A Simple Single-fed Left/Right-Hand Circular Polarization Antenna for GPS Applications

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Abstract – A simple single-feeding circular polarization (CP) antenna with controlled left/right-hand characteristics is proposed and investigated for GPS L2 band applications. To achieve the CP characteristics, four arc-shaped cutting corners with different sizes are removed from a circular patch to give 90° phase difference to implement CP. By adjusting the radius of the four arc-shaped cutting corners, the antenna can be controlled to get left/right-hand circular polarization (L/RHCP). The proposed CP antenna is modeled, simulated, fabricated and measured, and the results demonstrate that the antenna provides an axial ratio beamwidth over 180 MHz, and impedance bandwidth of 20 MHz for L/RHCP. Additionally, the devised CP antennas have good directional radiating patterns, making them suitable for GPS L2 band applications.

Index Terms – arc-shaped slots, GPS, left/right-hand circular polarization antenna, L2 band.

I. INTRODUCTION

Circularly polarized (CP) antennas have been widely used in recent years due to their stable signal transmission and reception characteristics in bad weather,polarization rotation and flexible directionality between transmitter and receiver [1–19]. For satellite and global positioning system (GPS) applications, to improve the accuracy and flexibility of GPS systems, there is a high demand to get thin, lightweight and high gain CP antennas [5, 20, 21]. In the past few decades, a lot of research on various CP antennas including microstrip antennas, horn antennas and spiral antennas has been done [22, 23]. Microstrip antennas have been widely used in military and civil fields due to their advantages of small size, low cost, easy manufacturing and easy expansion into arrays [24, 25]. For developing patch antennas, a simple way to achieve CP operation is to feed the patch in two orthogonal directions to excite two resonant modes [26]. The dual feed mechanism increases the antenna size, the geometric complexity of the antenna, and leads to additional losses that reduce the gain [27]. In order to overcome the complexity of double feed, the patch antenna with single feed is studied [28]. Single-fed microstrip antenna is the simplest structure to realize CP radiation. With the development of microstrip antennas, various single-fed CP microstrip antennas have been reported by adjusting the physical size of the patch or etching the slot [29, 30].

In [31], an antenna is fed by two L-shaped probes in the feed network with a 90° broadband balun. By inserting a small metal sheet between two probes, the current distribution on the patch is changed, and axial ratio (AR) can be adjusted flexibly and the bandwidth could be broadened. A single-fed high-gain CP antenna with loading of shorting pins is proposed in [32]. Two sets of pins are first symmetrically introduced and moved outward along the diagonals of a square patch. After that, two degenerate modes are properly split to produce CP radiation by means of perturbing the position of one pair of the pins.

The characteristics of broadband CP are studied by using the topological structure of antenna in [33]. Impedance and AR bandwidth are achieved by using a new vertically coupled resonator structure and inherent 90° phase difference between the two coupling paths. The neutralization line is then used to improve the isolation between the two polarities. The antenna can achieve CP characteristics due to the U-shaped slots etched on metal patches [34–36].

A microstrip CP antenna loaded with arc-shaped cutting corners is proposed with single feed, which uses four unequal arc-shaped cutting corners in its diagonal. The CP antenna can be used as left/right-hand circular polarization (L/RHCP) antenna by controlling the size of each of the arc-like cutting corners. The proposed

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antenna is modeled, created, simulated and analyzed, and the results show that the modeled antenna has good CP characteristics, directional radiation patterns, which is suitable for GPS L2 band.

II. ANTENNA GEOMETRY AND DESIGN

A. Geometries of the proposed microstrip antenna

The geometry of the proposed CP microstrip antenna is drawn in Fig. 1, where the designed CP antenna resonates at the center frequency of 1.228 GHz. The circular patch is printed on RO5880 substrate with a dielectric constant of 2.2, height of 1.575 mm, and loss tangent of 0.0009. In addition, the circular patch is fed by a coaxial probe, which has the distance of x0 away from the center of the patch. Four arc-like cutting corners are loaded around the radiating patch, and their radius are r1, r2, r3 and r4 respectively. By slightly changing the radius of the four arc-like cutting corners, the proposed antenna can not only generate CP radiation, but also realize polarization for L/RHCP. The antenna has a radius of 67.5 mm, and the other parameters are listed in Table 1.

