Progress In Electromagnetics Research Letters, Vol. 50, 29–34, 2014

A Broadband Circularly Polarized Square Slot Antenna

Chao Tian*, Yong-Chang Jiao, and Weilong Liang

Abstract—A new broadband circularly polarized slot antenna with a rotated slot for bandwidth enhancement is proposed. The antenna has a simple structure, consisting of a microstrip feed line, a substrate, and a rotated rectangular slot with two opposite slots etched on the plane. By appropriately adding the rotated rectangular slot and two opposite slots on the ground-plane, the impedance bandwidth of the antenna is enlarged, and its wide axial-ratio (AR) bandwidth is achieved. Experimental results show that the proposed antenna has good right-hand circular polarization (RHCP) characteristics. The measured −10-dB return loss impedance bandwidth and 3 dB axial-ratio bandwidth are 38.8% (1.5 GHz∼2.2 GHz) and 25.6% (1.56 GHz∼2.02 GHz) at the center frequency of 1.8 GHz.

1. INTRODUCTION

Due to the advantages such as low profile, light weight, ease of conforming to carriers, and integrating with active devices, the slot antennas have been widely used in many fields [1–3]. In addition, the slot antennas are easy to generate circular polarization (CP) operation through using various perturbation configurations, which operate on the same principle of detuning degenerate modes of asymmetrical slot antenna.

The CP slot antenna receives more attention in satellite communications as it can launch and receive CP electromagnetic waves, relatively less sensitive to their respective orientations. Typically, CP slot antennas can be classified as a single-fed antenna and a dual-fed antenna, in terms of feeding approach type. For the single-fed one [4–6], the antenna structure is relatively simple, as no external feed network is required to provide the 90° phase difference for the two orthogonal resonant modes. In [4], apertures are introduced to change the current path for resonant modes of the same amplitude and 90° phase difference. In [5], a single-fed CP antenna consists of a stacked structure is proposed. But the usable impedance and axial ratio bandwidths are usually narrow. For the dual-fed design [7–10], the excitation can be easily accomplished by employing a feeding network such as the hybrid or Wilkinson power divider. This feeding approach is attractive for the broadband CP antenna designs, but at the expense of increasing the production cost.

To achieve relatively wide impedance and AR bandwidths, the printed slot antennas with CP characteristic have been proposed in [5, 11], and the 3 dB axial ratio bandwidth of 18.85% and 12% are obtained, respectively. A proper rotation angle with respect to the center of square wide slot is selected to obtain the other resonant mode operating near one of the conventional wide-slot antennas [12]. The opposite slot in the ground makes the surface current distribution varies anticlockwise and generates the circular polarized radiation. However, the design of single-feed slot antenna with wide AR bandwidth and impedance bandwidth remains a challenging problem for antenna designers.

In this Letter, a new single-feed slot antenna with broad AR bandwidth and impedance bandwidth is presented. In the proposed antenna, the circular polarization can easily be implemented by embedding two branches on the plane. By choosing a proper rotation angle with respect to the center of rectangular

Received 29 September 2014, Accepted 27 October 2014, Scheduled 19 November 2014
* Corresponding author: Chao Tian (tianchaocat@aliyun.com).
The authors are with the National Key Laboratory of Antenna and Microwave Technology, Xidian University, Xi'an, Shaanxi 710071, People's Republic of China.

slot, it can be expected that another resonant mode operating near one of the conventional wide-slot antennas can be obtained. Hence within the operating bandwidth, two resonant modes having similar slot radiation patterns and the same polarization planes make significant CP bandwidth enhancement of the proposed slot antenna possible. This new single-feed slot antenna has more compact size or much wider bandwidth than previous designs [4–6, 11]. Details of the proposed slot antenna design and experiment results are presented and discussed.

