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A Single-Feed Dual-Band Dual-Sense Circularly Polarized Microstrip Antenna

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Abstract—A single-feed dual-band dual-sense circularly polarized (CP) microstrip antenna is proposed. The antenna consists of a circular radiating patch with a ring slot, two substrates with an air layer sandwiched between them and a capacitive coupling feed. The two resonant frequencies are controlled by the size of the circular radiating patch and the ring slot. By introducing the perturbation, the fundamental resonant mode splits into two orthogonal degenerate modes, and the CP radiation pattern is obtained. Capacitive disk coupling feed is also used in the design to enhance the bandwidth. The key parameters of the design are investigated to show how to obtain dual-band and dual-sense CP. The proposed antenna prototype is fabricated and measured, and experimental results show that good CP radiation performances are obtained at both resonant frequencies.

1. INTRODUCTION

In recent years, there has been an increasing demand for antennas with higher transmission capacity. An effective way is to utilize an antenna with orthogonally CP at two discrete operating frequencies. The reason is that incoming waves of any polarization can be received by a right-hand circularly polarized (RHCP) antenna except the one of left-hand circular polarization (LHCP), and vice versa. Therefore, the antenna operating frequency can be reused to enlarge the overall capacity in the wireless transmission. Dual-band dual-sense CP antennas have become a popular study in this research area during the last few years. Several dual-frequency designs for antenna structures have been proposed in [1–11], including slot antenna, notched printed monopole antenna, multifunction hybrid antenna, dual-feed antenna arrays.

However, relatively few designs of dual-frequency microstrip antenna with dual orthogonal CP have been reported. Microstrip antennas have advantages of low profile, light weight, and easy fabrication [12–14]. Compared to slot antennas, microstrip antenna has the attractive features of higher gain and unidirectional radiation pattern. Moreover, by careful design, we can produce two different operating frequency bands and CP radiation and obtain as wide bandwidth as that of a slot antenna.

In this paper, a dual-band dual-sense CP microstrip antenna which utilizes a circular radiating patch with a ring slot is proposed. The two operating bands can be controlled by the size of the circular radiating patch and the ring slot. By introducing a pair of stubs, the symmetry of the circular patch will be perturbed. The perturbation will split the fundamental resonant mode into two orthogonal degenerate modes for CP radiation of the lower operating band. And a rectangular slot is also introduced to perturb the symmetry of the ring slot for the upper CP radiation resonant frequency. Coupling fed by a top-loaded circular disk [15], the antenna is etched on two substrates with an air layer. Compared with a single-feed microstrip antenna [16–18], the capacitive coupling feeding technique can effectively improve the impedance bandwidth. The obtained impedance bandwidths across the operating band of the proposed antenna are about 15.4% (2.28 GHz $\sim$ 2.66 GHz) and 5.0% (3.76 GHz $\sim$ 3.95 GHz), the 3-dB AR bandwidths are about 3.7% (2.36 GHz $\sim$ 2.45 GHz) and 1.9% (3.76 GHz $\sim$ 3.83 GHz),

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respectively. Section 2 shows the structure of this antenna and discusses the mechanism of this antenna. Section 3 and Section 4 show the simulated and measured results of this antenna and the parametric study. All the structures are simulated and optimized by Ansoft high frequency structure simulator (HFSS v13.02).

2. ANTENNA DESIGN

The geometry configuration and photograph of the proposed antenna is shown in Figure 1. Both of the substrates are 2 mm-thick with a dielectric constant of $\varepsilon_r = 2.65$ and a loss tangent of 0.002. The antenna is composed of a radiating patch with a ring slot, two substrates with an air layer sandwiched between them, a metal ground and a capacitive coupling feeding disk. The optimum dimensions are shown in Table 1. Taking the center of the substrate as the coordinate origin, the proposed antenna is placed on XOY plane. For the lower band (RHCP), the resonant frequency is controlled by the circular patch with a radius of R. By introducing a pair of stubs, the symmetry of the circular patch will be perturbed. The perturbation will split the fundamental resonant mode into two orthogonal degenerate modes for CP radiation. The stubs with a width of W_2 and a length of L_2 are at 45° and 225° from the feed point. For the upper band (LHCP), the resonant frequency is controlled by the ring slot with a radius of R_1. Then a rectangular slot is inserted into center of the radiating patch. The rectangular slot with a width of W_1 and a length of L_1 can also introduce asymmetry on the ring slot. In this way, CP radiation patterns at both the frequencies can be obtained.

