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A Low Profile Wideband Circularly Polarized Crossed-Dipole Antenna

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***Abstract*—A low profile crossed dipole antenna with wide bandwidth is investigated in this paper. The double-sided printing crossed dipoles consisting of four stepped rectangular patches are fed by a pair of vacant-quarter printed rings, generating circularly polarized (CP) radiation. Two adjacent axial ratio (AR) passbands with AR < 3 dB are generated due to the stepped rectangular patches, and they are merged together by adding an additional dielectric slab above the ground plane, resulting in a very wide AR bandwidth. Also, an irregular ground plane is used for the antenna, which can desirably enhance the boresight gain without involving high-profile cavity. To verify the feasibility of the proposed design, a prototype operating at C band has been fabricated and measured. Reasonable agreement between the simulated and measured results is obtained. The prototype has a low profile of 0.13 λ_0 (in terms of the center frequency of passband), a 10-dB impedance bandwidth of 66.9%, a 3-dB AR bandwidth of 55.1%, and an average gain of ~10.4 dBic within passband.**

***Index Terms*—circularly polarized antenna, crossed dipole antenna, wideband antenna, low profile.**

I. Introduction

In recent years, crossed dipole antenna has received extensive attentions due to its superior circular polarization performance [1-9]. Various wideband crossed dipole antennas were investigated to meet the requirement of modern wireless communication systems [1-5]. For example, four parasitic loops were added to a printed crossed dipole to produce an additional axial ratio (AR) minimum point, giving a bandwidth of 25.2% [1]. In [2], four rotating circular dipoles were added to widen the bandwidth to 47.8%. Besides the technique of using parasitic elements, bandwidth can also be enhanced by using wider planar dipoles [3-5], such as rectangular patch dipoles (27%) [3], bowtie dipoles (43.5%) [4], and elliptical dipoles (96.6%) [5]. However, all above wideband designs have relatively high profiles of ~0.25 λ_0. The height of the ultra-wideband design [5] is even higher than 0.34 λ_0, since a composite cavity with crossed fins was used. High profile antennas are not suitable for space constrained applications, and they are also not conformal to carriers and may encounter large wind resistance.

To reduce the height, artificial magnetic conductor (AMC) was introduced to the crossed-dipole antenna as a reflector [6-7]. By using different configurations of AMC and dipole antennas, a profile of 0.16 λ_0 and a bandwidth of 19.3% were obtained in [6], whereas a much lower profile of 0.088 λ_0 and a narrower bandwidth of 8.3% were obtained in [7]. The crossed dipole antenna loaded with two metallic strips also shows a very low profile of 0.005 λ_0 [8], but its bandwidth is as narrow as 3.3%. Obviously, the bandwidth was greatly sacrificed in these designs when reducing the profile, which is undesirable.

In this paper, a circularly polarized (CP) crossed dipole antenna featuring both low profile and wide band is investigated. Planar dipoles consisting of stepped rectangular patches are used to generate two adjacent AR passbands, whereas a parasitic dielectric slab is added above the ground plane to lower the AR in the middle band, leading to a broad usable bandwidth of ~55.1% and a low profile of ~0.13 λ_0. To demonstrate the idea, a prototype operating at C band was designed. Its reflection coefficient, AR, radiation pattern, and antenna gain were simulated by ANSYS HFSS and verified by measurements.

