A Compact Broadband Circularly Polarized Slot Antenna for Universal UHF RFID Reader and GPS

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Abstract ─ A novel compact printed broadband circularly polarized slot antenna is proposed in this paper. The antenna consists of an inverted L-shaped coplanar waveguide feed structure and a square ground plate loaded with three rectangular slots. The antenna achieves good impedance matching and circular polarization characteristics by adjusting the size of the L-shaped band and the rectangular slot. The simulation results show that the antenna has a 10-dB impedance bandwidth of 1360 MHz (690-2050 MHz) and a 3 dB axial ratio (AR) bandwidth of 490 MHz (770-1260 MHz). Additionally, the maximum gain reached 4.02 dBi. The antenna proposed in this paper can be applied to UHF RFID and GPS frequency bands.

Index Terms ─ Axial Ratio (AR), Coplanar Waveguide (CPW), Circularly Polarized (CP), Global Positioning System (GPS), RFID reader, Ultrahigh Frequency (UHF).

I. INTRODUCTION

Radio Frequency Identification (RFID) technology is a non-contact automatic identification technology [1], which uses the spatial coupling effect of electromagnetic waves to send and receive information between the electronic tag and the reader. RFID can be used in various harsh environments and high-speed moving objects and can identify multiple electronic tags simultaneously [2]. It has the advantages of waterproof, anti-magnetic, high-temperature resistance, and ample storage data capacity. At present, RFID technology has been widely used in supermarkets, automated production, logistics, access control, transportation, and other fields [3].

The tags and readers of the RFID system have their antennas. In actual use, the tag antenna is mostly linearly polarized (LP) [4]. While the circularly polarized antenna can receive electromagnetic waves of any polarization type signal and reduce space loss caused by multipath effects, RFID reader antennas are mostly circularly polarized (CP) antennas.

At present, the frequency bands used by RFID in each country have strict standards. For example, the UHF RFID frequency bands used in China are 840.5-844.5 MHz and 920.5-924.5 MHz, and North America are 902-928 MHz, Japan is 950-955 MHz, Europe is 866-869 MHz, and South Korea is 908.5-914 MHz [5-6], etc. Given the different frequency band standards of various countries, we need to design a reader antenna applied to all UHF frequency bands.

In recent years, people have done a lot of research on RFID reader antennas. In [7], a circularly polarized reader antenna using coaxial line feed was proposed. In [8-9], a patch antenna with an asymmetric circular slot was presented, and the size of the antenna was reduced by slotting. In [10], the air dielectric layer is used to broaden the impedance bandwidth. However, the above-mentioned antenna structure has the disadvantages of too narrow bandwidth and too large volume. To achieve full coverage of the UHF frequency band, in [11-13], a wide frequency band was achieved by using a laminated structure, while these antennas also face problems such as excessive size and complex feeding structure. The use of CPW-fed slot antennas solves the problems mentioned above to a certain extent. In [14-15], the bandwidth to cover the UHF band was obtained by using a suitable CPW feed structure and loading slots on the floor.

Global Positioning System (GPS) is a high-precision positioning system based on artificial earth satellites. In the working frequency band of the GPS, the L2 frequency band (1.215-1.237 GHz) is used for military operations, and the L1 frequency band (1.575 GHz) is used in the civil field [16], and the L5 frequency band (1176.45 MHz) is used for high-precision positioning. In recent years, there has been some research work focusing on the integration of RFID and GPS antennas. In [17-18], a dual-frequency circularly polarized antenna applied to RFID and GPS frequency bands was presented, while the AR bandwidth and impedance bandwidth of the proposed antenna only cover a part of the RFID. A planar tri-band antenna for RFID, GPS, and WLAN was proposed in [19], while the antenna did not achieve circular polarization and the bandwidth only covered part of the RFID frequency band.

In this paper, we present a compact printed

Submitted On: January 29, 2021
Accepted On: April 17, 2021

https://doi.org/10.47037/2020.ACES.J.360513

broadband circularly polarized slot antenna for universal UHF RFID readers and GPS. By adjusting the size of the L-shaped patch and the rectangular slots loaded on the floor achieves wider impedance bandwidth and good AR bandwidth. The experimental results show that the proposed antenna obtains a 10-dB return loss bandwidth of 1360 MHz (690-2050 MHz) and a 3-dB AR bandwidth of about 490 MHz (770-1260 MHz), and the impedance bandwidth and AR bandwidth of the antenna cover RFID UHF and GPS L2 and L5 frequency bands.

