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Wideband Circularly-Polarized Antenna with Dual-Mode Operation

Xianling Liang, *Senior Member, IEEE*, Jie Ren, Lina Zhang, Chong He, Junping Geng, *Senior Member, IEEE,* Weiren Zhu, *Senior Member, IEEE,* Ronghong Jin, *Fellow, IEEE,*

***Abstract*—This paper presents a simple structure of a single-fed broadband circularly-polarized antenna. The antenna consists of four L-shaped strips that rotate in sequence and a double vacant-quarter ring. The double vacannt-quarter primarily contribute to the wide axial-ratio bandwidth, while the L-shaped strip primarily contributes to the wide axial-ratio beamwidth, with the two modes combined to achieve a wideband CP operation. A prototype antenna was designed, fabricated and measured. The measured results show that the proposed antenna yields a 10-dB impedance bandwidth of 92.8% (4.5-12.3 GHz), a 3-dB axial-ratio bandwidth of 67.5% (5.3-10.7 GHz), and a 3-dB gain bandwidth of 62.3% (5.3-10.1 GHz) with a peak gain of 12.4 dBic.**

***Index Terms*—Circularly-polarized, wideband, dual-mode.**

I. Introduction

Circularly-polarized (CP) antenna was widely used as a transmitter or receiver in many wireless networks and satellite communication systems for its unique characteristics, which can mitigate multipath interference and immune to Faraday rotation effect when waves transverse through the ionosphere. One of CP antenna design challenges is its wide CP bandwidth. The principle of a CP antenna is producing two orthogonal fields with equal amplitudes and 90° phase difference [1]. A wideband CP antenna design means to realize the orthogonal fields stable, including amplitude and phase. Thus, many techniques were proposed to design wideband CP antennas. *i.e.,* microstrip patch antennas [2], [3] and dielectric resonator antennas [4] were popularly selected as CP elements, but their CP bandwidths are limited by multi-mode operation, commonly less than 30%. Printed monopole antennas and wide-slot antennas exhibit their ultra-wideband performance but normally with the linear polarization (LP) radiation. To realize these antennas with the CP radiation, *i.e.,* T. Fujimoto *et al.* proposed a rectangular monopole antenna with the asymmetrical ground plane and feed structure, which achieves a 3-dB axial-ratio bandwidth of 56.2% and a 10-dB impedance bandwidth of 51.4% [5]. J.-S. Row *et al.* proposed a printed circular wide slot with a parasitic circular patch and the L-shaped feed. Two CP modes of slot and patch are combined to achieve a maximum 3-dB aixal-ratio bandwidth of 45% and a 10-dB impedance bandwidth of 45% [6]. Both antennas exhibit 3-dB aixal-ratio and impedance bandwidths of about 50%, but their bidirectional radiations result in low broadside gains. The magneto-electric dipole antenna is a classical CP antenna. It is a good axial-ratio due to perfect symmetry of radiation patterns in E-and H-planes. This type of CP antennas can operate in a wide bandwidth, 43.7% for a hanging feed [7] and 81.8% for dual hanging feed with a six-branch hybrid coupler [8], but they are not suitable for high-frequency applications due to manufacturing limitation.

Recently, crossed dipole antennas with a double vacant-quarter ring were proposed to realize a wideband CP operation, and their simple structures gathered much attention [9]–[14]. *i.e.,* in [9], a printed crossed strip dipole was proposed to obtain a 3-dB aixal-ratio bandwidth of 15.6%, and it is extended to 28.6% by using parasitic loop resonators [10]. Meantime, replacing the strip dipole in [9] with an asymmetric bowtie dipole [11] and a step rectangular dipole [14], the 3-dB axial-ratio bandwidths became 51.0% and 55.1%, respectively, and then reaches 58.6% for crossed bowtie dipoles with an parasitic element [12]. Moreover, L. Zhang *et al.* proposed the elliptical dipole instead of the strip dipole and a composite cavity, it finally achieves a 3-dB aixal-ratio bandwidth of 96.6% [15], but this antenna structure is not easy to process at high frequencies. In this letter, four L-shaped strips excited with a double vacant-quarter ring are used to obtain a 3-dB axial-ratio bandwidth of 67.5% in X-band. Different from above mentioned crossed dipoles, the L-shaped strip improves the antenna axial-ratio beamwidth and provides a nearly CP radiation itself at lower frequencies, which was ever used as a feed [6] or a radiator [16] for CP antenna designs.

