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A Broadband Circularly Polarized Antenna Based on Cross-Dipoles

Zhanbiao Yang[1, *], Xin Huai Wang[1], Le Kang[1], Hao Wang[1], Jianhui Bao[2], and Xiaowei Shi[1]

Abstract—In this paper, based on cross-dipoles, a right-handed circularly polarized (RHCP) antenna with both broad impedance and axial-ratio (AR) bandwidth is proposed. Moreover, metal vias and branches are loaded to the cross-dipoles aiming to decrease the size of the antenna. The measured results show that a broadband impedance matching bandwidth ranging from 1.83 to 3.42 GHz for S_{11} less than -10 dB is obtained. Meanwhile, the 3-dB axial-ratio bandwidth is more than 29.0%, and the peak gain of the antenna is about 7.3 dBi with small variation at 2.5 GHz. A prototype is fabricated and measured for validating the design. The good agreements between the simulated and measured results show that the proposed antenna maybe a good candidate in circularly polarized (CP) antenna family.

1. INTRODUCTION

Circularly polarized microstrip patch antennas are highly popular in a vast number of applications such as Satellite Communications Systems, Global Positioning System (GPS), and Radio Frequency Identification (RFID) [1–3]. They have several attractive advantages including low profile, lightweight, and low cost. However, the performance of microstrip antennas are limited by the bandwidth of antennas. For high-speed transmission in wireless communications, the antennas with wide bandwidth are required. Therefore, a high gain, low-profile antenna with wide axial-ratio bandwidth CP antenna is urgently required for high data rate wireless communication. Recently, a set of techniques are proposed to widen the axial ratio bandwidths of CP antenna, such as the single L-shaped probe feed [4] and the dual feed [5–7] and so on. However, most of these antennas are developed with complex structures. In addition, the compact crossed dipole antenna is another effective method to enhance the AR bandwidth of CP antennas. In [8–12], CP characteristics are produced by crossing two dipoles through a 90° phase delay line of a vacant-quarter printed ring. Although the appropriate 3-dB AR bandwidth of the antenna in [13] is achieved, its impedance bandwidth is narrow and the gain of the antenna is not satisfactory.

In this paper, A RHCP antenna with wide impedance bandwidth is presented for ISM (Industrial Scientific Medical). Based on the above analysis, a new loop loading technique is proposed to broaden the bandwidth and improve the gain of the antenna. The metal vias and branch basis of this structure are added, the absolute bandwidth of the improved can reach 1.59 GHz and 3-dB AR bandwidth is 29.0% ranging from 2.21 to 2.93 GHz. Unlike the traditional cross-dipoles antenna, the proposed antenna is designed with four small radiating patches instead of wide open-ends, which could reduce the area of the surface of the radiator. A wide input impedance of the antenna can be realized by adjusting the length and width of the radiation patch. The measured results show that the proposed antenna has a peak gain of 7.3 dBi at 2.5 GHz. The antenna design and its application are introduced in the Section 2. The comparison between the simulated results and the measured results are presented in Section 3. The last section summarizes the whole paper and illustrates the study result and reality significance.

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* Corresponding author: Zhanbiao Yang (854134662@qq.com).
[1] Science and Technology on Antenna and Microwave Laboratory, Xidian University, Xi'an, Shaanxi 710071, China. [2] Hebei University of Technology, Tianjin 300130, China.

2. ANTENNA ANALYSIS AND DESIGN

The geometry of the CP patch antenna is shown in Figure 1, which is composed of two printed dipoles and a plane reflector. The printed cross dipoles are fabricated on both layers of a square FR4 substrate with a thickness of 1.6 mm. The thickness of the copper on each layer of the FR4 substrate is 35 µm. The designed antenna with an overall size of $70 \times 70\,\text{mm}^2$ is printed on an FR4 with a dielectric constant 4.4, loss tangent 0.02 and center-fed by a $50\,\Omega$ coaxial feed line. The inner conductor of the coaxial cable is extended through the substrate to feed the crossed arms at the top layer of the substrate, and the outer conductor is welded to the crossed arms at the other layer. The symmetrical radiation patterns in the whole operating bandwidth can be realized by the center-fed.

