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# DUAL-BAND CIRCULARLY POLARIZED MICROSTRIP ANTENNA WITH SMALL FREQUENCY RATIO

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**Abstract**—A compact single-feed dual-band circularly polarized (CP) microstrip antenna is evaluated numerically and experimentally. The dual-band performances with small frequency ratio (about 1 : 1.1) are achieved by a circular patch and a narrow annular-ring, which have small difference in radius. The CP characteristics are achieved by an unequal cross-slot embedded in the circular patch and two orthogonal linear stubs spurred from the annular-ring. The antenna is easy to fabricate. Good agreement is obtained between measured and simulated results.

## 1. INTRODUCTION

Microstrip patch antennas have been widely used in circular polarization (CP) applications due to their low profile, low weight and useful radiation characteristics. In the last decade, the development of modern wireless systems has prompted increased investigation on microstrip dual-band CP antennas. Dual-band circularly polarized antennas employing two layers have been reported [1–4], which were realized by using stacked patches with an aperture-coupled feed network [1], an electromagnetically-coupled feed [2] or a two-layer annular-ring structure [3]. However, the stacked structure will incur an increase in material cost and difficulty in manufacturing for mass production. Therefore, single-layer single-feed patch antennas for dual-band circular polarization have been proposed [5–8], which were realized by loading two pairs of arc-shaped slots in a circular patch [5], or Y-shaped or T-shaped slots in square patch [6]. Although good dual-band CP characteristics can be achieved, their frequency ratios are larger than 1.76. However, dual-band CP antennas with small

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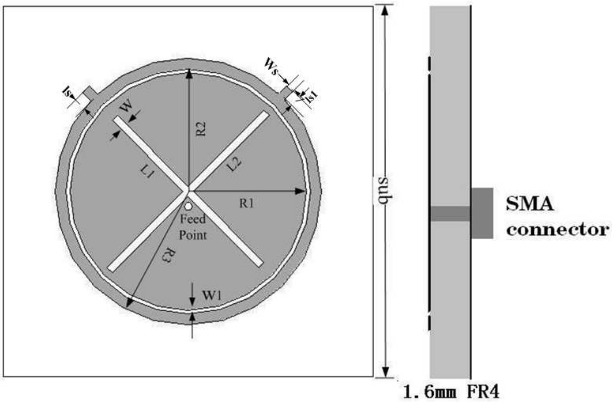



**Figure 1.** Geometry of the proposed dual-band CP antenna.

frequency ratio are required in some applications, and it is difficult to achieve the characteristics using single patch. In [9] and [10], small frequency ratios about 1 : 1.2 and 1 : 1.1 were obtained by corner-truncated square-ring patch and annular-ring patch with unequal cross-slot ground plane respectively, but the cross-slots in ground planes lead to bidirectional radiation patterns.

In order to achieve high performances dual-band CP antenna with small frequency ratio, a novel design of single-feed dual-band circularly polarized patch antenna surrounded by an annular-ring is proposed. As seen in Fig. 1, the CP operation is achieved by a cross-slot etched on the circular patch. Two orthogonal linear stubs spurred from the annular-ring are used for tuning better CP characteristics besides the cross-slot. The upper resonant mode 2.200 GHz and the lower resonant mode 1.995 GHz are obtained by the circular patch and annular-ring, respectively. The measured and simulated results show good circular polarization performance, and small frequency ratio is achieved.

## 2. ANTENNA DESIGN

The proposed dual-band antenna consists of an annular-ring surrounding a circular patch as shown in Fig. 1. A circular patch of radius $R_1$ is in the centre of the narrow annular-ring of inner radius $R_2$ and outer radius $R_3$, and the two linear stubs lengths are $Ls$ and $Ls_1$ with the same stub width $Ws$. The stub arm is selected for optimum CP performance and matching. The gap between the annular-ring and centre circular patch is $W_1$. The cross-slot in the circular patch has unequal laterals lengths of $L_1$ and $L_2$, and width of $W$. A 50 ohm coaxial probe feeds the inner top circular patch through a hole in the bottom. When the feed point is located on the 45 degree diagonal of the cross-slot, the upper and lower resonances can be split into two orthogonal modes with nearly equal amplitude. The distance between the feed point and the centre of the patch is $d$. In general, the approximate original value for the radius of circular patch is given by [11]

