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COMPACT DUAL-BAND CIRCULARLY-POLARIZED ANTENNA WITH C-SLOTS FOR CNSS APPLICATION

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Abstract—A novel compact single-feed circularly-polarized (CP) microstrip patch antenna is proposed for CNSS dual-band application. The antenna comprises a square patch with embedded four symmetrical C-slots parallel to the edges and a slit in the center. The dual resonance frequencies (1616 MHz and 2492 MHz) can be separately controlled by the square patch and the C-slots. The CP characteristics is mainly achieved by adjusting the slit length. The antenna has a low profile and a small size. Details of design and results for the proposed antenna are presented and discussed.

1. INTRODUCTION

Circularly-polarized (CP) antennas are frequently used in wireless communication to overcome the misalignment between the transmitter and the receiver. In the last decades, the Global Positioning System (GPS) has been developed greatly. In China, the Compass Navigation Satellite System (CNSS) or "BeiDou" in its Chinese name, began to provide navigation and positioning services in late 2001 [1]. The uplink and downlink of CNSS are located at the frequencies of 1610–1626.5 MHz and 2483.5–2500 MHz, respectively. Thus, as essential components of the mobile devices, antennas should be designed in operating at both bands for CNSS application. In addition, it has been a hot spot and a development trend to be smaller in size, lower in profile and lighter in weight for the antenna design, which can meet the miniaturization demand for mobile terminals.

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Microstrip patch antennas have been widely used in circular polarization applications due to many attractive features, such as low profile, light weight, easy fabrication and so on. In recent years, many designs of dual-band circularly-polarized microstrip antennas have been reported. For stacked microstrip antennas can easily achieve good dual-band CP characteristics, they have been widely used in modern wireless communication [2–4]. However, it will incur increasing material cost and be difficult in manufacturing when mass production is required. Hence, more and more attention has been paid to the single-feed and single-layer patch antennas for dual-band CP application. An annular patch by placing an L-shaped strip connected to two orthogonal sides of the inner boundary [5], or a complementary two turns spiral resonator (CSR2) [6], can obtain dual-frequency for circular polarization. Nevertheless, the frequency ratio of two bands is more than 3, which is too large to be used for CNSS applications. In [7], although the frequency ratio can be reduced by an unequal cross-slot loaded in the ground plane, it leads bidirectional radiation patterns and besides adds to the disadvantage of integrated system at the same time. A square microstrip patch with T-shaped or Y-shaped slots [8], or a circular patch loading two pairs of arc-shaped slots [9], can achieve good dual-band CP performance. However, their dimensions are still larger to meet the miniaturization requirements of portable mobile devices.

In this paper, a novel single-feed microstrip patch antenna optimized for simplicity in design and feeding is proposed for dual-band CP application. The antenna comprises a square patch with embedded four symmetrical C-slots parallel to the edges and a slit in the center. It can work at 1616 MHz and 2492 MHz frequencies for CNSS dual-band application. Small size is achieved and good dual-frequency circularly-polarized characteristics are demonstrated. Simulated and measured results are presented and discussed in the following section.

2. ANTENNA DESIGN

The geometry of the proposed antenna is illustrated in Fig. 1. It comprises a square patch on top with four symmetrical C-slots parallel to the edges and a slit in the center. Each C-slot has a width of $W2$ and a distance of $L5$ from the patch center. The length and width of the slit are $L1$ and $W1$, respectively. The feed position is located at a distance D from the square center and an angle of 50° with respect to the narrow slit. The antenna is fabricated on an FR4 substrate, which has a relative permittivity of 4.4, a thickness of 1.6 mm and a loss tangent of 0.02. A 50 ohm coaxial probe (SMA connector) feeds

