

A wideband circularly polarized S-shaped slot antenna

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Abstract

This article introduces a simple wideband circularly polarized (CP) S-shaped slot antenna for ISM band wireless communication applications. By using a wide curve S-shaped slot patch on the top side and a T-shaped feeding line on the bottom side of the substrate, the wideband CP wave is generated. The overall size of the proposed antenna is $0.85\lambda \times 0.85\lambda \times 0.011\lambda$ (λ is the wavelength of the lowest operating frequency) and it has a broad impedance bandwidth of 68.1% between 1.66 and 3.44 GHz for $S_{11} < -10$ dB and a 3 dB axial-ratio bandwidth of 57.1% between 1.68 and 3.06 GHz. Within the axial-ratio bandwidth, the measured gain of the proposed antenna ranged from 2.1 to 5.4 dBi. The measured results are in good agreement with simulated results. The new type of slot antenna with wide bandwidth and simple structure is a good candidate for various RFID applications.

KEYWORDS

circularly polarized antenna, slot antenna, wideband antenna

1 | INTRODUCTION

Since the circularly polarized (CP) antennas can reduce the multi-path fading and eliminate the polarization mismatching between transmitting antennas and receiving antennas in wireless communications, which are widely employed in current communication systems.¹ More and more wideband antennas with a compact configuration are simultaneously provided in multiple wireless communication systems. Many different wideband CP antennas including wideband cross-dipole CP antenna,² dielectric resonator CP antennas,³ spiral antennas,⁴ monopole antenna,⁵ and metasurface antenna⁶ have been studied and reported. Since the printed slot antenna has obvious advantages such as low profile, wideband, and easy manufacturing, broadband CP slot antenna have been widely studied.⁷ Some proposed broadband CP slot antennas include various antennas fed by coplanar waveguide (CPW)^{8,9} and antennas coupled fed by micro-strip.¹⁰⁻¹² In Reference 8, two

spiral slots and a vertical tuning stub were utilized to generate a broadband CP slot antenna. Using a wide-slot antenna with asymmetric CPW feeding technique to generate wideband CP radiation is illustrated in.⁹ An ultra-wideband (UWB) CP slot antenna with L-shaped radiator and defective ground plane was described in Reference 10. In addition, combining slot array and feeding network to generate broadband CP radiation were demonstrated in References 11,12. Although these antennas have achieved wideband CP radiation, most of them have complex structures or need to be adjusted with more parameters.

In this article, a novel S-shape slot wideband antenna with CP is proposed. This new antenna consists of a ground plane and a T-shaped feeding line. To achieve a circular polarization (CP), a wide curving S-shaped slot was peeled from the ground plane. By adjusting the width of the S-shaped slot, a wide axial ratio (AR) bandwidth can be realized. In addition, a T-shaped feeding line is used to extend the operating bandwidth.

