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BROADBAND CPW-FED CIRCULARLY POLARIZED ANTENNA WITH AN IRREGULAR SLOT FOR 2.45 GHz RFID READER

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Abstract—A coplanar waveguide-fed slot antenna with wideband circular polarization characteristic is presented. The proposed antenna consists of an irregular slot with a stair-shaped edge and an L-shaped feed line. The stair-shaped edge can improve the circular polarization of the antenna. The simulated and measured results show that the antenna has an impedance bandwidth (VSWR < 2) about 1040 MHz (42%@2.47 GHz) and an axial ratio (AR) bandwidth (AR < 3 dB) about 640 MHz (25.8%@2.48 GHz) for 2.45 GHz RFID applications. The RHCP gain in the main radiation direction varies between 2.3 dBi and 3.8 dBi.

1. INTRODUCTION

Nowadays circular polarization is getting more attention in many applications such as radio-frequency identification (RFID), satellite navigation and wireless communication. Radio-frequency identification (RFID) technology becomes more attractive for many applications such as product tracking, access control, inventory management and telemetry. With a circularly polarized (CP) antenna, a RFID system allows flexible orientation of a reader and a tag. As we know, two orthogonal linearly-polarized modes with equal amplitude and 90° phase difference can achieve circular polarization. In recent years, various antennas are investigated to achieve circular polarization. Because of the advantages of low profile, design simplicity and robustness, many CP antennas are designed with slots [1–13]. Slot-rings [3–6], square slot [7–11], and U-shaped slot [12, 13] are effective

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methods to achieve circular polarization. In order to simplify the feeding structure and save space, a coplanar waveguide (CPW) approach is adopted in CP antennas [14–21]. In [14, 15], CP antennas with tuning rectangular slot fed by CPW are discussed. The antenna in [15] has an over-lapped bandwidth of 17.39% (2.31 GHz–2.75 GHz) with the size of $54 \times 54\,\mathrm{mm}^2$; A uniplanar trapezoidal antenna fed by CPW is presented in [16] with an impedance bandwidth of 80% and a 3 dB AR bandwidth of 8% in the size of $55 \times 50\,\mathrm{mm}^2$. In [20], a regular-hexagonal slot antenna with L-shape monopole is presented. The antenna in [20] comprises an L-monopole and a regular hexagonal ring combined with a pair of inverted-L strips. The side length of the regular-hexagonal substrate is 31 mm, and the size is bigger than $2 * (31\times31)\,\mathrm{mm}^2$. The measured 3-dB AR bandwidth is about 50% (2.25–3.75 GHz) at 3 GHz. A circularly polarized square slot antenna is designed in [21]. The antenna consists of a square slot ground and a fork shaped feed line with an additional strip attached to the right side. To optimize the performance of the antenna, a fork shape strip, two L-shape strips, two inverted L-shape strips, two rectangle chips and two horizontally loaded strips are added. The antenna in [21] has a size of $40 \times 40\,\mathrm{mm}^2$ and obtains a 3 dB AR bandwidth of 36% (2112–3056 MHz) for lower band I and 9% (5292–5837 MHz) for band II. Although the performances of the antennas in [20, 21] are quite good, the structures of the antennas might be complex.

A novel wideband CP slot antenna fed by CPW is proposed in this paper. This antenna consists of an irregularly slot and an L-shaped feed line. A stair-shaped edge of the slot could improve the circular polarization of the antenna. The planar structure of the antenna makes it easy to fabricate. The impedance bandwidth of the antenna is 42% at 2.47 GHz and the 3 dB AR bandwidth is 25.8% at 2.48 GHz. The RHCP gain of the antenna is about 3 dBi over the frequency band of operation.

