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BROADBAND MONOPOLE ANTENNA WITH WIDE-BAND CIRCULAR POLARIZATION

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Abstract—A novel broadband monopole antenna design with wideband circular polarization (CP) characteristic is presented. This antenna consists of a feed line and a step-shaped ground plane which is formed by cutting a notch in the upper left corner of an asymmetric ground plane. The asymmetric ground plane is capable of exciting two orthogonal electric field vectors with equal amplitude and 90° phase difference (PD) for CP. By cutting a notch, the 10-dB impedance-bandwidth can be enhanced greatly and the 3-dB axial ratio (AR) bandwidth is also improved meanwhile. The measured impedance-bandwidth is about 5.96 GHz (84.7%) from 4.06 to 10.02 GHz, and the measured AR-bandwidth is about 2.64 GHz (36.5%) from 5.91 to 8.55 GHz. The results show that the antenna can achieve wide impedance-bandwidth and wide AR-bandwidth simultaneously.

1. INTRODUCTION

In recent years, printed monopole antennas have been developed rapidly due to their attractive features such as simple structure, low profile, light weight, wide impedance-bandwidth, and omnidirectional radiation pattern. Generally, printed monopole antennas can only radiate linearly polarized radiation waves and it is very difficult for them to radiate circularly polarized radiation waves. The most significant characteristic of polarization diversity is their superior signal reception performance in the multipath fading environment. Therefore, CP antennas have attracted much attention and they are often used in modern communication systems, such as radar, navigation and satellite systems. If monopole antennas can generate

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circularly polarized radiation waves, their applications will be greatly enhanced.

Unfortunately, until now, only few studies [1, 2] of CP monopole antenna have been investigated. In [1], the antenna achieves CP by locating the feedline at the left of the ground plane and has an AR-bandwidth of 14.5%. The quasi-loop antenna reported in [2] has a wider AR-bandwidth and a relatively complex geometry compared to antenna [1]. Typically, the planar CP antenna is achieved through using microstrip patch antenna [3–8] and printed slot antenna [9–12]. However, most of these antennas have relatively narrow impedance-bandwidths, narrow AR-bandwidths, large sizes, or complex geometries. Note that the widest AR-bandwidth of the antenna in [12] is not completely covered by its impedance-bandwidth.

This paper proposes a microstrip-fed printed monopole antenna that is capable of realizing CP radiation. The antenna has simple structure, small size and is easy to be integrated with active devices. The measured impedance-bandwidth is about 5.96 GHz from 4.06 to 10.02 GHz; the measured AR-bandwidth is about 2.64 GHz from 5.91 to 8.55 GHz. The AR-bandwidth of the proposed antenna is larger than those in [1–11], and it can be fully enclosed by its impedance-bandwidth. These results indicate that the proposed antenna can achieve broad impedance-bandwidth and wide AR-bandwidth simultaneously.

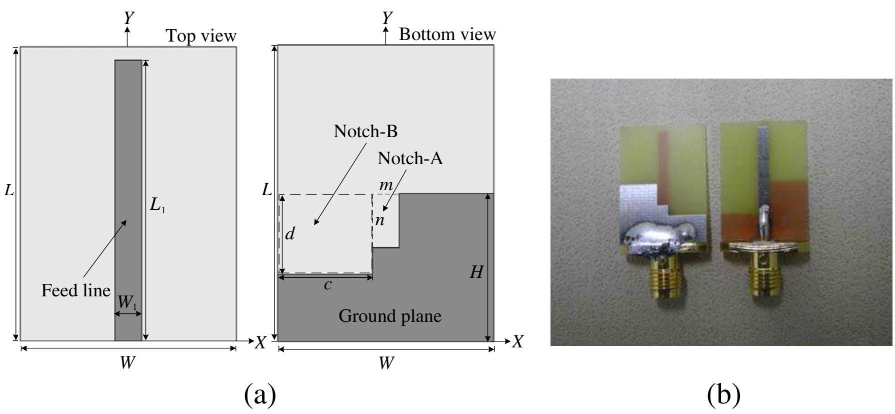


Figure 1. Geometry of proposed antenna and photograph of prototype. (a) Geometry of proposed antenna, (b) photograph of prototype.