The simulated time-varying surface current distributions of the proposed antenna, shown in Figure 2, can be employed to explain the CP radiation principle. The current distributions in the figure are viewed from the $+z$ direction, showing the direction of the distributed current at different time phases (w_t), from 0° to 270°, with an interval of 90°. In this figure, it is obvious that the current of the patch travels in the counterclockwise direction as w_t increases, which results in exciting a RHCP

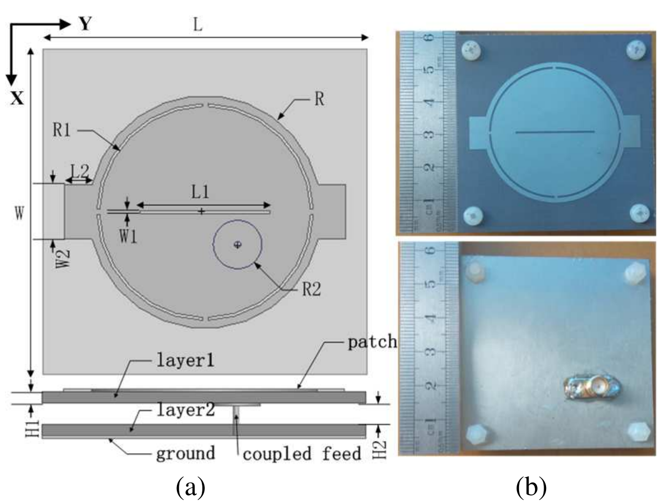
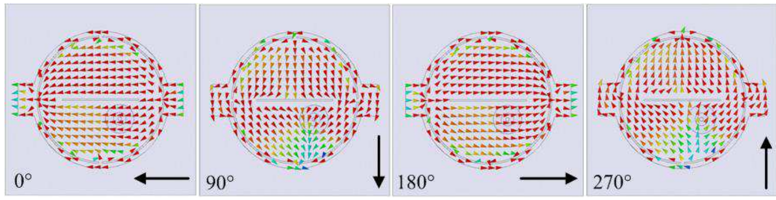


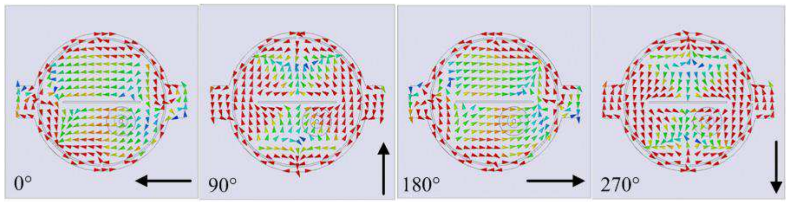
Figure 1. Geometry and photograph of the proposed dual-band dual-sense CP micro-strip antenna. (a) Geometry. (b) Photograph.

Table 1. Optimum parameters of the proposed antenna (unit: mm).

W	L	W_1	W_2	L_1	L_2
60	60	0.5	10	24	5.1
R	R_1	R_2	H_1	H_2	
21.5	19.5	4.5	2	4	



(a) 2.4 GHz



(b) 3.8 GHz

Figure 2. Surface current distributions of the proposed antenna in 0°, 90°, 180° and 270° phase. (a) 2.4 GHz. (b) 3.8 GHz.

