Dual-Band Circularly Polarized Rotated Patch Antenna With a Parasitic Circular Patch Loading

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***Abstract*—A dual-band circularly polarized (CP) rotated patch antenna is proposed in this letter. Dual-band CP operation of the proposed antenna is achieved by adopting a circular patch below the rotated rectangular patch. The extra circular patch not only provides a higher band, but is also employed to tune the operating frequency of the lower band, which is generated by the rotated rectangular patch. The rectangular patch and the circular patch can be arranged on the front and back of a thin substrate and fed by a single slot. The dual CP operating bands can be tuned separately with a small frequency ratio of 1.18. A prototype of the proposed antenna is built to validate the design strategy. The measured 3-dB axial-ratio (AR) bandwidth is 2.1% (2.238–2.285 GHz) for the lower band and 2.0% (2.645–2.695 GHz) for the higher band, with the reflection coefficient being lower than −10 dB. The radiation pattern and gain are also measured and compared to the simulated ones.**

***Index Terms*—Circular polarization, microstrip antenna, multifrequency antenna.**

I. Introduction

CIRCULARLY polarized (CP) patch antennas are widely adopted in wireless communication systems for their merits of insensitivity to the polarization matching between the transmitter and the receiver [1]. In some cases, the multiband spot coverage, compared to the entire frequency coverage, is actually an advantage in terms of reducing the out-of-band interference [2].

Various techniques can be found in literature for multiband CP patch antenna designs [2]–[10]. For example, dual-band circular polarization provided by dual resonant elements on different substrate layers have been reported in [2]–[5]. Perturbations, caused by asymmetrical U-shaped slot [2] and truncated corners [3], achieve to excite two stacked patches through the probe feed. In [4], a two-stage Wilkinson power divider network is adopted to feed the crossed slot for dual-band CP operation. A similar method is used in [5], which uses four sequentially located L-probes to excite two stacked circular patches. In addition, dual-band CP patch antennas with single layer are demonstrated to simplify antenna structure in [6]–[9]. In [6]–[8], single resonant element is presented, which adopts perturbation method. In [6], by inserting four T-shaped slits at the patch edges or four Y-shaped slits at the patch corners, TM_{10} and TM_{30} modes are excited at different bands. A method similar to [6] is used in [7], where TM_{11} and TM_{12} modes are excited by embedding two pairs of arc-shaped slots with different subtending angles on the circular patch. In [8], a frequency ratio of 1.28 can be achieved by cutting an asymmetrical S-shaped slot on the patch. Arranging dual resonant elements on a single layer is also presented in [9]. The feeding line is used to excite phases of 0°, 90°, 180°, and 270° in series for inner patch and outer ring.

Achieving a small frequency ratio and wide axial-ratio (AR) bandwidth with a simple and compact structure for dual-band CP antenna is still a challenge. A novel method of arranging two resonant elements on the front and back of a substrate is presented in [10]. The proposed stacked annular-ring patch antenna is excited by two orthogonal H-shaped slots, fed by a 3-dB hybrid network. By tuning two concentric annular-ring patches, a minimum frequency ratio of 1.28 and AR bandwidth of 2% for dual band can be achieved. In this letter, we have proposed an aperture-fed patch antenna for dual-band CP operation. A rotated rectangular patch and a circular patch fed by a single slot are arranged on the front and back of the substrate to generate dual-band circular polarization. Compared to [10], the proposed antenna has a much simpler feed-network and a smaller minimum frequency ratio.

II. Antenna Design

The geometry of the proposed antenna is shown in Fig. 1, where two layers of FR4 substrate are separated by an air gap of thickness h_1. The two substrate layers have the same thickness of 0.8 mm, with relative permittivity $\varepsilon_{\mathrm{r}} = 4.0$ and $\tan\delta = 0.02$. A rectangular patch and a circular patch are positioned on the front and back of the upper substrate. The size of the rectangular patch is $l_1 \times w_1$ with a rotated angle of α from y-axis. The radius of the circular patch is r. Both the rectangular patch and the circular patch are fed from an aperture of width w_3 and length l_3. The aperture is etched on the ground plane along y-axis, which is on the front of the lower substrate. A 50-Ω open-ended stub is arranged on the back of the lower substrate. The offset part of the microstrip feeding line is at distance l_2 from the center of the aperture. The designed antenna in this prototype produces left-handed circular polarization (LHCP) in