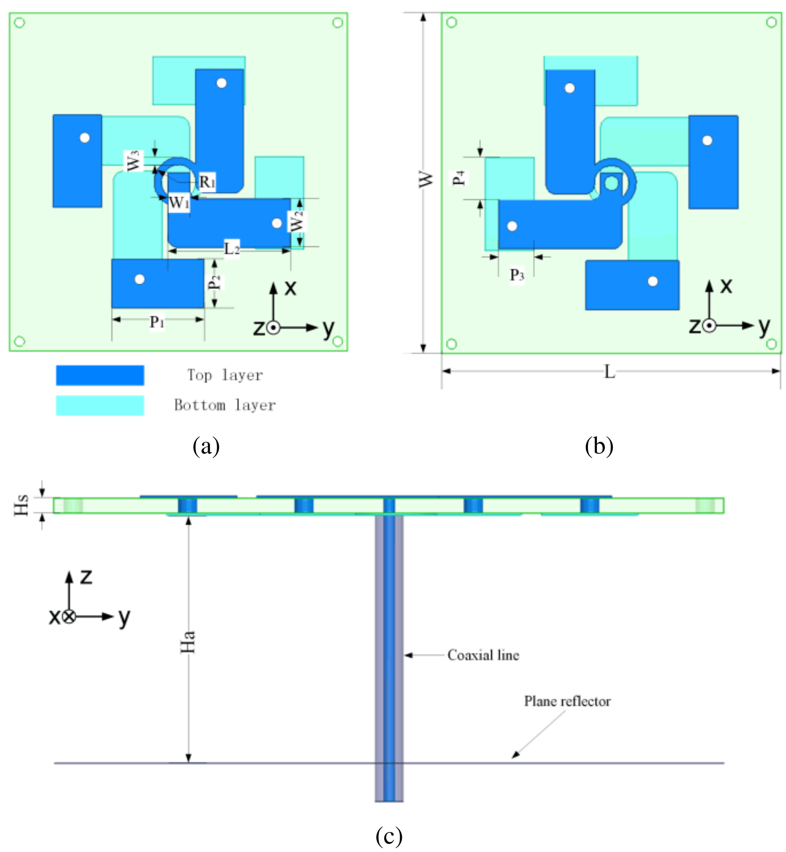


Figure 1. Geometry of the proposed antenna. (a) Top view. (b) Bottom view. (c) Side view with a plane reflector.

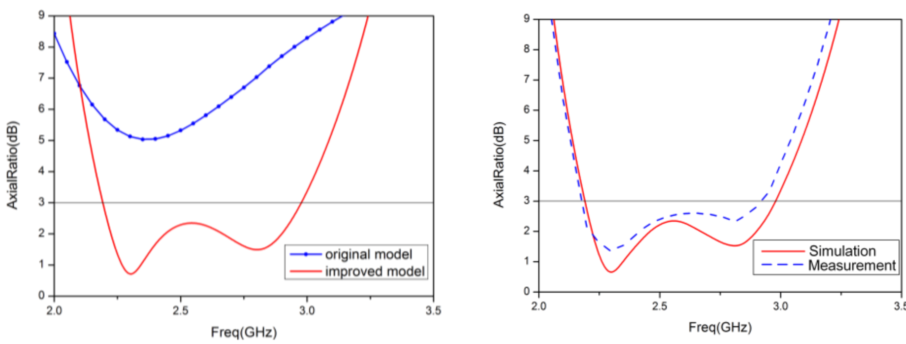
CP waves are generated from two orthogonal polarized independent radiation waves. Perfect CP waves can be achieved when the phase shift between the two waves is set to 90° and their amplitudes are equal. The phase difference is provided by two orthogonal cross-dipoles elements fed by a circular phase delay line, which could excite the CP radiation effectively. The four radiation patches connect with crossed-dipoles through metal vias, which could increase the electrical length. These two cross-dipoles have the same structure. The resonant frequency is determined by the value of $P_1 + P_2$. The distance between the bottom surface of FR4 substrate and the plane reflector is Ha. The substrate plate is supported by four same height plastic columns.

