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A Broadband Crossed Dipole Antenna with Wide Axial Ratio Beamwidth for Satellite Communications

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Abstract—This letter presents a broadband circularly polarized (CP) crossed dipole antenna with wide axial ratio (AR) beamwidth. The antenna consists of a crossed dipole fed by two baluns, a wideband feed network and a cylindrical metallic cavity. To broaden the beamwidth, circular arms are introduced. Meanwhile, the metallic cavity is utilized to broaden the AR beamwidth. Measurements show that the antenna has an impedance bandwidth of 70.6% (1.87–3.91 GHz) for voltage standing wave ratio (VSWR) ≤ 2 and a 3-dB AR bandwidth of 62.4% (1.92–3.66 GHz). In addition, the 3-dB AR beamwidth of the antenna is larger than 100°, and the gain varies from 4 dBic to 6 dBic over the whole CP operation bandwidth. Owing to the high-gain and wideband operation, the proposed CP antenna is potentially capable for satellite applications and high-gain applications.

1. INTRODUCTION

Circularly polarized (CP) antennas have the advantages of reducing multipath effects and antenna relative orientation constrains. Thus, CP antennas have been widely used in modern wireless communication systems, including satellite communication, radio frequency identification (RFID), and wireless local area networks, etc. In addition, to enhance signal reception quality in wireless communications, CP antennas with wide AR beamwidth are required.

Generally, CP antennas are divided in two categories: single-feed antennas and dual-feed antennas. In [1–4], single-feed CP antennas have been discussed. The proposed single-feed antennas can achieve a 3-dB AR beamwidth of over 150°. However, these antennas usually suffer from narrow AR bandwidth, thus they are only suitable for the applications of narrow band wireless communication. For dual-feed CP antennas, an external feed network is required in general. In [5], by using a feed network consisting of four broadband baluns and an impedance matching circuit, a broadband CP antenna is proposed, which achieves a 3-dB AR bandwidth about 41%. In recent years, owing to superior circular polarization performance, crossed dipole antennas [6–11] have received extensive attention. In [6], a CP antenna with wide AR beamwidth is presented, which has a 3-dB AR bandwidth of 33%. In CP passband, the 3-dB AR beamwidth is $85^\circ \pm 2^\circ$. A crossed dipole antenna placed inside a cylindrical back cavity is proposed in [7], which has a 3-dB AR beamwidth of over 230° and a 3-dB gain beamwidth of 150°. In [8], a GNSS antenna with a miniaturized choke ring achieves a 3-dB AR bandwidth of 31% and a high front to back ratio about 25 dB. In its CP passband, the 3-dB AR beamwidth is about 140°. Moreover, a modified satellite antenna with isoflux pattern using a crossed dipole is reported in [9], which achieves a 3-dB AR beamwidth about 180°. In [10], by introducing a wideband divider as a feed network, a crossed bent dipole realizes a 2-dB AR bandwidth of 76.3% and a 3-dB beamwidth of greater than 88°.

In this letter, a broadband crossed dipole antenna with wide AR beamwidth is presented. In the design, the feed network provides equal amplitude and 90° phase difference for the crossed dipole.

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Therefore, the antenna generates CP field. Moreover, a cylindrical metallic cavity is introduced to considerably broaden the AR beamwidth. The measured AR bandwidth for AR ≤ 3 dB reaches 62.4% (1.92–3.66 GHz), and the 3-dB AR beamwidth is larger than 100° over the CP operation bandwidth.

2. ANTENNA DESIGN AND CHARACTERISTICS

Figure 1 shows the configuration of the proposed CP antenna with dimensional parameters in detail. As shown in Figure 1(a), the antenna is composed of a crossed dipole fed by two baluns, a metallic cavity on the ground and a feed network comprising a Wilkinson power divider and a wideband 90° phase shifter proposed in [11]. Figure 1(b) shows the geometry of the dipole. The dipole consists of two straight arms and two circular arms, which is printed on the back side of a 0.6 mm thick FR4 substrate with relative permittivity of $\varepsilon_r = 4.4$ and a size of $hsub \times Wsub$. Moreover, the balun which achieves the transition from microstrip feed to slot-line feed is printed on the front side of the substrate. Its bottom end passes through the rectangular hole on the ground and is connected to the feed network. In order to make the two substrates inserted into each other perpendicularly, a slit is fabricated on the two substrates. Referring to Figure 1(c), the feed network is printed on a 0.6 mm thick square substrate with relative permittivity of $\varepsilon_r = 2.65$ and size of $Gw \times Gw$. The feed network can provide equal amplitude and 90° phase difference over a wide frequency range.

