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A Novel Circularly Polarised Antenna with Wide Power and Axial-Ratio Beamwidth by Using Tilted Dipoles

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Abstract—A novel circularly polarised antenna with wide 3 dB axial-ratio beamwidth (ARBW) and half power beamwidth (HPBW) is proposed in this letter. By using two pairs of tilted dipoles, the ARBW of the antenna is significantly enhanced to about 160° and 162° in the XZ- and YZ-planes, respectively. Meanwhile, its HPBW is also broadened to above 116° in the dual planes. A prototype is manufactured and measured to validate the method. The measured results show that $|S_{11}| < -10$ dB reaches about 38.8% (1.37 GHz–2.03 GHz), and the AR at broadside bandwidth is 14% (1.51 GHz–1.74 GHz). The gain of the antenna also keeps above 4.19 dBic. Meanwhile, acceptable agreements can be obtained between the simulated and measured results. As such, the proposed CP antenna with wide beamwidth can be used in various navigation systems.

1. INTRODUCTION

Recently, circularly polarised (CP) antennas have been widely used in many wireless applications, such as global positioning systems (GPS), compass navigation satellite system (CNSS) and wireless local area network (WLAN) system. Generally, a CP antenna with 3-dB axial-ratio beamwidth (ARBW) wider than 120° can transmit and receive signals at any place on the earth in GPS and CNSS. Thus, it has attracted great attention to widen the beamwidths of CP antennas. A few researches have been performed to achieve wide ARBW during past decades. The 3-dB ARBW of the CP antenna can be broadened by mechanically mounting a basic CP radiator on a folded ground [1] or a conducting cavity. However, this approach has an inherent drawback because it is difficult to manufacture the ground and combine it with the radiator. Later on, parasitic structures were introduced above or around a CP radiator to widen the ARBW [2]. However, this approach enlarges the antenna dimension with a complexity structure and relative narrow HPBW. Several researches on low profile wide ARBW CP antennas were reported including an asymmetric microstrip antenna with integrated circular and stub-patches [3, 4]. In [5], a planar CP antenna combining two pairs of linear dipoles in a square contour is proposed. Its 3-dB ARBW was extremely improved to 126°. However, its HPBW was relatively narrow as 74°. As reported in [6], a CP antenna with wide ARBW of about 120° is achieved by using a suspended substrate, whereas the antenna also has a narrow HPWB as 78°. To increase the HPBW of the antenna, a number of approaches have been investigated. In [7], thick and high-permittivity substrates were adopted to increase the surface wave in the horizontal direction. Unfortunately, this method leads to an increase in antenna losses and reduction in the bandwidth. The HPBW can also be improved by reshaping the radiator and ground plane of the antenna to improve the radiation at low-elevation angles [8]. However, this method will enlarge the total size of the antenna. Thus, a high efficiency antenna with wide ARBW and HPBW is imperatively required.

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In this letter, a novel approach is proposed with wide HPBW and ARBW by adopting tilted dipoles. The measured 3-dB AR beamwidth is extremely improved to 160° and 162° in XZ- and YZ-planes, respectively. Particularly, the HPBW of the antenna reaches about116° in XZ-plane and 114° in YZ-plane at 1.6 GHz. Simultaneously, AR < 3 dB, $|S_{11}| < -15$ dB and gain > 4.19 dBic are satisfied over 1.51 GHz–1.74 GHz, which covers the GPS-band and CNSS-band.

