximum radiation direction of both the microstrip line and the printed loop. If the two orthogonal polarizations are equal in amplitude and have 90° difference in phase, the proposed antenna can radiate circularly polarized wave at the $+Y$-axis ($\theta = 90°$, $\varphi = 90°$).

To verify the fact that the microstrip line part provides vertical polarization and that the printed loop provides horizontal polarization, the microstrip line part and printed loop part are simulated and analyzed independently. With y-axis as the dividing line, the proposed antenna is cut apart to obtain the microstrip line part and printed loop part. All the simulations are conducted with the commercial software Ansys High Frequency Structure Simulator (HFSS). Values of the designed parameters are listed in Table 2.

Table 2. Optimized values of design parameters of the proposed antenna.

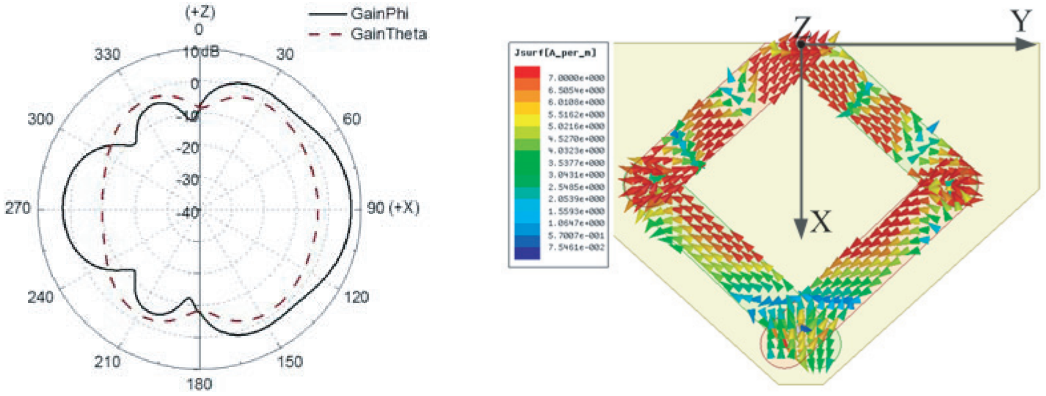
Name	W_s	L_{s1}	L_{s2}	w_1	w_2
Value	55 mm	44.4 mm	22.6 mm	5.5 mm	5.3 mm
Name	l_1	l_2	l_3	$\alpha1$	$\alpha2$
Value	27 mm	16.3 mm	16.7 mm	47.3°	46.6°

It has been studied that the microstrip transmission line can radiate vertical polarization component [13]. The simulated radiation pattern in X-Z plane of the microstrip line part at 9 GHz is presented in Fig. 2(a). It is shown that the co-polarization is the vertical polarization and that the main beam points at $+X$ direction. The shape of the ground is modified to improve the front-to-back ratio. The vertical polarization is shown as the electric field distribution of the microstrip line part at 9 GHz in Fig. 2(b).



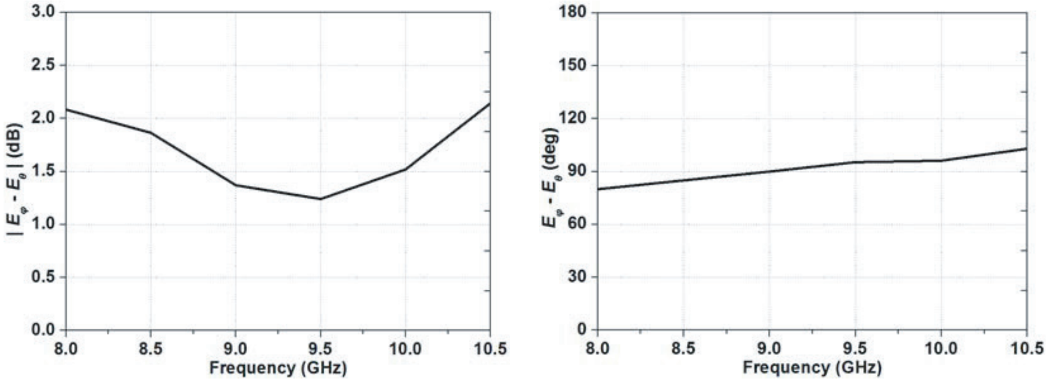
(a) (b)

Figure 2. Simulated radiation pattern and electric field distribution of the microstrip line part at 9 GHz. (a) Radiation pattern in X-Z plane. (b) Electric field distribution.