The design and optimization of the proposed antenna was realized by using the commercial electromagnetic (EM) software HFSS. The optimized antenna design parameters are as follows: $W_1 = 4.5\,\text{mm}$, $W_2 = 10\,\text{mm}$, $W_3 = 1.5\,\text{mm}$, $R_1 = 5.1\,\text{mm}$, $L_2 = 25.5\,\text{mm}$, $P_1 = 19.1\,\text{mm}$, $P_2 = 10.05\,\text{mm}$, $P_3 = 7.47\,\text{mm}$, $P_4 = 8.9\,\text{mm}$, $L = 70\,\text{mm}$, $W = 70\,\text{mm}$, $Hs = 1.6\,\text{mm}$, $Ha = 26\,\text{mm}$.

The process of antenna design is shown in Figure 2. The initial design in Figure 2(a) used four small square radiating patches instead of wide open-ends, which could make the area of the surface of the substrate effectively utilized. Compared with the antenna proposed in [13], the AR bandwidth in this design is better. Then, the structure of radiating patches has been improved with the P_1 increment and the size of dipoles reduction, which is shown in Figure 2(b), in order to enhance the AR bandwidth. It can be seen from the Figure 2(b) and Figure 3(a), the improved model occupies a smaller area while exhibits a wider 3-dB AR bandwidth. Measured and simulated 3-dB ARs of improved model are presented in Figure 3(b).

(a) (b)

Figure 2. The process of antenna design. (a) Square radiating patches, (b) improved model.



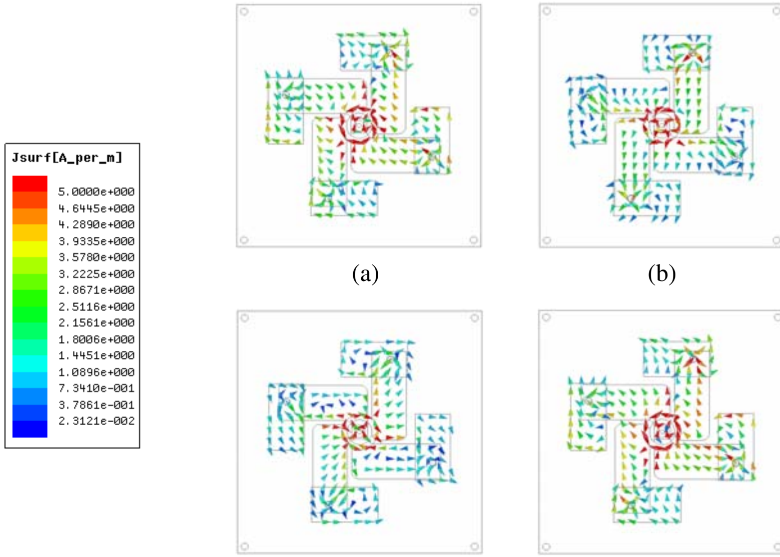
(a) (b)

Figure 3. (a) Simulated axial ratio for original and improved model. (b) Measured and simulated axial ratio.

Polarization for an antenna can be represented by surface current. The surface current distributions of the proposed antenna at 2.5 GHz, shown in Figure 4, can be employed to explain the CP radiation performance. It can be found that the current distributions are located in each dipole for four phase angles of 0°, 90°, 180°, and 270°, respectively. The two individual half-wavelength dipole antennas also have typically larger relative current near the middle and zero current at the ends of the dipole arms. To achieve a better understanding of the effect of the current distributions in Figure 4, it can be seen that the majority of the current flows at an angle on the rectangle metal. It is observed that the current is flowing in a counter clockwise direction, so the resulting polarization is RHCP.

3. RESULTS AND DISCUSSION

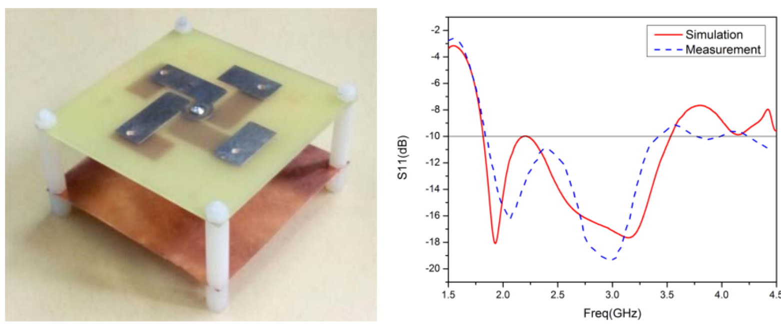
A prototype of the antenna and reflection coefficients of the fabricated antenna are shown in Figure 5. The results indicate that impedance bandwidth ranges from 1.83 to 3.42 GHz indicating a fractional bandwidth of 63.6% around the center frequency. Here an analysis has been done on P_1 and P_2 parameters, which have a significant influence on the AR bandwidth. Figures 6(a) and (b) show the simulated 3-dB AR bandwidth with different values of P_1 or P_2. As can be seen from Figure 6(a), the 3-dB AR bandwidth is the broadest when $P_1 = 19.1$ mm and $P_2 = 10.05$ mm. Figure 6(a) also shows that varying P_1 from 19 mm to 19.2 mm with 0.1 mm steps, the 3-dB AR bandwidth increases. However, when $P_1 = 19.1$ mm and $P_2 = 10.05$ mm, the AR bandwidth experiences fluctuation at 4.25 GHz. Thus,