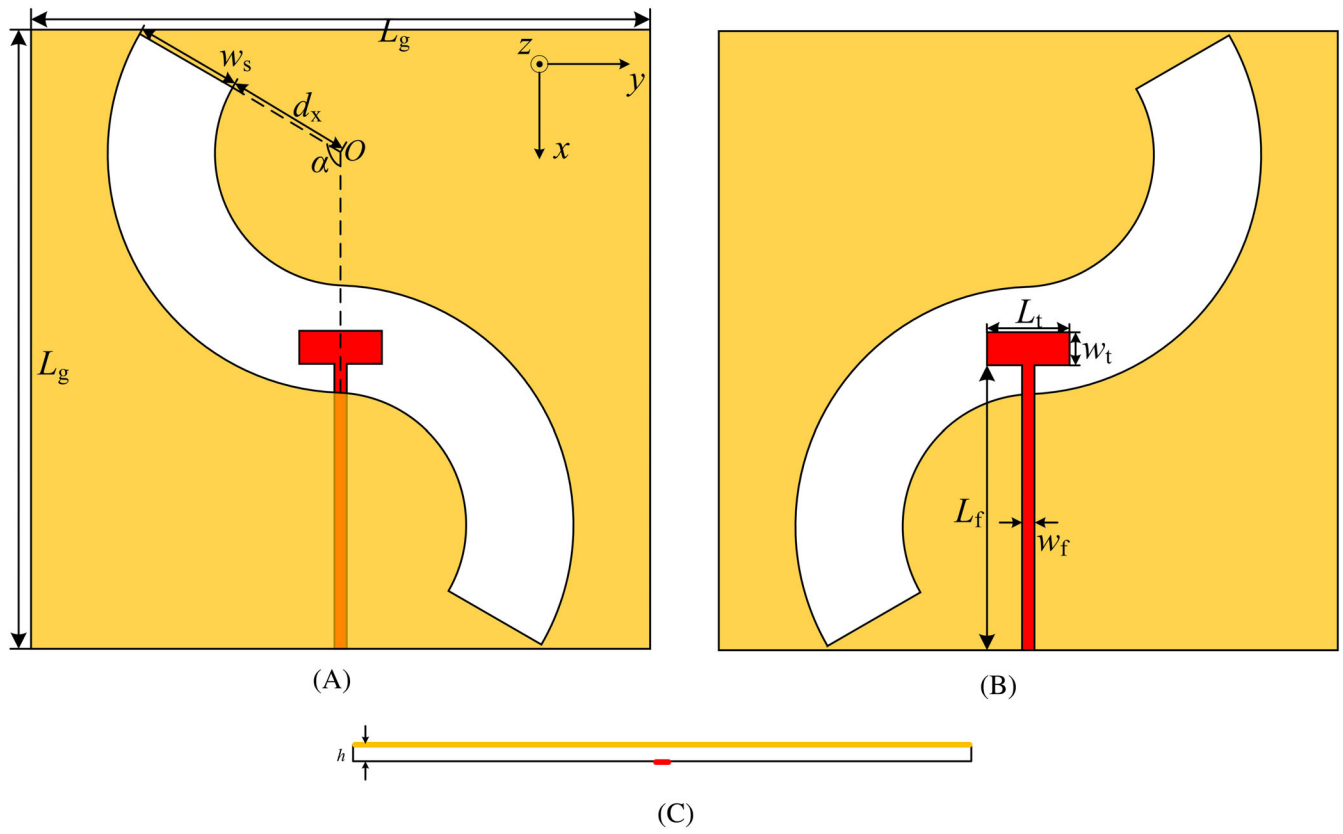


FIGURE 1 Structure of the proposed antenna (A) top view, (B) bottom view, (C) side view. $L_g = 150$ mm, $L_f = 69$ mm, $L_t = 20$ mm, $w_f = 3$ mm, $w_t = 8$ mm, $w_s = 25$ mm, $d_x = 20$ mm, $\alpha = 118$ deg, $h = 2$ mm