(a) (b)

Figure 3. Simulated radiation pattern and current distribution of the loop part at 9 GHz. (a) Radiation pattern in X-Z plane. (b) Current distribution.



(a) (b)

Figure 4. Amplitude difference and the phase difference between E_θ and E_φ: (a) amplitude difference, (b) phase difference.

The simulated radiation pattern in the X-Z plane of the loop part at 9 GHz is presented in Fig. 3(a). It is shown that the co-polarization is the horizontal polarization and that the main beam points at $+X$ direction. The horizontal polarization is shown as the current distribution of the loop part at 9 GHz in Fig. 3(b). The current distribution can be changed with the variation of the loop size, which results in different radiation patterns [14].

It is well known that in order to realize circular polarization, two orthogonal electric fields with equal amplitude and phase difference of 90° are required. In the proposed antenna, the microstrip line part mainly provides the vertical polarization (E_θ), and the horizontal polarization (E_φ) is generated by the loop part. Fig. 4 gives the amplitude difference and the phase difference between E_θ and E_φ. Spatial orthogonality is naturally guaranteed by E_θ and E_φ. In addition, it can be seen from Fig. 4 that E_θ and E_φ have an almost equal amplitude and a phase difference about 90° from 8 GHz to 10.5 GHz. As a result, circular polarization can be achieved by the proposed antenna.

The slits in the ground plane improve the current distribution and contribute to the 3-dB AR bandwidth improvement. Axial ratios of the proposed antenna with/without slits in the ground plane are illustrated in Fig. 5. As shown in Fig. 5, the AR of the proposed antenna at low frequency band is improved with slits in the ground plane. Then the 3-dB AR bandwidth of the proposed antenna is improved.

3. RESULTS

The proposed antenna is simulated, fabricated, and measured. The optimized values of design parameters of the proposed antenna are listed in Table 2. Photographs of the prototype of the proposed antenna are shown in Fig. 6.

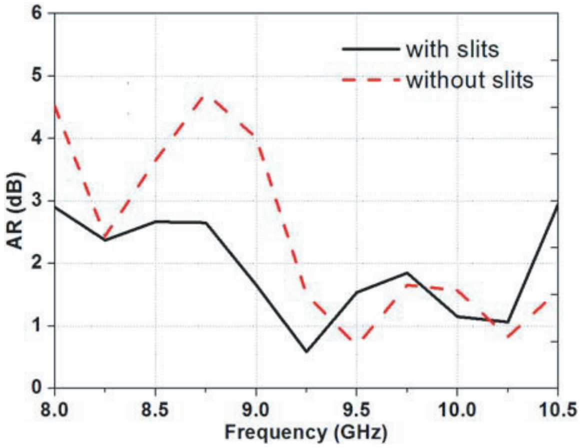
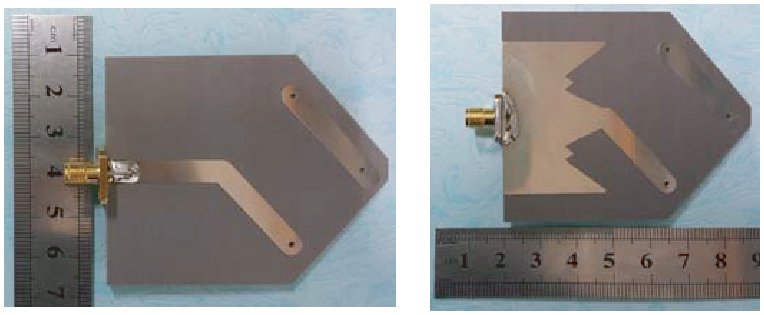
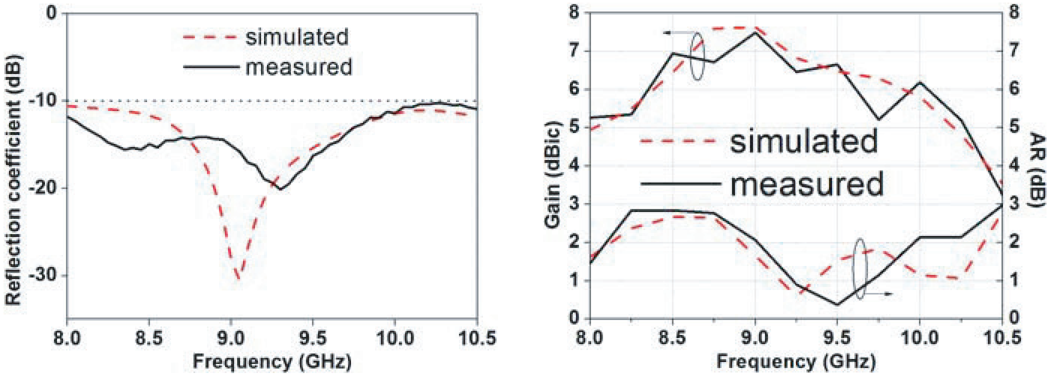