2. ANTENNA DESIGN

The geometry of the proposed antenna and the photograph of the fabricated prototype are shown in Figure 1. This antenna consists of a feed line, a step-shaped ground plane and is designed on an FR4 substrate with dielectric constant 4.6 and loss tangent 0.02. The overall dimension of the antenna is $16\times22\times1\,\text{mm}^3$. A 50 Ohm SMA connector is used to excite it. This antenna is designed and optimized by Ansoft High Frequency Structure Simulator (HFSS). The final dimensions of the optimized antenna are listed in Table 1. Simulated ARs and return losses for different values of W_1 and L_1 have been exhibited in Figure 2, respectively. As shown in Figure 2, W_1 has significant effects on AR, while L_1 has strong effects on return loss.

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

W	W_1	L	L_1	H	m	n	c	d
16	2	22	21	11	2	4	7	6

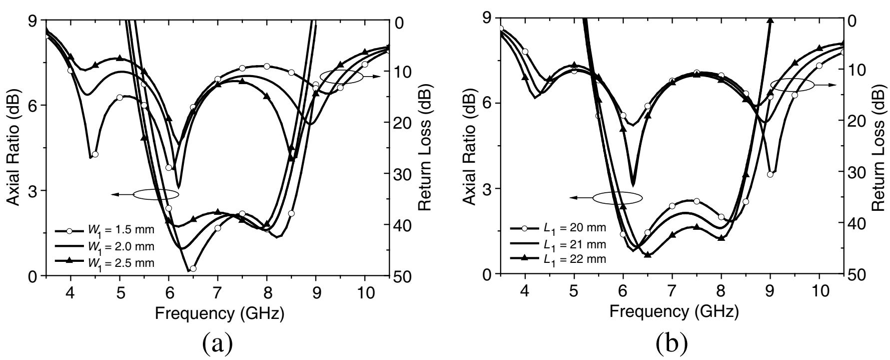


Figure 2. Simulated ARs and return losses for different values of W_1 and L_1.

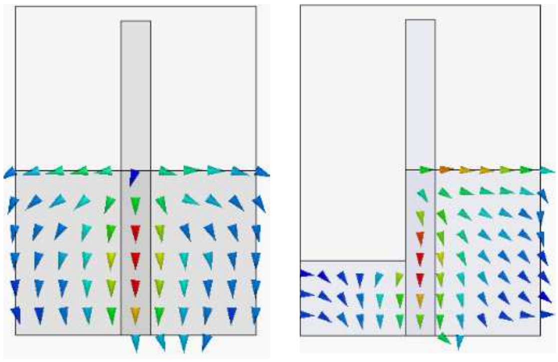
In the following, we will discuss the design techniques used for this antenna, which include a method to generate CP and a means to increase the impedance-bandwidth.

2.1. The Method to Excite CP

In general, the behavior of a monopole antenna is either vertical or horizontal linearly polarized. Conventional monopole antennas are difficult to radiate circularly polarized radiation waves. CP is generated by two orthogonal electric field vectors with equal amplitude and 90° PD.

To achieve CP radiation, an asymmetric ground plane is used in the antenna design. For explaining this method, the surface current distributions for symmetric and asymmetric ground planes are shown in Figure 3. Moreover, the surface current distribution of the proposed antenna at 7 GHz is shown in Figure 4. It can be seen that the surface current distribution for symmetric ground plane can be divided into vertical and horizontal currents. The distribution of the horizontal current excites two components that are 180° out of phase. The radiation in the far field in the horizontal direction is very weak, so the conventional monopole antenna with symmetric ground plane can not excite CP. Asymmetric ground plane, however, can generate two orthogonal currents (vertical current and horizontal current) that have equal-amplitude and 90° PD. Therefore the asymmetric ground plane can excite circularly polarized radiation waves.

The simulated ARs of symmetric and asymmetric ground planes at the broadside direction are exhibited in Figure 5. The degree of asymmetry of the ground plane is decided by the size of notch-B ($c \times d$). The effects of notch-B on AR can be seen from Figures 6 and 7. It can be drawn from these results that the AR-bandwidth depends on the degree of asymmetry of the ground plane, and the widest AR-bandwidth can be reached by properly adjusting the lengths of c and d. Besides, asymmetric ground plane has little impact on impedance-bandwidth.



