A Wideband Circularly Polarized Antenna With Conical-Beam Radiation

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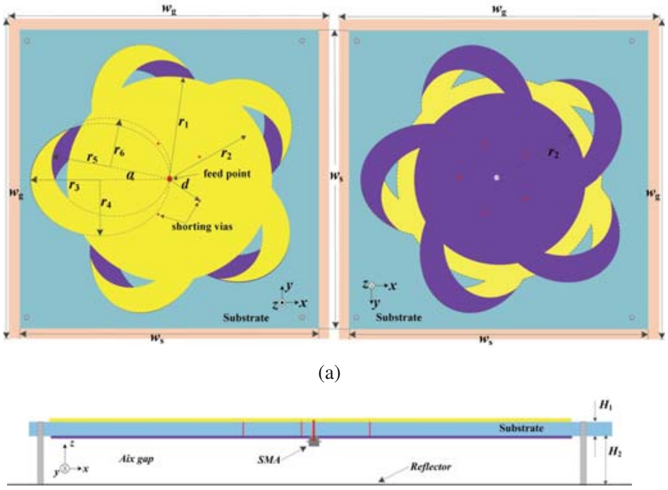
***Abstract*—In this paper, a novel circularly polarized (CP) antenna is proposed to meet conical beam radiation. The designed antenna consists of a monopolar patch fed by a probe in the center, two sets of arc hook branches, a set of conductive shorting vias and a reflector plane. The monopolar patch which connects to ground plane by set of conductive shorting vias, whose two resonant modes are utilized to achieve wide impedance bandwidth. A horizontally polarized electric field and a vertical polarized electric field can be generated by the arc hook branches and the monopolar patch, respectively. To adjust the parameters of the arc hook branches appropriately, the conical beam CP radiation can be obtained. The proposed antenna has a wide impedance bandwidth ($S_{11} < $ -10 dB) of 17.5% (5.7 to 6.75 GHz) and a 3-dB AR bandwidth of about 26.5% (5.19 to 6.78 GHz). Moreover, the stable omnidirectional conical-beam radiation patterns can be maintained within the whole operation bandwidth.**

***Index Terms*—Circularly polarized antenna, conical-beam radiation, omnidirectional radiation field, wideband antenna**

I. Introduction

Recently, circularly polarized (CP) antenna with conical beam radiation has been widely used in the satellite communication, indoor communication and vehicles communication region for its attractive advantages, such as omnidirectional radiation in a wider azimuth planes [1]–[3]. In [4], a feeding network is used to feed four inclined monopoles for obtaining CP radiation with conical beam. However, the axial ratio (AR) bandwidth is only 2.8%. Besides, TM01 and TE01 orthogonal modes were simultaneously excited to produce CP conical-beam pattern with an AR bandwidth of 4.8% [5].

In order to meet the rapid development of wireless communication systems, wideband CP antennas with conical-beam radiation have been studied [6]–[9]. A conical beam CP antenna with a wideband monopolar patch and eight parasitic loop stubs has been designed with a 3-dB AR bandwidth of 14.4% in [6]. A center-fed patch with eight shorting vias and surrounded by eight modified elliptical-ring slots could achieve a wide AR bandwidth of 24.8% [7]. By loading a parasitic conducting strip with the rectangular dielectric resonator antenna, a wideband AR bandwidth of more than 25% could be achieved [8]. In [9], by combining multiple identical customized parasitic patch elements arranged around the monopole, a 3-dB AR bandwidth of 17% is obtained.



(a)

(b)

Fig. 1. Geometry of the proposed antenna. (a) top view (left) and bottom view (right), (b) side view

Although these achieve a wide AR bandwidth, they are complex in geometry and large in size, which causes harshness in fabrication.

In this paper, we propose a novel method to achieve conical beam CP antenna. The designed antenna exhibits wide impedance bandwidth and AR bandwidth, good omnidirectional conical-beam radiation pattern and high gain. The proposed antenna can generate an impedance bandwidth of 17.5% and a 3-dB axial ratio bandwidth of 26.5%, respectively. The antenna can be applied to automotive vehicles communication system and wideband indoor communication system.