2. ANTENNA GEOMETRY AND DESIGN

The geometry of the proposed design is shown in Figure 1. A rectangular patch of $100 \times 100\,\mathrm{mm}^2$ is fabricated on an FR4 substrate of thickness 1.6 mm and permittivity 4.4. The overall dimension of the proposed antenna is $100 \times 100 \times 1.6\,\mathrm{mm}^3$. The 50-$\Omega$ microstrip feed-line and the slot are etched on the opposite sides of the FR4 substrate. The rectangular slot embedded on the ground plane is with equal slot length G, and the two branch slots embedded on the ground plane are with unequal slot lengths W and L. Numerical simulations for the antenna, including a SMA connector model, are carried out using a commercially available software package HFSS. The final dimensions of the proposed antenna are listed in Table 1.

Circular polarization is produced when two or more orthogonal linearly polarized modes, of equal amplitude and 90° phase difference, are independently excited. Figure 2 shows the surface current distributions of the proposed antenna without the opposite slot. When the opposite slot does not exist, the surface current distribution of the antenna is symmetrical; therefore the circular polarization cannot be generated.

In order to illustrate why the CP can be generated by the proposed antenna, we examine how the surface current distribution varies with time. Figure 3 shows surface current distributions of the proposed antenna at 1.85 GHz for four different time phases, from 0° to 270°, with an interval of 90°. At $\omega t = 0°$, the predominant surface current flow is in u direction. When $\omega t = 90°$, a dominant v directed current flow is observed. It can be observed that the surface current distribution at $\omega t = 180°$ (270°) is approximately equal in magnitude and opposite in phase of (90°). As time changes, the surface currents located at the azimuth angle turn in the anticlockwise direction. Hence the polarization sense is right-hand CP wave in $-z$. Moreover, as shown in Figure 3, the main function of both the two branches on the ground plane is to break the surface current distributions balanced on ground-plane,

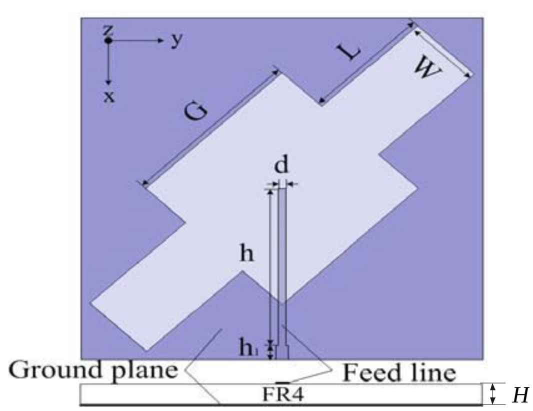


Figure 1. Configuration of the proposed antenna.

Table 1. Dimensions of the optimized antenna design.