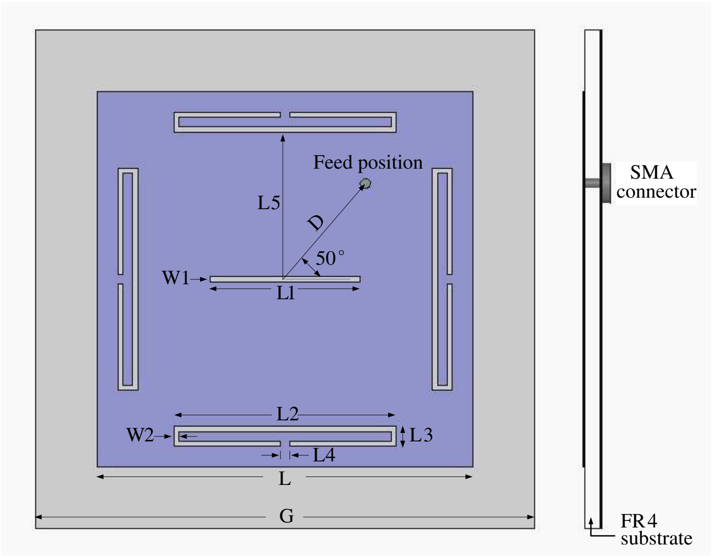


Figure 1. Geometry of the dual-band circularly-polarized antenna.

the top patch through a via hole in the bottom. The top and bottom square patches have different side length with L and G, respectively. In general, the original value for the side length of the square patch is about half-wavelength, which is

$$L = \frac{\lambda}{2} = \frac{c}{2\sqrt{\varepsilon_r} f_r} \tag{1}$$

where c is the speed of the light, ε_r the approximated effective dielectric constant, and f_r the fundamental resonant frequency of the proposed antenna.

The two resonant modes of TM_{10} and TM_{30} are used for the dual-band CP radiation in the proposed design, as shown in Fig. 7. By inserting four symmetrical C-slots, the lower (TM_{10}) and upper (TM_{30}) resonances can be reduced at the required frequencies. It is expected that, due to the perturbation of the slit embedded in the patch center, the equivalent excited patch surface current path of the TM_{10} mode along the direction perpendicular to the slit is lengthened while the one parallel to the slit orientation is only slightly affected. And so it is for the TM_{30} mode. In other words, the lower and upper resonances can be split into two near-degenerate modes with equal amplitude and 90° phase shift for dual CP characteristics. So circularly-polarization is obtained. By adjusting the slit length and the distance between the feed point and the patch center, good dual-frequency and circularly-polarization characteristics can be achieved.

To better understand the excitation behavior of the proposed antenna, the distributions of simulated electric field are plotted in Fig. 2. It can be observed that the lower resonance frequency (1616 MHz) is controlled by the square patch and the C-slots and the upper (2492 MHz) is mainly affected by the C-slots. From $t = 0$ to $t = T/8$, the region with little electric field, as pointed by the arrow, flows in a anticlockwise direction, yielding a right-hand circularly polarized (RHCP) wave in the upper-half space.

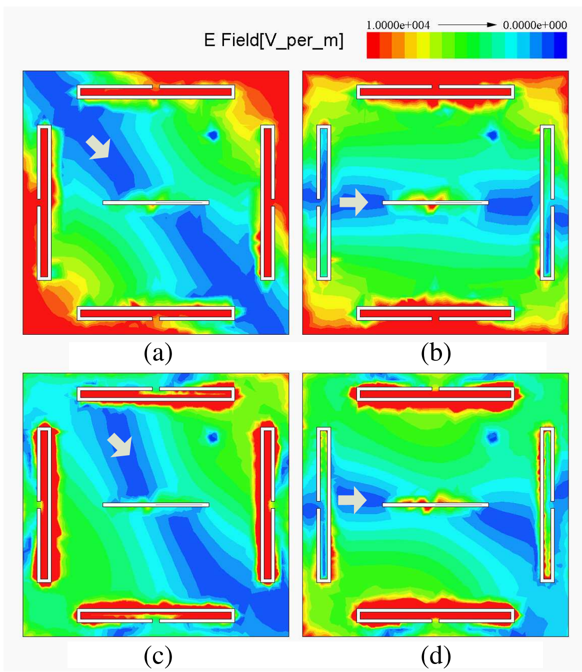


Figure 2. Distributions of simulated electric field. (a) 1.616 GHz@$t = 0$, (b) 1.616 GHz@$t = T/8$, (c) 2.492 GHz@$t = 0$, (d) 2.492 GHz@$t = T/8$.