II. Design of the proposed antenna

Figure 1 presents the configuration of the proposed wideband conical-beam CP antenna, which consists of a center fed monopolar patch, two sets of arc hook branches, a set of conductive shorting vias and a reflector plane. The monopolar patch is composed of two circular patches, which is respectively printed on both sides of a 65×65 mm^2 Rogers RO4003C substrate with a thickness of 1.524 mm, a relative permittivity of 3.55, and a loss tangent of 0.0027. As shown

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TABLE I
ANTENNA PARAMETERS

r_1	r_2	r_3	r_4	r_5	r_6
22mm	19mm	15mm	12mm	13mm	10.4mm
α	w_s	w_g	d	H_1	H_2
12deg	65mm	80mm	8mm	1.524mm	15mm

in Fig. 1(a) and (b), the radius of big circular patch is denoted by r_1 and the radius of small circular patch is denoted by r_2. Each arc hook branch can be formed after a small ellipse is dug by a big ellipse. The big ellipse is located in Fig.1(a), where r_3 and r_4 denote radius of long axis and short axis of the big ellipse, respectively. The small ellipse is located in the back of Fig. 1(a), where r_5 and r_6 denote radius of long axis and short axis of the small ellipse respectively. In Fig. 1(a), α denotes angle between two long axises of two ellipses, w_s denotes the width of the substrate, w_g denotes the width of the relector plane, and d denotes the distance between the circle center and each shorting via. In Fig1. (b), H_1 denotes the thickness of the substrate, and H_2 denotes the height of the proposed conical-beam CP antenna from the reflector plane. One set of arc hook branches is wrapped around the circular patch on the upper surface of the substrate. The other set of arc hook branches is wrapped around the patch on the bottom surface of the substrate, which is mirror image of the former set. A horizontally polarized electric field and a vertical polarized electric field can be generated by the arc hook branches and the monopolar patch, respectively. By appropriately adjusting the parameters of the arc hook branches, the conical beam CP radiation can be obtained. Two resonant modes of the monopolar patch which connects to ground plane by set of conductive shorting vias are utilized to achieve wide impedance bandwidth. In addition, placing a relector plane of 80×80 mm^2 size below the antenna at a proper distance, the optimal antenna performance can be achieved. The geometrical parameters of the proposed antenna are optimized to maximize the overlapping bandwidth, which is determined by the criteria of S_{11} < -10 dB and AR < 3dB. The optimized geometrical parameters of the proposed antenna are tabulated in Table I.

III. SIMULATION, MEASURMENT AND ANALYSIS OF THE PROPOSED ANTENNA

The wideband conical-beam CP antenna is simulated and optimized accurately by employing a commercially available software package ANSYS Electronics Desktop 17.2. Moreover, the proposed antenna is fabricated and measured to verify the design concept. The fabricated prototype of the proposed antenna is shown in Fig. 2. The simulated and measured reflection coefficients of the proposed antenna are shown in Fig. 3. As shown, the simulated impedance bandwidth is 17.5% for S_{11} < -10 dB, covering from 5.7 to 6.75 GHz, and the measured S_{11} agrees reasonably with the simulated result.

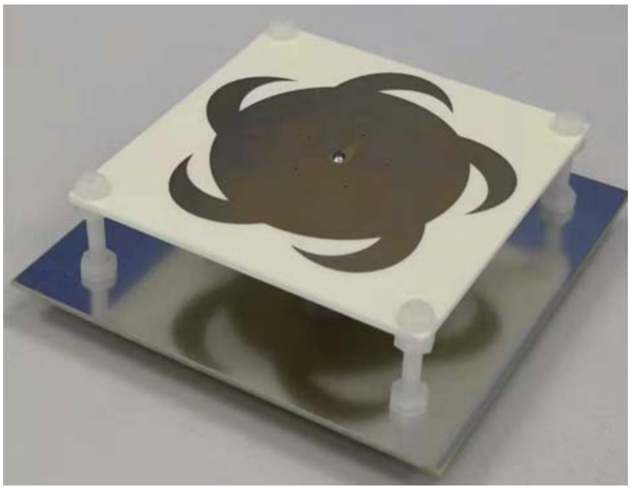

Fig. 2. The photo of the proposed antenna.

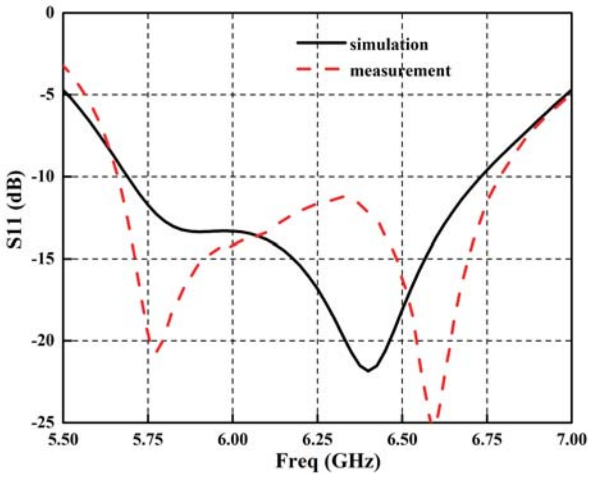

Fig. 3. The S_{11} of the proposed antenna.