2. ANTENNA DESIGN AND PARAMETRIC DISCUSSION

The geometry of the proposed antenna is shown in Fig. 1. The antenna consists of four tilted dipoles sequentially placed at the four corners of a rhombus contour and a feeding network constructed on an F4B substrate with a relative permittivity of $\varepsilon_r = 2.65$ and thickness of 1 mm at 1.6 GHz. Besides, the feeding network is printed on the top side to supply the equal amplitude with 90° phase difference to these tilted dipoles, which are located on the top and bottom layers of the substrate for each arm and

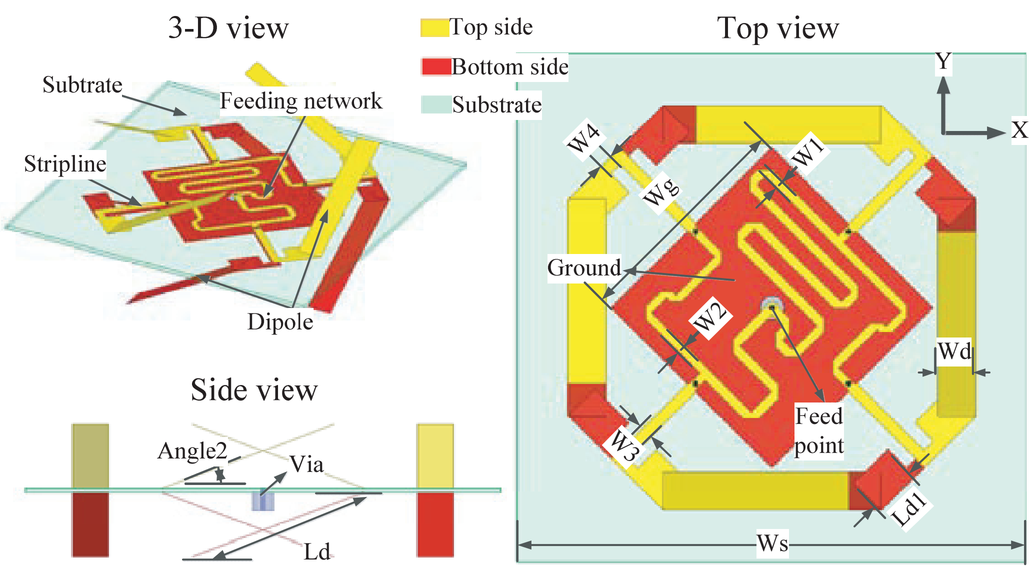


Figure 1. Geometry of proposed CP antenna.

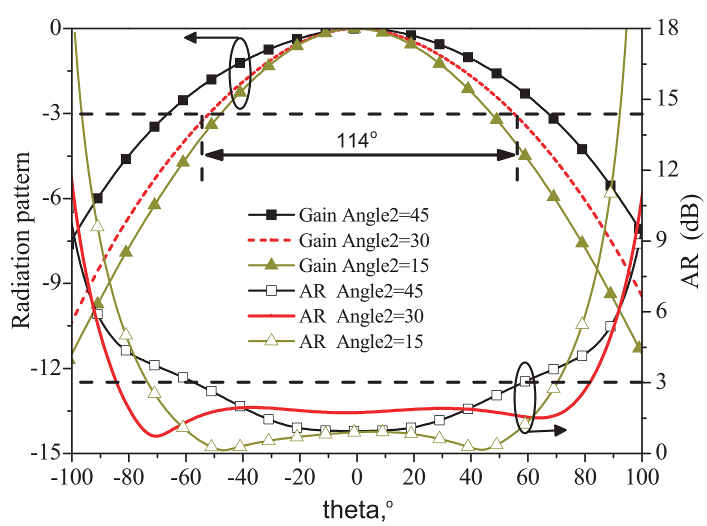
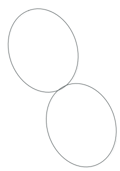
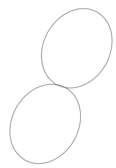
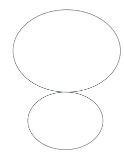


Figure 2. Simulated AR and Radiation pattern with different Angle 2 at the XZ-plane at 1.6 GHz.

Table 1. HPBW and ARBW with different Angle 2.

Angle 2	45°	30°	15°
HPBW	133°	114°	94°
ARBW	116°	162°	148°

Table 2. Wide beamwidth of a pair of tilted dipoles.