II. Antenna Design and Parametric Study

The geometry of the proposed antenna is shown in Fig. 1, which composes of four sequentially rotated L-shaped strips, a double vacant-quarter ring, and a circular cavity. Four L-shaped strips and a pair of vacant-quarter ring are both etched on two sides of a laminate substrate (Rogers RT/duroid 5880 with a relative permittivity of ε_r = 2.2, a loss of $\tan\delta$ = 0.0009 and a thickness of h_s = 0.787 mm). The double vacant-quarter ring connects to a coaxial line with an SMP connector, where the inner and the outer conductors connect to the vacant-quarter ring on the top layer and the bottom layer, respectively.

The operational principle of the proposed wideband CP antenna comes from two parts, the double vacant-quarter ring and the L-shaped strip. At higher frequencies, the double

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Xianling Liang, Jie Ren, Chong He, Junping Geng, Weiren Zhu and Ronghong Jin are with the Department of Electronic Enginee, Shanghai Jiao Tong University, Shanghai 200240, China (e-mail: liangxl@sjtu.edu.cn).

Lina Zhang is with Research Institute of Shanghai Aerospace Electronic Communication Equipment, Shanghai 201109, China.

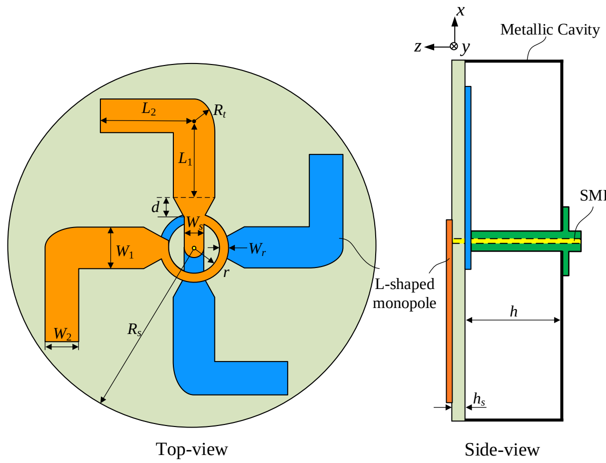


Fig. 1. The geometry of the proposed antenna. (L_1 = 14, L_2 = 15.5, R_s = 34, W_1 = 6, W_2 = 5, r = 1.5, W_s = 1.8, W_r = 0.2, d = 3.5, R_t = 2.5, h_s = 0.787 and h = 8, item: mm)

vacant-quarter ring provides an excitation of a sequential phase step length of nearly 90°, both four straight strips and four L-shaped strips obtain good CP performance, as shown in Fig. 2. At lower frequencies, because the phase step lengths of adjacent strips are decreasing, the axial-ratio performance of four straight strips deteriorates in the normal direction, though it is good at some angles due to spatial phase compensation, while that of the four L-shaped strips is still good in a wide beamwidth. It is means that the L-shaped strip improves antenna CP performance. In order to more clearly illustrate the mechanism of the proposed antenna, antenna surface currents in one period at lower and higher frequencies are shown in Fig. 3. For each L-strip at 6 GHz, the electric-length of the straight segment (L_1) approximates to a quarter of a wavelength, surface currents on the bent segment (L_2) have a delay phase of about 90° compared to those on the straight segment (L_1), thus a CP radiation is obtained. The radiation beam produced by the L-shaped strip antenna is slightly tilted, while the four L-shaped strips rotated in sequence can achieve a relatively wide CP beamwidth, which is also confirmed in Fig. 2. At 10 GHz, comparing currents at different times (0, T/4, T/2, 3T/4), we see that the right-hand CP radiation can be obtained due to the double vacant-quarter ring providing four sequentially rotated L-shaped strips with phases of 0°, -90°, -180° and -270°. Combining two different CP modes, this CP antenna obtains a wide impedance bandwidth and a wide axial-ratio beamwidth. Moreover, a circular cavity with a depth of $\lambda_0/4$ (where $\lambda_0/4$ is the free space wavelength corresponding to the center frequency) is used to avoid the bidirectional radiation.