II. Antenna Design

A. Antenna Configuration

Fig. 1 shows configuration of the proposed crossed-dipole antenna, which consists of two pairs of double-sided patch dipoles, a thin dielectric slab and an irregular ground plane. With reference to Fig. 1(a), the double-sided dipoles are fabricated on the top and bottom surfaces of the sup-substrate (ε_{r1} = 3.38, h_1 = 0.813 mm), whereas the dielectric slab and ground plane are fabricated from the sub-substrate (ε_{r2} = 2.2, h_2 = 3 mm). Between the two substrates, an air gap with height of h is introduced. Fig. 1(b) shows details of the crossed dipoles. It can be seen that the two pairs of dipoles are crossed perpendicularly to each other, and each pair is composed by two same stepped-patch arms with dimensions given by l_1, l_2 and w_1, w_2 respectively. The arms are connected by a pair of vacant-quarter printed rings with length of ~λ_g/4 (λ_g is the guided wavelength at the center frequency), and therefore 90^o phase difference between the adjacent elements is realized, generating CP radiation [3-7]. Due to the stepped patch element, two separated AR passbands are generated in adjacent frequency bands. It will be shown in following subsection that the two bands can be desirably merged together by introducing the thin dielectric slab, leading to a wide bandwidth. An irregular ground plane is used as the reflector for the crossed dipole antenna, with part of its corners

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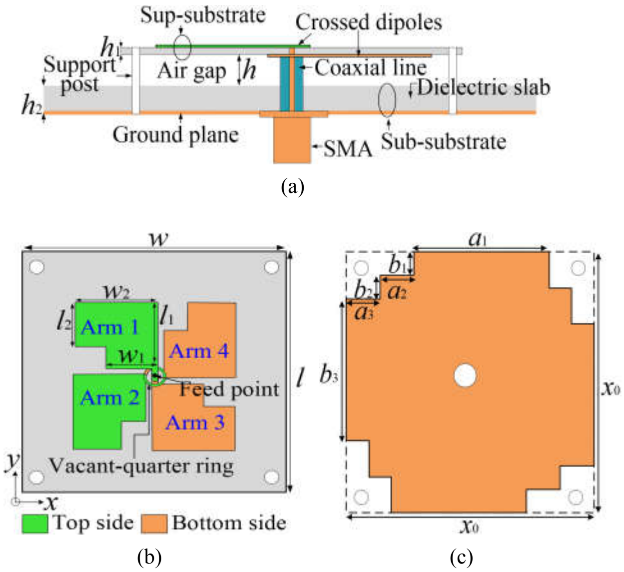

Fig. 1 Configuration of the proposed CP crossed dipole antenna. (a) Side-view. (b) The Crossed dipoles. (c) The irregular ground plane. l = w = 70 mm, l_1 = 19 mm, w_1 = 13.8 mm, l_2 = 12.5 mm, w_2 = 21.6 mm, h_1 = 0.813 mm, h_2 = 3 mm, h = 3.3 mm, x_0 = 110 mm, a_1 = 35 mm, b_1 = 15 mm, a_2 = 20 mm, b_2 = 15 mm, a_3 = 25 mm, b_3 = 35 mm.

removed to refine the antenna gain, as shown in Fig. 1 (c). The whole antenna is centrally fed by a coaxial cable, whose inner conductor is soldered to the top dipole arm 1, whereas the outer conductor is connected to the bottom arm 3 and the ground plane. The proposed antenna of Fig. 1 generates right-hand CP (RHCP) fields, and left-hand CP (LHCP) fields can be generated by connecting the inner and outer conductors of the coaxial feedline to the dipole arms 2 and 4 respectively.

B. Antenna Mechanism

Three reference antennas are investigated to show how a wide AR bandwidth (55.1%) can be achieved by using such a low profile ($0.13\lambda_0$) design. Fig. 2 shows configurations of the reference antennas, including Antenna I which has rectangular patch dipoles and regular rectangular ground plane, Antenna II which has stepped patch dipoles but also rectangular ground plane, and Antenna III which has an additional dielectric slab above the rectangular ground plane. Fig. 3 shows reflection coefficient, AR and boresight gain of the reference antennas. Also, the results of the proposed antenna that uses the irregular ground plane (Fig. 1) are included. For ease of comparison, same dimensions are used for each antenna, as listed in the captions of Fig. 1. With reference to Fig. 3(a), the reflection coefficient or input impedance varies considerably for each configuration, but good matching is maintained across a wide impedance passband, and bandwidth of more than 58% can be easily obtained. However, significant changes have happened in the AR. As shown in Fig. 3(b), two AR passbands can be obtained at ~4.9 and 7.5 GHz by using the simple rectangular patch dipoles. The 3-dB AR bandwidths of the two bands are 16% and 3.2% respectively, narrower than that (27%) of the similar design in [3]. This is as expected because a much lower profile is used in the present antenna and low profile generally results in narrower bandwidth. When using stepped dipoles in Antenna II, the lower AR passband shifts downward from 4.9 to 4.5 GHz, and simultaneously, the higher AR band