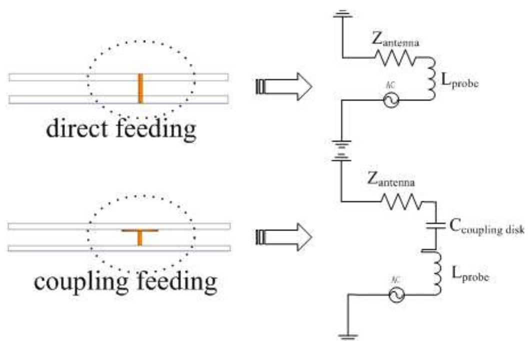


Figure 3. Equivalent circuit of the coupling feed in the proposed dual-band dual-sense CP microstrip antenna.

radiation for the lower band and the current of the patch travels in the clockwise direction as w_t increases, which results in exciting a LHCP radiation for the upper band.

Coupling fed by a top-loaded circular disk with a radius of R_2, the antenna is etched on two substrates with an air layer sandwiched between them. Compared with the general single-feed microstrip antenna, the capacitive coupling feeding technique can effectively improve the bandwidth.

As shown in Figure 3, the reason is that the feeding probe is an inductive element in the equivalent circuit of the proposed antenna, which restricts the working bandwidth of the antenna. But the coupling disk is a capacitive element, so adjusting the size of the coupling disk appropriately can reduce the undesirable effect of the feeding probe. By this way, the bandwidth is widened effectually.

3. SIMULATION AND RESULTS

3.1. *S*-Parameters

Computer simulation has been used to study the performance of the proposed dual-band dual-sense CP microstrip antenna. And the proposed antenna has been fabricated and measured. The simulated and measured $|S_{11}|$ of the final design are shown in Figure 4. The results in Figure 4 show that the 10-dB impedance bandwidths in the lower and upper bands are 15.4% (2.28 GHz $\sim$ 2.66 GHz) and 5.0% (3.76 GHz $\sim$ 3.95 GHz).

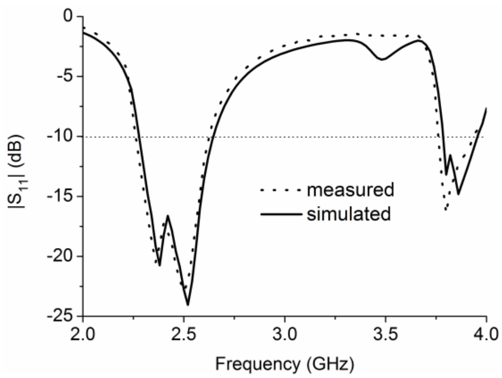


Figure 4. $|S_{11}|$ of the proposed dual-band dual-sense CP microstrip antenna.

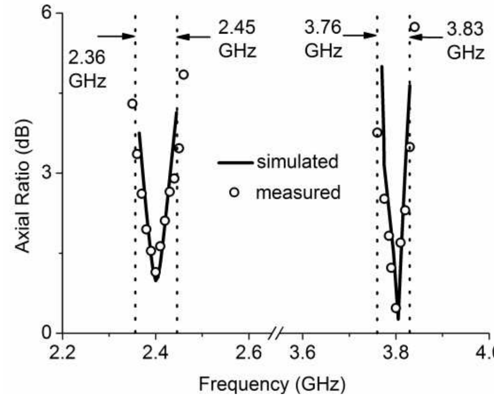


Figure 5. AR of the proposed dual-band dual-sense CP microstrip antenna.

