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DESIGN OF DUAL-BAND DUAL-SENSE CIRCULARLY POLARIZED SLOT ANTENNA

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Abstract—Based on a construction of concentric deformed annular slots with a stepped microstrip feed line, two designs of dual-band dual-sense circularly polarized slot antenna are proposed in this paper. Compared with the first antenna, the second design possesses the merits of simple structure by devising a twin-slot with less adjusted parameters to achieve the same satisfactory output responses. The results from simulations and measurements demonstrate that both of the antennas have good quality of impedance matching and dual-sense circular polarization at 1.6 GHz and 2.5 GHz.

1. INTRODUCTION

With the rapid development of wireless communication, higher transmission capacity has become a supreme need. Utilizing an antenna with orthogonally circular polarizations at two discrete working frequencies has been proved to be an efficient way to fulfill such a demand. This is simply because a left-hand circularly polarized antenna can normally receive incoming waves of any polarization except the one of right-hand circular polarization [RHCP], and vice versa. As a result, the antenna working frequency can thus be reused to enlarge the overall capacity in the wireless transmission. Therefore, dual-band dual-sense circularly polarized antennas have become a hot study in this research area during the last few years. Various antenna structures have been proposed to devise two orthogonal circular polarizations at different frequencies. Slot antennas [1–6], microstrip patch antennas with partially filled substrate [7], notched

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printed monopole antennas [8], and dual-fed antenna arrays [9, 10] are the common types to realize such a design. Among these, slot antenna is the most popular candidate to achieve circular polarizations [11–15]. And the good isolation between the radiating elements and feeding network makes slot antenna become a prior choice to the design of dual-band dual-sense of circularly polarized antennas [1–6, 9] and multi-band circularly polarized antennas [16–19].

However, most of the proposed dual-band dual-sense circularly polarized slot antennas in present literatures have relatively complex structures with several optimized parameters in order to achieve orthogonally circular polarization at two different working frequencies. And the most difficulty issue for such an antenna design lies on the fact that these variables in the antenna structure working together to determine the impedance matching and circular polarization performance. Therefore, these variables are not ideally independent, but strongly related and one parameter will affect the selection of other parameters. As a result, it is not easy to have two axial ratio bands of the antenna coincide with the antennas working frequencies where impedance matching is satisfied. In addition, even a proposed design can function well with dual-band dual-sense circular polarization, but based on a complex structure, it would be complicated if we want to reproduce the design into another frequency band.

In this paper, two designs of dual-band dual-sense circularly polarized slot antenna are proposed based on a construction of concentric deformed annular slots with a stepped microstrip feed line. Both antennas are devised to work at 1.6 GHz with left-hand circular polarization (LHCP) and 2.5 GHz with RHCP, which can be applied in the Chinese BeiDou Navigation Satellite System (BDS). The two structures are simulated, manufactured and measured. Both of the two antennas exhibit the desirable performance of impedance matching and circularly polarization in the two frequency bands. The second structure is a simplified design with less parameters on the basis of the first antenna to achieve the same satisfactory output responses, and has the merits of easy replication and implementation in the practical engineering application.

2. ANTENNA CONFIGURATION AND DESIGN

The geometry of proposed dual-band dual-sense circularly polarized Antenna-1 and Antenna-2 are shown in Fig. 1. Both of the two antennas are printed on 1.6 mm-thick FR4 substrate with the dielectric constant $\varepsilon_r = 4.4$, and fed by a stepped microstrip line printed on the bottom of the substrate, consisting of an impedance transformer with