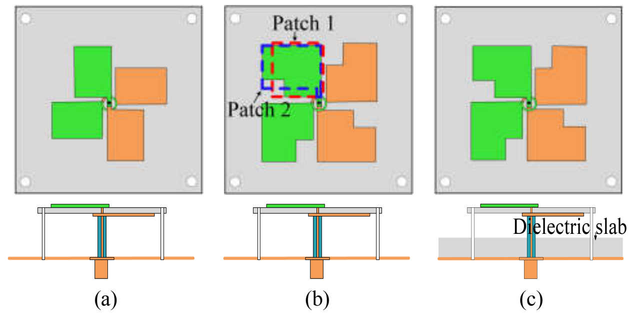

Fig. 2 Configuration of the reference antennas. (a) Antenna I with rectangular patch dipoles and regular rectangular ground plane. (b) Antenna II with stepped patch dipoles and regular rectangular ground plane. (c) Antenna III with stepped patch dipoles, regular rectangular ground plane and parasitic dielectric slab.

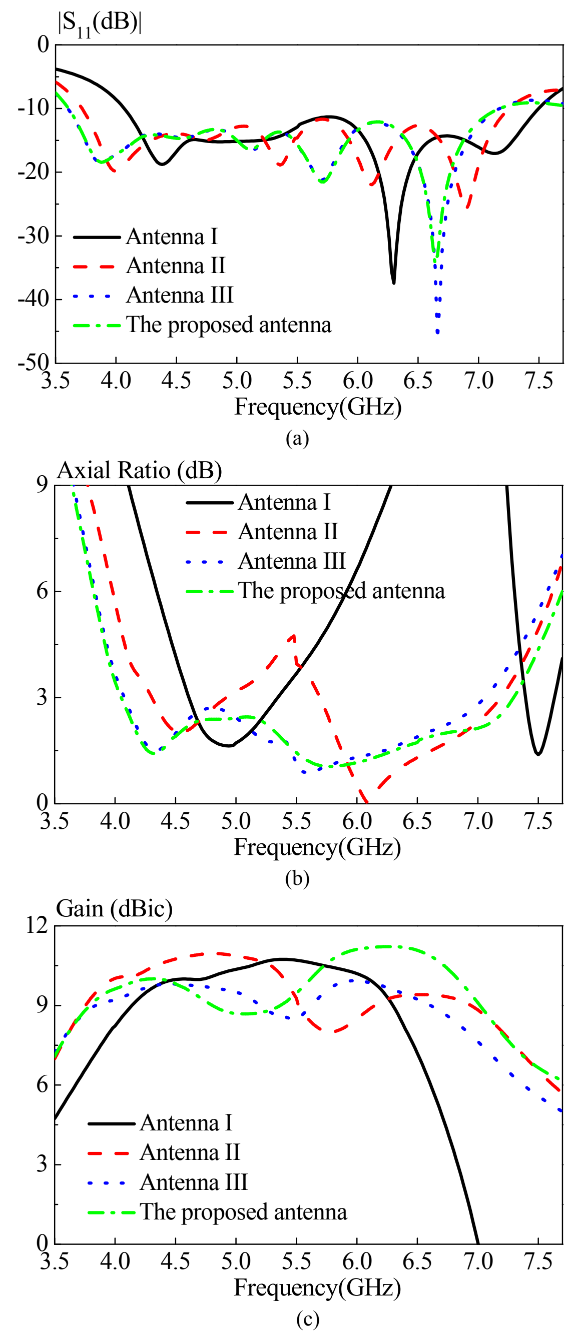

Fig. 3 Simulated reflection coefficient, AR and gain of the reference antennas and proposed design. (a) Reflection coefficient. (b) AR. (c) Boresight gain.