Table 1: Dimensions of the antenna (UNIT: mm)

Parameter \ Polarization	LHCP	RHCP
r1	13.4	9.7
r2	9.7	13.4
r3	8.45	13.55
r4	13.55	8.45

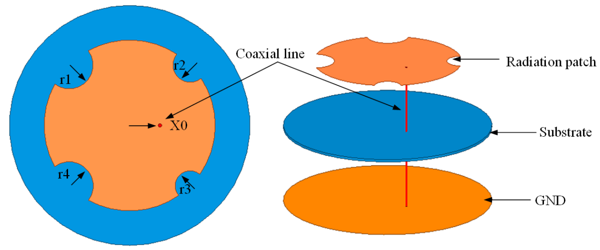

Fig. 1. Model of the CP antenna. (a) Top view. (b) 3-D view.

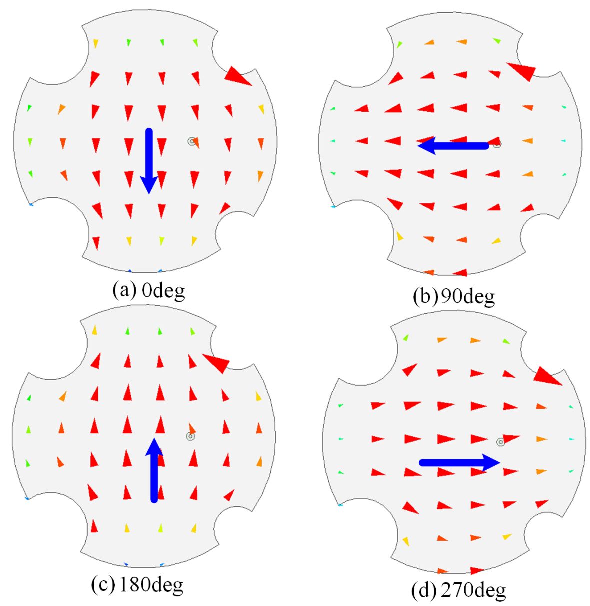

Fig. 2. Surface current distribution for the LHCP antenna at 1.228 GHz.

B. Operating principle of CP radiation

In order to understand the principle of CP antenna design, Fig. 2 shows the surface current on the radiating patch at 1.228 GHz. Before the arc-shaped corners are etched, there is only current vector in the horizontal direction. When the arc-shaped cutting corners are etched, the new current vector is observed in the vertical direction, as shown in Figs. 2 (a) and 2 (d). This clearly shows that due to the asymmetric arc-shaped corner structures, a second resonant mode is generated, which helps to achieve the CP design. In addition, the surface current vector rotates clockwise, which means that the proposed microstrip antenna is LHCP. By changing the radius of the arc-shaped corners, the CP of the antenna can be converted from LHCP to RHCP, as shown in Fig. 3.

For left-handed circular polarization, we have:

$$r4 > r1 > r2 > r3. \quad (1)$$

For right-handed circular polarization, we use:

$$r3 > r2 > r1 > r4. \quad (2)$$

In the design, degeneracy mode can be eliminated by introducing appropriate asymmetry into antenna structure, where a mode increases with frequency and an orthogonal mode decreases by the same amount. Because the frequencies of the two modes are slightly different, with proper design, the field of one mode can produce a 90° phase difference required for circular polarization (CP). Herein, the asymmetric arc-shaped cutting corner helps to generate a second resonant mode, which has a slightly different frequency from the original resonant mode, with a phase difference of 90°. Therefore, CP radiation of the antenna is realized.