To better understand the design of the proposed antenna, several key parameters in terms of L_1, L_2 of the L-shaped strip, r of vacant-quarter ring and h of the cavity are analyzed. The effect of parameters L_1 and L_2 on antenna performance, including reflection coefficient, axial-ratio and broadside gain, are shown in Fig. 4 and Fig. 5. Since the antenna resonance is determined by the total length (L_1+L_2) of the L-shaped strip, Both segment lengths have an impact on lower frequency

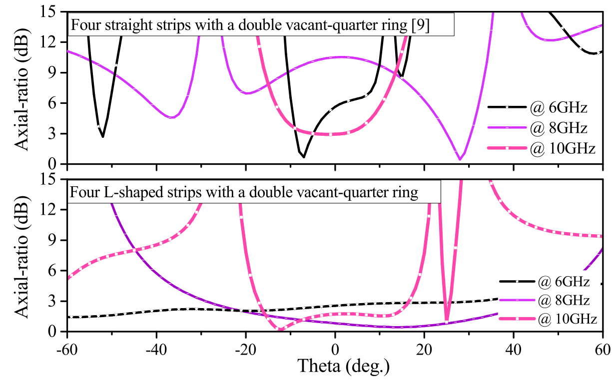
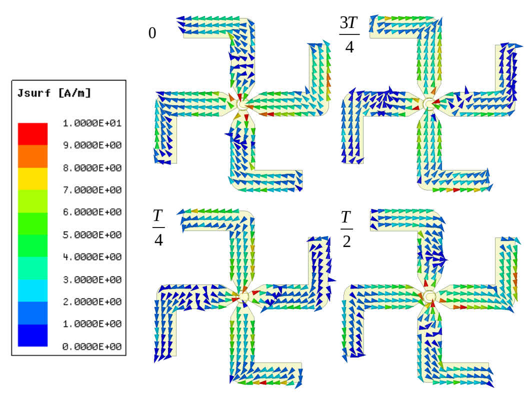


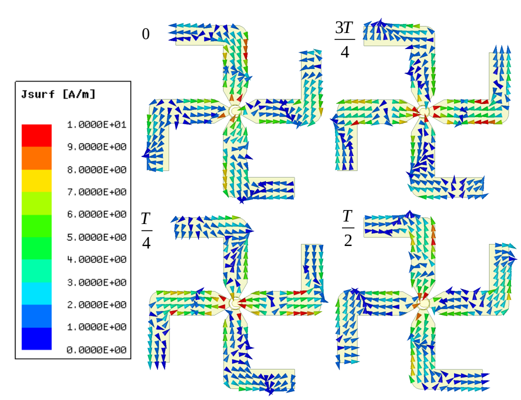
Fig. 2. Simulated axial-ratio comparison.

performance, especially the bent segment (L_2). L_1 has an obvious affection to broadside gain and axial-ratio of higher frequency. It can be understood that the variation of L_1 changes the delay phase of surface currents between the bent segment (L_2) and the straight segment (L_1). Also, the ratio of L_1 and L_2 affect the magnitude of currents on straight and bent segments, a ratio value of ($L_2/L_1 \approx 1.1$) is optimized to realize a good CP radiation.

Fig. 6 shows that how the radius r of the vacant-quarter ring affect antenna reflection coefficient, axial-ratio, and broadside



(a) 6 GHz



(b) 10 GHz

Fig. 3. Surface current distributions.

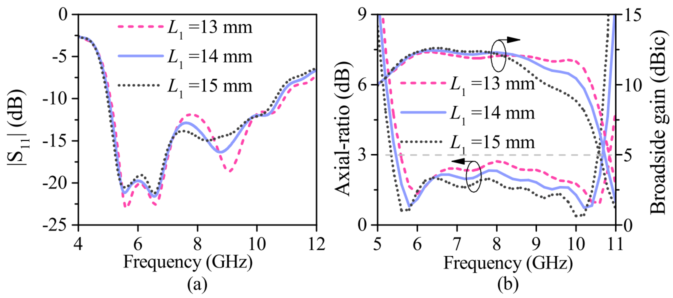


Fig. 4. (a) $|S_{11}|$ and (b) axial-ratios and broadside gains for different values of L_1.

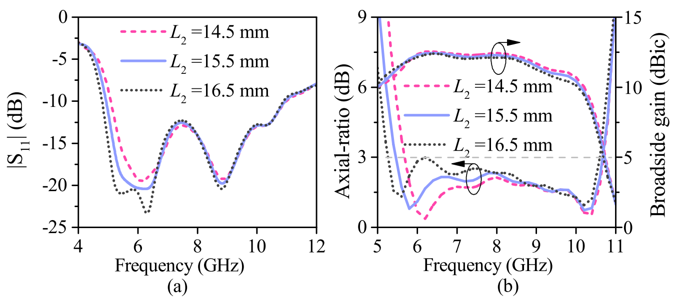


Fig. 5. (a) $|S_{11}|$ and (b) axial-ratios and broadside gains for different values of L_2.