(a) (b)

(c) (d)

Figure 4. The simulated current distribution on the crossed dipoles at 2.5 GHz for (a) 0°, (b) 90°, (c) 180°, (d) 270°.



(a) (b)

Figure 5. A prototype and the reflection coefficients of the fabricated antenna.

the best choice for P_1 will be 19.1 mm. From Figure 6(b), as P_2 varies from 10.07 mm to 10.03 mm in decrements of 0.02 mm and P_1 is kept at 19.1 mm, the 3-dB AR bandwidth increases at first, and then decreases. The optimal value is $P_2 = 10.05$ mm. It means that the input impedance of the antenna and phase difference can be changed by properly adjusting the length (P_1) or width (P_2) of the radiating patch. The radius (R_1) and width (W_1) of the curved-delay line also have significant effect on the CP radiation pattern. As shown in Figures 6(c) and (d), a wider 3-dB AR bandwidth can be achieved when $R_1 = 5.1$ mm and $W_1 = 4.5$ mm.

Figures 6(e) and (f) show the reflection coefficients and RHCP gain with varying Ha from 24 mm to 28 mm with 2 mm steps. As can be seen from Figure 6(e), reflection coefficients are similar when $Ha = 26$ mm, 28 mm, and the reflection coefficient of $Ha = 24$ mm is more than -10 dB at 2.23 GHz. Considering the size of the antenna, the optimal reflection coefficient is obtained when $Ha = 26$ mm. Figure 6(f) shows that the RHCP gain is little influenced by Ha. The simulated maximum gain is 7.8 dBi at 2.5 GHz when $Ha = 26$ mm.

It is observed that the radiation patterns at 2.2, 2.5, and 2.9 GHz are presented in Figure 7, and the antenna has a stable radiation pattern in x-z plane across the operating frequency. The proposed antenna with two patch dipoles is rotationally symmetric with respect to the two tangential to the plane axes. The 3-dB AR beam width is 78°, and the measured peak gain is 7.3 dBi at 2.5 GHz. The value of the front-to-back is low due to the large ground reflector.