C. 3-dB AR beamwidth

The 3 dB AR beamwidth of the two main planes (XOZ and YOZ planes) of the antenna at 1.228 GHz are plotted in Fig. 4, where the AR beamwidth is more than 180°. Therefore, the proposed antenna can cover the whole upper hemisphere and has a good application prospect.

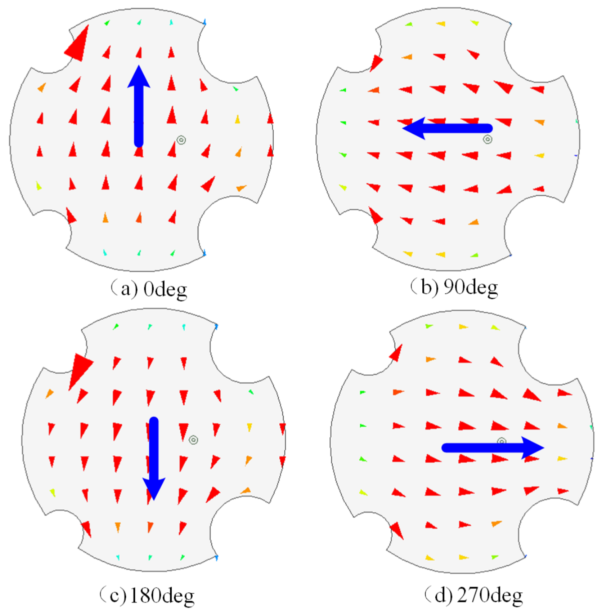

Fig. 3. Surface current distribution for the RHCP antenna at 1.228 GHz.

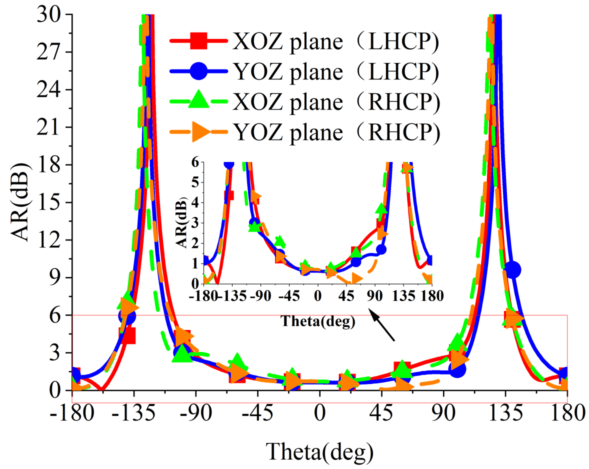

Fig. 4. AR beam-width for the L/RHCP antenna at XOZ and YOZ planes.

III. ANTENNA PARAMETRIC ANALYSIS

In order to better explain how to realize CP operation of the antenna, the dimensions of arc-like cutting corners are studied. Only one parameter is changed each time, and the other parameters remain unchanged.

A. Different r1

Figure 5 shows the S11 and AR of the designed CP antenna with different r1, where the CP antenna is realized by the arc-like corners to get two resonant modes. As r1 increases, the working bandwidth becomes narrower. By optimizing the radius, the two orthogonal resonant modes achieve the same amplitude and 90° phase difference to implement CP radiation of antenna. When the radius r1 is 13.4 mm, the antenna has the best CP performance.

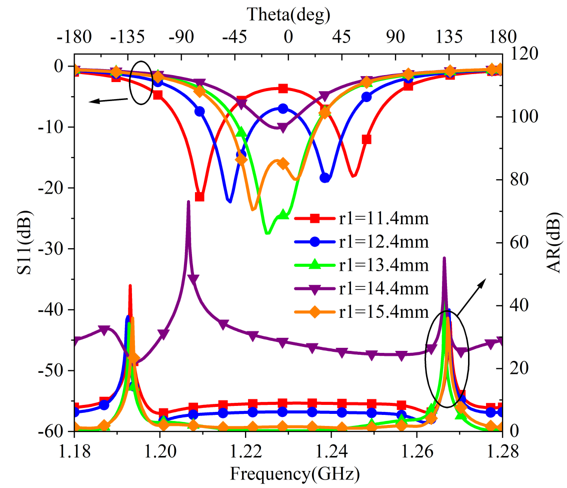

Fig. 5. S11 and AR with variation of r1.