3. NUMERICAL ANALYSIS

The characteristics of the proposed CP antenna are simulated by the software Ansoft HFSS v12.1. In order to achieve dual-frequency and circularly-polarized operation, a detailed parametric study of the antenna is made discussed. To decrease the complexity of the design, the following antenna parameters are selected as: $G = 50$ mm,

$L3 = 2\,\text{mm}$, $L4 = 1\,\text{mm}$, $W1 = W2 = 0.5\,\text{mm}$, $D = 12.5\,\text{mm}$. The side length L of the square patch, the length $L1$ of the slit, the length $L2$ of each C-slot and the distance $L5$ between the C-slot and the patch center are initially examined.

3.1. The Effects of Variation of *L*

As the side length L of the square patch is varied, the antenna performance also varies. The return loss dependence on this parameter is shown in Fig. 3. It is observed that the matching of the dual-frequency antenna is very sensitive to this parameter. With the side length L of the square patch lengthened, the lower resonant frequency is reduced while the upper is increased. Therefore, the parameter L needs to be optimized to provide circular polarization with good dual-frequency matching. In this paper, the value of this parameter for the proposed antenna is selected as $L = 37.6\,\text{mm}$.

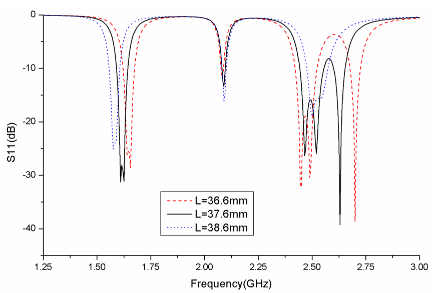


Figure 3. Simulated results of S_{11} for the proposed antenna with different L.

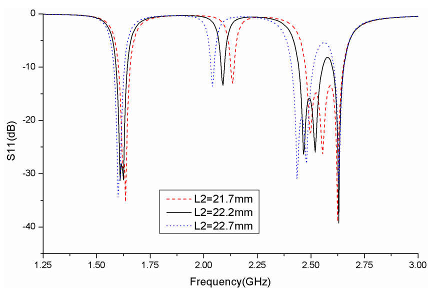


Figure 4. Simulated results of S_{11} for the proposed antenna with different $L2$.

3.2. The Effects of Variation of *L*2

With increasing the parameter $L2$, the surface current paths for both resonances are lengthened. So the two resonant frequencies are reduced. As shown in Fig. 4, it is seen that the upper resonant frequency is varied largely with different $L2$ while the lower is affected lightly. In another word, the upper frequency can be controlled with little effect to the lower. Here, the value of $L2$ is selected as $L2 = 22.2\,\text{mm}$.

3.3. The Effects of Variation of $L5$

The effects of the varying parameter $L5$ on the antenna performance is just the opposite to the variation of L. With the distance $L5$ between each C-slot and the patch center lengthened, the upper resonant frequency is reduced while the lower is increased. It is clearly seen that in Fig. 5, the upper frequency shows heavy dependence while the lower one is scarcely affected by this parameter. So adjusting $L5$ together with $L2$, the upper frequency can be separately controlled. The value of $L5$ is selected as 11.75 mm.

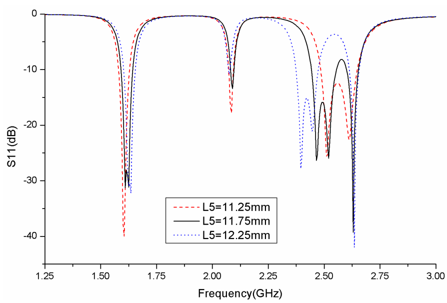


Figure 5. Simulated results of S_{11} for the proposed antenna with different $L5$.