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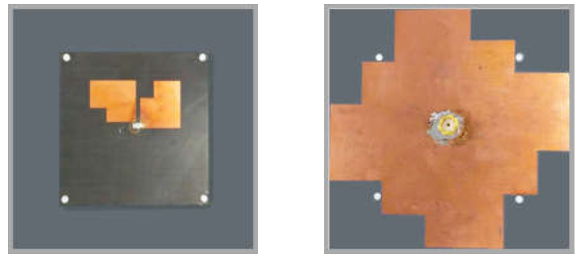
shifts downward from 7.5 to 6.5 GHz and its bandwidth is enhanced significantly from 3.2% to 23.3%. This is due to the fact that the stepped patch, as shown in Fig. 2(b), can be regarded as two different rectangular patches when seen from different directions, i.e., rectangular patch 1 if seen from x axis, and rectangular patch 2 if seen from y axis. By simulation, it is found that the antenna with rectangular patch 1 has two AR passbands at ~4.6 and 7.0 GHz, whereas the one with rectangular patch 2 has two AR passbands at ~4.4 and 6.2 GHz. When the stepped patch is used, these passbands interact and combine with each other, forming the results as shown in the red dash line. Next, in Antenna III, a dielectric slab with permittivity of 2.2 and height of 3 mm is added above the ground plane. Seen from the blue dot line in Fig. 3(b), it is interesting to note that the above two AR passbands remain almost unchanged, but the AR values in the middle frequency band reduce significantly to below 3 dB, providing a broad AR bandwidth of 53.1%. The introduction of dielectric slab also affects the antenna gain significantly. As can be seen from Fig. 3(c), the gain is enhanced in the middle frequency range, however it is degraded significantly at other frequencies, especially at upper band. To tackle the problem, an irregular ground plane is used in the proposed antenna. As shown by the green dash dot line, the small modification of ground plane has slight effect on the reflection coefficient and AR, but it can reduce the sidelobe of higher order modes and increase the boresight gain correspondingly. As a result, an average gain of ~10 dBic is obtained without using metallic cavity.

Here, it is worth concluding that the resonant modes and wide impedance bandwidth are generated by the crossed dipole antenna itself, and the irregular ground plane and dielectric slab are mainly introduced to perturb the filed distribution of the crossed dipole antenna, to provide more degrees of design freedom, and thus to affect (or improve) the AR, radiation pattern, as well as gain.

III. Simulated and Measured Results

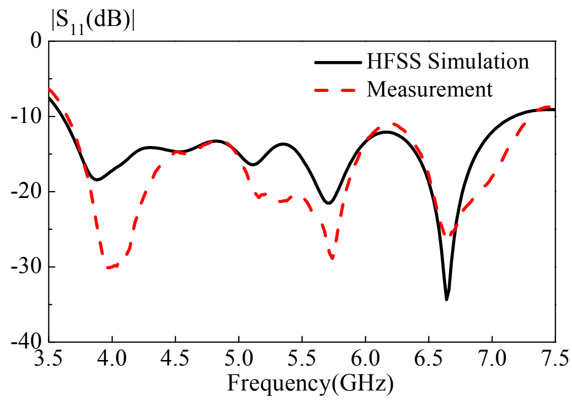
For demonstration, a prototype of the proposed crossed dipole antenna was designed, fabricated and tested. Fig. 4 shows two photographs of the prototype, in which four Teflon posts are used to assemble and fix the two substrates of the antenna. In this paper, the reflection coefficient is measured by HP8510C network analyzer, whereas AR, gain and radiation patterns are obtained by Satimo Starlab System.