II. PROPOSED ANTENNA CONFIGURATION

Figure 1 shows the geometric structure of the compact printed broadband circularly polarized slot antenna proposed in this paper. The antenna is etched on an FR4 substrate with a relative dielectric constant of 4.4, loss tangent value of 0.02, and thickness of 1.6 mm. The side length of the substrate is L=120 mm, and a square groove with a side length of W=94 mm is engraved in the middle of the substrate. A rectangular slot with a size of W7 × L8 in the square ring to place the antenna's feeder, and three rectangular slots of different sizes were loaded on the right side of the square ring. The size of the proposed antenna can be roughly estimated by the following formula [6]:

$$L = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r + 1}}\ , \tag{1}$$

where ε_r is the dielectric permittivity, c is the speed of light in free space, and f is the resonant frequency.

In order to understand the principle of the proposed antenna model clearly, we present the three-step design process of the antenna prototype (Ant.1, Ant.2, and Ant.3) in Fig. 2. The simulation results of impedance bandwidth and axial ratio at each stage are shown in Fig. 3. Ant.1 is the most original antenna that consists of a reverse L-shaped strip and a square floor with rectangular slots on the right. From Fig. 3 (a), we can see that the reflection coefficients S_{11} of Ant.1 near 825 MHz and 1.57 GHz is less than -10dB, while the polarization type of the antenna is linear polarization. To improve the performance of the antenna, a rectangular slot (L4 × W4) was loaded base on Ant.1 to obtain Ant.2, and then Ant.2 expands the impedance bandwidth generated by the two resonance points of Ant.1, and generates a new resonance point near 700 MHz, thereby expanding the impedance bandwidth of the antenna. It can be seen from Fig. 3 (b) that the Ant.2 achieves circular polarization around 1.25 GHz. The third step is to introduce a rectangular slot (L5× W5) on the basis of Ant.2 to obtain the final Ant.3. The Ant.3 has good impedance bandwidth and circular polarization characteristics. Table 1 lists the dimensions of the proposed antenna, and the physical diagram of the proposed antenna is shown in Fig. 1 (c).

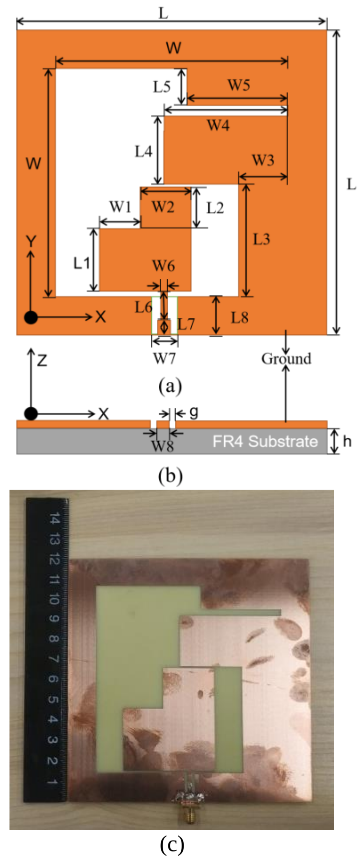

Fig. 1. The geometric structure and physical picture of the proposed antenna: (a) geometry (top view), (b) geometry (side view), and (c) physical picture.

Table 1: Parameters of the proposed antenna (unit: mm)

Parameter	Size	Parameter	Size
L	120	W	92
L1	30	W1	20
L2	20	W2	25
L3	52	W3	19.5
L4	25	W4	50
L5	11.5	W5	39.5
L6	10	W6	2
L7	5	W7	5
L8	14	W8	4
g	0.5	h	1.6

Fig. 2. Three step design process of the circularly polarized slot antenna.