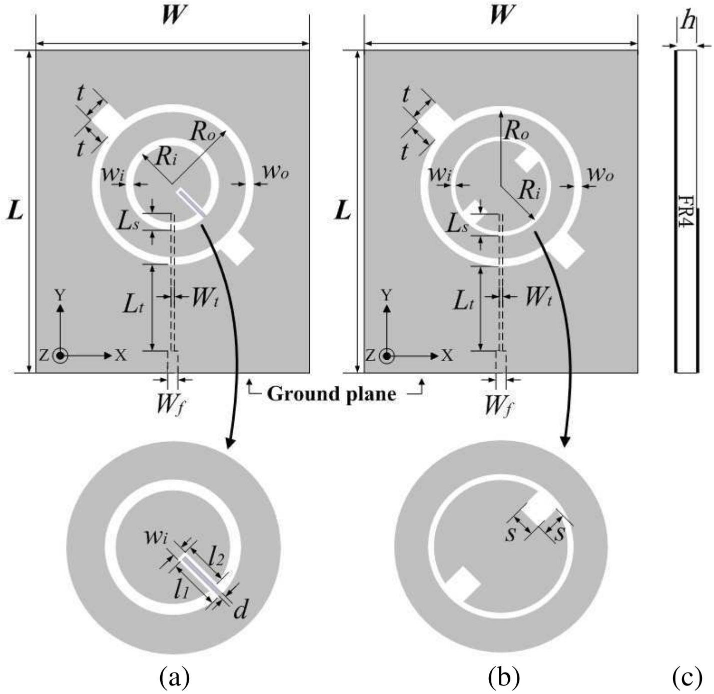


Figure 1. Geometry of the two antennas. (a) Top view of Antenna-1, (b) top view of antenna of Antenna-2, (c) side view of the two antennas.

the dimensions of L_t and W_t, and a transmission line of the same width and a L_s long stub to feed the two annular slots. The detailed dimensions of Antenna-1 are $W = 80\,\text{mm}$, $L = 95\,\text{mm}$, $R_i = 12.5\,\text{mm}$, $R_o = 22.5\,\text{mm}$, $w_i = 2\,\text{mm}$, $w_o = 2\,\text{mm}$, $t = 8\,\text{mm}$, $l_1 = 10.5\,\text{mm}$, $l_2 = 9.1\,\text{mm}$, $d = 0.8\,\text{mm}$, $h = 1.6\,\text{mm}$, $W_f = 3\,\text{mm}$, $W_t = 1\,\text{mm}$, $L_t = 25\,\text{mm}$, $L_s = 5\,\text{mm}$, while the dimensions of Antenna-2 are $W = 80\,\text{mm}$, $L = 95\,\text{mm}$, $R_i = 14\,\text{mm}$, $R_o = 22.5\,\text{mm}$, $w_i = 1\,\text{mm}$, $w_o = 2\,\text{mm}$, $t = 7.5\,\text{mm}$, $s = 5\,\text{mm}$, $h = 1.6\,\text{mm}$, $W_f = 3\,\text{mm}$, $W_t = 1.3\,\text{mm}$, $L_t = 25.5\,\text{mm}$, $L_s = 7\,\text{mm}$. The two proposed antennas are fabricated and their prototypes are shown in Fig. 2.

Generally, a typical route to design a dual-band dual-sense circularly polarized antenna design basically follows two steps. In the first place, we can use two annular slots to determine the antenna working frequencies, and then we may devise the deformed notch parts on the slots to have the dual-sense CP. Therefore, an easy implementation of the antenna is that we can employ two circular polarized annular slot antennas to perform a direct sum up. Antenna-

Figure 2. Photograph of the two proposed antennas.

1 is just such an outcome. The outer slots of Antenna-1 is an deformed annular slot with a pair of square notches placed outward at 135° and 315° with respect to the x-axis, and the inner one is based on the structure introduced in [11], which is an annular-ring slot antenna with a meandered slot section placed at 135° with respect to the x-axis. The meandered slot has a protruded rectangular slot and a metallic strip of narrow width centered in the rectangular slot section. The width of the rectangular slot is equal to that of the inner annular slot, and its length l_2 is related to the metallic strip's length l_1 with the expression of $l_2 = l_1 - 0.5w_i - 0.5d$ to make the slot around the strip be uniform. The two working frequencies are mainly controlled by the circumferences of the inner and outer deformed annular slots. The square notches in the outer annular slot and the meandered slot section in the inner annular slot provide dual-sense circular polarization at the two frequencies by perturbing the symmetry of the annular slots in order to split the fundamental resonant mode into two orthogonal degenerate resonant modes, which lead to LHCP radiation in $+z$ direction at 1.6 GHz and RHCP radiation in $+z$ direction at 2.5 GHz, respectively.