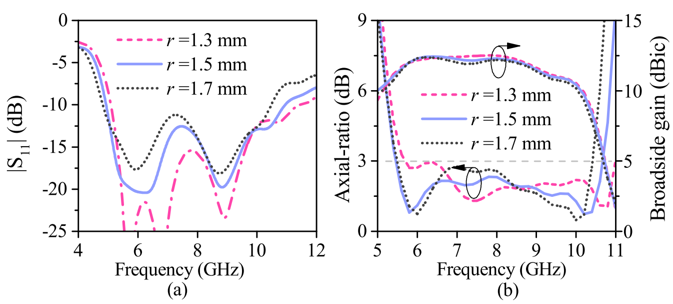


Fig. 6. (a) $|S_{11}|$ and (b) axial-ratios and broadside gains for different values of r.

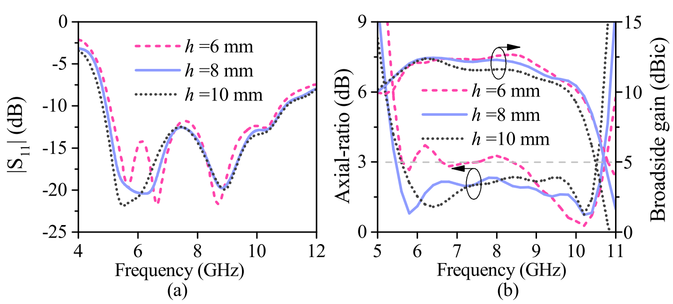


Fig. 7. (a) $|S_{11}|$ and (b) axial-ratios and broadside gains for different values of h.

gain. Since the double vacant-quarter ring provides an excitation of a sequential phase step length at higher frequencies, r has a considerable effect on axial-ratio performance at higher frequencies, and the CP operation frequency increases as r decreases. Besides, small r causes coupling between strips, and also brings the fabrication difficulty, especially the

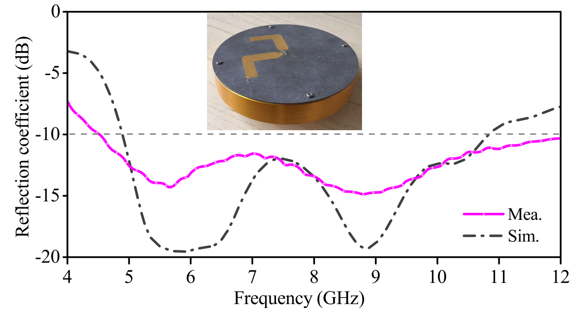


Fig. 8. Measured and simulated reflection coefficients.

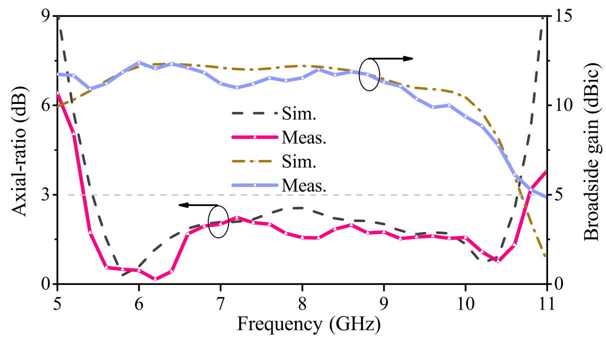


Fig. 9. Measured and simulated axial-ratios and broadside gains.

feed part welding. Fig. 7 shows the cavity depth h affection on antenna's reflection coefficient, axial-ratio, and broadside gain. It is seen that h is more sensitive to axial-ratio and broadside gain than to the reflection coefficient. Its optimal value approximates to a quarter-wavelength corresponding to the center frequency of CP band.

III. Measured and Simulated Results

A prototype was fabricated and measured to verify the proposed design. The reflection coefficient measurement was carried out with an Agilent network analyzer and the radiation performances were measured in an anechoic chamber. Fig. 8 shows the simulated and measured reflection coefficient with a photo of the fabricated antenna. The simulated 10-dB impedance bandwidth is 72.6% (5.0-10.7 GHz) and that measured results is 92.8 % (4.5-12.3 GHz). Due to the antenna was manually assembled, especially the feed part welding, there excites a bandwidth difference between the simulation and measurement, but the two curves are still similar. Fig. 9 plots a comparison between simulated and measured axial-ratio and broadside gains of the proposed antenna. The simulated 3-dB axial-ratio bandwidth is 62.5% (5.5-10.5 GHz), whereas that measured result is 67.5% (5.3-10.7 GHz). The maximum RHCP gains of simulated and measured are the same of 12.4 dBic. 3-dB gain bandwidths up to 61.5% (5.5-10.1 GHz) in simulation and 62.3% (5.3-10.1 GHz) in measurement are obtained. The radiation patterns of the proposed antenna at 6 GHz, 8 GHz and 10 GHz in the two principal planes (ϕ = 0° and ϕ = 90°) are shown in Fig. 10. The measured results nearly consistent well with the simulated ones. Table I compares the measured key characteristics of the proposed CP antenna