3.4. The Effects of Variation of $L1$

The CP operation of the proposed antenna is mainly affected by the slit inserted in the center of the patch. Experimental results of the measured input impedance for different values of the parameter $L1$ are presented in Fig. 6. It is known to us that a loop instead of a dip will be observed in the impedance locus if the two modes are excited at frequencies far apart and in addition, the loop becomes bigger with the two modes further apart. As expected, from Fig. 6, the two modes are further apart when $L1$ is increased. Besides, it should be noted that, as the value of $L1$ equals 15 mm, a dip is generated in the lower band impedance locus while a loop in the upper. That is because the frequency difference for the lower band (TM_{10}) is smaller than the one for the upper band (TM_{30}), which is generated by different current paths of the excited patch surface. In other words, the CP performance of both bands couldn't be best at the same time. Balancing them, the slit length is selected as $L1 = 15$ mm.

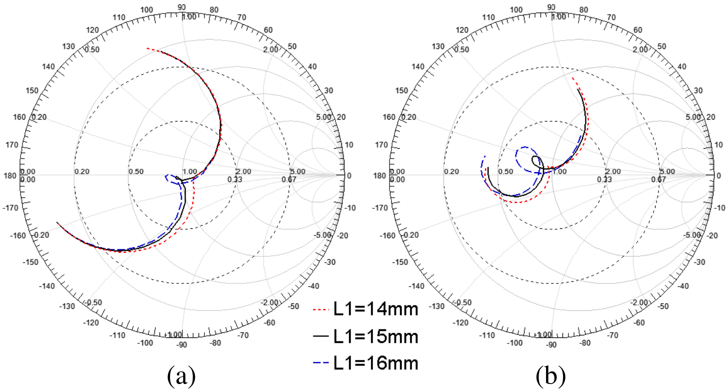


Figure 6. Measured input impedance for the proposed antenna at (a) 1.55–1.7 GHz and (b) 2.42–2.58 GHz.

4. SIMULATED AND MEASURED RESULTS

According to the results of the numerical analysis, the optimized parameters of the proposed antenna dimensions are as follows: $G = 50\,\text{mm}$, $L = 37.6\,\text{mm}$, $L1 = 15\,\text{mm}$, $L2 = 22.2\,\text{mm}$, $L3 = 2\,\text{mm}$, $L4 = 1\,\text{mm}$, $L5 = 11.75\,\text{mm}$, $W1 = W2 = 0.5\,\text{mm}$, $D = 12.5\,\text{mm}$. The photo of the fabricated antenna is shown in Fig. 7.

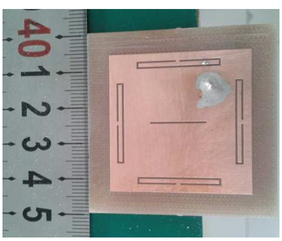


Figure 7. Photo of the fabricated antenna.

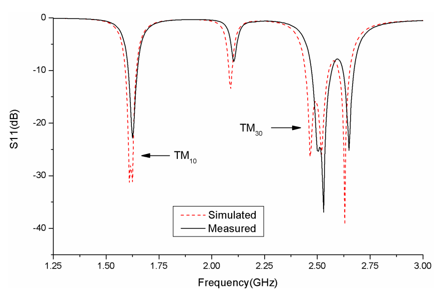


Figure 8. Simulated and measured results of S_{11} for the proposed antenna.

As seen in Fig. 8, the measured result of return loss shows good agreement with the simulation. The measured 10 dB return loss bandwidths are approximately 3.4% (55 MHz) with respect to 1.616 GHz and approximately 4.0% (100 MHz) with respect to 2.492 GHz for CNSS dual-band application. The measured axial-ratio against frequencies in the outdoor test system are in Fig. 9. It can be seen that the measured result is better than the simulation. The measured bandwidths of the axial-ratio which are less than 3 dB are 15 MHz (about 0.93% with respect to 1.616 GHz) and 26 MHz (about 1.04% with respect to 2.492 GHz). Figs. 10 and 11 respectively show the simulated and measured normalized radiation patterns in XOZ-plane at 1.616 GHz and 2.492 GHz. It is confirmed that the RHCP and LHCP radiation patterns are excited in the upper and lower half space, respectively.