However, in such a design by simply combining two circularly polarized slot antennas, there are as many as 10 parameters that need adjusting, such as R_o, R_i, w_o, w_i, L_t, L_s, W_t, t, l_1, l_2, and d, which make the antenna design complex. Among these parameters, the ring slots with R_o, R_i, w_o, w_i determine the two resonant frequencies of the Antenna-1, and the stepped feed line with L_t, L_s and W_t are devised accordingly in order to have the impedance matching. Ring slots having the merits of symmetry and concise are the simplest construction. Therefore, these 7 parameters are necessary in this design. However, to realize the CP, the inner annular slot is relatively complex by using l_1, l_2 and d. Clearly, if we can reduce these 3 parameters to 1, and employ only a square notch as the outer one, the workload of parameter adjustment should decrease immensely. Based on this consideration, another structure is proposed by changing the inner slot of Antenna-1 to a more simplified one, which is similar to the outer slot with the square notches placed inward with the orientation orthogonal to the outer ones to obtain inverse circular polarization at 2.5 GHz, as is shown in Fig. 1(b). Besides the radius and the width, the new inner slot structure has only one parameter, which is the side length of the square slot, while the inner slot of Antenna-1 possesses 3 parameters. As a result, the new structure, having a twin-slot structure with two parameters less than Antenna-1, should be much easier in the design and implement to other frequencies.

3. RESULTS AND DISCUSSION

Both the full wave simulations (HFSS ver.13) and measurements have been carried out to verify the proposed designs. It can be seen from Fig. 3 that the antenna bandwidth with 10-dB return loss in the lower and upper bands are 25% (1.29 GHz∼1.69 GHz) and 10.8% (2.38 GHz∼2.65 GHz) for Antenna-1, and 25.6% (1.27 GHz∼1.68 GHz) and 20% (2.06 GHz∼2.56 GHz) for Antenna-2. For the lower frequency, two antennas are similar because they have the same outer slot structure. While for the upper frequency, the impedance bandwidth of Antenna-2 is a little larger than that of Antenna-1. However, both of the antennas function considerably well and cover the two bands of Chinese BDS.

The axial ratios in $+z$ direction of the two antennas are shown in Fig. 4. The 3-dB axial ratio bandwidths are 5.6%

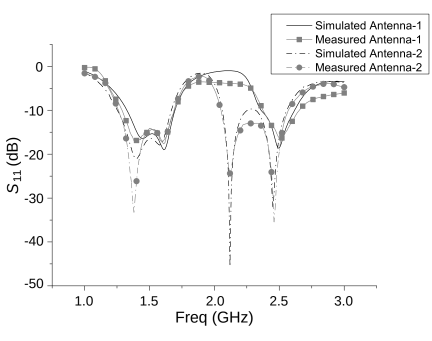


Figure 3. S_{11} of the two antennas.

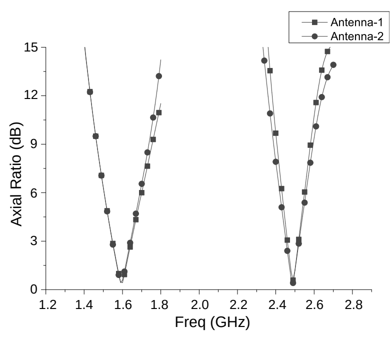


Figure 4. Axial ratio of the two antennas.