2. ANTENNA DESIGN AND ANALYSIS

2.1. Antenna Design

The structure of the proposed antenna in this paper is shown in Fig. 1. This CP antenna is printed on a FR4 substrate with a dielectric constant of 4.4, a loss tangent of 0.02, and a thickness of 1 mm. The size of the proposed antenna is $52\times52\,\mathrm{mm}^2$, which is designed at $0.42\lambda_0$ (λ_0 is the wavelength of 2.45 GHz in free space). The detailed dimensions of the proposed circularly polarized antenna are listed in Table 1. The antenna has an irregularly slot etched on the ground plane. An L-shaped feed line is against one edge of the slot (Fig. 1(b)). The 50-Ω

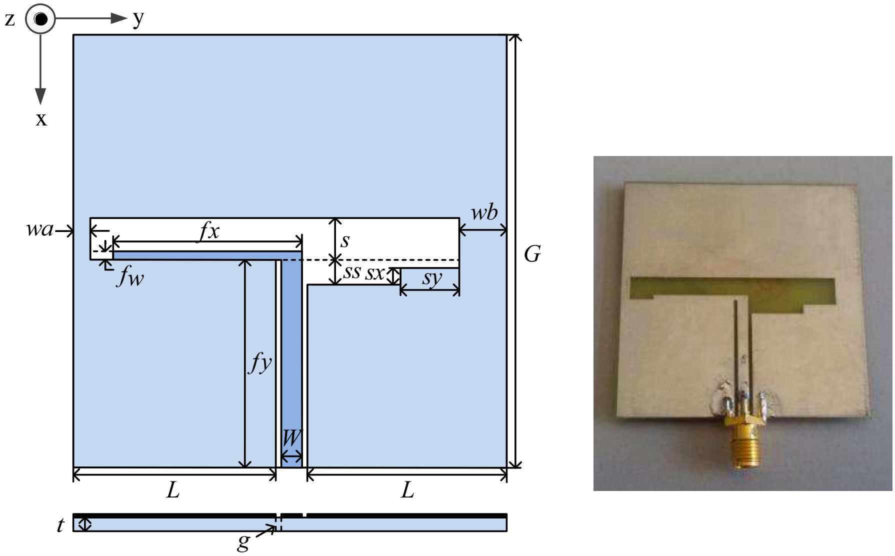


Figure 1. Geometry of the proposed antenna. (a) Configuration of the proposed antenna. (b) Photo of the fabricated antenna.

Table 1. Dimensions of the proposed antenna (Unit: mm).

G	*L*	*W*	*g*	*t*	*fx*	*fy*
52	24.1	2.2	0.8	1	20	25
fw	*wa*	*wb*	*s*	*ss*	*sx*	*sy*
1	2	6	5	3	2	7

CPW has a strip width $W = 2.2\,\text{mm}$ and gaps width $g = 0.8\,\text{mm}$ between the strip and the ground plane. The stair-shaped edge of the slot could optimize the circular polarization characteristics (Table 2).

For clarifying the improvement process, three prototypes of the antenna are defined as follows (Fig. 2): Ant. I is the original antenna with an I-shaped slot and an L-shaped feed line; Ant. II has an I-shaped slot with changed dimensions; Ant. III is the final contracture which is added a stair-shaped edge of the slot on the basis of Ant. II. These three prototypes are simulated by a high frequency structure simulator (HFSS 13.0) and the detailed performances are presented in Table 2: Ant. I has no circularly polarized characteristic, while the circular polarization of Ant. II is good. Further, Ant. III has a 3 dB

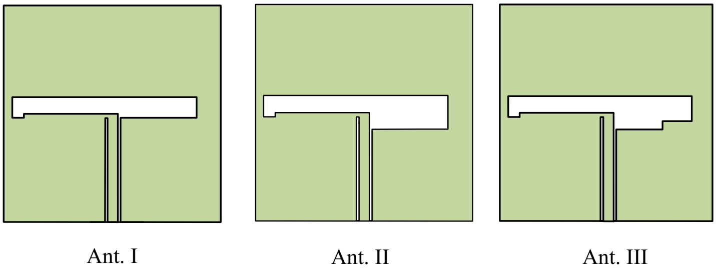


Figure 2. Three prototypes of the antenna.

Table 2. Comparison of characteristics of Ant. I–Ant. III.