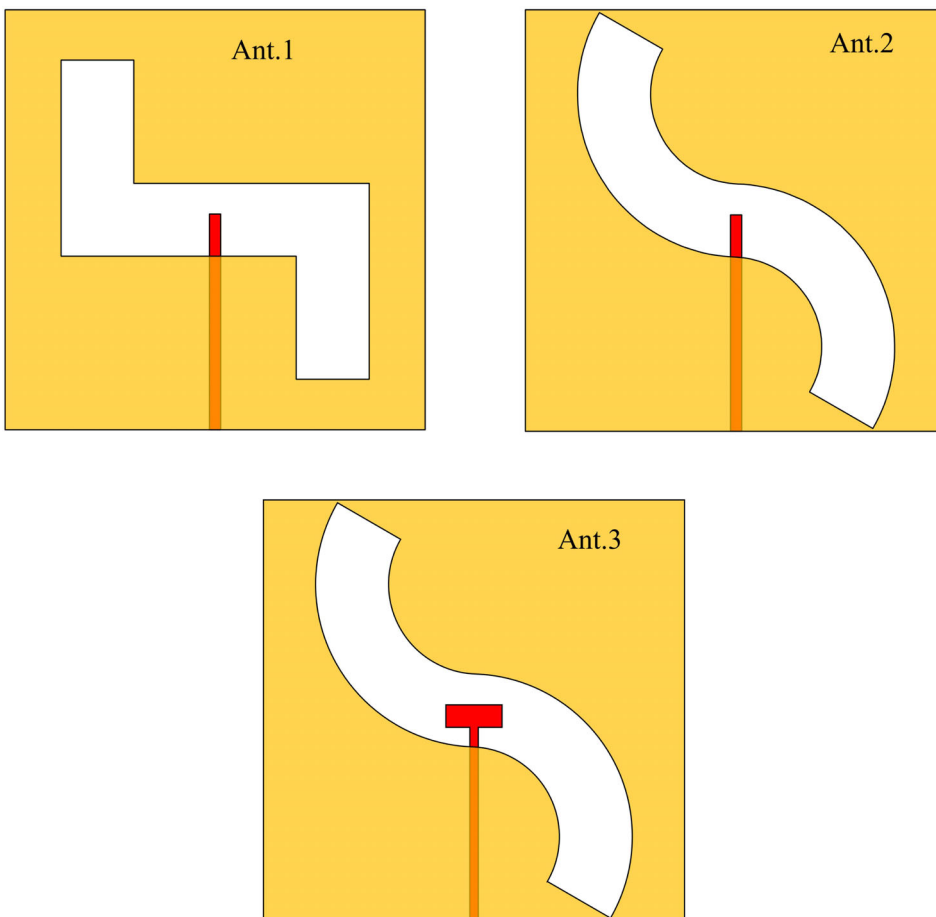


FIGURE 2 Antenna design evolution

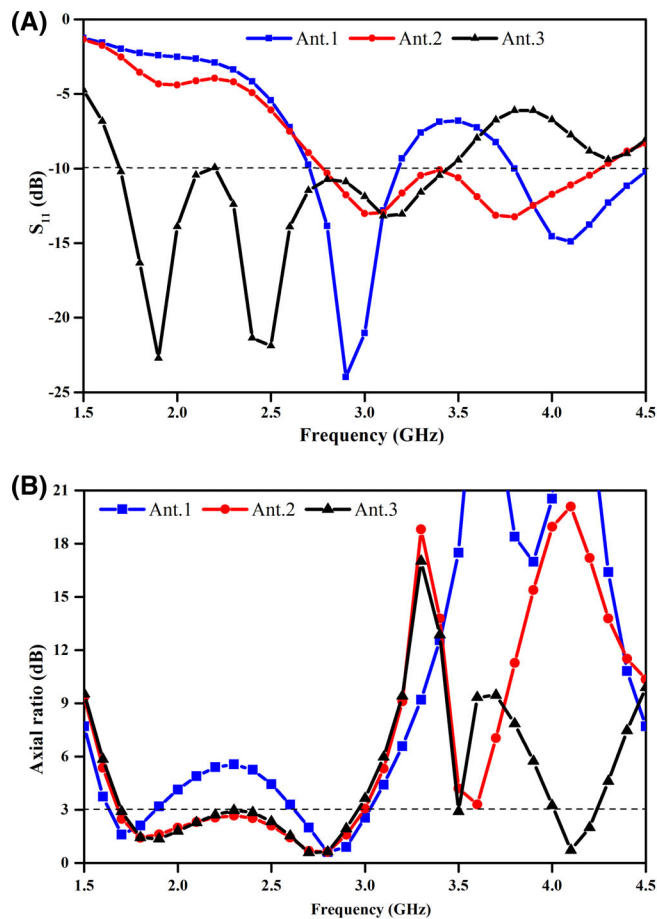


FIGURE 3 Simulation performance for Ant. 1 to 3. (A) S_{11} , (B) Axial ratio

The antenna is fabricated on a single substrate in a cost-effective and easier manner using a simple process. The experiment obtained a wide 3 dB AR bandwidth of 57.1% (1.70–3.06 GHz), which is fully contained in the measured -10 dB reflection coefficient bandwidth of 68.1% (1.66–3.44 GHz). The proposed CP slot antenna has the characteristics of simple structure, wide 3 dB AR bandwidth and wide impedance bandwidth.

2 | ANTENNA DESIGN AND ANALYSIS

Figure 1 shows the geometry of the proposed wideband S-shaped slot CP antenna which is printed on a $L_g \times L_g$ mm² FR4 substrate. The antenna is fed by a T-shaped feeding line which placed on the back side of the substrate, and the T-shaped feeding line consists of a vertical stub of length L_f and width w_f and a horizontal stub of length L_t and width w_t . The upper surface of the substrate is the antenna ground plane, and a wide curve S-shaped slot is peeled from the ground plane. As shown in

Figure 1, the S-shaped slot is obtained by a partial ring with a width of w_s rotating 180° around the z-axis, the partial ring is formed by sweeping a line of width w_s around the vertical axis centered on the “O” point, where the sweeping angle is α . The final values of the antenna parameters are shown in Figure 1.

Figure 2 is the process of antenna design, which clearly shows that the wide curve S-shaped slot can generate wideband CP radiation. As shown in Figure 2, Ant. 1 is an Inverted-Z-shaped slot fed by a 50Ω microstrip line. Ant. 2 uses a wide curve S-shaped slot to replace the Inverted-Z-shaped slot in Ant. 1, and still uses the 50Ω microstrip line feed. The slot in Ant. 3 is the same as the slot in Ant. 2, but the feeding line is replaced by a T-shaped feeding line. The simulation results of three antennas are shown in Figure 3. Although Ant. 1 is circular polarization in the frequency bands around 1.7 and 2.8 GHz, the impedance matching in these frequency bands is very poor, and the antenna cannot work. For Ant. 2, although $S_{11} < -10$ dB and AR < 3 dB are realized in a wide frequency band, it is a pity that the two bands do not overlap. From Figure 3, when the feeding line in Ant. 2 is replaced by a T-shaped feeding line, that is, Ant. 3, a new resonance is generated at low frequency band. Although the AR bandwidth is not changed, the impedance bandwidth is expanded to a lower frequency, so that the AR bandwidth is completely included in the impedance bandwidth.