$$R = \frac{K}{\left[1 + \frac{2h}{\pi \varepsilon_r K}\left\{\ln\left(\frac{\pi K}{2h}\right) + 1.7726\right\}\right]^{1/2}} \tag{1}$$

where $f_r$ is the free space resonant frequency in GHz of the antenna, and $\varepsilon_r$ is the approximated effective dielectric constant. $h$ is the thickness of the substrate, and $K$ is given by

$$K = \frac{8.794}{f_r\sqrt{\varepsilon_r}} \tag{2}$$

Thus, the original values of radius with $R_1$ can be calculated according to equation (1), where $f_r$ is the upper design space resonant frequency. Due to the lower and upper frequencies are close to each other, the original value of $R_2$ can be estimated by the value of $R_1$. The feed point and lengths of cross slot and stubs are optimized in simulator software Ansoft HFSS 11.0.

The proposed structure can excite two orthogonal modes with nearly equal amplitude and 90 degree phase difference, by adjusting the lengths of the cross-slot arms. One frequency operation is obtained by the central circular patch with the cross-slot, and the other frequency operation is achieved by the annular-ring. The circular patch is fed by the coaxial cable directly, and the annular-ring is fed by electromagnetic coupling. Because the gap between the annular-ring and centre circular patch is small, the small frequency ratio is excited. The introduction of the stub arms can be used to reduce the resonant frequency and at the same time provide the necessary phase perturbation for circular polarization. The lower resonant frequency is determined by the annular-ring dimensions and lengths of the stub arms $Ls$ and $Ls_1$. The resonant frequency of the high frequency mode is determined by the radius of the central circular patch and gap $W_1$. Hence, dual-frequency circular polarization senses can be realized simultaneously by adjusting the lengths of the cross-slot and two stubs arms. In order to provide the best matching and optimum performance, a parametric study based on these initial dimensions of antenna is present.

## 3. SIMULATED AND MEASURED RESULTS

The proposed antenna was etched on a square FR4 substrate with relative permittivity of $\varepsilon_r = 4.4$. The total size of the square substrate is $50 \times 50 \times 1.6\,\text{mm}^3$. The characteristics of the proposed CP antenna are simulated by software Ansoft HFSS 11.0. In order to design the high performance dual-band CP antenna, a detailed parametric study of the antenna is made. The simulated return loss is shown in Fig. 2 for different values of the outer annular-ring radius $R_3$. It can be seen that the bandwidth of the lower frequency decreases when increasing radius $R_3$, and at the same time, it has an effect on the impedance matching of higher resonant frequency. Then the values of the centre circular patch radius $R_1$ is varied, and the return loss curves are shown in Fig. 3. It can be seen that as the radius $R_1$ increases, the upper resonant frequency decreases; the lower resonant frequency increases; the frequency ratio decreases. Fig. 4 illustrates that the stub width $Ws$ has a great impact on the frequency ratio.

By the optimization, the geometric dimensions of the proposed antenna are as follows: $R_1 = 13.1\,\text{mm}$, $R_2 = 13.5\,\text{mm}$, $R_3 = 14.2\,\text{mm}$, $W = 0.8\,\text{mm}$, $L_1 = 22.9\,\text{mm}$, $L_2 = 22\,\text{mm}$, $Ws = 0.9\,\text{mm}$, $Ls = 1.6\,\text{mm}$, $Ls_1 = 1.5\,\text{mm}$ and $d = 2.0\,\text{mm}$.