Antenna	Bandwidth (VSWR < 2)	3 dB AR	BW (VSWR < 2 and AR < 3 dB)
Ant. I	2.11–2.25 GHz	–	–
Ant. II	2.19–2.95 GHz	2.02–2.61 GHz	420 MHz
Ant. III	2.16–3.19 GHz	2.06–2.71 GHz	550 MHz

AR bandwidth of 650 MHz, which is much wider than that of Ant. II. It is observed that the stair-shaped edge has positive influence on circular polarization of the antenna.

The proposed antenna is designed to realize right-hand circular polarization (RHCP) in $+Z$ direction. Fig. 3 illustrates the surface current distribution of the antenna presented in this paper. The orientation of surface currents on the ground plane is shown at 2.45 GHz as the phase changes from 0° to 270°. The current amplitude at phase = 0° is almost as same as that at phase = 180°, however, their directions are opposite. It is obvious that the current flows from the x-axis to the y-axis, generating a RHCP radiation for the presented antenna.

2.2. Parameter Study

In previous section, the geometry of the proposed antenna is presented. It is of practical interest to investigate the antenna performance when some of the geometrical parameters are changed. Throughout the studies presented in this section, all other parameters that have not been mentioned are fixed to the dimensions which are listed in Table 1.

Figures 4 and 5 show the studies of ss and $\Delta = wb - wa$ of the proposed antenna in this paper. When ss is reduced, the minimum

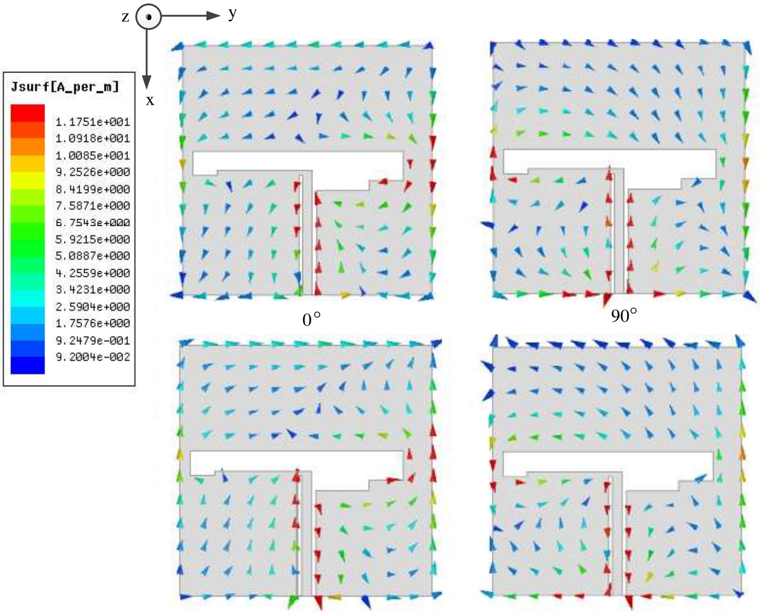


Figure 3. Surface current of the proposed antenna.

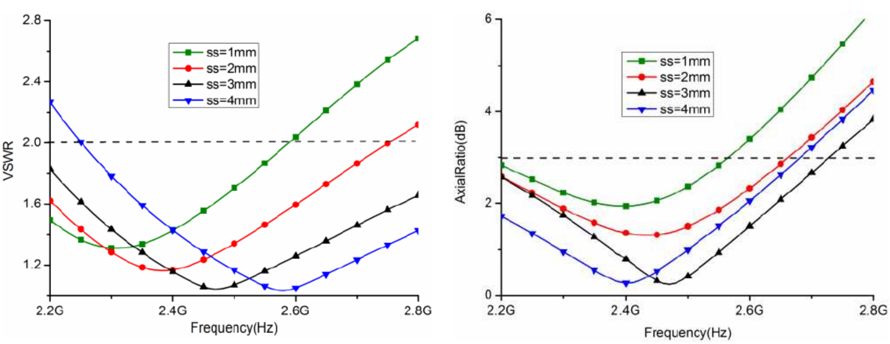
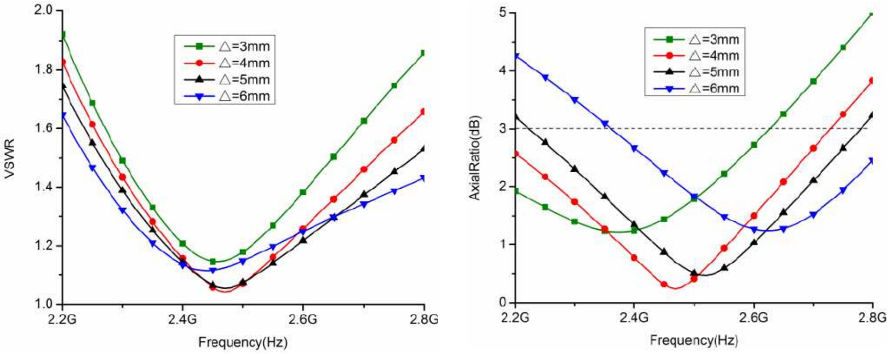