Parameters	G	L	W	d	h	h_1
Values (mm)	48	33.5	20	2	46	4

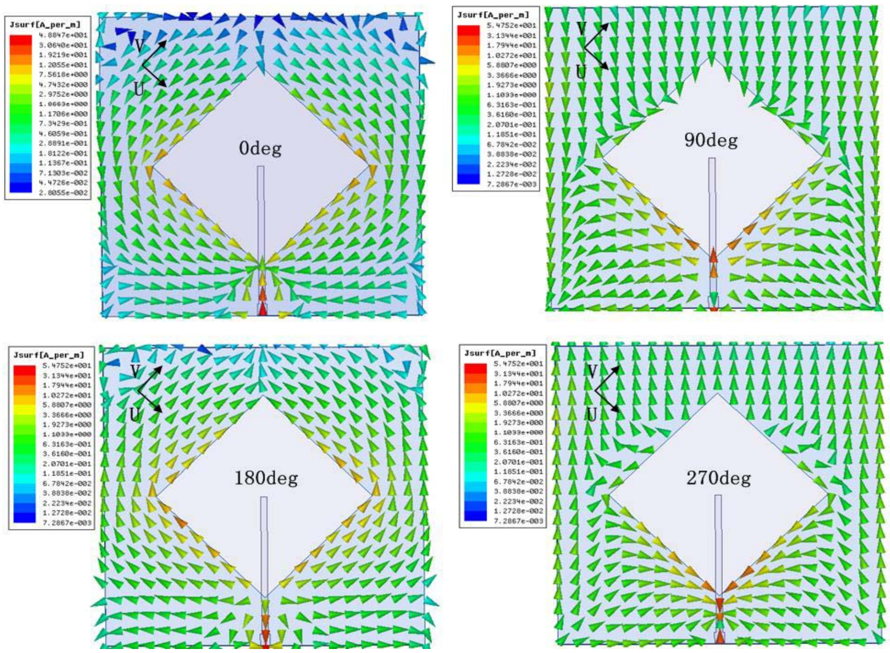


Figure 2. Simulated surface current distributions of the antenna without the opposite slot at 1.85 GHz for four different time instants. $\omega t = 0°$, $\omega t = 90°$, $\omega t = 180°$, $\omega t = 270°$.

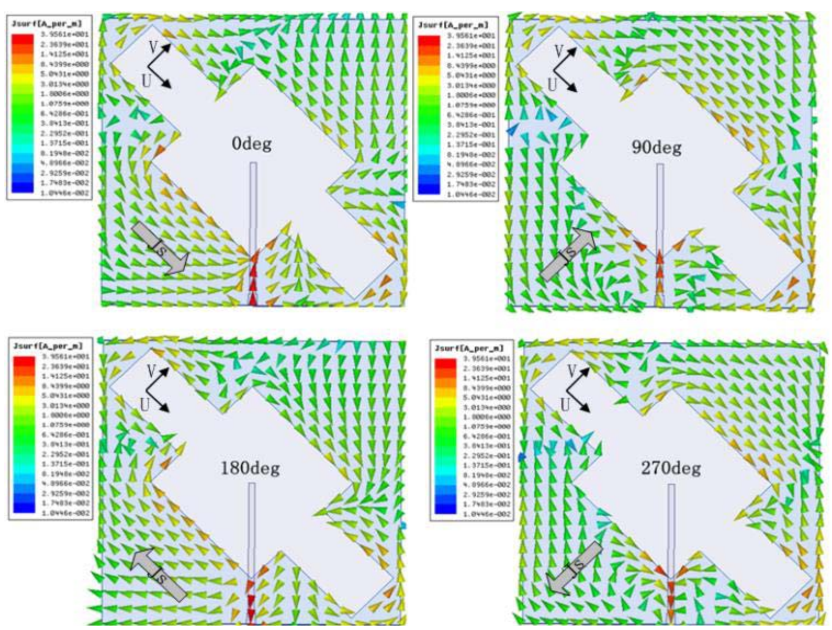


Figure 3. Simulated surface current distributions of the proposed antenna at 1.85 GHz for four different time instants. $\omega t = 0°$, $\omega t = 90°$, $\omega t = 180°$, $\omega t = 270°$.

so the antenna can radiate CP waves.

The printed wide slot is chosen to be a rectangle in order to excite two modes with close resonant frequencies. The length G of the symmetry rectangular shaped slot determines the resonant frequency during the impedance bandwidth. For exciting the operating frequencies at around 1.8 GHz, this printed rectangular slot rotates with an angle 45°.

By adjusting length G of the rectangular slot, the length L and width W of the two branches can get a very wide impedance bandwidth and the CP bandwidth for the GPS applications. A photograph of the proposed antenna is shown in Figure 4.

3. SIMULATION AND MEASUREMENT RESULTS

The comparison between simulated and measured performances of the proposed antenna obtained by using HFSS ver. 13 and the WILTRON37269A vector network analyzer is shown in Figure 4. Apparently, the measured −10-dB return loss impedance bandwidth and 3 dB axial-ratio bandwidth are 38.8% (1.5 GHz∼2.2 GHz) and 25.6% (1.56 GHz∼2.02 GHz) at the center frequency of 1.8 GHz, which show approximate agreement with the simulated results. The differences may be due to the effect of the SMA connector and measurement condition.