E-plane of one tilted dipole		E-plane of the opposite tilted dipole		Product of radiation pattern
	+		=	

fed by a double-sided and balanced stripline. As investigated in [5], two conditions should be satisfied to achieve a wide AR beamwidth. The first one is that the two parallel dipoles in perpendicular arrangement should be excited with the same amplitude and 90° phase difference. The other is that the E- and H-plane radiation patterns should be almost the same in a wide angular range for each pair of dipoles. Thus, the distance between two parallel dipoles determines the AR beamwidth. When the distance between two parallel dipoles is $0.45\lambda_0$, the H-plane pattern can match the E-plane pattern in beamwidth. Table 2 shows a novel approach to achieve wide HPBW. It is easy to know that the radiation pattern of each dipole can overlie in a wide angular range by the tilted dipoles. In order to achieve a wide beamwidth, the top and bottom layer arms tilt the angle of Angle 2 to $+z$ and $-z$ directions, respectively. Fig. 2 and Table 1 exhibit the effects of various Angle 2 on radiation patterns and ARBW in the XZ-plane. The results illustrate that the HPBW is enhanced by increasing Angle 2. In order to strike a balance between the best ARBW and HPBW characteristics at 1.6 GHz, Angle 2 at 30° is chosen for the final design. To validate that the proposed antenna can generate CP wave in Fig. 8, the current distribution on the strip conductor of the four dipoles is simulated at different phases of 0°, 90°, 180°, 270°, which stands for the periodicity of electromagnetic wave at 1.6 GHz. As shown in Fig. 9, the two pairs of dipoles are excited with almost the same amplitude and 90° phase difference, and they result in radiating the CP wave as a superposition of two orthogonal LP waves. By using the ANSYS HFSS, the proposed antenna with detailed dimensions as below is simulated and optimized.

$Ws = 82$ mm, $W1 = 1.55$ mm, $W2 = 1.4$ mm, $W3 = 2$ mm, $W4 = 2.2$ mm, $Wg = 40$ mm, $Ld = 35.6$ mm, $Ld1 = 12.2$vmm, Angle 1 = 45° and Angle 2 = 30°.

3. EXPERIMENTAL RESULTS AND DISCUSSION

A prototype of the proposed antenna is fabricated, and its photographs are shown in Fig. 8. The measurement is carried out by using a network analyser Angilent N5230A and NSI300V-30X30 far-field measurement system. Fig. 3 and Fig. 4 show the simulated and measured results of reflection coefficients ($|S_{11}|$), peak LHCP gain and AR with respect to frequency. The measured results agree quite well with the simulated ones. The measured $|S_{11}| < -10$ dB reaches about 38.8% (1.37–2.03 GHz) as depicted in Fig. 3. The AR and gain as a function of frequency is illustrated in Fig. 4. The results depict that the measured 3 dB AR at broadside bandwidth is 14% (1.51 GHz–1.74 GHz), and the gain of the antenna also keeps above 4.19 dBic. The measured and simulated ARs with respect to theta at XZ- and YZ-planes are demonstrated in Fig. 5, and the results show that the ARBWs are above 160° in dual planes. Fig. 6 illustrates the simulated and measured far-field radiation patterns at 1.6 GHz at XZ- and YZ-planes. CP radiation patterns over a wide range of polar angle are performed in both the dual planes. Fig. 7 demonstrates the measured and simulated radiation efficiencies of the proposed antenna, which keep above 90% in the operating band. A comparison of the CP radiation performance is made between the proposed antenna and the previous designs in [5] and [9], as shown in Table 3. The data show that wider 3 dB ARBW and HPBW can be realized by the tilted dipoles. In general, the presented antenna has better AR performance. Based on these results, the designed CP antenna can well cover the GPS-band and CNSS-band as a candidate in wireless communications.