Figure 4. VSWR and AR curves of the propose antenna with varying values of *ss*. (a) VSWR. (b) AR.

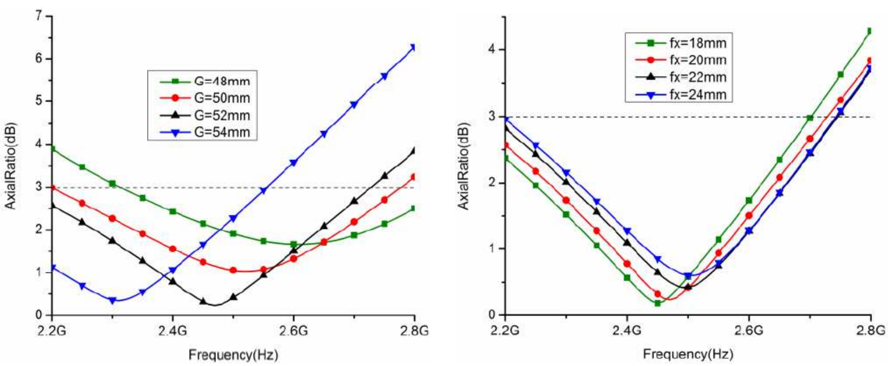
frequency of VSWR is shifted downwards as the circular polarization is seen to get worse as shown in Fig. 4(b). The variation of Δ in Fig. 5 shows that the circular polarization is greatly influenced by the difference between *wa* and *wb*.

As depicted in Fig. 6, the AR curves are sensitive to the variations of *G*and *fx*. It is shown that the minimum frequency of AR is shifted



(a) (b)

Figure 5. VSWR and AR curves of the proposed antenna with varying values of $\Delta = wb\text{-}wa$. (a) VSWR. (b) AR.



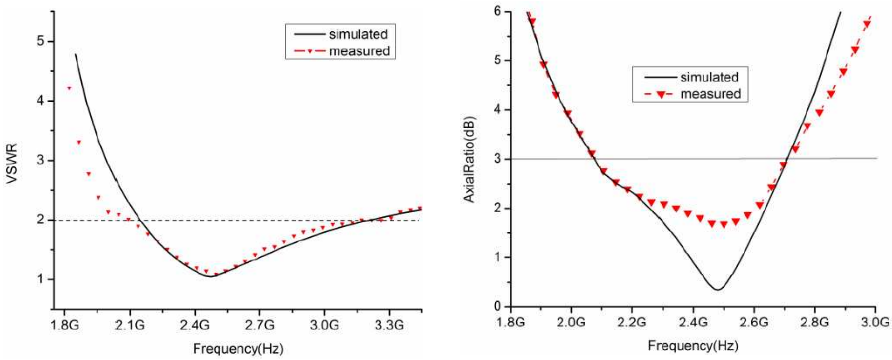
(a) (b)

Figure 6. AR curves of the propose antenna with varying values of G and fx. (a) Different values of G. (b) Different values of fx.

downwards as G is increased. Changing the value of fx would shift the minimum frequency of AR and has a little effect on the value of the AR. The fx could be modified to make the frequency band of AR matches the frequency band of VSWR.