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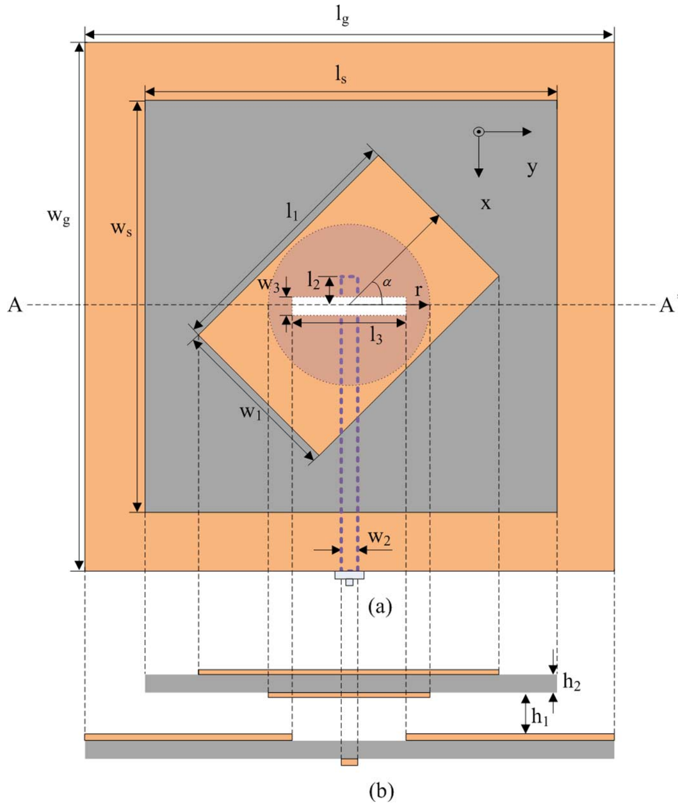

Fig. 1. Geometry of the proposed antenna. (a) Top view. (b) Cross-sectional view of A-A′ plane.

TABLE I
DETAILED DIMENSIONS (UNIT: MILLIMETERS)

l_g	w_g	l_s	w_s	l_1	w_1	l_2
100	100	80	80	48	40	6.5
w_2	l_3	w_3	r	α	h_1	h_2
1.6	35	2	18	41°	7	0.8

dual bands. The detailed values of each parameter are optimized using Ansoft HFSS software and listed in Table I.

In [11], a rotated patch is introduced to achieve CP operation. Two orthogonal modes are excited at the edges of the patch. Based on this structure, a circular patch is added on the back of the upper substrate to generate dual-band circular polarization, as shown in Fig. 1. The circular patch plays two different roles in dual bands. In the lower band, it serves as a capacitive loading and feeds energy to the top rectangular patch. In the higher band, it provides another resonant frequency for circular polarization. Simulated reflection coefficient and AR of the proposed antenna with and without the circular patch are shown in Figs. 2 and 3. It is found that dual bands for reflection coefficient and AR bandwidths are achieved after adding a circular patch below the rotated rectangular patch. Fig. 4 shows the complex magnitude distribution of current on the rectangular patch and circular patch. Considering the circular patch under the rectangular patch, strong current concentrates in the overlapped part of both patches. For lower frequency, the current on the rectangular patch is stronger than the circular patch. Strong current also appears along the edges. For higher frequency, the current

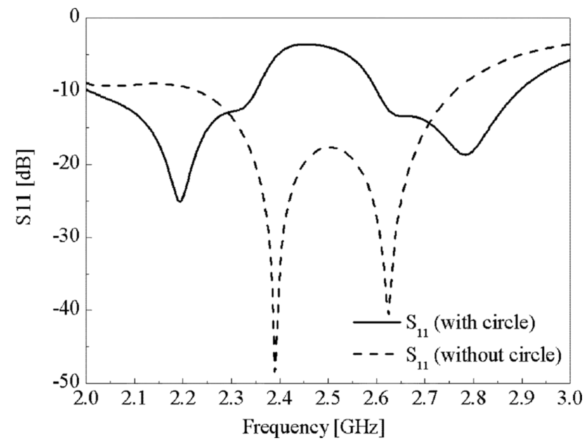

Fig. 2. Simulated reflection coefficient with/without circular patch.