In addition, a metallic cavity with the height of ch and radius of $R1$ is welded to the ground. And the cavity can broaden the AR beamwidth of the antenna significantly. Meanwhile, a photograph of the fabricated antenna is shown in Figure 1(d). According to the antenna structure shown in Figure 1, the antenna generates RHCP field. The detailed dimensional parameters of the antenna are as follows: $Gw = 70$ mm, $W = 55$ mm, $hsub = 38$ mm, $R1 = 34$ mm, $ch = 16$ mm, $h1 = 4$ mm, $h2 = 2$ mm,

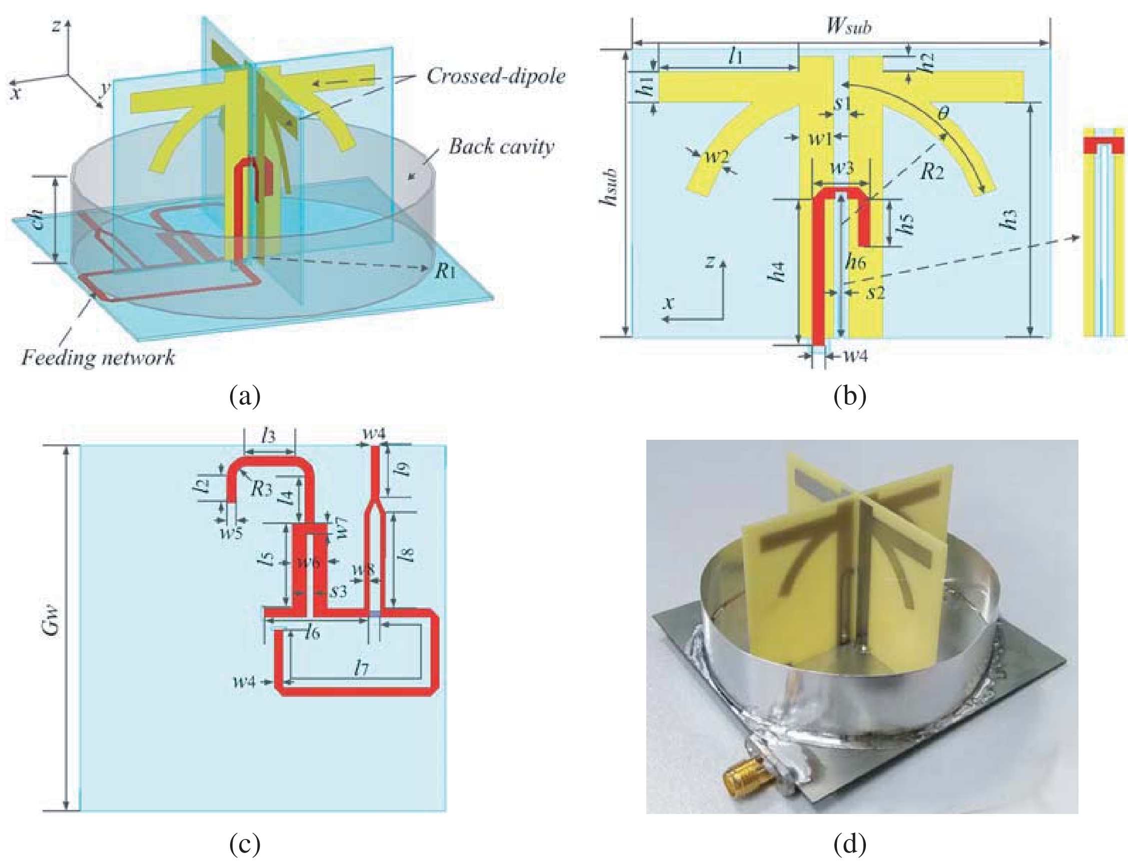

Figure 1. Configuration of the proposed antenna. (a) 3D view. (b) Top view of the dipole. (c) Feed network. (d) Photograph of the fabricated antenna.