The measured and simulated return loss is shown in Fig. 5. It can be seen that the measured result is better than the simulated one. The discrepancy is due to tolerances in the dielectric constant and loss tangent of the laminate. The measured impedance bandwidths (10 dB return loss) are approximately 80 MHz at 1.995 GHz and approximately 50 MHz at 2.200 GHz. The small frequency ratio about 1.1 is obtained. The measured and simulated axial ratio against frequency in the

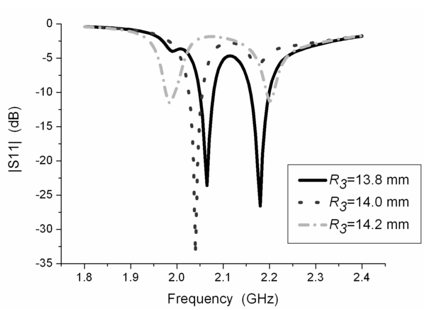



**Figure 2.** Simulated results of $S_{11}$ for the proposed antenna with different $R_3$.

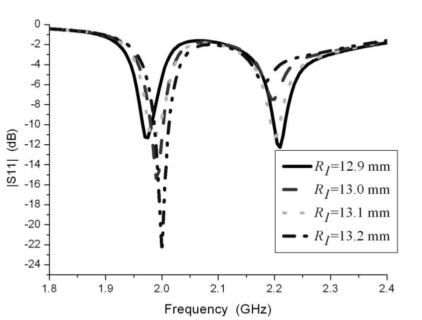



**Figure 3.** Simulated results of $S_{11}$ for the proposed antenna with different $R_1$.

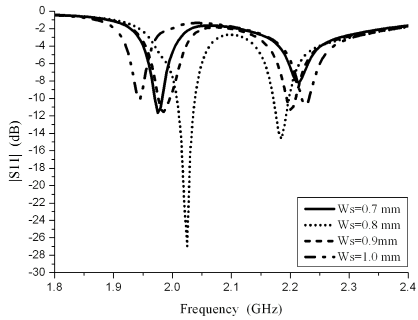



**Figure 4.** Simulated results of $S_{11}$ for the proposed antenna with different $Ws$.

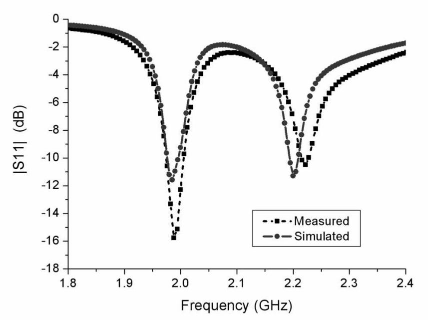



**Figure 5.** Simulated and measured $S_{11}$ for the proposed antenna.

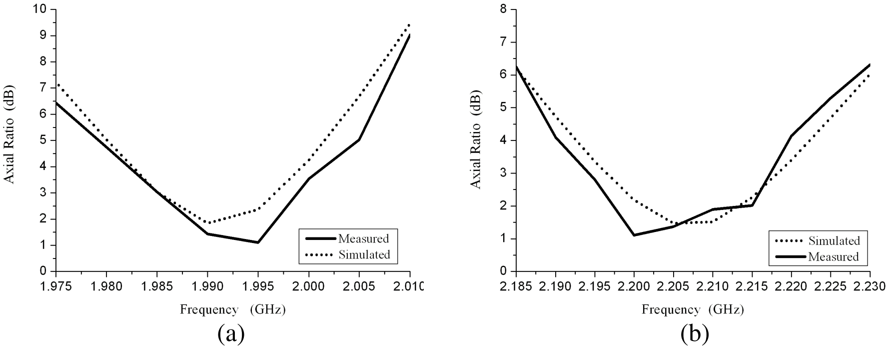
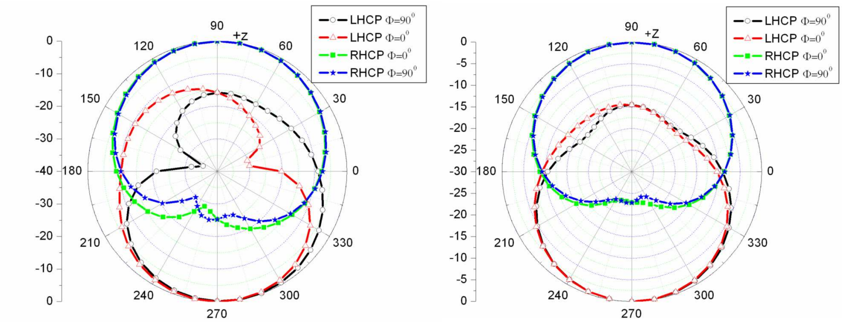