B. Different r2

S11 and AR of the CP antenna is presented in Fig. 6 with different r2. When r2 varies from 7.35 mm to 11.35 mm, the bandwidth gradually decreases. When r2 =10.35 mm, the antenna achieves the widest working bandwidth, but the AR bandwidth does not meet the requirements. For good balance, r2 =9.7 mm was selected. This time, the impedance bandwidth of the antenna is 20 MHz, and the 3 dB beam-width is about 180°.

C. Different r3

The effects on S11 and AR with varying r3 are studied, and the results are presented in Fig. 7 for r1 =11.5 mm, r2 = 9.35 mm, and r4 =13.55 mm. From Fig. 7, it can be seen that once r3 increases, the antenna bandwidth gradually decreases. When r3 =8 mm and 9 mm, the impedance bandwidth and AR meet the requirements. However, when r3 =8.45 mm, the antenna has better resonance and axial ratio performance.

D. Different r4

R4 changes from 11.55 mm to 15.55 mm to optimize the antenna bandwidth, and the result is presented in Fig. 8. With the increase of r4, the bandwidth gradually increases. For r4 =13.55 mm, the antenna has the widest operating bandwidth and is able to generate two orthogonal modes for providing CP radiation.

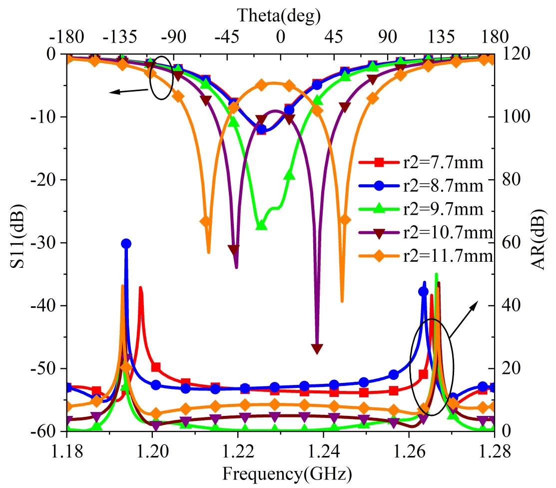

Fig. 6. S11 and AR with variation of r2.

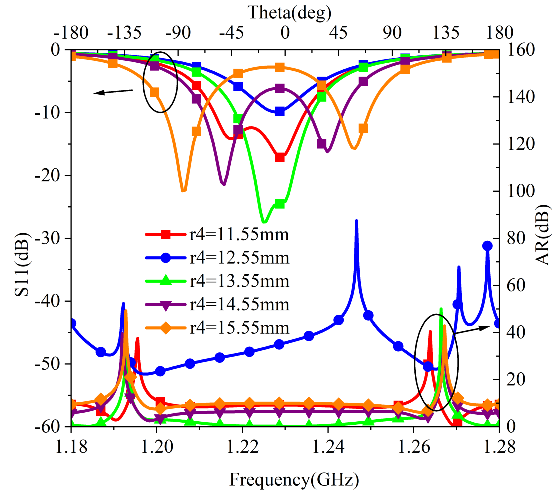

Fig. 8. S11 and AR with variation of r4.

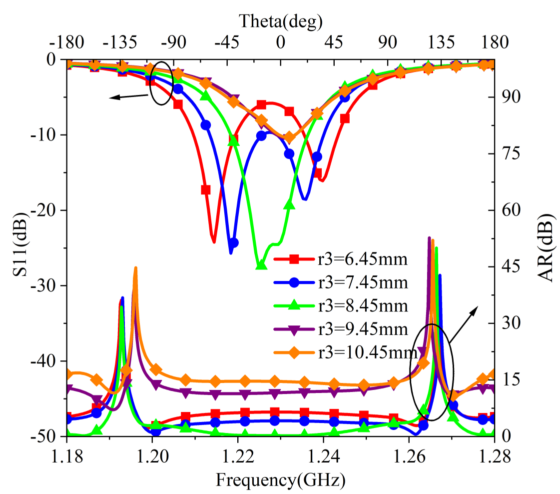

Fig. 7. S11 and AR with variation of r3.