$h3 = 31$ mm, $h4 = 19.2$ mm, $h5 = 6.2$ mm, $h6 = 19$ mm, $w1 = 4.5$ mm, $w2 = 3$ mm, $w3 = 7.6$ mm, $w4 = 1.6$ mm, $w5 = 1.8$ mm, $w6 = 6.6$ mm, $w7 = 2$ mm, $w8 = 0.9$ mm, $l1 = 18.5$ mm, $l2 = 5$ mm, $l3 = 9$ mm, $l4 = 9$ mm, $l5 = 16.2$ mm, $l6 = 20.15$ mm, $l7 = 62.55$ mm, $l8 = 18.3$ mm, $l9 = 10.2$ mm, $R2 = 19.2$ mm, $R3 = 3$ mm, $\theta = 71$ deg, $s1 = 2$ mm, $s2 = 0.6$ mm, $s3 = 1.3$ mm.

3. ANTENNA PERFORMANCE

For realizing circular polarization, the wide feed network is simulated. The simulated amplitude and phase responses are depicted in Figure 2. It can be seen that the feed network can provide nearly equal amplitude and $90° \pm 5°$ phase difference to output ports over the frequency range of 2–3.75 GHz. And the simulated isolation between the two output ports is better than 14.0 dB. The proposed antenna structure is modeled and simulated by using ANSYS HFSS. And for verification, the antenna is fabricated and measured. In this letter, the VSWR is measured by Wiltron 37269A Network Analyzer, whereas AR, antenna gain and radiation pattern are measured by the time-gating method.

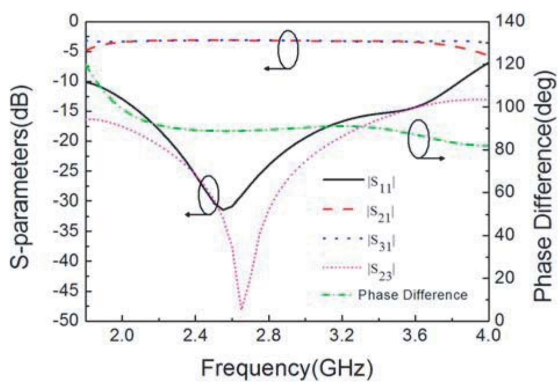

Figure 2. Simulated performance of the feed network.

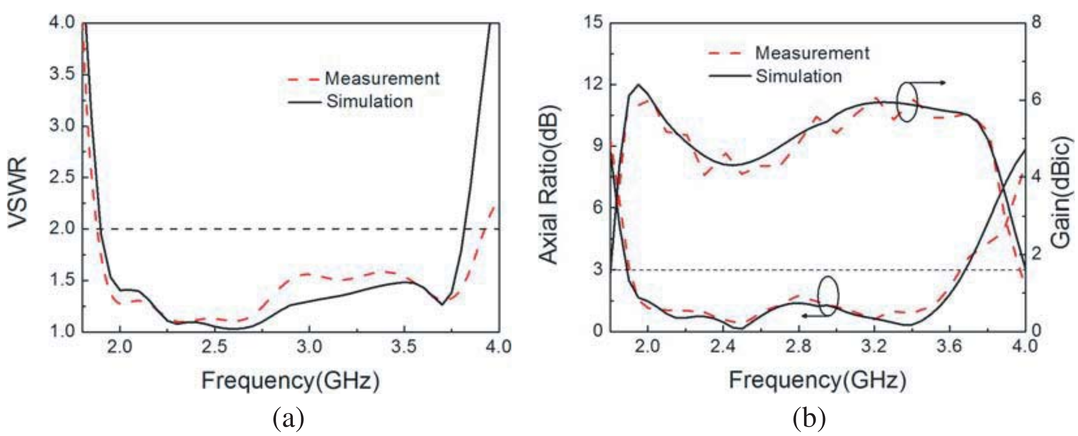

Figure 3. Measured and simulated VSWRs, ARs and gains of the proposed antenna. (a) VSWRs. (b) ARs and Broadside gains.

The measured and simulated results for the fabricated antenna are illustrated in Figure 3. It can be observed that the measured and simulated results are in reasonable agreement. With reference to Figure 3(a), the measured and simulated impedance bandwidths for VSWR ≤ 2 are 70.6% (1.87–3.91 GHz) and 67.1% (1.9–3.82 GHz), respectively. As shown in Figure 3(b), the measured and simulated 3-dB AR bandwidths are 62.4% (1.92–3.66 GHz) and 64.3% (1.9–3.7 GHz), respectively. With reference to the figure, the measured broadside gain of the antenna varies from 4 dBic to 6 dBic over the whole

AR bandwidth. It is noted that there is a reasonable difference between simulation and measurement, because of the error of fabrication and the imperfection of the test environment.