(1.55 GHz∼1.64 GHz) at the lower band (LHCP) for both two antennas and 2% (2.47 GHz∼2.52 GHz) and 2.4% (2.46 GHz∼2.52 GHz) at upper band (RHCP) for Antenna-1 and Antenna-2, respectively. As we can observe in Fig. 5, the axial ratios of both antennas are very small in the $+z$ direction, and the performance of circular polarization of antennas deteriorates as the angle of theta increases. The range of theta covered by 3-dB axial ratio at 1.6 GHz is larger than that at 2.5 GHz. Fig. 6 shows the radiation patterns in both xz-plane and yz-plane of the two antennas at 1.6 GHz and 2.5 GHz. The two antennas radiate microwaves in both $\pm z$ directions with inverse circular polarization. The peak gains of the two antennas in the direction of the main beam are 3.60 dBic and 3.63 dBic at 1.6 GHz (LHCP), and 3.96 dBic and 4.40 dBic at 2.5 GHz (RHCP), respectively, which can fulfil the needs of general wireless communication systems. And for the two bands of both the two antennas, the cross-polarization (RHCP at the lower band and LHCP at the upper band) are at least 20 dB lower than the co-polarization.

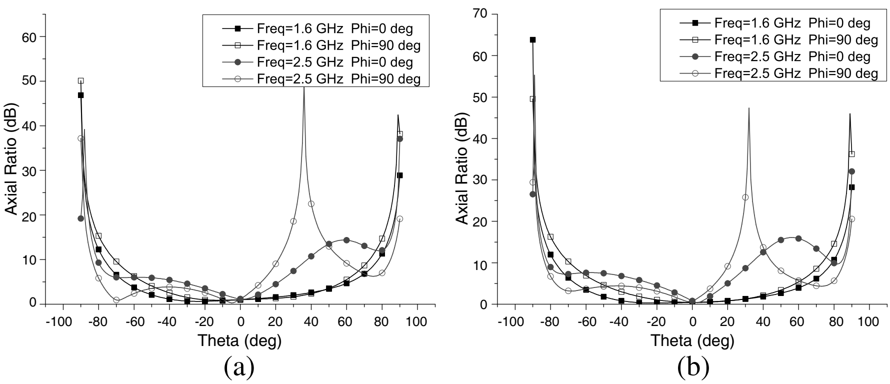


Figure 5. Axial ratio against theta of the proposed (a) Antenna-1 and (b) Antenna-2.

4. PARAMETRIC STUDY

Both of the two proposed antennas have many geometrical parameters. It is obvious that the two operating frequency bands are mainly determined by the outer and inner annular slots for each antenna. After setting the radius of the two annular slots according to the operating frequencies, some key parameters should be adjusted to obtain the ideal dual-band and dual-sense CP performance.