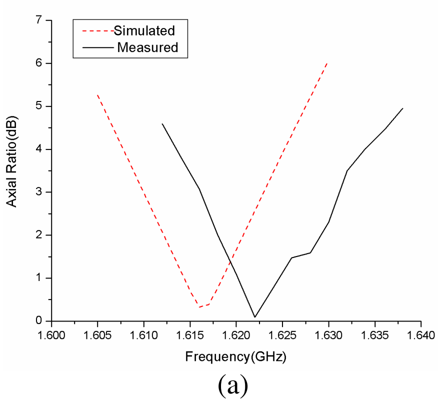


Figure 9. Axial-ratio against frequencies for the proposed antenna.

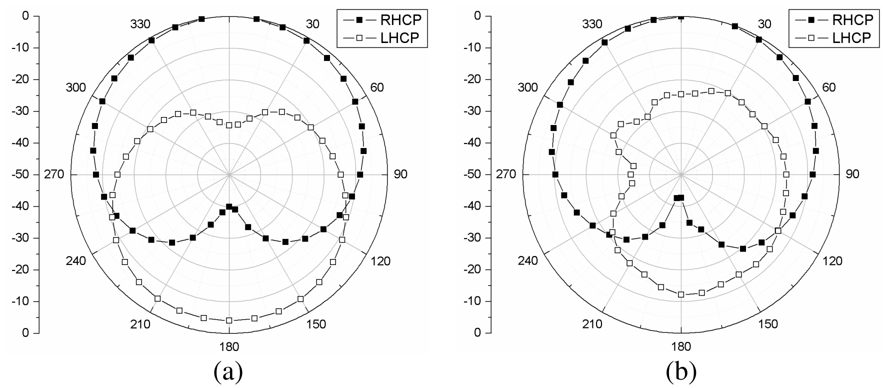
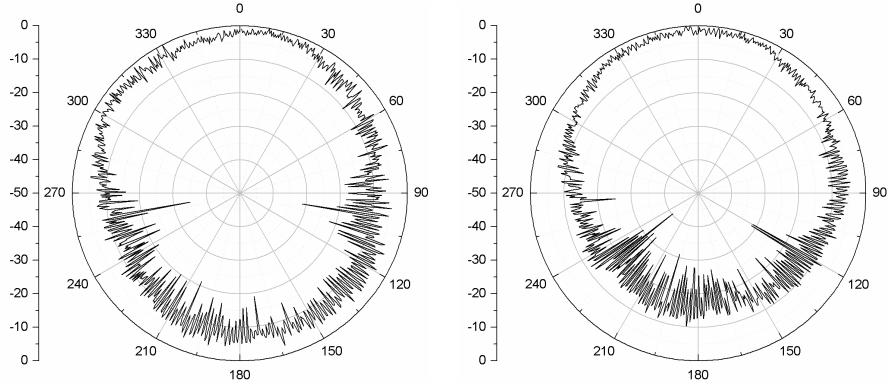


Figure 10. Simulated radiation patterns against frequencies for the proposed antenna at (a) 1.616 GHz and (b) 2.492 GHz.



(a) (b)

Figure 11. Measured radiation patterns against frequencies for the proposed antenna at (a) 1.616 GHz and (b) 2.492 GHz.

5. CONCLUSION

A novel single-feed microstrip patch antenna comprising a square patch with four symmetrical C-slots and a slit embedded is demonstrated to generate good dual-frequency circular polarization characteristics. The antenna is fabricated on FR4 substrate and could be used in CNSS application. Moreover, this structure can effectively reduce the patch size and make it easy to be implemented in applications requiring small size antennas.

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