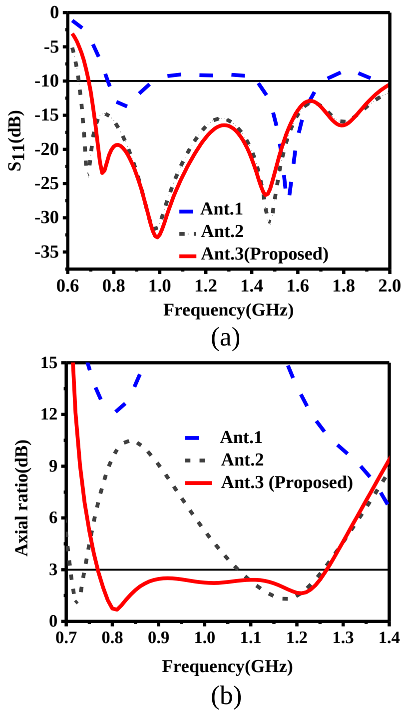

Fig. 3. Simulated reflection coefficients S_{11} (a) and axial ratio (b) for Ant 1, 2, and 3(proposed antenna).

III. PARAMETERS ANALYSIS AND DISCUSSION

In this paper, the simulation software Ansoft HFSS 18 is used to simulate the antenna. To determine the best antenna parameters, a detailed simulation analysis of each parameter is required. When analyzing the influence of a specific parameter on the antenna performance, other parameters remain unchanged.

Figure 4 shows the effect of the L1 change on impedance bandwidth. We can see that the resonance point of the antenna's low-frequency part shifts to the right when L1 increases from 25 mm to 35 mm, and the impedance matching becomes worse, on the contrary, the impedance matching of the high-frequency part becomes better. Therefore, we can adjust the value of L1 to obtain good impedance matching characteristics for the antenna.

The influence of adjusting the length of W1 on the simulated reflection coefficient S_{11} is shown in Fig. 5. When W1=16 mm, the reflection coefficient S_{11} of the antenna is only from 0.7 GHz to 1.6 GHz, and when W1 is increased to 20 mm, the antenna obtains a good impedance bandwidth. Meanwhile, we noticed that when W1 continues to increase to 24 mm, the impedance matching of the antenna will become very awful at 1.25 GHz.

The effect of changing the length of W6 on the reflection coefficient S_{11} of the antenna is shown in Fig. 6. It can be noted that changing the value of W6 has significant impact on the resonance depth of the S_{11} parameter. When W6 is increased from 1 mm to 2 mm, the impedance bandwidth of the antenna becomes more expansive. Adjusting W6 helps to broaden the impedance bandwidth of the antenna.

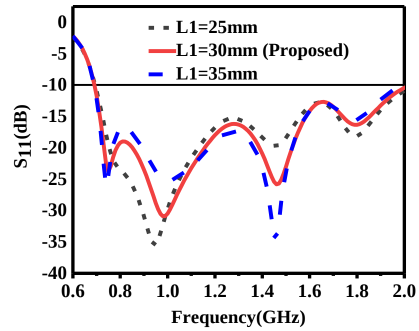

Fig. 4. Simulated reflection coefficients S_{11} with different L1.

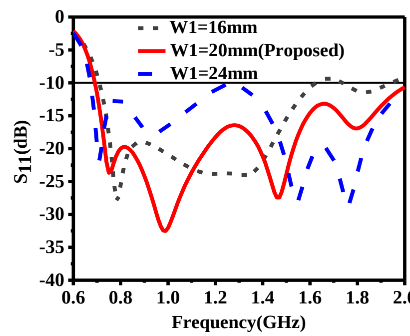

Fig. 5. Simulated reflection coefficients S_{11} with different W1.

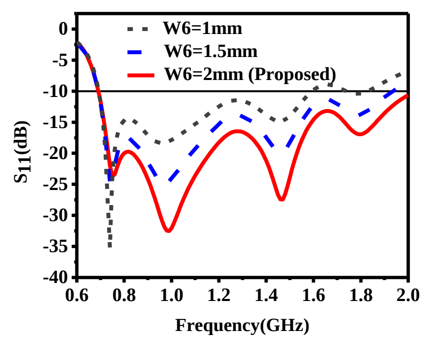

Fig. 6. Simulated reflection coefficients S_{11} with different W6.