(a) (b)

Figure 3. Simulated surface current distributions at 7 GHz. (a) Symmetric ground plane and (b) asymmetric ground plane.

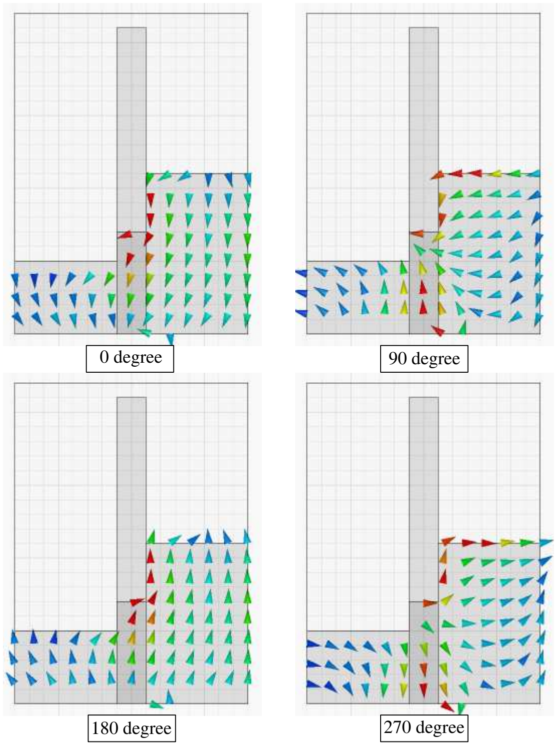


Figure 4. Simulated surface current distribution of the proposed antenna at 7 GHz.

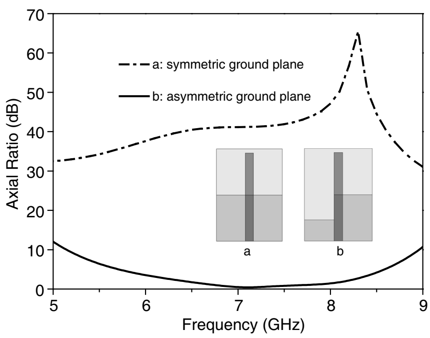


Figure 5. Simulated ARs of symmetric and asymmetric ground planes.

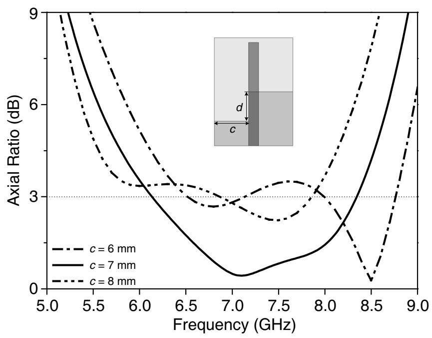


Figure 6. Simulated ARs for different values of c ($d = 6$ mm).

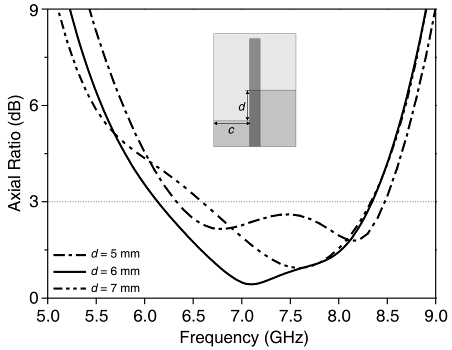


Figure 7. Simulated ARs for different values of d ($c = 7\,\mathrm{mm}$).

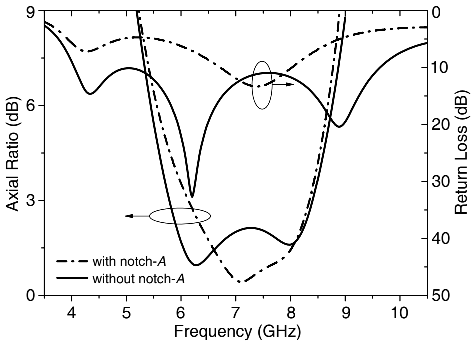


Figure 8. Simulated return losses and ARs of the proposed antenna with and without notch-A.