3.2. Radiation Patterns

The simulated and measured RHCP/LHCP radiation patterns measured in an anechoic chamber in XOZ and YOZ planes at the lower and the upper bands are plotted in Figure 5 and Figure 6. The measured results in Figure 5 show that the 3-dB AR bandwidths in the lower and upper bands are 3.7% (2.36 GHz $\sim$ 2.45 GHz) and 1.9% (3.76 GHz $\sim$ 3.83 GHz). Limited by the form of single-feed microstrip antenna, the AR bandwidth of the proposed antenna is narrow, relatively. But the AR bandwidth falls within the impedance bandwidth, the design approach is still desirable and valuable. There are two methods to enhance the AR bandwidth. The first method is connecting a resistor load to another capacitive disk at the opposite position. Secondly, CP bandwidth will increase while Q value decreases. The reduction of Q value can be achieved by increasing the thick of substrate and air layer and decreasing the dielectric constant of substrate. These methods proposed may enhance the

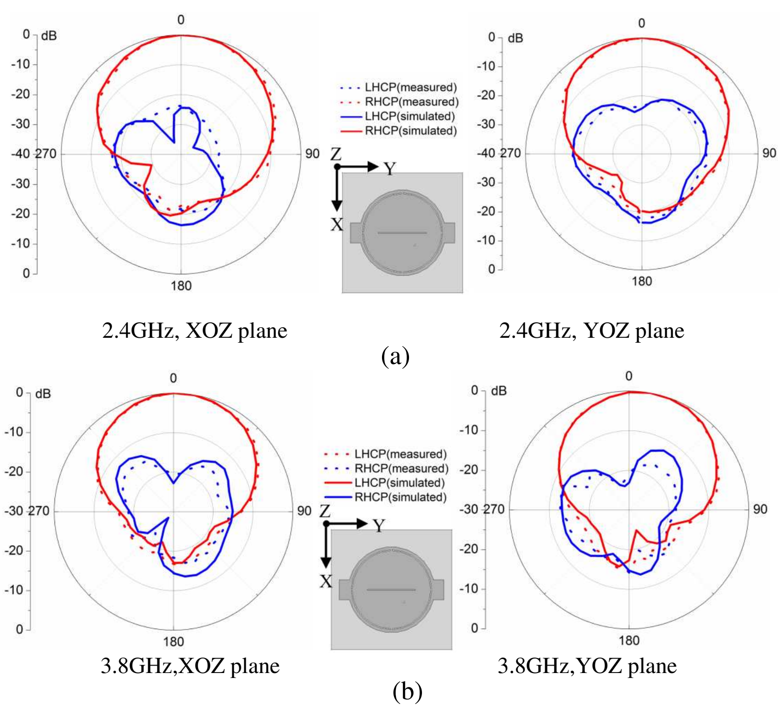


Figure 6. LHCP/RHCP radiation patterns of the proposed antenna in XOZ and YOZ planes. (a) 2.4 GHz. (b) 3.8 GHz.

AR bandwidth. But the first way may cause the decrease of gain and the second way can increase the profile of the antenna, the two methods are not used in our paper. Figure 6 shows the radiation patterns in XOZ plane and YOZ plane of the proposed antennas at 2.4 GHz and 3.8 GHz. Figure 7 shows the measured peak gains of the proposed antenna. The measured results show that the peak gains of the proposed antenna in the direction of the main beam are 7.8 dBi at 2.4 GHz (RHCP) and 6.1 dBi at 3.8 GHz (LHCP), respectively, which can fulfill the needs of general wireless communication systems.

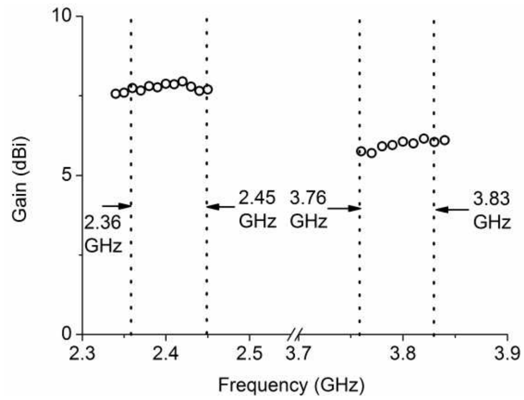


Figure 7. The measured peak gains of the proposed dual-band dual-sense CP micro-strip antenna.