Figure 7 shows the effect of W4 on the simulated AR bandwidth. As shown in the figure, when the value of W4 increases, it mainly affects the starting frequency of the AR bandwidth without influence the cut-off frequency of the antenna AR bandwidth. When W4=50 mm, the antenna obtains the best AR bandwidth, and when W4 increases to 52 mm, the AR bandwidth of the antenna becomes very poor. Therefore, adjusting W4 is beneficial to control the starting frequency of the AR bandwidth.

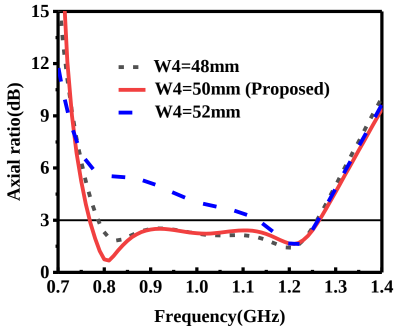

Fig. 7. Simulated results of axial ratio with different W4.

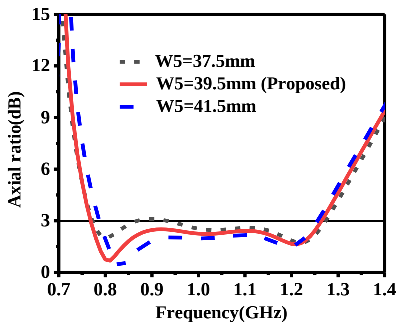

Fig. 8. Simulated results of axial ratio with different W5.

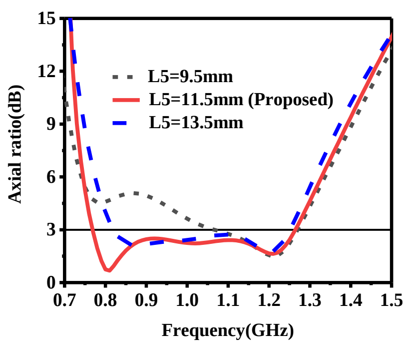

Fig. 9. Simulated results of axial ratio with different L5.

Figure 8 shows the influence of W5 on the simulated axial ratio bandwidth. It can be seen that the change in length of W5 mainly affects the low-frequency part of the axial ratio, while the impact on the axial ratio of cutoff frequency has less influence. Therefore, we can obtain the best axial ratio bandwidth by adjusting the length of W5.

As shown in Fig. 9, the value of L5 increased has a significant influence on the axial ratio between 0.77-1.1 GHz, while has a slight effect on the axial ratio after 1.1 GHz. Therefore, the starting frequency of the axial ratio bandwidth can be controlled by adjusting the value of L5.

IV. RESULTS AND DISCUSSION

Figure 10 shows the comparison between simulated and measured results of reflection coefficient and axial ratio. As shown in Fig. 10 (a), the antenna's impedance bandwidth simulated result is 1360 MHz (690-2050 MHz), and the measured result is 1420 MHz (680-2100 MHz). We notice that the simulated results of the reflection coefficient S_{11} are similar to the measured results, however, due to the differences between the simulation conditions and the measured environment, as well as the manufacturing tolerance, the resonance frequency of the reflection coefficient S_{11} shifts slightly to the right. It should be noted that the reflection coefficient S_{11} is measured by the vector network analyzer model of Agilent E5071C.

Figure 10 (b) illustrates the comparison between the simulated and measured results of the axial ratio bandwidth. As shown in the figure, the simulated axial ratio bandwidth is 490 MHz (770-1260 MHz), while the measured axial ratio bandwidth is 393 MHz (870-1263 MHz). The discrepancy between the simulated and the measured results at the starting frequency is mainly due to the antenna measuring system effect and tolerances in the manufacturing process, while the rest of the AR simulation and test results have a good consistency. It can be seen from Fig. 10 that the impedance bandwidth and axial ratio bandwidth of the proposed antenna have covered the RFID UHF frequency band and the L2 and 15 frequency bands of GPS. The far-field data of the antenna is measured in the anechoic chamber.

The simulated and measured maximum gain of the proposed antenna is shown in Fig. 11. It can be seen that the antenna gain in the entire circular polarization frequency band is greater than 2.5 dBi, and the gain in the GPS L2 and L5 frequency bands is greater than 3 dBi. The simulation and measurement results of maximum gain show good consistency.