2.2. The Means to Increase the Impedance-bandwidth

As shown in Figure 8, a wide AR-bandwidth has been obtained by using asymmetric ground plane, but the impedance-bandwidth is relatively narrow and cannot fully cover the AR-bandwidth. To achieve a wide impedance-bandwidth, notch-A is cut in the upper left corner of the asymmetric ground plane. It can be seen from Figure 8 that two new resonance modes can be excited by adding notch-A. Due to the combination of the three resonant modes, the impedance-bandwidth is increased greatly and can fully cover the whole AR-bandwidth. The effects of notch-A on impedance-bandwidth are exhibited in Figures 9 and 10. The experimental results verify that cutting notch-A in the upper left corner of an asymmetric ground plane can greatly increase the impedance-bandwidth. Furthermore, we can observe from Figure 8 that the AR-bandwidth is also be enhanced.

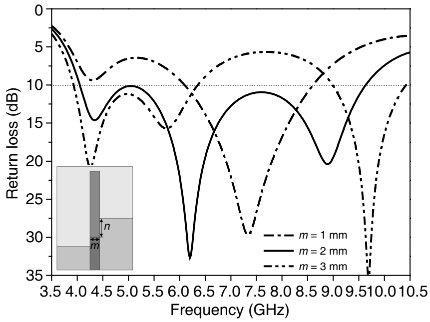


Figure 9. Simulated return losses for different values of m ($n = 4\,\mathrm{mm}$).

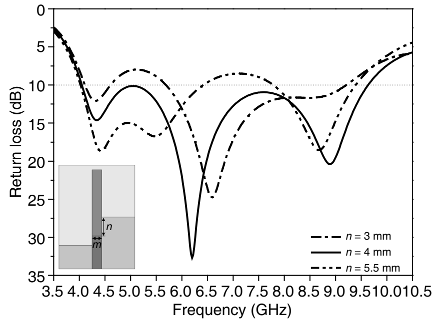


Figure 10. Simulated return losses for different values of n ($m = 2\,\mathrm{mm}$).

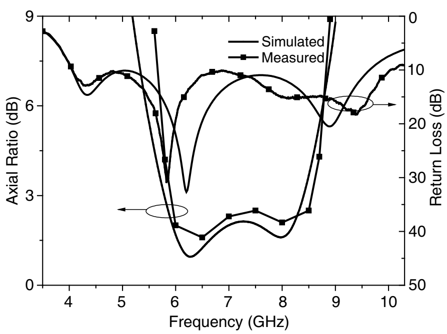


Figure 11. Simulated and measured return losses and ARs of the proposed antenna.

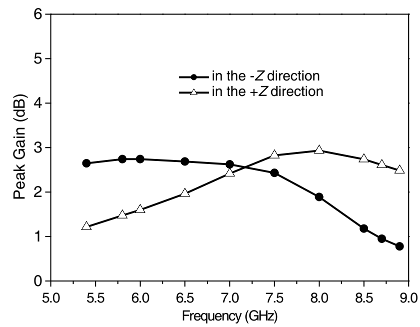


Figure 12. Peak gains of the proposed antenna in the $+z$ and $-z$ directions.

The results mentioned above show that the proposed antenna can achieve broad impedance-bandwidth and wide AR-bandwidth simultaneously.

3. RESULTS

The simulated and measured return losses and ARs of the proposed antenna are presented in Figure 11. The measured impedance-bandwidth is 5.96 GHz (84.7%) from 4.06 to 10.02 GHz. The measured AR-bandwidth is 2.64 GHz (36.5%) from 5.91 to 8.55 GHz. Good agreements can be observed between the simulated and measured results, except that the measured results slightly shift toward higher frequency compared to the simulated ones. Differences between simulated and measured results may be ascribed to the effects of the 50 Ohm SMA connector and the cable connected to the antenna. The measured results indicate that the proposed antenna is capable of realizing broad impedance-bandwidth and wide AR-bandwidth simultaneously.