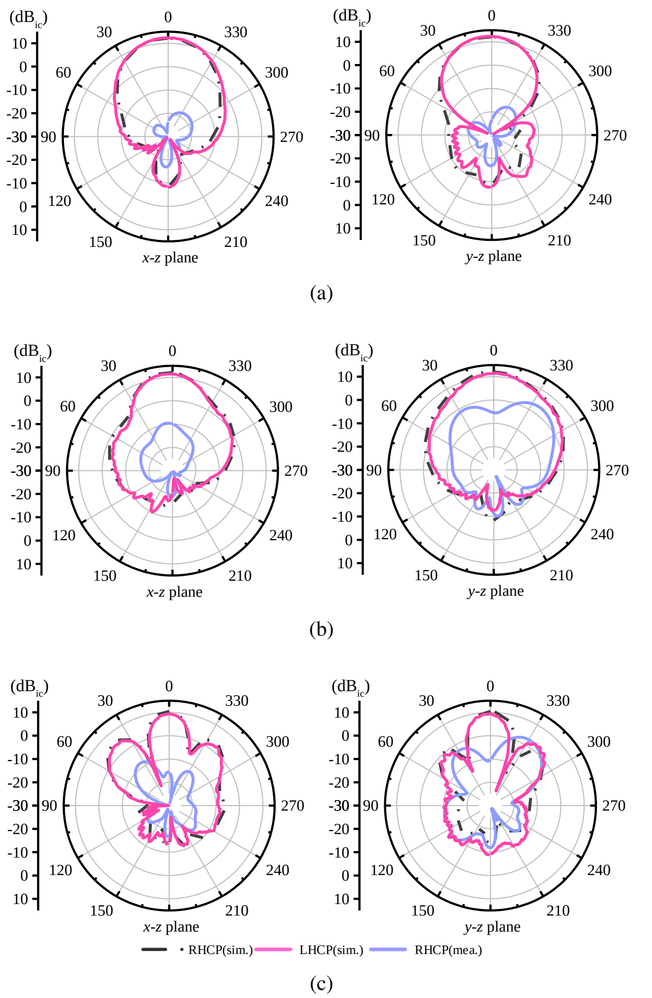


Fig. 10. (a) Radiation patterns of the proposed antenna at (a) 6 GHz, (b) 8 GHz, (c) 10 GHz.

TABLE I
COMPARISON BETWEEN PROPOSED ANTENNA AND PREVIOUS WIDEBAND CP ANTENNAS DESIGN

Ref.	Center Freq. (GHz)	Size (λ_0)	10-dB BW (%)	3-dB CP BW (%)	Max. Gain (dBic)
[9]*	2.31	0.92 × 0.92 × 0.22	30.7	15.6	7.5
[10]	2.63	1.05 × 1.05 × 0.25	38.2	28.6	8.7
[11]	2.75	1.01 × 1.01 × 0.3	57.0	51.0	10.7
[12]	2.90	0.79 × 0.79 × 0.27	68.9	58.6	9.4
[13]	2.57	ϕ 2.06 × 0.26	57.6	39.0	10.7
[14]	5.69	2.09 × 2.09 × 0.13	66.9	55.1	11.5
[15]	1.94	ϕ 1.68 × 0.36	106.5	99.6	12.0
Prop.	8.00	ϕ 1.81 × 0.23	92.8	67.5	12.4

* denotes only simulation results accessible.

and other wideband CP antennas. It is seen that the proposed antenna operated at the highest frequency and its operation aixal-ratio bandwidth just filled the gap between 58.6% and 96.6% and provides more aixal-ratio bandwidth options.

IV. CONCLUSION

A dual-mode wideband CP antenna with a simple structure has been presented in this paper. By combining two different CP modes, this antenna obtains a wide axial-ratio bandwidth and beamwidth. A prototype has been fabricated, and the measured results show that this antenna yields a 10-dB impedance bandwidth of 92.8% (4.5-12.3 GHz) and a 3-dB aixal-ratio bandwidth of 67.5% (5.3-10.7 GHz). In addition, this antenna has a measured 3-dB gain bandwidth of 62.3% (5.3-10.1 GHz) and a peak gain of 12.4 dBic. With these advantages of wide operation bandwidth, the proposed antenna can be a good candidate to modern wideband wireless communications.

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