In Table 2, we compare some antennas that work in the global UHF RFID and GPS frequency bands. As shown in Table 2, the antennas proposed in [11-12] and [15, 20, 21] use a stacked structure to obtain high gain, but there are problems of complex design and large volume. In addition, although the antenna in [22] has a small volume, its bandwidth only covers a part of the RFID UHF frequency band and GPS L5 frequency band, and it does not achieve circular polarization characteristics. Compared to above-mentioned antennas, the proposed antenna has achieved wider impedance and axial ratio bandwidth with a simpler and smaller structure.

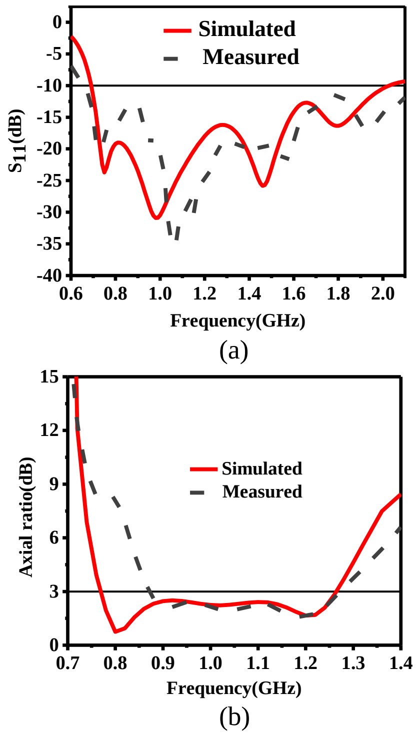

Fig. 10. Measured and Simulated results of reflection coefficients S_{11} and axial ratio of the proposed antenna. (a) Reflection coefficients and (b) axial ratio.

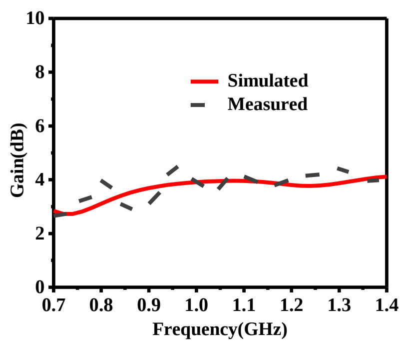

Fig. 11. Simulated and measured gain of the proposed antenna.

In order to understand the principle of circular polarization of the proposed antenna fully, Fig. 12 shows the simulated current distribution of the antenna in the four phases of 0°, 90°, 180°, and 270° at 900 MHz. As shown in the figure, with the increase of the phase angle, the current distribution on the antenna surface from the +z direction propagates in the clockwise direction. The currents at 0° and 90° have the same amplitude, but the phase is opposite, and the currents at 0° and 180° have the same amplitude and a relative phase shift of 180°, and then the antenna obtains left-handed circular polarization (LHCP) radiation in the +z direction.

Table 2: Comparison of the referenced and proposed antenna

Ref.	10-dB RL BW (MHz, %)	3-dB AR BW (MHz, %)	Gain (dBi)	Size (mm^3)
[11]	758-983 25.8	838-959 13.5	8.6	250×250 ×24.5
[12]	760-963 25.6	818-964 16.4	8.3	250×250 ×35
[15]	685-1125 48.6	836-986 16.5	8.6	250×250 ×60
[20]	833-960 14.2	846-926 9.3	7.3	150×150 ×25
[21]	730-990 30.2	760-970 24.2	5.3	150×150 ×21
[22]	900-1610 56.5	—	3.1	123×31× 1.6
Our work	690-2050 99.3	770-1260 48.3	4.02	120×120 ×1.6