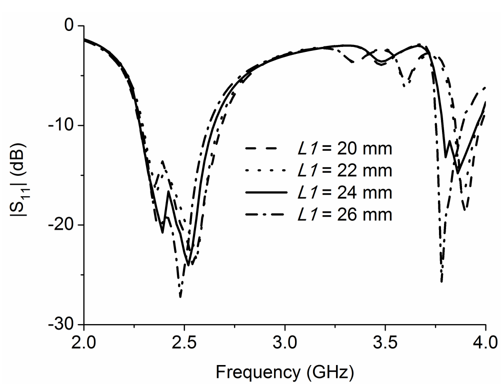


Figure 8. Simulated $|S_{11}|$ with different slot length L_1 for the proposed dual-band dual-sense CP microstrip antenna.

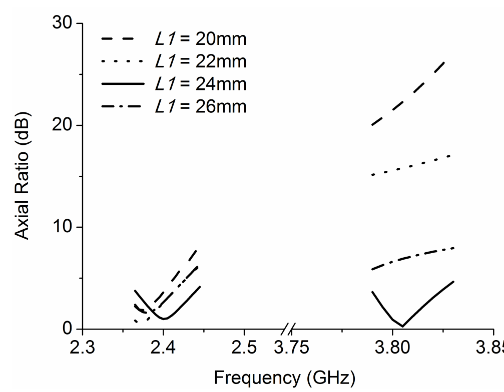


Figure 9. Simulated AR with different slot length L_1 for the proposed dual-band dual-sense CP microstrip antenna.

4. PARAMETRIC STUDY

All critical physical parameters, such as L_1, L_2, R, R_1 and R_2, should be adjusted carefully in order to achieve a dual-band dual-sense CP design with good performance. In this section, we will examine the effects of these parameters on impedance bandwidth and AR with only one parameter varying at a time.

As mentioned earlier, the lower frequency is decided by the circular radiating patch and the upper frequency decided by the ring slot, so it is obvious that the radius of patch (R) can affect the lower frequency while the radius of ring slot (R_1) can influence the upper one.

4.1. Effects of L_1

The effects of the slot length L_1 on the impedance bandwidth and AR of the proposed antenna are shown in Figure 8 and Figure 9, respectively. This is a critical parameter which decides the AR of

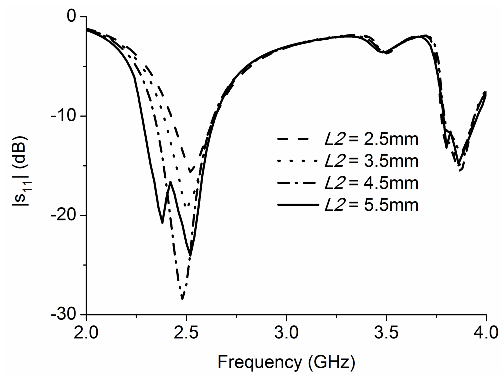


Figure 10. Simulated $|S_{11}|$ with different stub length L_2 for the proposed dual-band dual-sense CP microstrip antenna.

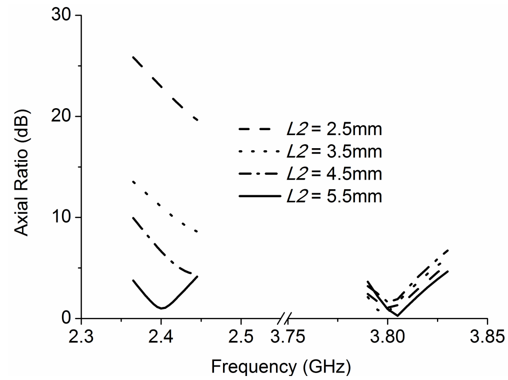


Figure 11. Simulated AR with different stub length L_2 for the proposed dual-band dual-sense CP microstrip antenna.