Figure 5 shows the effect of G on the return losses and ARs at the boresight direction for the

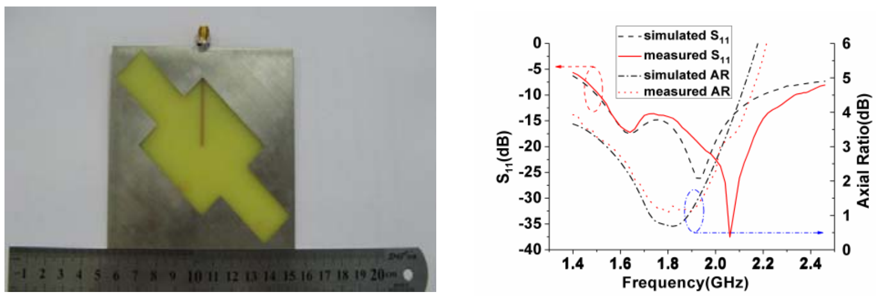


Figure 4. Photograph of the proposed antenna and corresponding results.

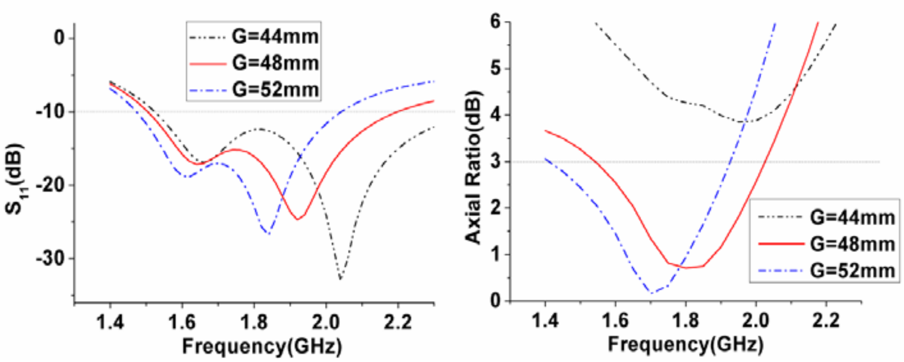


Figure 5. Simulated reflection coefficient and axial ratio for different values of G.