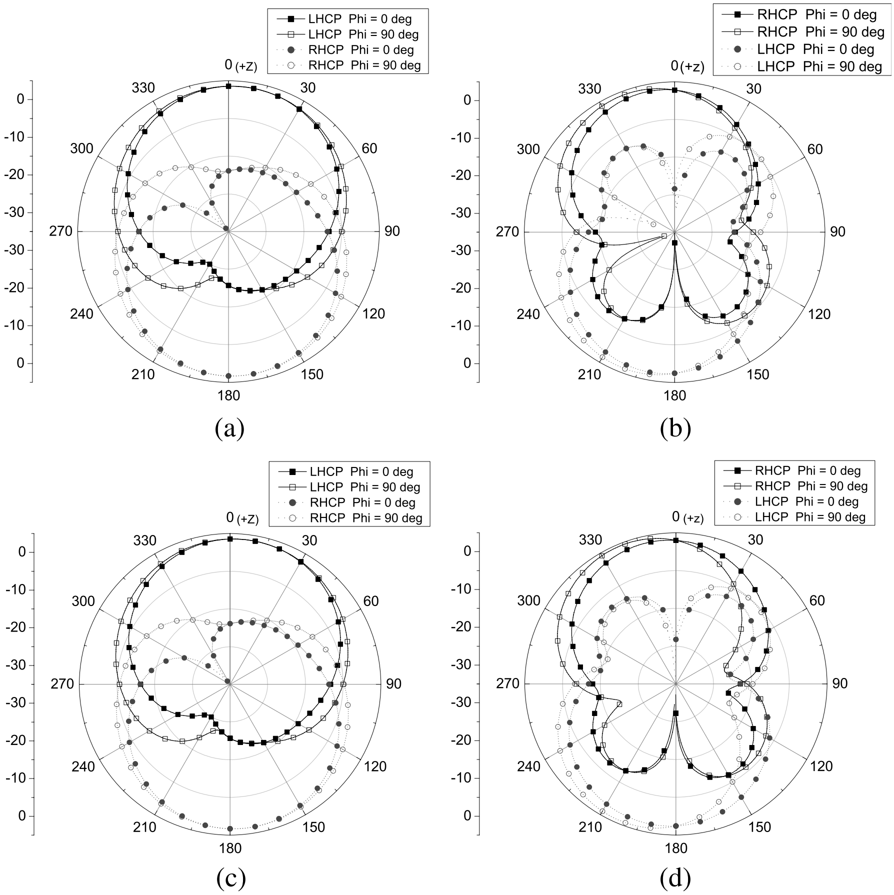


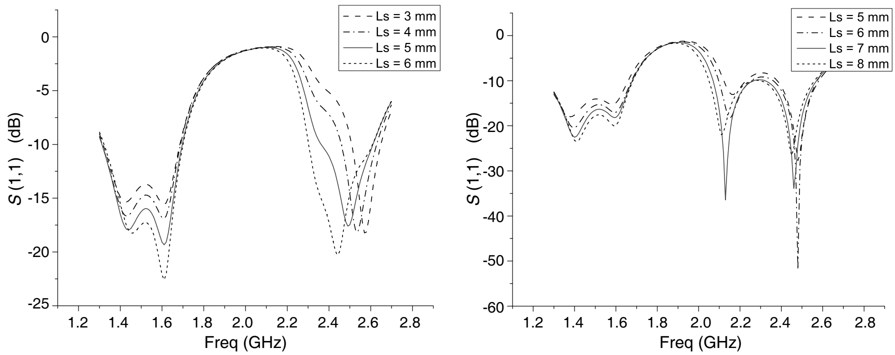
Figure 6. Radiation patterns of the proposed antennas. (a) Antenna-1 at 1.6 GHz, (b) Antenna-1 at 2.5 GHz, (c) Antenna-2 at 1.6 GHz, (d) Antenna-2 at 2.5 GHz.

4.1. Effects of L_s

The effects of stub length L_s on the return loss and axial ratio of the two proposed antennas are shown in Figs. 7 and 8, respectively. The figures show that the change of stub length L_s lead to frequency offsets on the impedance matching and CP performance of the upper band, but has small influences on that of the lower band.

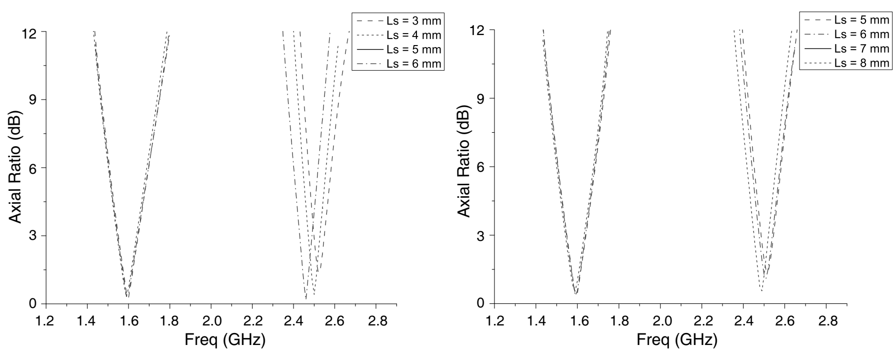
4.2. Effects of t and s

Figure 9 shows the comparison of the axial ratio of Antenna-2 at lower band and upper band with different side length of square notches of the



(a) (b)

Figure 7. Return loss against frequency of the proposed (a) Antenna-1 and (b) Antenna-2 for various L_s.