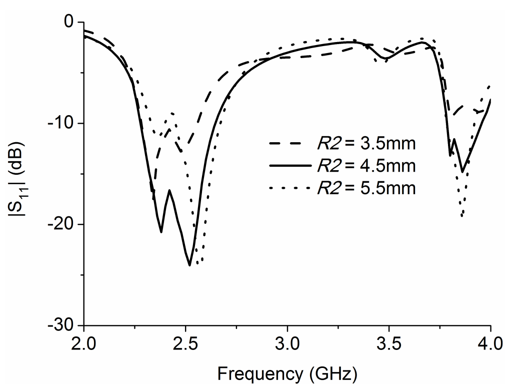


Figure 12. Simulated $|S_{11}|$ with different coupling disk radius R_2 for the proposed dual-band dual-sense CP microstrip antenna.

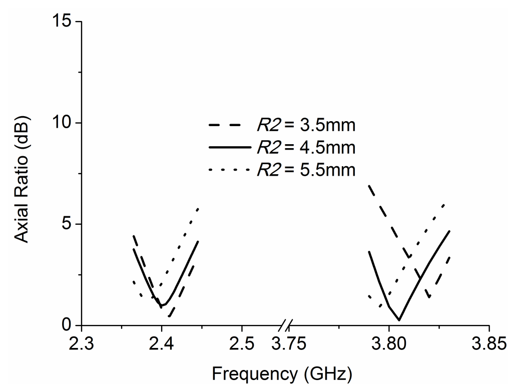


Figure 13. Simulated AR with different coupling disk radius R_2 for the proposed dual-band dual-sense CP microstrip antenna.

the upper frequency. Whether the value of L_1 is too small or too large, the CP performance will be deteriorated. It is noted that L_1 can also affect the impedance bandwidth of the upper frequency, while the impedance bandwidth and AR of the lower frequency is less sensitive to the length of L_1.

4.2. Effects of L_2

Figure 10 and Figure 11 show the impedance and AR bandwidth of the proposed antenna in the case of $L_2 = 2.5$, 3.5, 4.5 and 5.5 mm, respectively. It is found that the impedance and AR bandwidth of the upper frequency vary slightly with different L_2's, while there is an obvious variation in the impedance and AR bandwidth of the lower frequency when L_2 increases from 2.5 to 5.5 mm. To obtain good impedance matching and CP performance, L_2 should be set to 5.5 mm.

4.3. Effects of R_2

Figure 12 and Figure 13 show the effects of R_2, which is the radius of the coupling disk. As expected, R_2 has a great effect on the impedance bandwidth of both frequency, while AR is slightly affected. To realize impedance matching at both of the operating bands, R_2 must be optimized. Whether the value of R_2 is too small or too large, the impedance matching will be deteriorated. To obtain good impedance matching, R_2 should be set as 4.5 mm.

5. CONCLUSION

In this paper, a single-feed dual-band dual-sense circularly polarized microstrip antenna that utilizes a circular radiating patch with a ring slot has been proposed. By introducing different perturbations, the proposed antenna has circular polarization characteristics for both RHCP and LHCP. Impedance matching can be realized by a single-feed capacitive coupling disk, which can effectively improve the impedance bandwidth of the proposed antenna. The measured results show that two different CP radiation patterns at two resonant frequencies have been achieved, and the 10-dB impedance bandwidths in the lower and upper band are 15.4% (2.28 GHz $\sim$ 2.66 GHz) and 5.0% (3.76 GHz $\sim$ 3.95 GHz), respectively. The 3-dB AR bandwidths in the lower and upper bands are 3.7% (2.36 GHz $\sim$ 2.45 GHz) and 1.9% (3.76 GHz $\sim$ 3.83 GHz). The peak gains of the proposed antenna in the direction of the main beam are 7.8 dBi at 2.4 GHz (RHCP) and 6.1 dBi at 3.8 GHz (LHCP). The great performance makes it a good candidate for wireless communication.

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