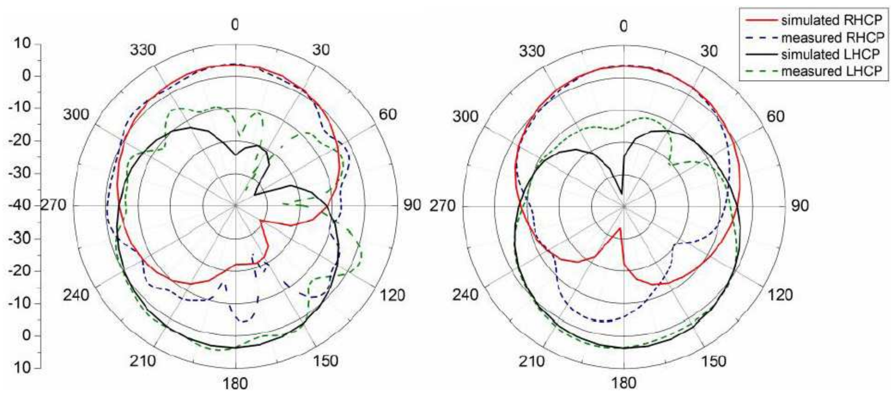
3. SIMULATED AND MEASURED RESULTS

The performance of the proposed antenna is simulated by a high frequency structure simulator (HFSS 13.0), and measured in anechoic chamber. The simulated and measured VSWR and AR values for



(a) (b)

Figure 7. Simulated and measured VSWR and AR of the proposed antenna. (a) VSWR. (b) AR.



(a) (b)

Figure 8. Simulated and measured radiation patterns in the azimuth plane (XZ) (phi $= 0°$) and elevation plane (YZ) (phi $= 90°$) at 2.45 GHz. (a) phi $= 0°$. (b) phi $= 90°$.

the proposed antenna are given in Fig. 7. The measured impedance bandwidth (VSWR < 2) is about 42% (2.15–3.19 GHz) at 2.47 GHz. The measured 3 dB axial ratio bandwidth is about 25.8% (2.07–2.71 GHz) at 2.48 GHz. There has been a good agreement between the simulated and measured results.

The RHCP and LHCP radiation patterns are measured in the XZ (phi $= 0°$) and YZ planes (phi $= 90°$) at the frequency of 2.45 GHz in Fig. 8. A left-hand circular polarization is considered to be the cross polarization in $+Z$ direction. Reasonably good patterns are found both

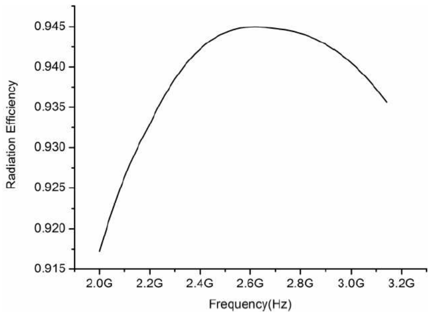


Figure 9. The simulated radiation efficiency of the proposed antenna.

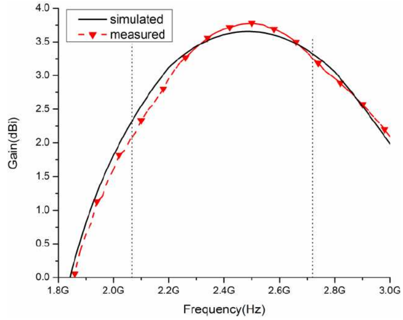


Figure 10. Simulated and measured RHCP gains against frequency for the proposed antenna.

in the XZ-plane and the YZ-plane. In Fig. 9, it can be observed that the simulated radiation efficiency is quite good. The measured and simulated RHCP gain of the proposed antenna is shown in Fig. 10. The measured result varies from 2.3 dBi to 3.8 dBi.

4. CONCLUSION

In this paper, a novel wideband CP slot antenna is proposed for 2.45 GHz RFID reader. The antenna is fed by CPW with an irregular slot. A stair-shaped edge of the slot can improve the circular polarization of the antenna. The overlap bandwidth (VSWR < 2 and AR < 3 dB) of the antenna is 22.4% (2.15–2.71 GHz). And the RHCP gain in main radiation direction is over 2.3 dBi.

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