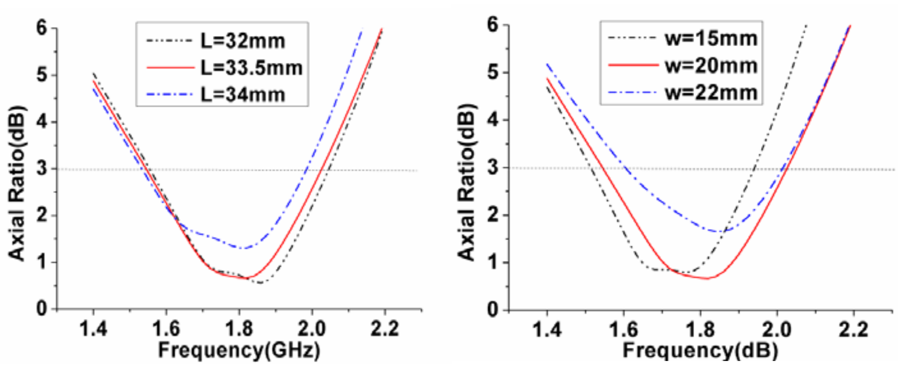
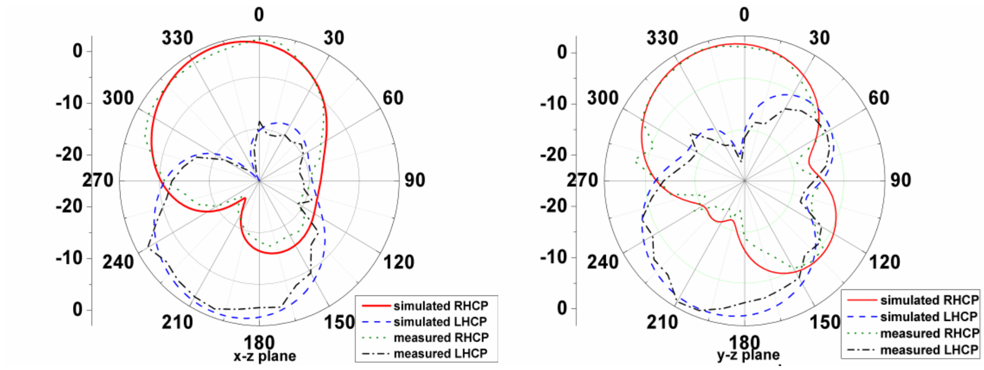
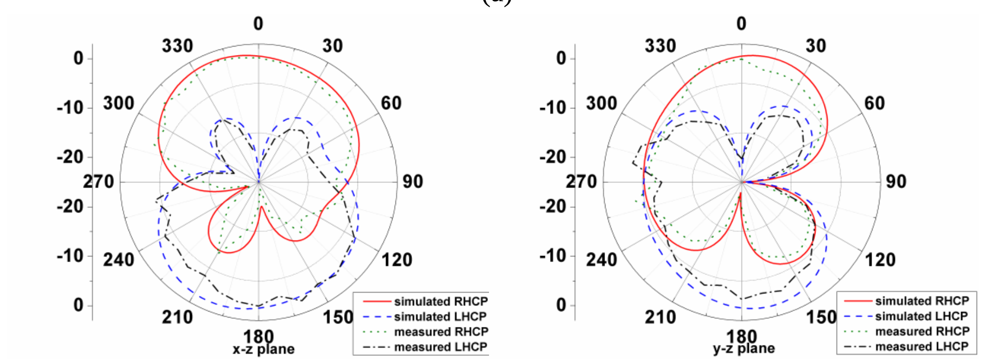


Figure 6. Simulated axial ratio for different values of L and W.



(a)



(b)

Figure 7. The simulated and measured antenna radiation pattern at (a) 1.56 GHz, (b) 1.78 GHz.

proposed antenna. The length G with three different lengths 44, 48, and 52 mm are analyzed as other parameters fixed. As shown in Figure 5, the length G can greatly affect the impedance matching, and it can also affect the AR bandwidth. In order to achieve the widest -10-dB impedance bandwidth and 3 dB AR bandwidth, a value of $G = 48$ mm is selected.

Figure 6 illustrates the axial-ratio (AR) at the boresight with different L and W. Both the length and width of the two branches can greatly affect the bandwidth and the frequency position of the axial-ratio. To get the circularly polarized wave for the global satellite communications (GPS 1.6 GHz), $L = 33.5$ mm, $W = 20$ mm is chosen for the best broadband circularly polarized antenna after repeated testing and optimization.

Figure 7 shows the far-field radiation patterns of the fabricated prototype at 1.56 GHz and 1.78 GHz. It can be seen from the far-field antenna radiation pattern that gain at different frequencies is 2.76 dBi and 1.48 dBi. Antenna has a good radiation characteristic with the right-hand circular polarization.

4. CONCLUSION

In this article, a new broadband CP slot antenna has been proposed and successfully implemented. The proposed antenna can achieve broadband just through etching slots on the ground plane, so it can be much easier to fabricate. The experimental results show that the proposed antenna has impedance bandwidth about 38.8% (1.5 GHz$\sim$2.2 GHz) and a 3 dB CP bandwidth about 25.6% (1.56 GHz$\sim$2.02 GHz) at the center frequency of 1.8 GHz, which is good enough for global satellite communication system.

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