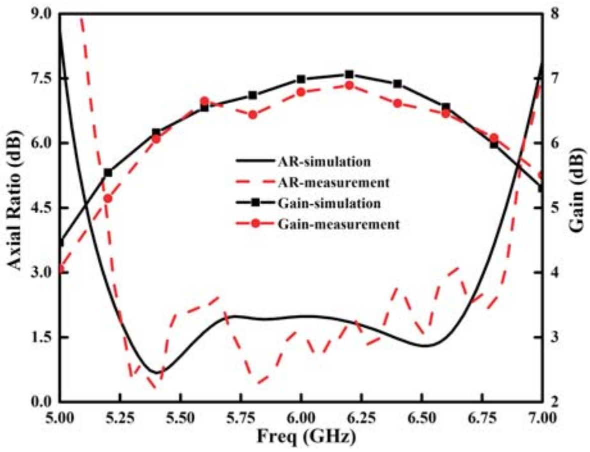

Fig. 4. The axial ratio and gain of the proposed antenna.

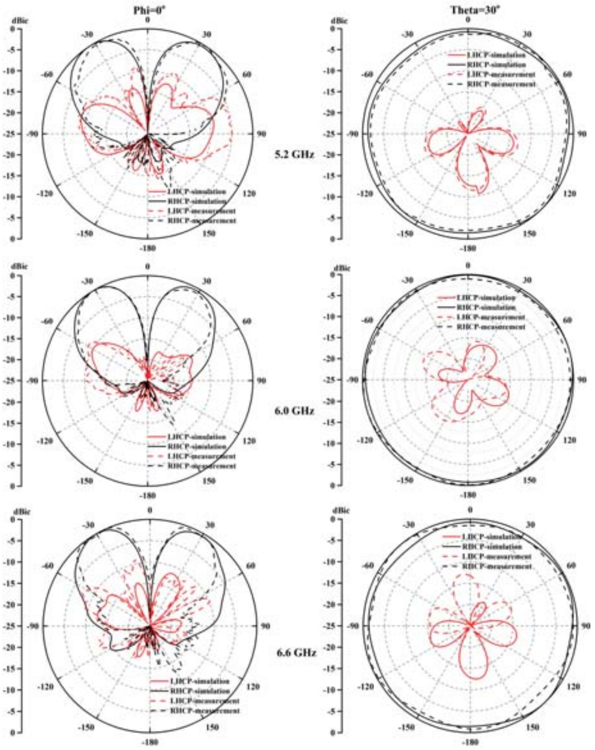

Fig. 5. The radiation patterns of the proposed antenna.

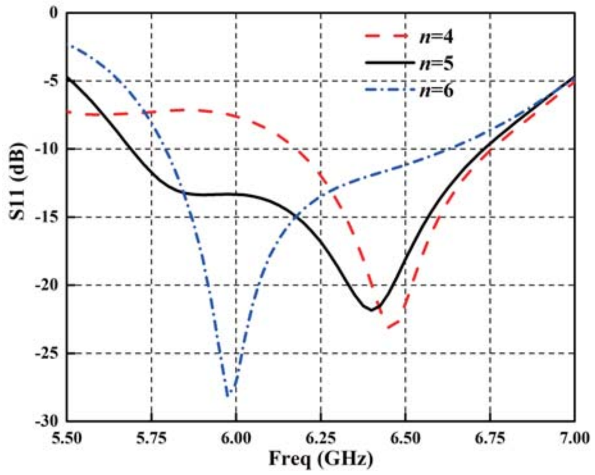

Fig. 6. The S_{11} of the proposed antenna with different *n*.

The simulated and measured ARs and gains are presented in Fig. 4. The simulated 3-dB AR bandwidth is about 26.5%, from 5.19 to 6.78 GHz, and the measured 3-dB AR bandwidth covers from 5.22 to 6.83 GHz. As shown in Fig. 4, the peak gain of measurement is 7 dBic at 6.2 GHz, and the average CP gain of 6.5 dBic is maintained within the whole operating bandwidth, and the measured results are consistent with the simulated results. Figure 5 shows the simulated and measured radiation patterns in the elevation plane ($\phi = 0°$) and azimuth plane ($\theta = 30°$) at different frequency points. As shown, the conical-beam radiation is achieved in the vertical plane while