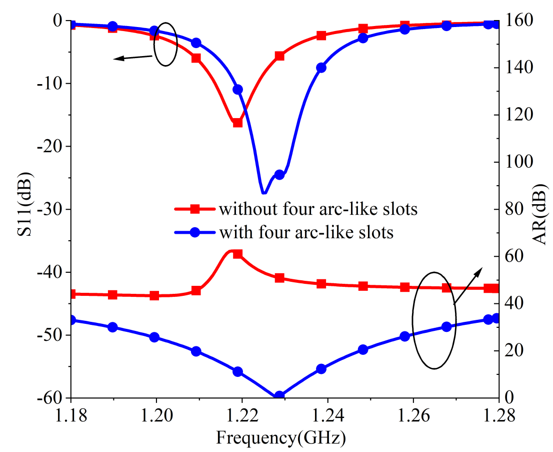

Fig. 9. The antenna S11 with and without the arc-like slots.

IV. SIMULATION AND MEASUREMENT RESULTS

A. Simulation comparisons with and without arc-like corners

S11 and AR of the antennas with and without arc-like corners are plotted in Fig. 9 for comparison. Before the addition of the arc-like slots, the bandwidth of the linearly polarized (LP) antenna is 10 MHz, and the AR is much larger than 3 dB. The antenna polarization changes from LP to CP and the AR is 0.18 dB at 1.228 GHz after the arc-like slots are added. In addition, the bandwidth of CP antennas extends to 20 MHz, which is wider than that of the LP antennas without arc-like slots. This shows that the added arc-like corners can effectively introduce the second resonance to form CP radiation and expand the antenna bandwidth.

B. Simulation and measurement comparisons

The prototypes of the devised CP antennas and the measurement setup are shown in Fig. 10. Figure 11 shows the simulated and measured S11 of the designed L/RHCP antenna, and the measured results are in good agreement with the simulation results. Simulation and measurement results show that the bandwidth of the designed antenna is 20 MHz, and mechanical errors in manufacture may lead to slight differences between the measurement and simulation results.

The proposed L/RHCP antenna has a peak gain of about 7.3 dBi and a 3-dB beam width of about 180°. The

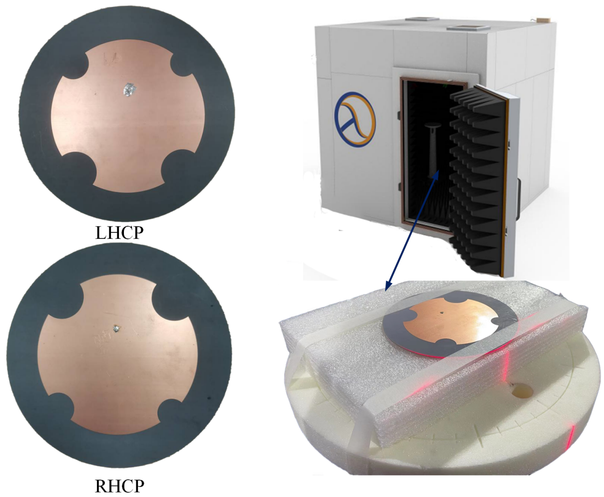

Fig. 10. Photographs of fabricated antennas.