The simulated surface current distributions at 2, 2.4, and 2.8 GHz of the proposed antenna is shown in Figure 4, which is used to explain the generation of CP radiation. As shown in Figure 4A, at 2 GHz, when $\omega t = 0^\circ$, the current flows the $-x$ direction, and when $\omega t = 90^\circ$, the current flows the $+y$ direction. The direction of the current rotates in the clockwise direction, which indicates that a left-hand circular polarization (LHCP) wave is generated along the $+z$ direction. Similarly, at 2.4 and 2.8 GHz, The direction of the current also rotates in the clockwise direction, which means a LHCP wave is excited. Therefore, the proposed antenna can generate CP radiation in a wide bandwidth.

In order to better illustrate the performances of the proposed antenna, it is necessary to optimize some key parameters of the antenna. The very significant parameters of w_s (the width of slot), α (the angle of curve S-shaped) and L_f (the length of feeding line) for the antenna are studied. Figure 5A,B on reveals the influence of varying the width of slot w_s S_{11} and AR. As shown, when the width w_s is increased, the reflection coefficient of the high frequency band gradually deteriorates while the low frequency band becomes better, and the overall impedance bandwidth becomes wider. In addition, the AR bandwidth is gradually extended as w_s increased.

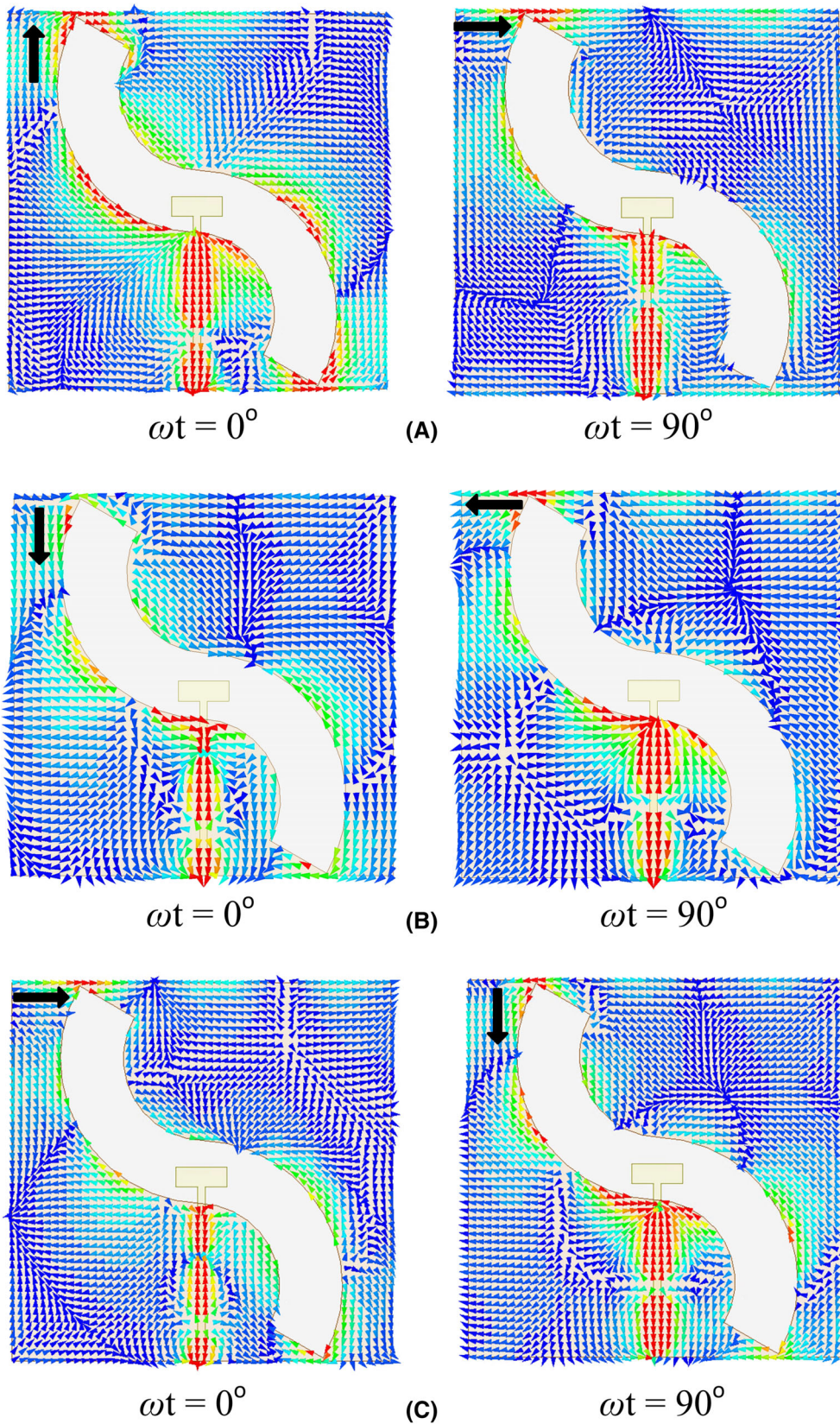


FIGURE 4 The simulation surface current distribution of proposed antenna at (A) 2 GHz, (B) 2.4 GHz, (C) 2.8 GHz