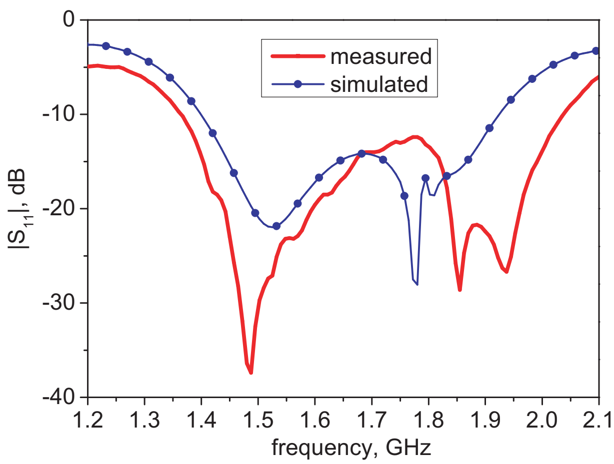


Figure 3. Simulated and measured $|S_{11}|$.

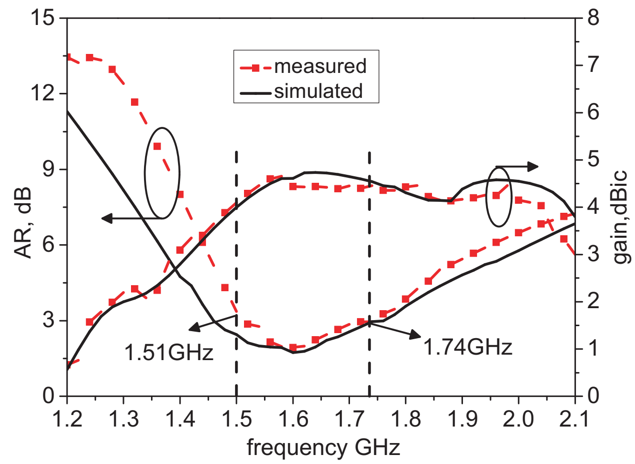
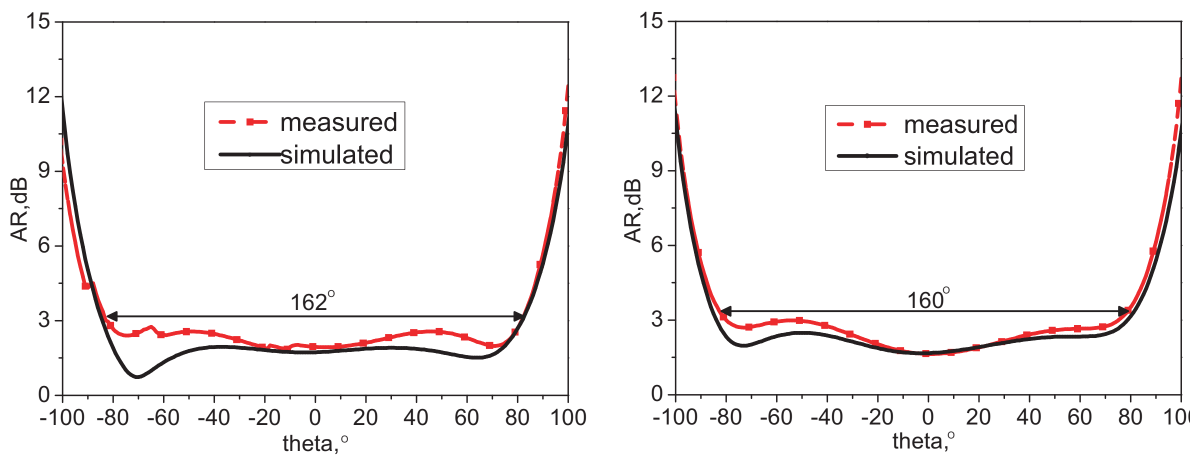


Figure 4. Simulated and measured ARs in the broadside direction and Peak LHCP gain.



(a) (b)

Figure 5. Simulated and measured AR as a function of the polar angle (theta) for the CP antenna at 1.6 GHz. (a) XZ-plane. (b) YZ-plane.

Table 3. Performance of the tilted antennas.