Figure 5. Axial ratios of the proposed antenna with/without slits in the ground plane.



(a) (b)

Figure 6. Photograph of the proposed antenna. (a) Top view. (b) Bottom view.



(a) (b)

Figure 7. Simulated and measured results of the proposed antenna: (a) reflection coefficient, (b) AR and RHCP gain at the $+x$-axis ($\theta = 90^\circ$, $\varphi = 0^\circ$).

Figure 7(a) gives the simulated and measured reflection coefficients of the proposed antenna. It can be observed that the measured and simulated results are in reasonable agreement, and the measured impedance bandwidth for reflection coefficient less than -10 dB is from 8.0 GHz to 10.5 GHz. The simulated and measured gains and ARs of the proposed antenna at the $+x$-axis ($\theta = 90°$, $\varphi = 0°$) are illustrated in Fig. 7(b). With reference to the figure, the measured 3-dB AR band covers 8.0 GHz to 10.5 GHz. It is observed that the RHCP gain of the proposed antenna over the frequency band from 8.0 GHz to 10.5 GHz is between 3 dBic and 8 dBic. And the measured gain agrees well with the simulated one.

The simulated and measured radiation patterns in X-Y plane and X-Z plane at 8 GHz, 9.25 GHz and 10.5 GHz are depicted in Fig. 8, Fig. 9 and Fig. 10, respectively. It is shown that proposed antenna can radiate end-fire RHCP wave parallel with its plane within the usable band. The measured radiation patterns agree well with the simulated ones.

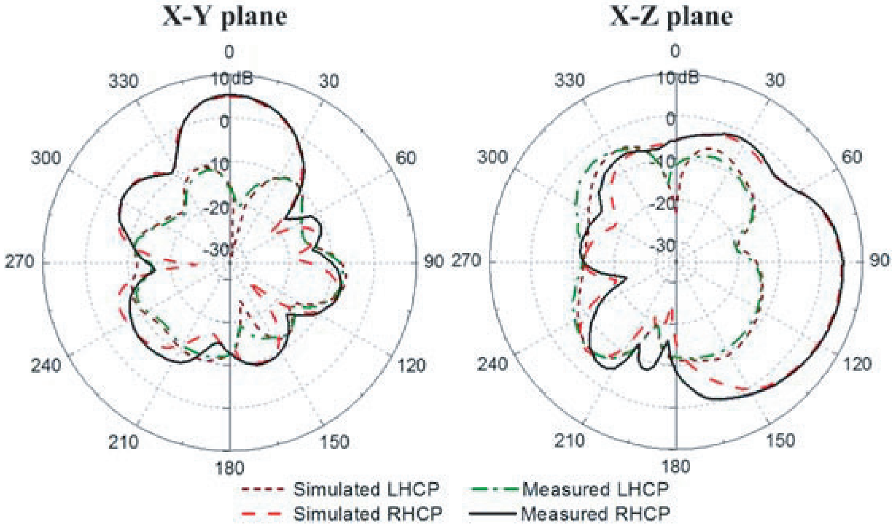


Figure 8. Simulated and measured radiation patterns of the proposed antenna at 8 GHz.