From the above analysis, the best value of the width w_s is 25 mm. Figure 6 explains the influence of the sweep angle α on the reflection coefficient and AR bandwidth. From Figure 6 when the value of the sweep angle α

increase, both the bandwidths of impedance and AR are extended toward both lower and higher frequency. However, when increasing of α larger than 118° , the value of AR in the middle frequency band will be greater than

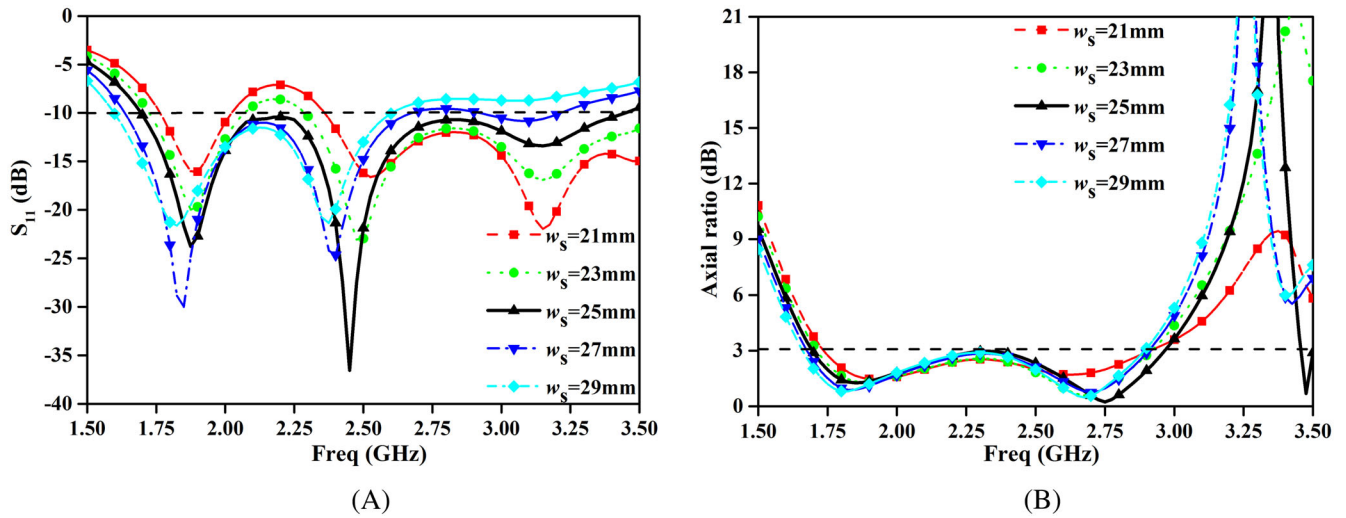


FIGURE 5 S_{11} and AR with different values of w_s . (A) S_{11} , (B) AR

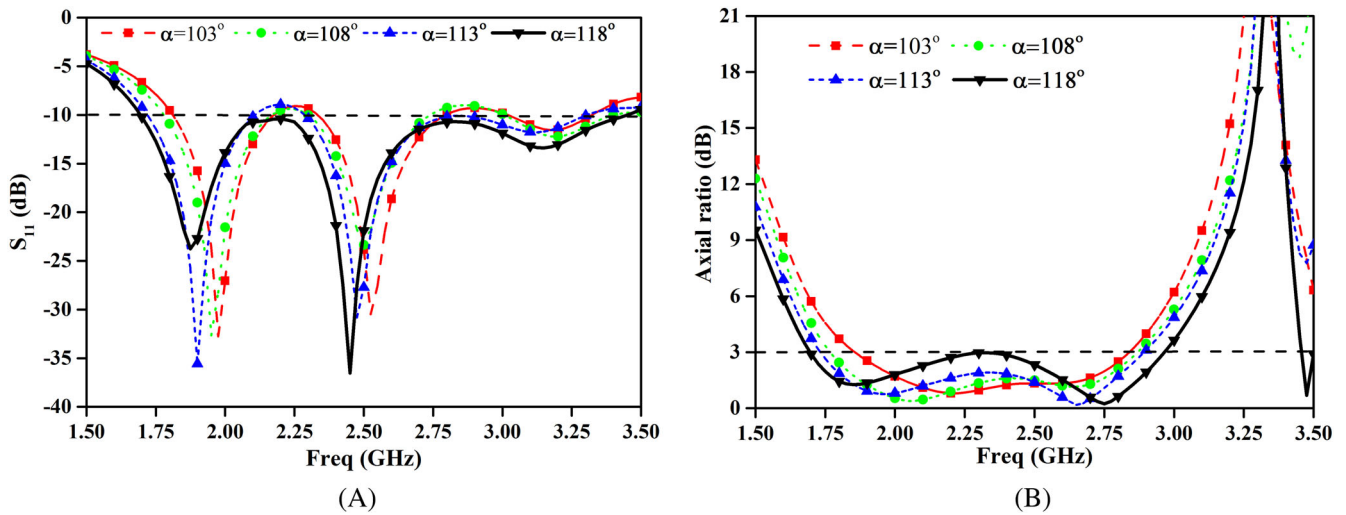


FIGURE 6 S_{11} and AR with variable values of α . (A) S_{11} , (B) AR

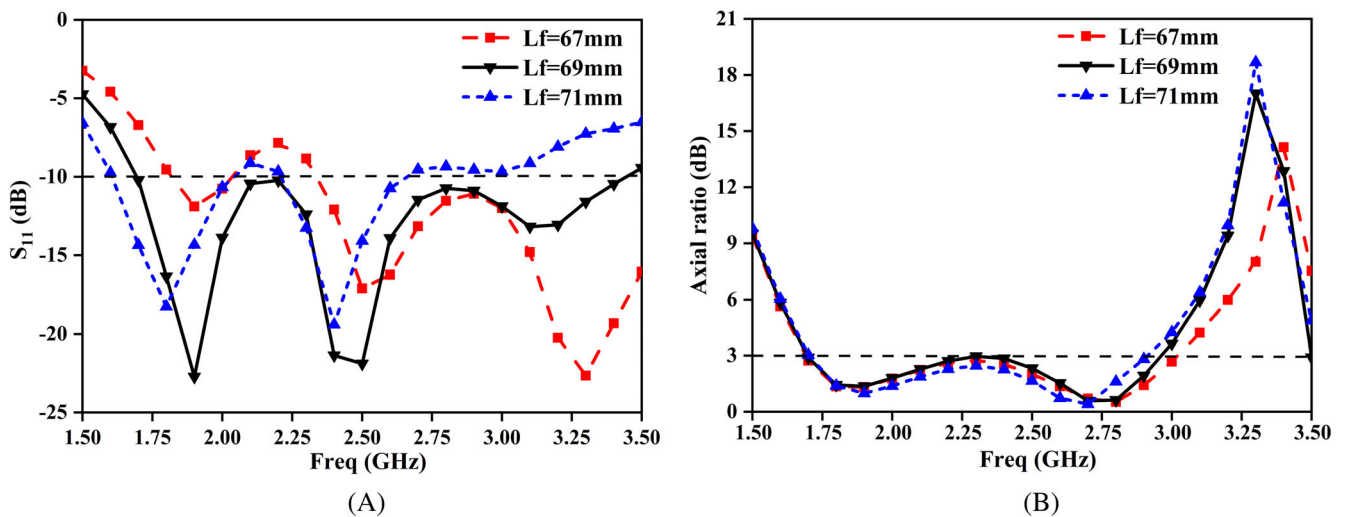


FIGURE 7 S_{11} and AR with variable values of L_f . (A) S_{11} , (B) AR

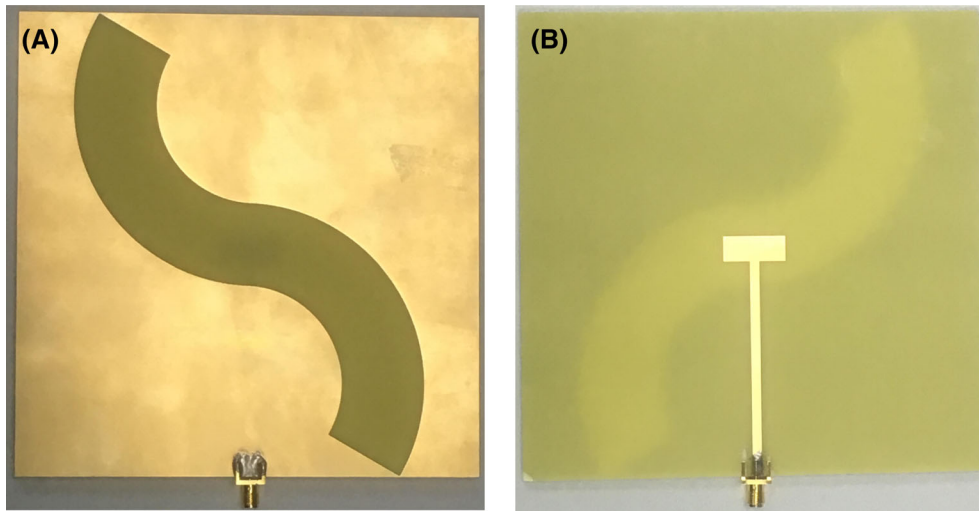


FIGURE 8 Photographs of proposed antenna prototype. (A) Top view, (B) bottom view