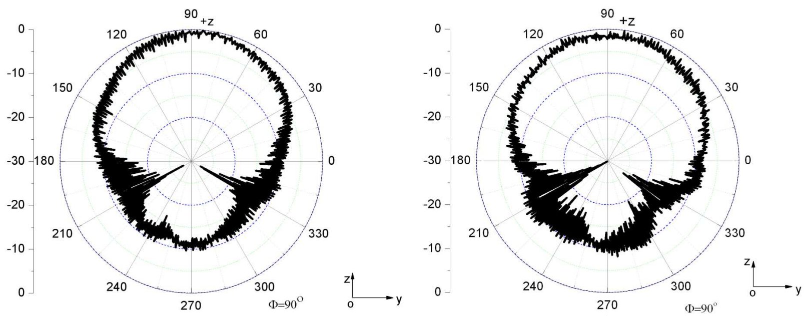

**Figure 6.** Simulated and measured the axis ratio of the proposed antenna. (a) 1.995 GHz, (b) 2.200 GHz.

broadside direction is shown in Fig. 6. The measured 3 dB axial ratio bandwidth for the low band is 13 MHz, from 1.985 to 1.998 GHz for RHCP, corresponding to about 0.65% with respect to 1.995 GHz, and the measured axial ratio bandwidth for the high band is 23 MHz, from 2.195 to 2.218 GHz for RHCP, corresponding to about 1.04% with respect to 2.200 GHz. Fig. 7 and Fig. 8 show the simulated and measured normalized radiation patterns for RHCP and LHCP in XOZ-plane and YOZ-plane at 1.995 GHz and 2.200 GHz respectively. The right-hand CP (RHCP) and left-hand CP (LHCP) radiation patterns are excited in $+z$ and $-z$, respectively. Fig. 9 shows measured gain of proposed antenna. Because the loss tangent of the substrate is large, the gain of the antenna is not very high. Fig. 10 shows the photo of the fabricated antenna.



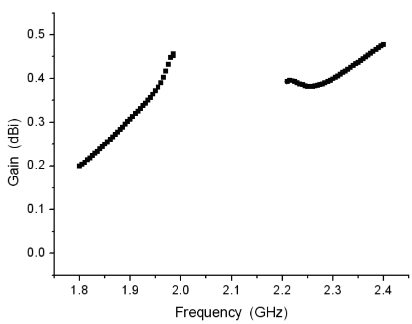

(a) (b)

**Figure 7.** Simulated radiation patterns for RHCP and LHCP at 1.995 and 2.200 GHz in the $XOZ$ plane ($\varphi = 0°$) and $YOZ$ ($\varphi = 90°$) plane, respectively. (a) 1.995 GHz, (b) 2.200 GHz.




(a) (b)

**Figure 8.** Measured radiation patterns at 1.995 and 2.200 GHz in the $YOZ$ plane, respectively.



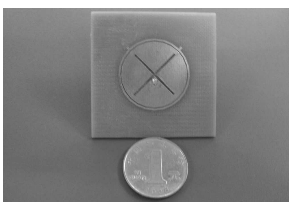



**Figure 9.** The measured peak gain versus frequency.

**Figure 10.** Photo of the proposed antenna.

## 4. CONCLUSION

A new single-layer single-feed dual-band antenna with a small frequency ratio has been proposed. The structure can effectively obtain good circular polarized characteristics. The antenna has been successfully designed, simulated, fabricated and measured, showing the advantages of compact, good dual-band and CP performances. Agreement between measured and simulated results is satisfactory.

## ACKNOWLEDGMENT

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