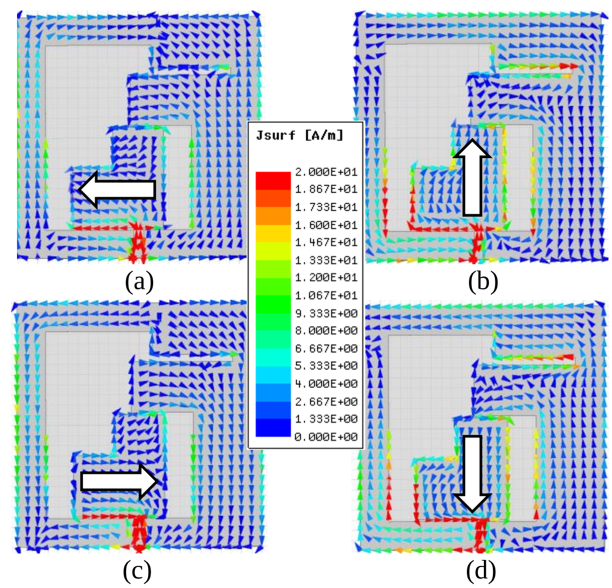

Fig. 12. Distribution of the surface current at 900 MHz with four phase angles: (a) 0°, (b) 90°, (c) 180°, and (d) 270°.

Figure 13 shows the simulated and measured radiation pattern of the proposed antenna at the XZ- plane (Phi=0°) and YZ-plane (phi=90°) at 0.9 GHz and 1.23 GHz. As shown in the figure, the simulated and measured radiation patterns are approximately equal to each other. It can be observed from Fig. 13 that the proposed antenna exhibits left-handed circular polarization (LHCP) in the +z direction and right-handed circular polarization (RHCP) in the -z direction. Therefore, the proposed antenna has good bidirectional radiation characteristics.

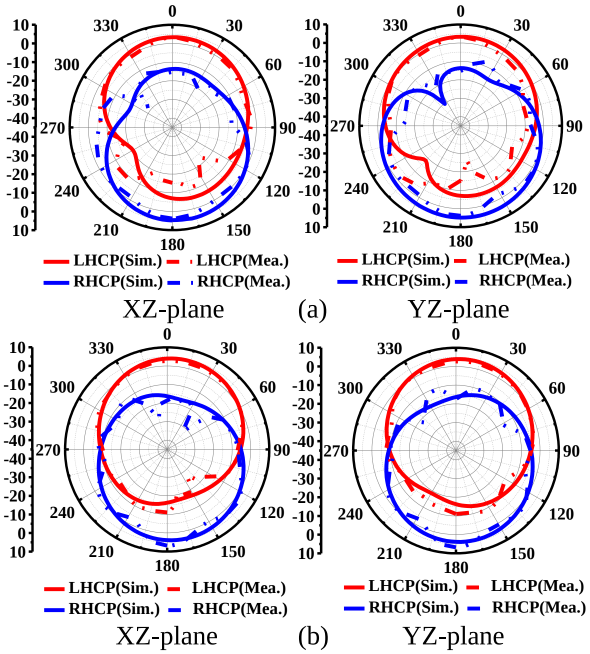

Fig. 13. Simulated and measured radiation patterns at: (a) 0.9 GHz and (b) 1.23 GHz of the proposed antenna.

V. CONCLUSION

In this paper, a compact broadband circular polarization slot antenna is proposed, which can work in RFID UHF and GPS L2 and L5 bands. The antenna consists of a reverse L-shaped CPW feeder and a square floor loaded with three rectangular slots. By adjusting the L-shaped strip and rectangular slot, the antenna can obtain good impedance matching and circular polarization characteristics. The simulation results show that the proposed antenna can achieve a 10-dB impedance bandwidth of 1360 MHz (690-2050 MHz) and a 3-dB axial ratio bandwidth of 490 MHz (770-1260 MHz), and the maximum gain reached 4.02 dBi. Compared with antennas of similar dimensions, the proposed antenna has achieved wider impedance and axial ratio bandwidth with simpler and smaller structure.

ACKNOWLEDGMENT

This work is supported by Key Project of the National Natural Science Foundation of China under Grants 62090012, 62031016 and 61831017 and the Sichuan Provincial Science and Technology Important Projects under Grants 2019YFG0498, 2020YFG0282, 2020YFG0452 and 2020YFG0028 and the Science and Technology Commission Project under Grant 19-163-21-TS-001-062-01.

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His research interests include integrated circuits design, RFID technology, embedded system, wireless communications, antennas and propagation, microwave & millimeter wave technology, smart information processing, electromagnetic compatibility and RF/ microwave devices & materials etc.