Fig. 5 shows simulated and measured reflection coefficients (Fig. 5(a)), ARs (Fig. 5(b)) and boresight gains (Fig. 5(c)) of the prototype. Reasonable agreement between simulation and measurement can be observed, and the small discrepancy is mainly caused by the fabrication error and experimental imperfections. With reference to Fig. 5(a) and Fig. 5(b), the simulated and measured 10-dB impedance bandwidths ($|S_{11}| < -10$ dB) of the prototype are 66.4% (3.6 to 7.18 GHz) and 66.9% (3.64 to 7.30 GHz), whereas the simulated and measured 3-dB AR bandwidths are 57.3% (4.05 to 7.30 GHz) and 55.1% (4.12 to 7.25 GHz), respectively. It is noted that the entire AR passband falls within the impedance passband, giving a usable overlapping bandwidth of 55.1%. As can be seen from Fig. 5(c), the measured gain varies from 8.0 to 11.5 dBic within the passband. The average gain is around 10.4 dBic, and the 3-dB gain bandwidth is 53.6%. Fig. 6 shows radiation patterns of the prototype at frequencies of 4.2, 5.5 and 7.0 GHz. Broadside radiation patterns are observed as expected. Due to the asymmetric feed scheme, the patterns are not perfectly symmetric (especially at 5.5 GHz), but the RHCP

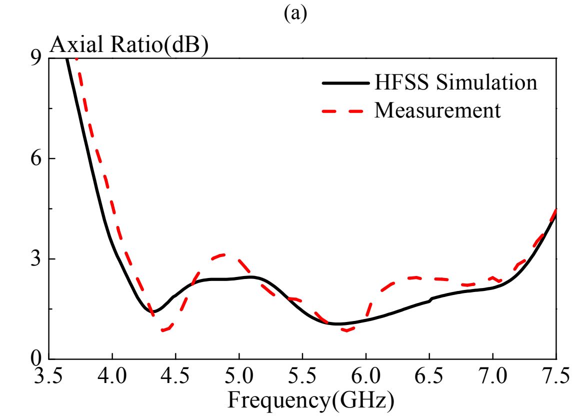


(a) (b)

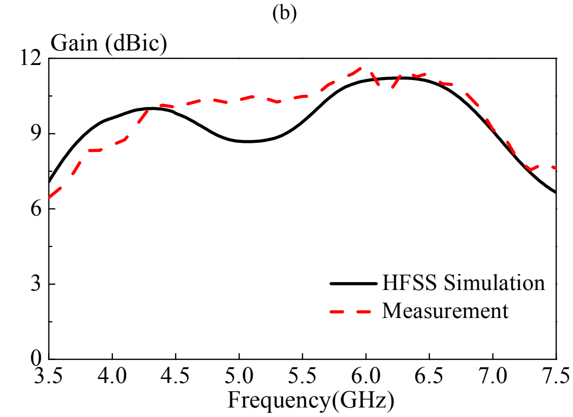
Fig. 4 Prototype of the proposed CP crossed-dipole antenna. (a) Top view of the dipole. (b) Bottom view of the ground plane.



(a)



(b)



(c)

Fig. 5 Simulated and measured reflection coefficient, AR and gain of the prototype. (a) Reflection coefficient. (b) AR. (c) Boresight gain.