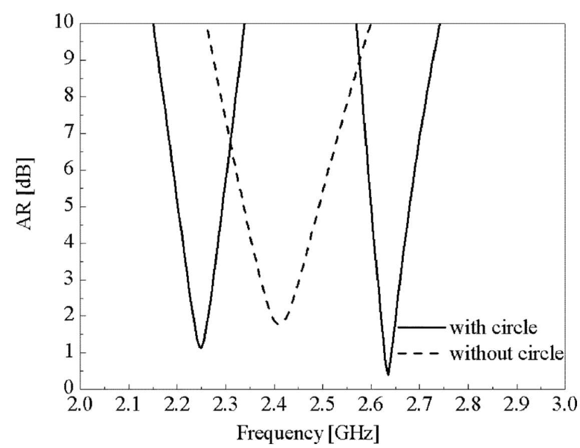

Fig. 3. Simulated axial ratio with/without circular patch.

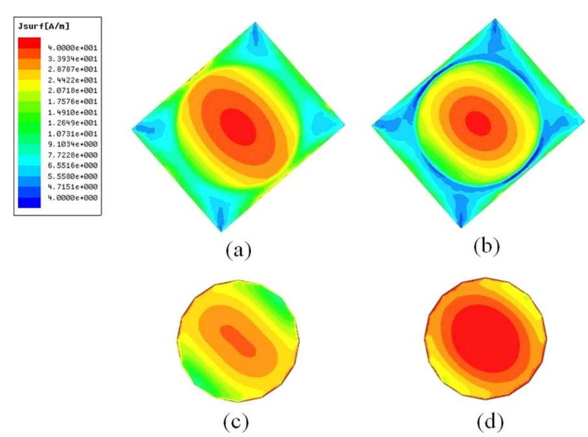

Fig. 4. Complex magnitude distribution of current: (a) on the rectangular patch at 2.245 GHz; (b) on the rectangular patch at 2.635 GHz; (c) on the circular patch at 2.245 GHz; (d) on the circular patch at 2.635 GHz.

on the circular is stronger. We can conclude that the lower frequency is mainly dictated by the dimension of the rectangular patch. The higher frequency is mainly dictated by the dimension of the circular patch.

A parametric study is carried out to validate the above discussion. It is also helpful to understand the effect of h_2, h_1, and r on the performance of dual-band CP operation. Fig. 5 shows the

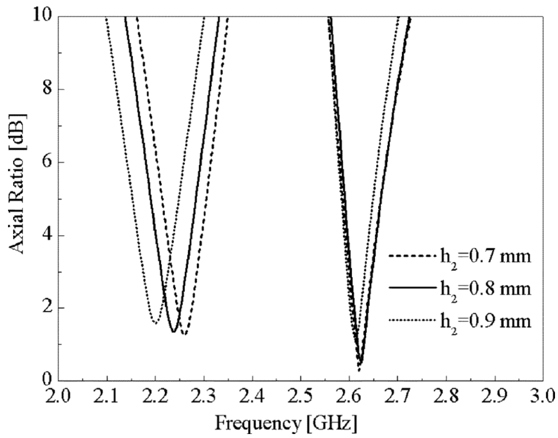

Fig. 5. Simulated axial-ratio with different h_2.

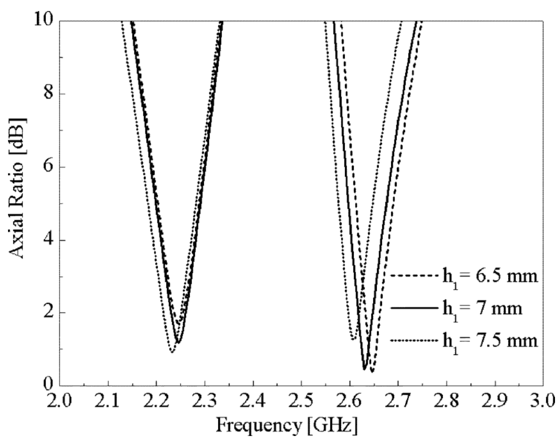

Fig. 6. Simulated axial-ratio with different h_1.

effect of h_2 on circular polarization. As h_2 increases, the minimum value of axial ratio at the lower band shifts to the lower frequency, whereas the operating frequency at the higher band changes slightly. It depicts that the lower resonant frequency is determined by the rectangular patch, and the circular patch plays the role of feeding energy to the top rectangular patch. Fig. 6 shows the effect of h_1 on circular polarization. As h_1 increases, the minimum value of axial ratio at the higher band shifts to the lower frequency, whereas the operating frequency at the lower band changes slightly. It depicts that the higher resonant frequency is determined by the circular patch, and the rectangular patch plays the role of perturbation for circular polarization. Fig. 7 shows the effect of r on circular polarization. As r increases, the minimum value of axial ratio at the lower and higher bands shifts to the lower frequency. It confirms that the circular patch serves as a capacitive loading at the lower band and provides another resonant frequency at the higher band.