The normalized 2D radiation patterns of the fabricated antenna at frequencies of 2.3 GHz and 3.3 GHz are shown in Figure 4. It can be observed that the antenna generates RHCP field and has low cross polarization level of less than -20.0 dB. The measured 3-dB AR beamwidths of co-polarization radiation patterns at 2.3 GHz and 3.3 GHz are 130° and 245°, respectively. The measured 3-dB gain beamwidths of co-polarization radiation patterns at 2.3 GHz and 3.3 GHz are about 95° and 94°, respectively.

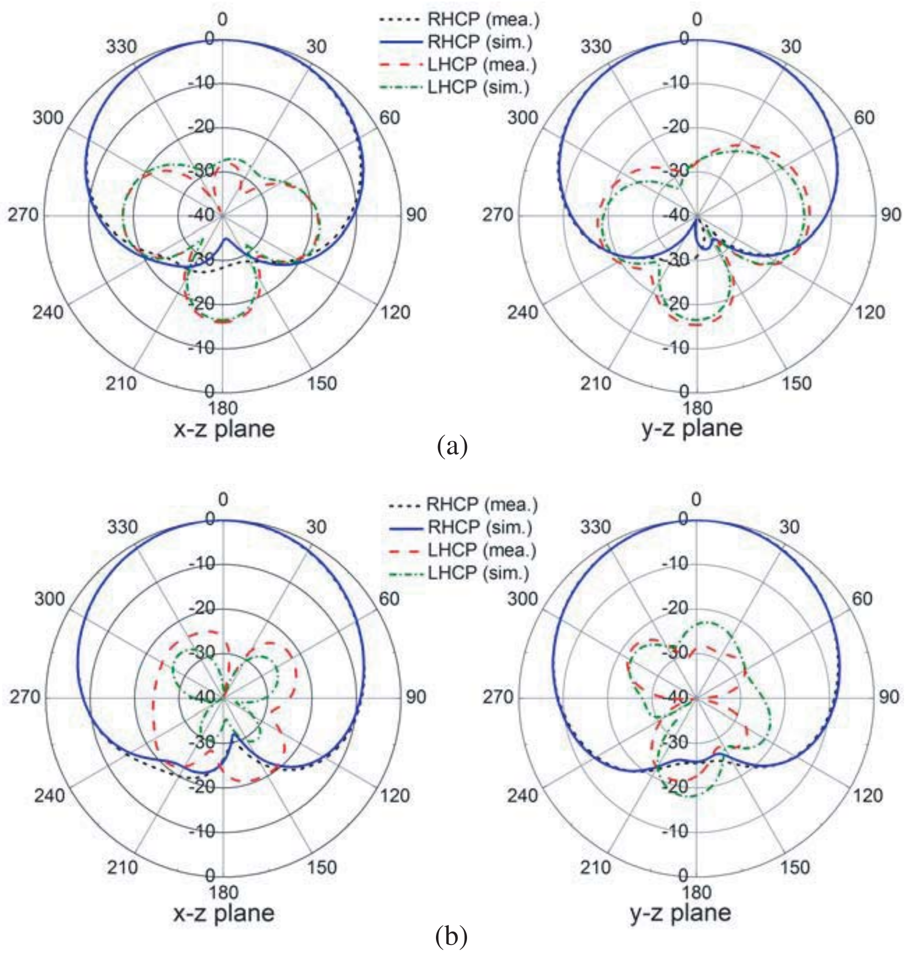

Figure 4. Measured and simulated normalized radiation patterns of the proposed antenna. (a) 2.3 GHz. (b) 3.3 GHz.

In addition, another four circular arms, which are connected with straight arms, are added in the design. To describe the effects of the circular arms on the beamwidth, the gain and AR radiation patterns in X-Z plane with $\theta = 50$ deg, 60 deg, and 70 deg at 2.8 GHz are illustrated in Figure 5(a). It can be seen that the gain and AR beamwidths increase with increasing parameter θ. Although the increase of gain beamwidth is small, there is a distinct improvement in AR beamwidth. The 3-dB AR beamwidth is about 136° at $\theta = 50$ deg. As $\theta = 70$ deg, the 3-dB AR beamwidth is greatly increased to 200°.