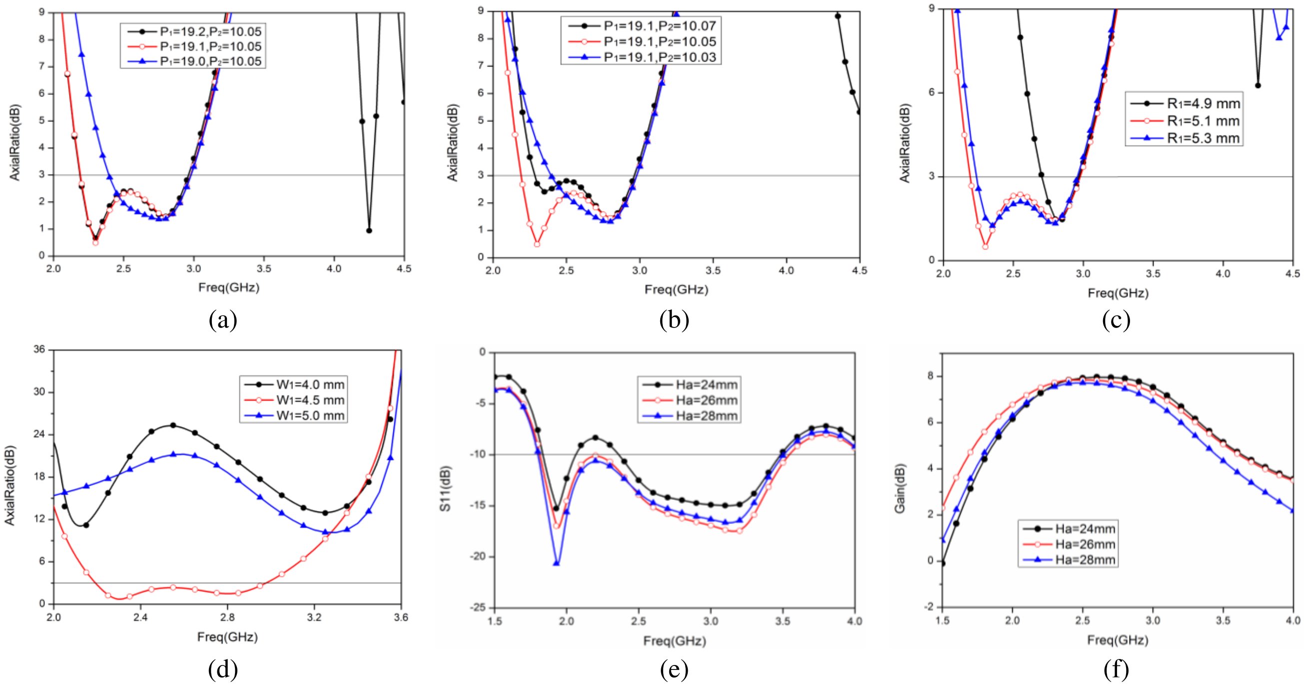


Figure 6. (a) Simulated axial ratio for different P_1. (b) Simulated axial ratio for different P_2. (c) Simulated axial ratio for different R_1. (d) Simulated axial ratio for different W_1. (e) Simulated reflection coefficients for different Ha. (f) Simulated RHCP gain for different Ha.

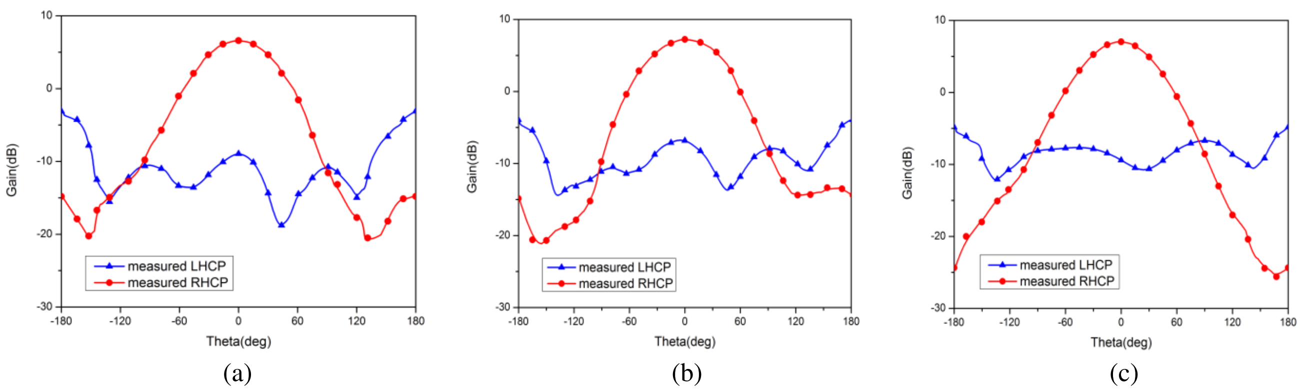


Figure 7. Radiation patterns of the antenna at (a) 2.2 GHz, (b) 2.5 GHz, (c) 2.9 GHz.

4. CONCLUSION

A broadband circularly polarized antenna based on cross-dipoles has been designed, fabricated, and measured. The broadband performance of the antenna is due to the broadband radiation element composed of two cross-dipoles which connect four patches with metal vias.

The measured impedance bandwidth of the proposed antenna is 1.59 GHz (1.83 GHz–3.42 GHz) for S_{11} less than -10 dB, and the 3-dB AR bandwidth is 720 MHz (2.21 GHz–2.93 GHz). The measured peak gain of the proposed antenna at 2.5 GHz is 7.3 dBi. The antenna's compact size, central feeding position and fixing make it widely applied to ISM purposes.

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