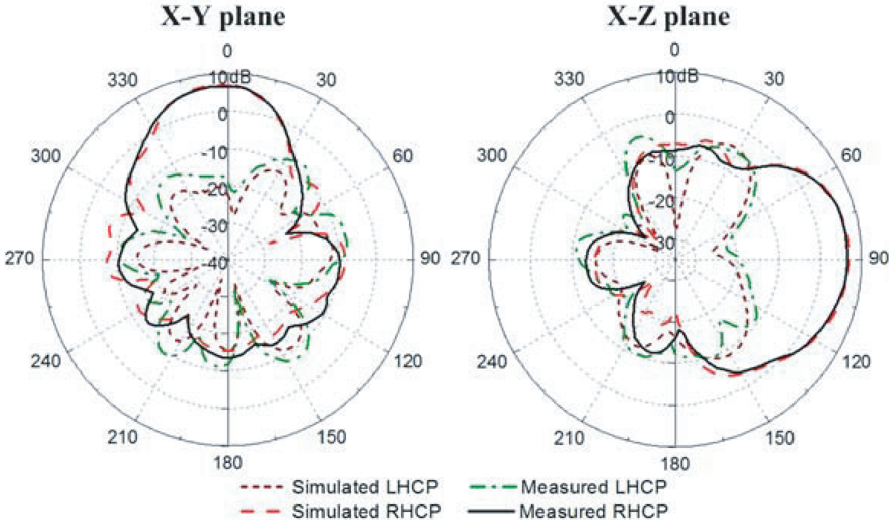


Figure 9. Simulated and measured radiation patterns of the proposed antenna at 9.25 GHz.

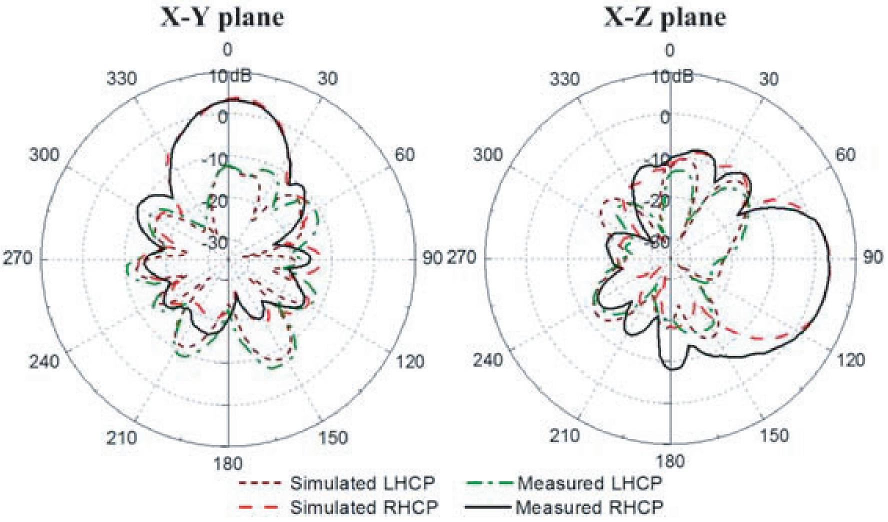


Figure 10. Simulated and measured radiation patterns of the proposed antenna at 10.5 GHz.

4. CONCLUSIONS

In this work, a microstrip-fed printed loop antenna with beam parallel with its plane is designed, fabricated and measured. The proposed antenna is the combination of a microstrip line and a loop on the same substrate. The microstrip line part mainly provides the vertical polarization, and the horizontal polarization is generated by the loop part. The simulated and measured results of the proposed antenna verify the theoretical analysis. Both 10-dB impedance band and 3-dB AR band are from 8.0 GHz to 10.5 GHz. And its CP gain varies from 3 dBic to 8 dBic within the whole operating band. The bandwidth of the proposed antenna may be further improved in the future research. One of the great advantages of the proposed antenna is the simple structure totally realized on a single-layer dielectric substrate with standard PCB process. The proposed antenna can be easily integrated with other microwave components on the same substrate and used for applications involving SICs that require circularly polarized signals radiating at the end-fire. It is very suitable to be mounted on the wings of the unmanned aerial vehicle and aircraft.

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