Meanwhile, a metallic cavity is also introduced. In order to illustrate the effects of the back cavity on the AR beamwidth, the AR radiation patterns of the antenna in X-Z plane at 2.3 GHz, 2.8 GHz, and 3.3 GHz are depicted in Figure 5(b). With reference to the figure, the 3-dB AR beamwidth of the antenna without cavity is narrow, only about 110° at these three frequency points. The 3-dB AR beamwidth increases when the cavity exists. The 3-dB AR beamwidths at 2.8 GHz and 3.3 GHz are

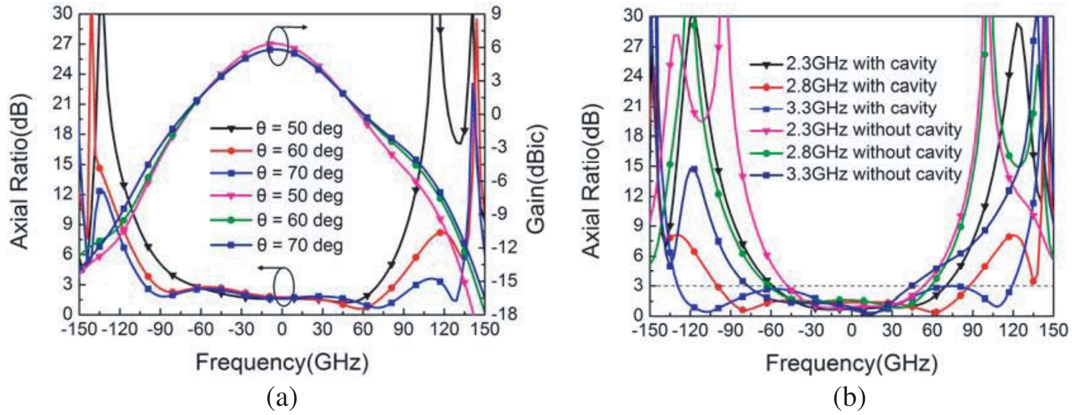

Figure 5. Gain and AR radiation patterns in X-Z plane. (a) Gain and AR radiation patterns with different θ at 2.8 GHz. (b) AR radiation patterns at 2.3 GHz, 2.8 GHz, and 3.3 GHz.

increased to 187° and 250°, respectively.

In Table 1, the performances in terms of AR bandwidth, 3-dB AR beamwidth, and gain of the proposed antenna are compared with other crossed dipole antennas reported previously. The proposed antenna has a wider AR bandwidth. Its AR beamwidth is also broad. Therefore, the proposed antenna is potentially capable for the application of satellite communications and can also be applied to wide wireless communications.

Table 1. Comparison between the proposed antenna and other CP antennas reported previously.

References	f_0 (GHz)	3-dB AR bandwidth	3-dB AR beamwidth	Gain (dBic)	Size (ka)
[5]	1.95	33%	85°	6.3	3.62
[6]	1.575	7.52%	230°	4.1	1.75
[7]	1.3875	31%	140°	7	1.85
[8]	2.075	4.8%	180°	–	–
This work	2.8	62.4%	187°	4.8	1.98

f_0: the center frequency of CP band.
k: the wave number at the lowest frequency of CP band.
a: the radius of a hypothetical sphere, which encapsulates the antenna.
The AR beamwidth in [8] is under the case of AR ≤ 5 dB.

4. CONCLUSION

In this paper, a broadband crossed dipole antenna with wide AR beamwidth is presented. The antenna consists of a crossed dipole fed by two baluns, a wideband feed network and a metallic cavity. The wideband feed network provides equal amplitude and 90° phase difference for the crossed dipole achieving circular polarization. Another four circular arms are introduced to broaden the AR beamwidth. By adjusting the length of circular arms and the height of the cavity, the AR beamwidth of the antenna is broadened greatly. The antenna has an impedance bandwidth of 70.6% (1.87–3.91 GHz) for VSWR ≤ 2, a 3-dB AR bandwidth of 62.4% (1.92–3.66 GHz). In addition, the 3-dB AR beamwidth is larger than 100°, and the gain varies from 4 dBic to 6 dBic over the whole CP operation bandwidth. Therefore, the proposed antenna has potential for high-gain/satellite applications.

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