III. Measurement Results

Fig. 8 shows the photograph of the fabricated antenna. Four parasitic screws are used to fix the two layers of FR4 substrate. Fig. 9 shows the measured reflection coefficient of the proposed antenna, which agrees well with the simulated result. The measured -10-dB reflection coefficient bandwidths are

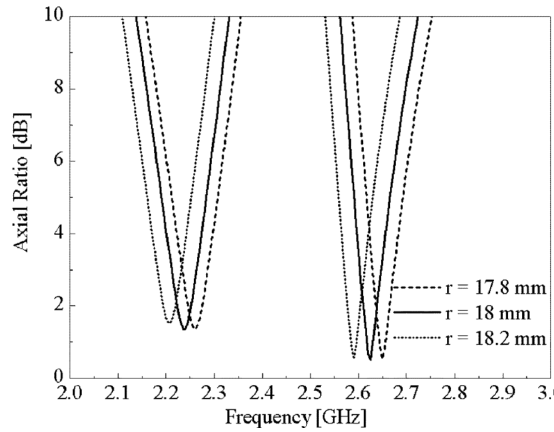

Fig. 7. Simulated axial-ratio with different r.

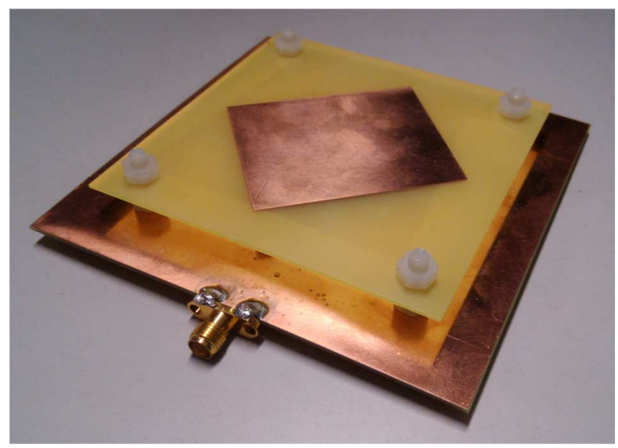

Fig. 8. Photograph of the fabricated antenna.

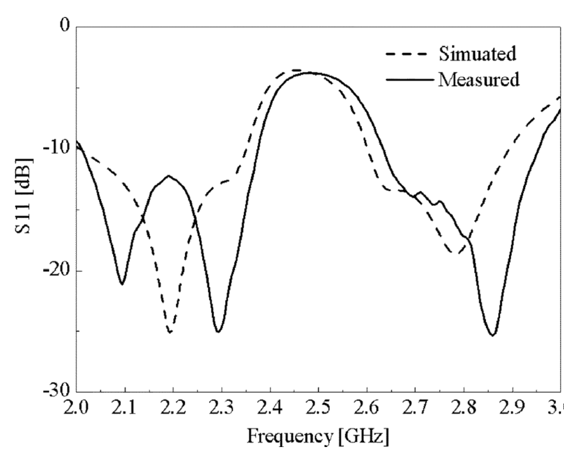

Fig. 9. Simulated and measured reflection coefficient.

355 MHz (2.015–2.37 GHz) at the lower band and 315 MHz (2.635–2.95 GHz) at the higher band, respectively.

Fig. 10 compares the measured and simulated AR at the broadside. It can be observed that the measured AR has a slight shift toward higher frequency. The shift mainly comes from the uncertain permittivity of the substrate. The measured minimum value of AR is achieved at 2.26 and 2.67 GHz for dual-band operation. The measured 3-dB AR bandwidths at the lower and higher bands are 2.1% (2.238–2.285 GHz) corresponding

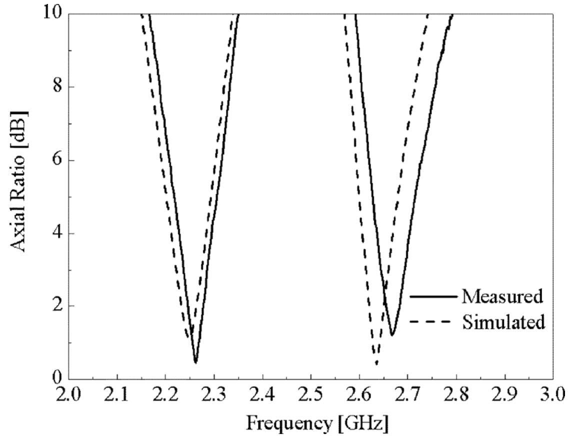

Fig. 10. Simulated and measured axial ratio.