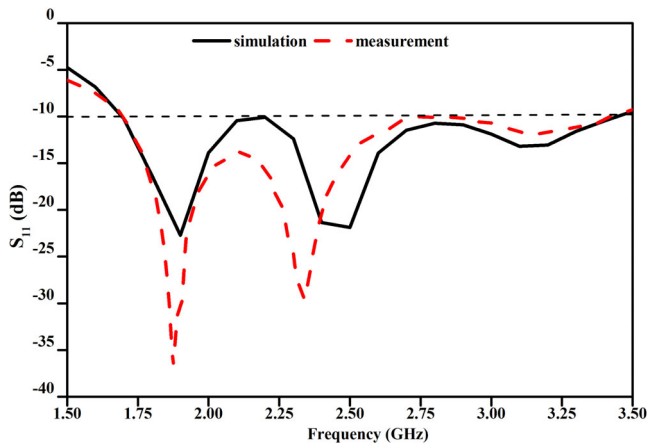


FIGURE 9 Simulated and measured S_{11} for fabricated antenna

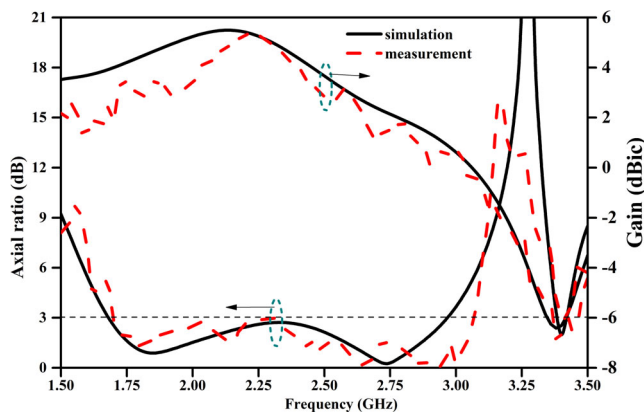


FIGURE 10 Simulated and measured AR and gain for fabricated antenna

3 dB. In other words, the variation of the sweep angle α has a more significant effect on the AR. When $\alpha = 118^\circ$, the best performance of AR can be obtained. Figure 7 illustrates the influence of L_f (the length of feeding line)

on the impedance bandwidth and AR bandwidth. As shown, when the length of feeding line L_f is increased, the impedance bandwidth tends to higher frequency. In contrast, the AR bandwidth has almost unchanged. According to this analysis, the best value of L_f is finally set to 69 mm to achieve the widest overlapping bandwidth.

3 | SIMULATION AND MEASUREMENT RESULT

In order to prove the above design principles, the proposed wideband S-shaped slot CP antenna is manufactured and measured. Figure 8 shows the manufacture prototype of the proposed antenna. The measured and simulated S_{11} of the proposed antenna are indicated in Figure 9. The measured impedance bandwidth is 68.1% for $S_{11} < -10$ dB (1.66–3.44 GHz), which is good agreement of the simulated results (1.66–3.44 GHz) except a slight deviation for the resonance frequency points. The simulated and measured results for AR and gain are presented in Figure 10. The measured AR bandwidth is about 57.1% from 1.68 to 3.06 GHz, and has a little discrepancy with simulation, which may be caused by the measurement and manufacturing errors. In addition, from Figure 10, the measured peak gain is 5.4 dBic at 2.24 GHz. Figure 11 indicates the RHCP-LHCP radiation patterns at 1.8 and 2.6 GHz (at xoz and yoZ planes). These patterns show fully agreement between simulated and measured results.

From the Figure 10A,B, it is can be seen that the antenna radiates LHCP waves in the $+z$ direction, and radiates RHCP waves in the $-z$ direction, which is consistent with the previous results of current analysis. The comparison with other reported low-profile slot antennas