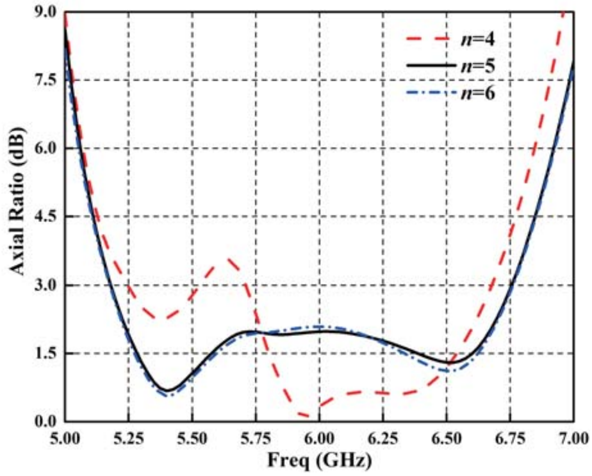

Fig. 7. The axial ratio of the proposed antenna with different *n*.

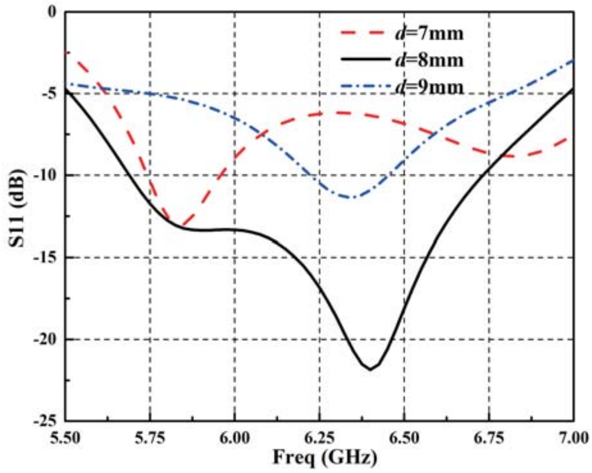

Fig. 8. The S_{11} of the proposed antenna with different *d*.

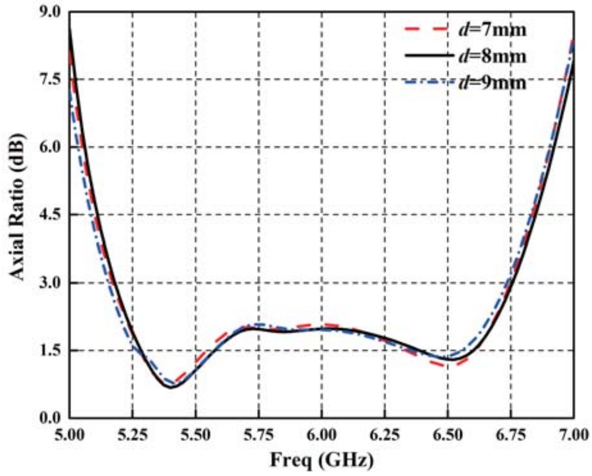

Fig. 9. The axial ratio of the proposed antenna with different *d*.

the azimuthal patterns are omnidirectional radiation. In the azimuth plane ($\theta = 30°$), the co-polarized (RHCP) fields are at least 15 dB stronger than cross-polarized (LHCP) fields. Stable omnidirectional conical-beam radiation patterns are observed in the frequencies of 5.2, 6 and 6.6 GHz.

In order to completely understand the characteristics of the antenna, the parameters of the antenna are optimized. The very important parameters of n (the number of shorting vias) and d (the distance of shorting vias and feed point) for the antenna are studied. The S_{11} and AR of the proposed antenna with the changes of n are shown in Fig. 6 and Fig. 7, respectively. As illustrated from the figures, the number of shorting vias has a significant influence both on S_{11} and AR. The reason for this result is that the number of shorting vias changes the resonant mode of the antenna. When n=5, the optimal result was obtained. Figure 8 and Figure 9 indicate that the parameter d has a considerable influence on S_{11}, but little influence on AR. When d=8 mm, the optimal result of impedance bandwidth was obtained.

IV. Conclusion

A novel wideband CP antenna with conical-beam radiation has been proposed and analyzed. The proposed antenna is composed of a center fed monopolar patch, two sets of arc hook branches, a set of conductive shorting vias and a ground plane. The proposed antenna provides a wide impedance bandwidth ($S_{11} <$ -10 dB) of 17.5% from 5.7 to 6.75 GHz and a 3-dB AR bandwidth of about 26.5% from 5.19 to 6.78 GHz. Besides, the average CP gain of 6.5 dBic is maintained within the whole operating bandwidth and the maximum gain of 7 dBic is achieved. Moreover, the conical-beam radiation is achieved in the vertical plane while the azimuthal patterns are omnidirectional radiation. Due to the conical-beam radiation and wideband CP performance feature, the proposed antenna is suitable for automotive vehicles communication system and wideband indoor communication system.

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