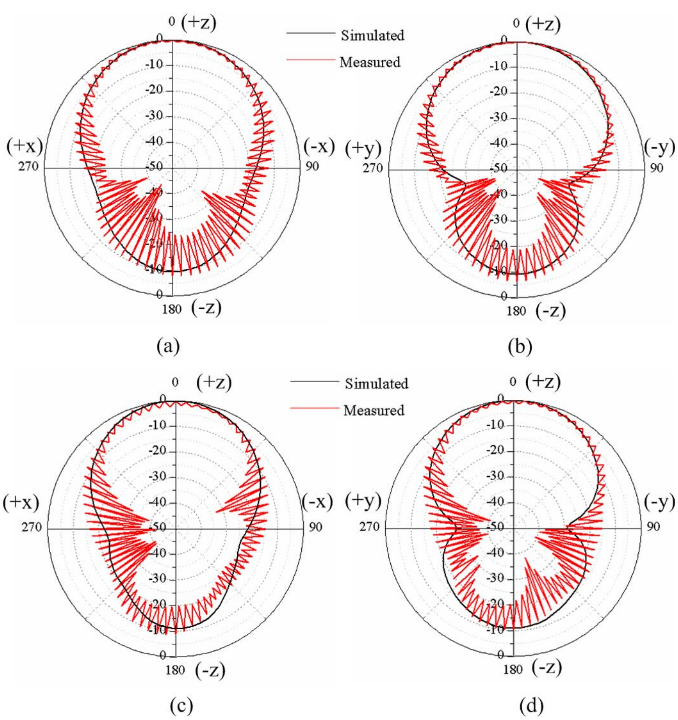

Fig. 11. Simulated and measured normalized radiation patterns. (a) 2260 MHz at xz-plane. (b) 2260 MHz at yz-plane. (c) 2670 MHz at xz-plane. (d) 2670 MHz at yz-plane.

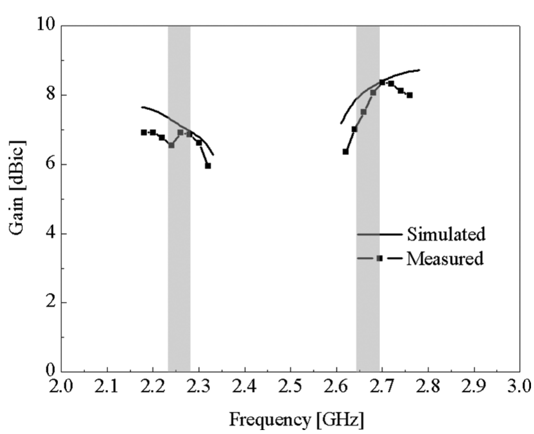

Fig. 12. Simulated and measured gain.

to 2.26 GHz and 2.0% (2.642–2.695 GHz) corresponding to 2.67 GHz, which are within the -10-dB reflection coefficient bandwidths. In this letter, we mainly focus on the AR bandwidth tuning. The reflection coefficient, which is lower than -10 dB, is acceptable for practical applications. The measured frequency ratio is 1.18, which is smaller compared to the frequency ratio of 1.28 in [10].

Fig. 11 shows the measured normalized radiation patterns at 2.26 and 2.67 GHz in yz-plane and xz-plane. Good AR is achieved at the broadside. The measured front-to-back ratio is about 10 dB. The measured gain is shown in Fig. 12 and compared to the simulated result. At the lower band, the measured gain is greater than 6.5 dBic, and the peak gain is 7 dBic. At the higher band, the measured gain is greater than 6.8 dBic, and the peak gain is 8.3 dBic.

IV. Conclusion

An aperture-fed circularly polarized patch antenna operated at 2.26 and 2.67 GHz is presented in this letter. The dual-band circular polarizations are achieved by arranging a rectangular patch and a circular patch on the front and back of the upper substrate. Measured 3-dB axial-ratio bandwidths are 2.1% at the lower band and 2.0% at the higher band, which are within the reflection coefficient bandwidths. A small frequency ratio of 1.18 is achieved. Compared to the dual-feed antenna in [10], the proposed single-feed antenna has the same AR bandwidths, a simpler feed network, and a smaller minimum frequency ratio.

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