Antenna	3 dB AR Beamwidth (°)	3 dB HPBW Beamwidth (°)
Proposed	160	116
Ref. [5]	126	74
Ref. [9]	135	84

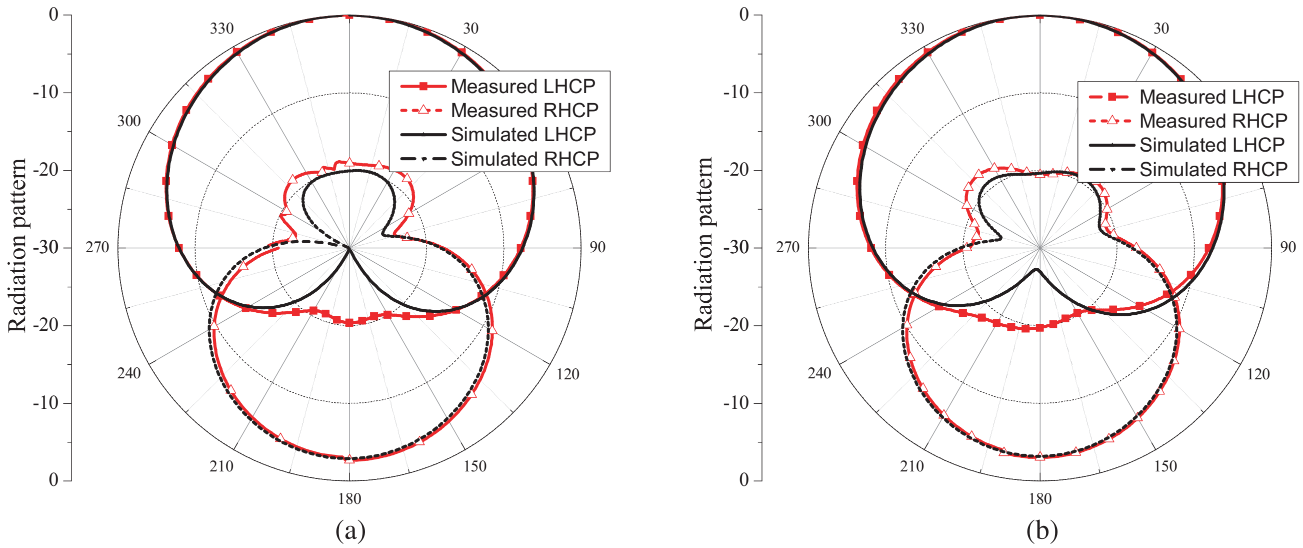


Figure 6. Measured and simulation radiation patterns of proposed antenna at 1.6 GHz. (a) XZ-plane. (b) YZ-plane.

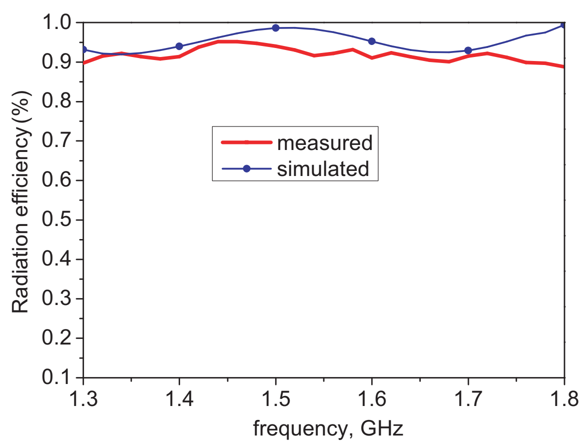


Figure 7. Measured and simulation radiation efficiency of proposed antenna.