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TABLE I
COMPARISON BETWEEN THE PROPOSED CROSSED DIPOLE ANTENNA AND PREVIOUSLY REPORTED DESIGNS

Ref	Size (λ_0^3)	Impedance Bandwidth	AR Bandwidth	Overlapping Bandwidth	Average Gain (dBi)
[1]	1.04 × 1.04 × 0.25	38.2%	28.6%	25.2%	8.5
[2]	0.74 × 0.74 × 0.26	72.2%	47.8%	47.8%	6.0
[3]	0.48 × 0.48 × 0.25	50.2%	27%	27%	6.2
[4]	0.97 × 0.97 × 0.25	57%	51%	43.5%	9.6
[5]	1.69 × 1.69 × 0.34	105.6%	96.6%	96.6%	9.0
[6]	0.64 × 0.64 × 0.16	40%	19.3%	19.3%	6.6
[7]	0.58 × 0.58 × 0.09	16.7%	8.3%	8.3%	5.2
Prop.	2.06 × 2.06 × 0.13	66.9%	55.1%	55.1%	10.4

λ_0: wavelength at the center frequency of passband

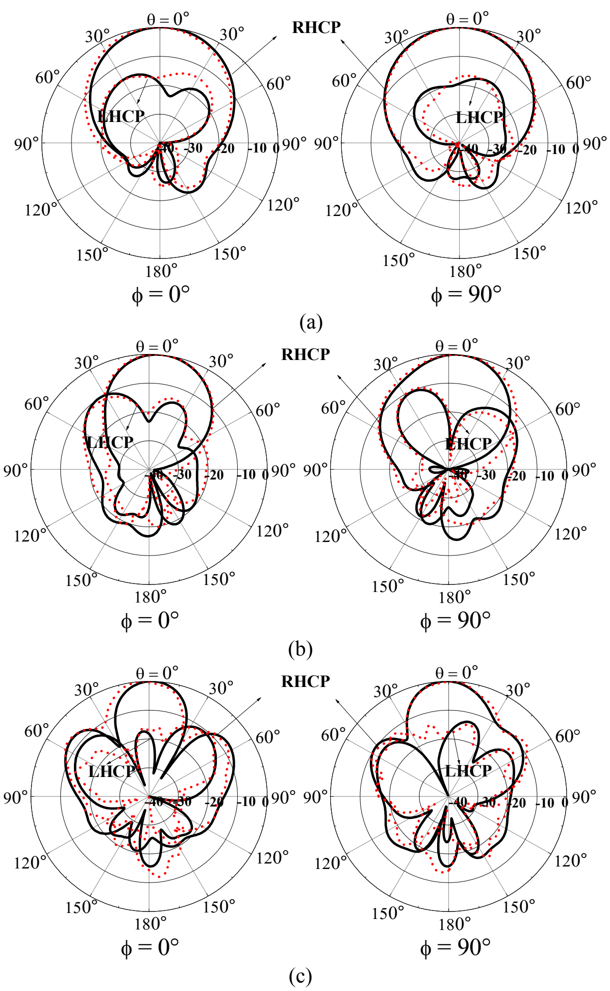

Fig. 6 Simulated and measured radiation patterns of the prototype. (a) 4.2 GHz. (b) 5.5 GHz. (c) 7.0 GHz. ——— Simulated ------ Measured

fields at boresight direction are always stronger than that of the LHCP counterparts by more than 15dB, verifying it is a RHCP antenna. As the frequency increases, a narrower beam is obtained, but the side-lobe and cross-polarization levels are enhanced due to the excitation of higher order modes. This explains why the gain decreases significantly at the upper band edge. Similar results have been reported in [5].

A comprehensive comparison between the proposed crossed dipole antenna and previously reported designs is tabulated in Table I. It can be seen that the present antenna simultaneously has a low profile, a wide usable bandwidth, and a high gain. However, due to the large ground plane, the covered area of the proposed antenna is a bit larger than others.

IV. Conclusion

A low profile, wideband and high gain crossed dipole antenna consisting of two stepped patch dipoles, a thin dielectric slab and an irregular ground plane is investigated in this paper. It has been shown that the stepped rectangular patches are able to generate two adjacent AR passbands, whereas the dielectric slab can reduce the AR in the middle band, providing a broad usable bandwidth of ~55.1% and a low profile of ~0.13 λ_0. Also, it has been shown that the use of irregular ground plane can desirably enhance the boresight gain to ~ 10.4 dBic without involving high-profile cavity.

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