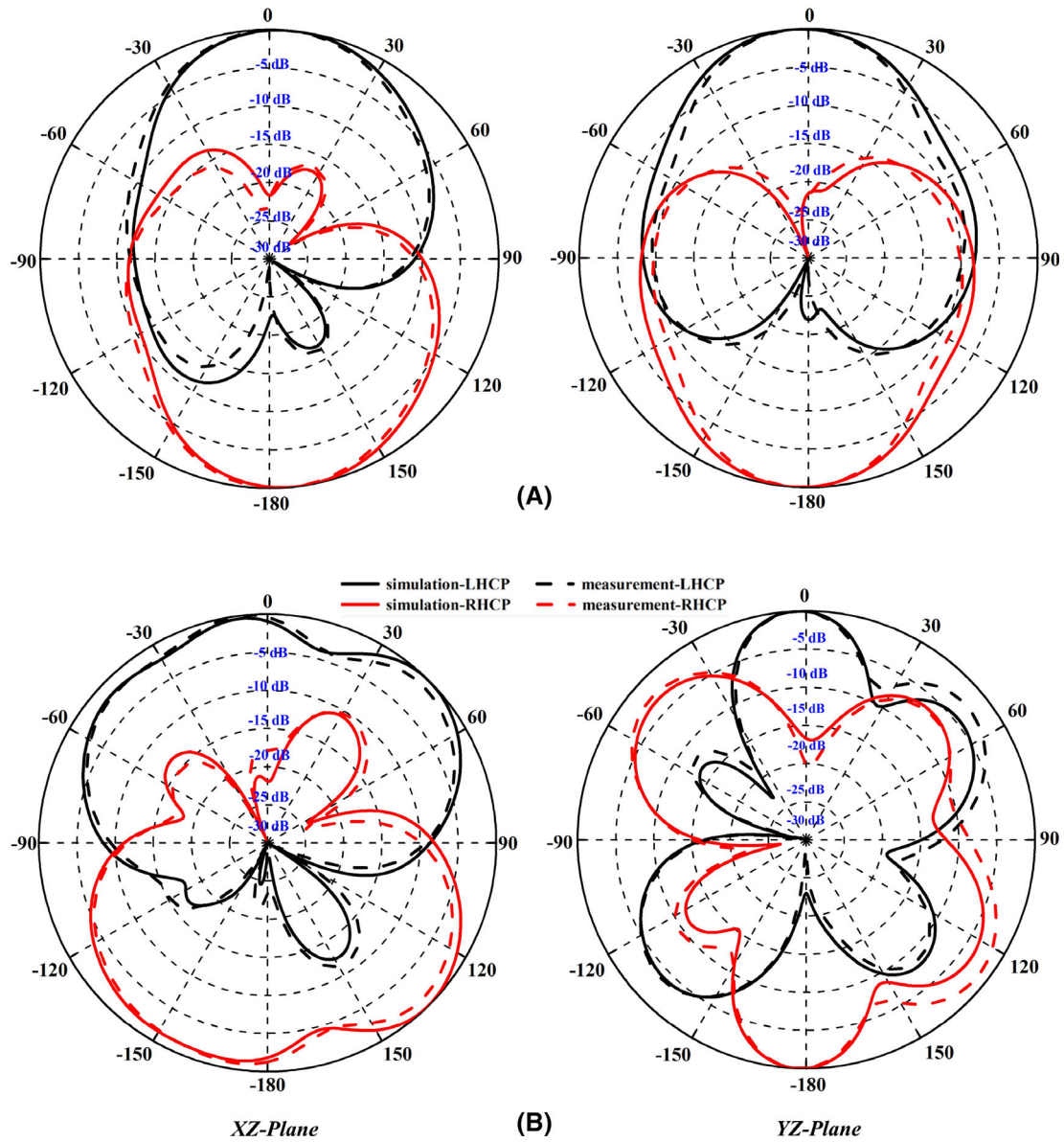


FIGURE 11 Simulated and measured radiation patterns for fabricated antenna. (A) 1.8 GHz, (B) 2.6 GHz

TABLE 1 Comparison with other CP slot antennas. (λ_0 is the wavelength of the lowest operating frequency)

References	Size (λ_0^3)	Axial ratio bandwidth (%)	Impedance bandwidth (%)	Peak gain (dBic)
2	$0.45 \times 0.45 \times 0.24$	27	50.2	6.2
3	$1.38 \times 1.38 \times 0.6$	54.3	54.9	14.2
5	$0.78 \times 0.74 \times 0.021$	33.3	60.5	4.7
6	$1.546 \times 1.546 \times 0.057$	15.9	19	5.6
7	$0.86 \times 0.67 \times 0.13$	14.3	14.3	4.2
9	$0.32 \times 0.33 \times 0.01$	49	62	3.3
11	$0.83 \times 0.83 \times 0.013$	5.5	6.3	5.7
12	$1.35 \times 1.35 \times 0.27$	11.8	15.9	12.5
This work	$0.85 \times 0.85 \times 0.11$	57.8	68.1	5.4

are given in Table 1. It can be seen that the proposed antenna not only has low profile but also has a wider impedance bandwidth and 3-dB AR bandwidth.

4 | CONCLUSION

This article proposed a novel simple wideband S-shaped slot antenna with CP. The proposed antenna is consists of a wide curve S-shaped slot and a T-shaped feeding line. The S-shaped slot can generate CP radiation for a wideband, while the impedance bandwidth can be improved by using the T-shaped feeding line. Measured results illustrate that the impedance bandwidth is 68.1% and AR bandwidth is 57.1%. And the maximum broadside direction gain of the proposed antenna is 5.4 dBic. Due to the low profile, simple structure, and broadband CP characteristics, the proposed antenna can be suitable applied to many wideband wireless applications.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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AUTHOR BIOGRAPHIES



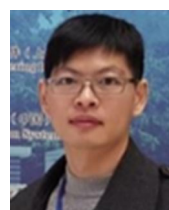
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