Shown in Figure 12 is the peak antenna gains in the $+z$ and $-z$ directions. The simulated and measured left-hand circularly

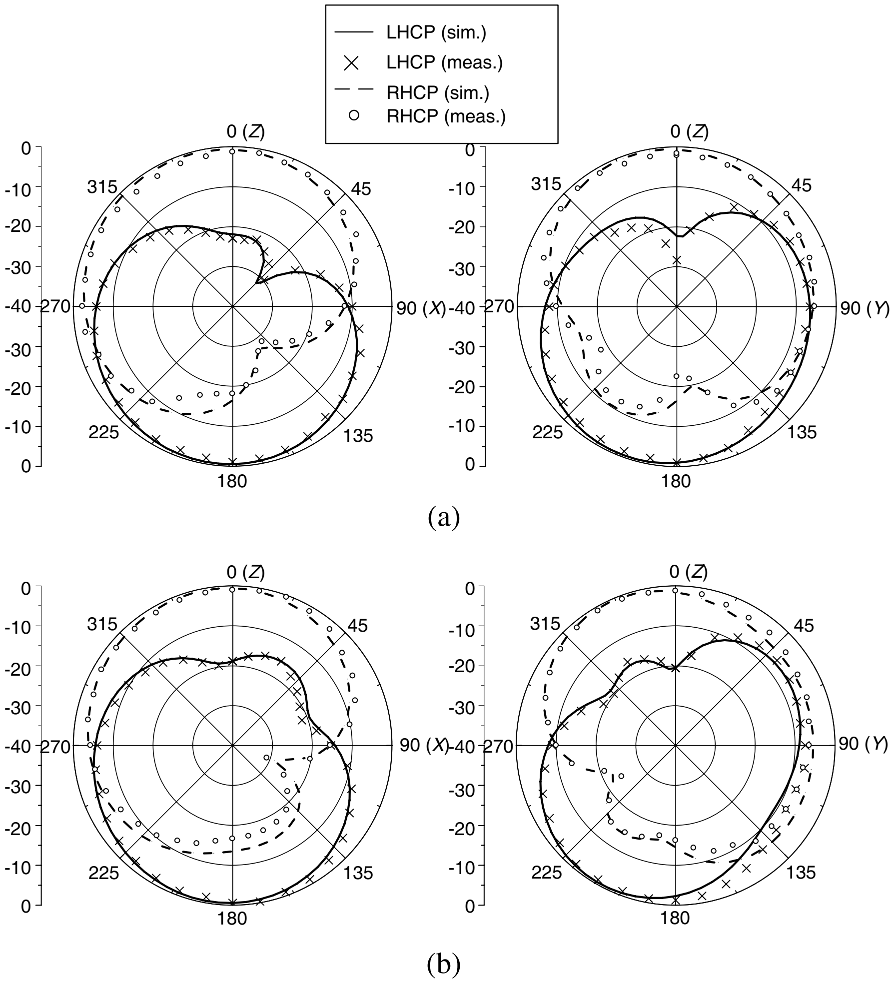


Figure 13. Simulated and measured radiation patterns in XZ- and YZ-planes. (a) 6 GHz and (b) 7 GHz.

polarized (LHCP) and right-hand circularly polarized (RHCP) radiation patterns in XZ- and YZ-planes at 6 and 7 GHz are shown in Figure 13, respectively. The patterns are mainly LHCP for $z < 0$ and RHCP for $z > 0$ and the cross-polarization can keep more than 15 dB lower than the co-polarization in each plane. Experimental results show the proposed antenna has good CP characteristics for both RHCP and LHCP.

4. CONCLUSION

In this paper, we propose a novel microstrip-fed printed monopole antenna capable of realizing broad impedance-bandwidth and wide AR-bandwidth simultaneously. The proposed monopole antenna has been implemented, and the detail antenna designs and experimental results have been presented and discussed. Experimental results show the proposed antenna has good CP characteristics for both RHCP and LHCP. Besides, this antenna has a simple structure, a small size of dimensions $16 \times 22 \times 1\,\text{mm}^3$ and is suitable for various wireless communication systems.

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