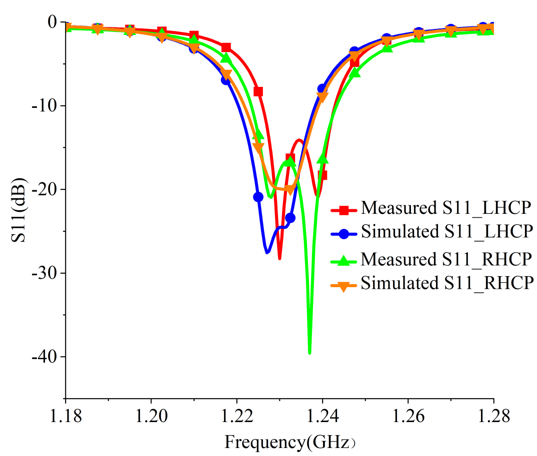

Fig. 11. The simulated and measured S11 of the L/RHCP microstrip antenna.

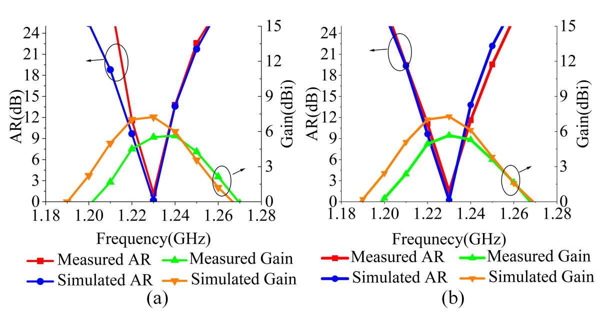

Fig. 12. The simulated and measured AR and gain of the antenna. (a) LHCP antenna. (b) RHCP antenna.

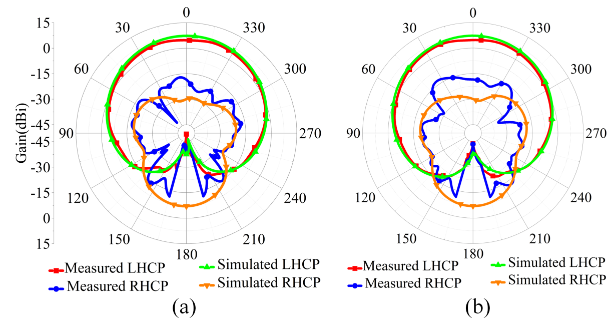

Fig. 13. Measured and simulated radiation patterns of LHCP antenna at the (a) phi=0deg, and (b) phi=90deg planes.

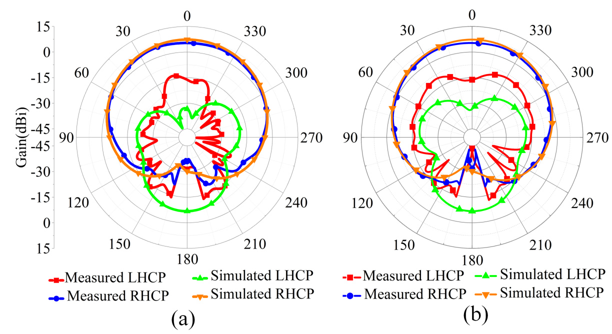

Fig. 14. Measured and simulated radiation patterns of RHCP antenna at the (a) phi=0deg, and (b) phi=90deg planes.

simulated and measured ARs and CP gains of L/RHCP antenna in relation to frequency are given in Fig. 12. The AR are in good agreement with the measurement results, while the measured gain is about 2 dB less than the simulated gain due to the feedline effects.

The proposed L/RHCP antenna is simulated and measured in XOZ and YOZ planes as placed in Figs. 13 and 14. The results show that the simulated radiation pattern is in good agreement with the measured radiation patterns. It is also clear that the antenna presents a good transverse radiation pattern. In the future, the proposed antenna can be used for MIMO system developments. Also, the size of the proposed antenna can be reduced using high dielectric constant substrate, and the antenna can be modeled to construct antenna array or MIMO antennas [37–44].

V. CONCLUSION

Four arc-like corners are used to develop a circular polarized antenna using single feed. The antenna is modeled, simulated, and briefly discussed for GPS L2 band application. The antenna can be used as LHCP and RHCP applications by controlling the dimensions of the four arc-like corners. The results show that the antenna has a good AR and, directional radiating, which is considered a good candidate for GPS applications.

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