(a) (b)

Figure 8. Axial ratio against frequency of the proposed (a) Antenna-1 and (b) Antenna-2 for various L_s.

outer slot and inner slot, respectively. These two parameters determine the circular polarization performance of two frequencies. The figure shows that the axial ratio would get deteriorated if t and s are larger or smaller than the optimal value. Since the two antennas share the same structure of outer ring-slot, the effects of t on axial ratio of Antenna-1 should be similar.

4.3. Effects of l_1 and d

l_1 and d are the two critical parameters which determine the circular polarization performance of Antenna-1 at upper frequency. Although the meandered slot section of Antenna-1 have three parameters which

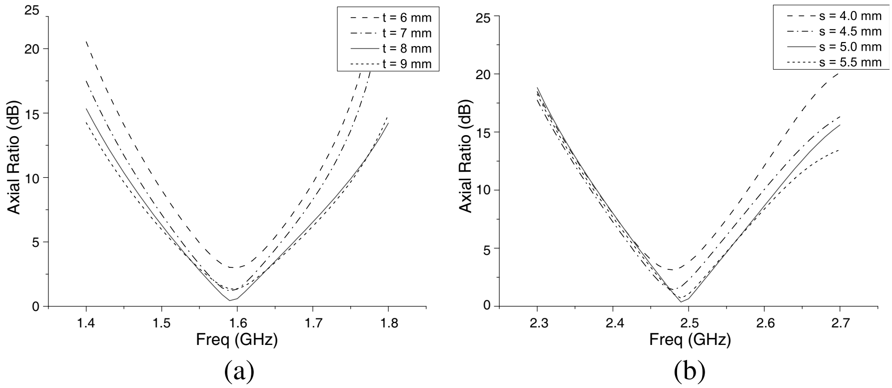


Figure 9. Axial ratio against frequency of Antenna-2 (a) at lower band for various t and (b) at upper band for various s.

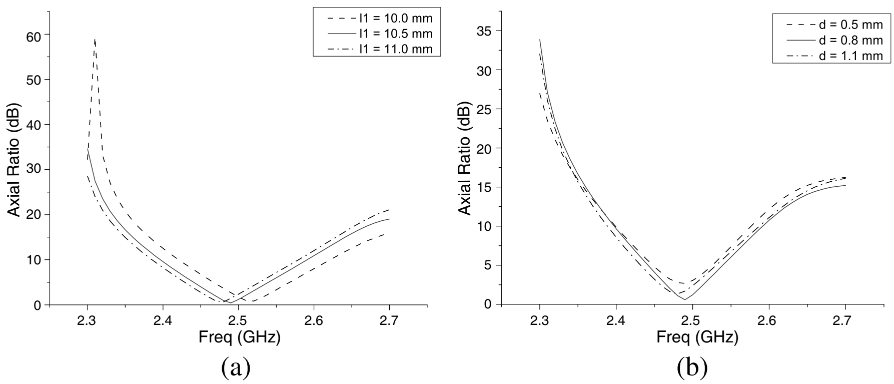


Figure 10. Axial ratio against frequency of Antenna-1 at the upper band for various (a) l_1 and (b) d.

are l_1, l_2 and d, the width of the gap around the metallic strip are kept equal in the design in order to simplified the structure. Thus through tuning the size of the metallic strip, the optimal circular polarization performance can be achieved. Fig. 10 shows the effects of l_1 and d on axial ratio at the upper band of the proposed Antenna-1.

5. CONCLUSION

We have proposed two structures of dual-band dual-sense of circular polarization antenna in this paper, both of which have good performances of impedance matching and circular polarization at

1.6 GHz and 2.5 GHz. By using a twin-slot, the second structure offers a simplified design with less parameters on the basis of the first antenna, but can also provide the same satisfactory output response. The present design, as good candidates in the application in Chinese BDS, will pave a way to novel antennas in the contemporary wireless communication requires higher transmission capacity.

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