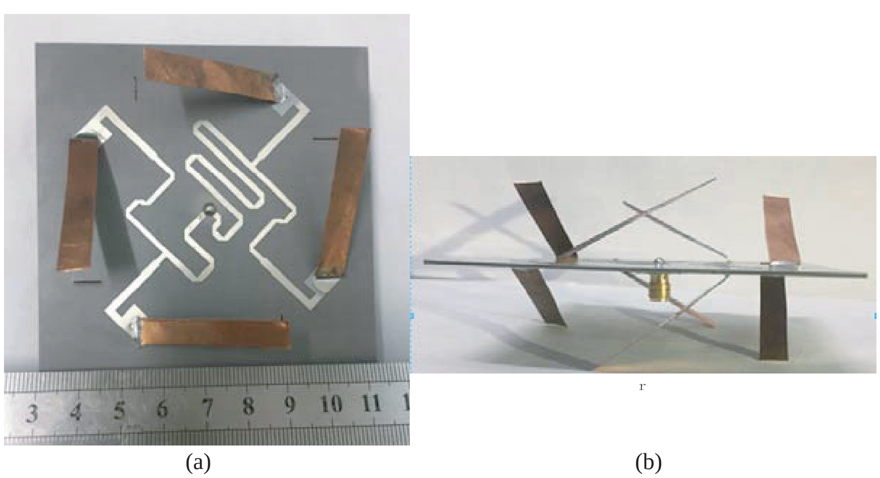


Figure 8. Photograph of the fabricated antenna. (a) Top view. (b) Side view.

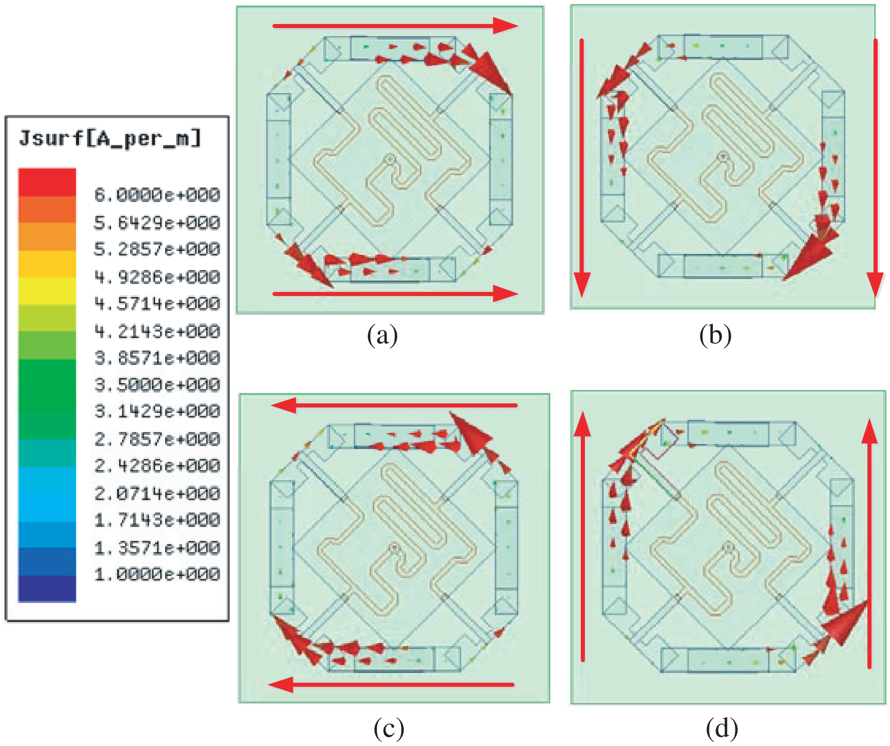


Figure 9. Current distribution of the proposed antenna at 2.9 GHz for different values of the phase angle. (a) 0°. (b) 90°. (c) 180°. (d) 270°.

4. CONCLUSION

In this letter, a novel antenna with wide ARBW and HPBW is designed, fabricated, and tested. It is easy and effective to broaden the ARBW and HPBW by tilted dipoles. The antenna exhibits a wide beamwidth radiation pattern, such as 160° for the 3 dB ARBW and 114° for the HPBW of the antenna at 1.6 GHz. As such, this novel antenna can be well applied to various navigation systems.

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