Circularly Polarized Patch-Helix Hybrid Antenna With Small Ground

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***Abstract*—A new design of circularly polarized (CP) patch-helix hybrid antenna with small ground is presented. The proposed antenna consists of a driven patch, a parasitic patch, and a helix connected with the parasitic patch. The hybrid antenna has a relatively small ground, making the overall antenna compact. The proposed antenna can be packaged in a thin cylinder and can be easily mounted in the space-limited systems. Good impedance matching was achieved by capacitive coupling between the driven patch and the parasitic patch, while high gain was obtained with a small ground due to relatively uniform current along the helix. A prototype antenna for 5.8-GHz Wireless Local Area Network (WLAN) was fabricated and tested to verify the design idea. The measured impedance bandwidth ($S_{11} \leq -10$ dB) was 19% (5.22–6.30 GHz), and the corresponding peak gain was 10.85–13.35 dBic. Excellent CP performance (axial ratio $\mathrm{AR} \leq 3$ dB) was achieved over the whole impedance bandwidth.**

***Index Terms*—Circular polarization, compact antenna, helix, radiation pattern.**

I. INTRODUCTION

CIRCULARLY polarized (CP) antennas are attractive for radar, navigation, satellite, and mobile systems [1]. Circular polarization provides distinct advantages over linear polarization: It is less sensitive to their respective orientations between transmitters and receivers and enhances polarization efficiency of the receivers [2]. Meanwhile, it presents better mobility and weather penetration as well as reduction in multipath reflections and other kinds of interferences. Moreover, in satellite communications, circular polarization is capable of combating Faraday rotation caused by the ionospheric plasma containing free electrons and ions.

Axial-mode helical antenna, first presented by Kraus [3], is an attractive candidate for circularly polarized applications. It has good CP performance and desired radiation pattern over a wide bandwidth, which is inherent in traveling wave propagation property of the antenna shape without the need for a special and complicated feeding arrangement. Numerous I methods have been reported to improve the antenna gain in the past decades [4]–[9]. Nakano *et al.* increased 1 dB in gain by using a parasitic helix as a director for the traditional axial-mode helical antenna without an increase in the axial length of the antenna [4]. Wu *et al.* studied a helical antenna with a cylindrical ring as a director; the proposed antenna boosted a maximum of 3.8 dB in gain over the working bandwidth while hardly affecting impedance bandwidth and other antenna characteristics [5]. Djordjevic *et al.* found that the size and shape of the ground conductor of axial-mode helical antennas have significant impact on the antenna gain [6]. The helical antenna above a cylindrical cup ground was proposed to increase the antenna gain by 1.4 dB, when compared to the helical antenna above an infinite ground plane [7]. The helical antenna above a conical ground illustrated lower axial ratio (AR) and sidelobe levels and exhibited an increase of about 4-dB in gain with respect to an infinite ground plane [6], [8].

However, most of the grounds in [4]–[8] are larger than 1λ, which is unpractical for some portable or space-limited applications with finite-size ground. In order to reduce the size of ground used in a helical antenna, a 10-turn axial-mode helical antenna with two loops, instead of the conventional ground plane, was proposed in [9], and the two loops with a distance of about $\lambda/3-\lambda/2$ were used as driver and reflector, respectively.

This letter presents the design of a patch-helix hybrid antenna. The proposed antenna is with a relatively small ground, making the overall antenna compact while maintaining a high gain. The proposed antenna was designed and analyzed using HFSS, and its performance was verified by fabrication and measurements. The measured impedance bandwidth for $S_{11} \leq -10$ dB was 5.22–6.30 GHz, and the corresponding peak gain was 10.85–13.35 dBic. Excellent CP performance ($\mathrm{AR} \leq 3$ dB) was achieved over the whole impedance bandwidth.

II. ANTENNA DESIGN

The geometry of the proposed antenna is depicted in Fig. 1. The antenna comprises a 10-turn helix connected to a parasitic patch, a dual-feed CP driven patch, and a quadrature hybrid. The driven patch is printed on a single-sided metallized substrate, while the quadrature hybrid is printed on a double-sided metallized substrate. Both structures share a common ground plane and use the same kind of substrate (Teflon, $\varepsilon r = 2.65, \tan\delta =$

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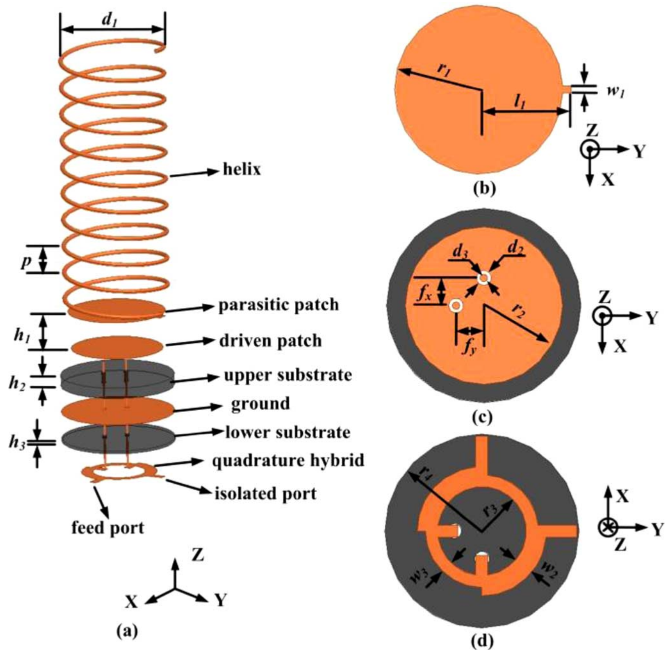

Fig. 1. Geometry of the proposed patch-helix hybrid antenna (not to scale). (a) Panoramic view of the proposed antenna. (b) Top view of parasitic patch. (c) Top view of the feed patch. (d) Bottom view of the quadrature hybrid.

TABLE I
DETAILED DIMENSIONS OF THE PROPOSED ANTENNA

parameters	h_1	h_2	h_3	d_1	d_2	d_3
value(mm)	5	2	0.5	19	1.6	0.8
parameters	r_1	r_2	r_3	r_4	l_1	w_1
value(mm)	9	8.5	4.8	10.5	9.9	2
parameters	w_2	w_3	f_x	f_y	p	
value(mm)	2.2	1.3	3	3	13	

0.002). Table I shows the detailed dimensions of the proposed antenna.

In traditional design, the axial-mode helix is mounted on a large ground, and the impedance characteristic and radiation property deteriorate when the size of the ground plane decreases.

In our design, a driven patch with left-hand circular polarization (LHCP) is fed by circular quadrature hybrid, and the helix is connected to a parasitic patch. Good impedance matching could be achieved by appropriately tuning the capacitive coupling between the driven patch and parasitic patch.

The working mechanism of the proposed hybrid structure is illustrated in Fig. 2. It can be found that the current along the helix with small ground decays exponentially near the input, which can be explained as a transition between a helix-to-ground mode and a pure helix mode [9]. In the proposed design, a more uniform current can be observed without exponential attenuation near the input, in respect that the helix was capacitively coupled between the driven patch and the parasitic patch. The helix in the proposed structure was isolated from the ground by the driven patch and the parasitic patch and made it free from ground-plane limitation. High gain is obtained even with a small ground due to relatively uniform current along the helix.

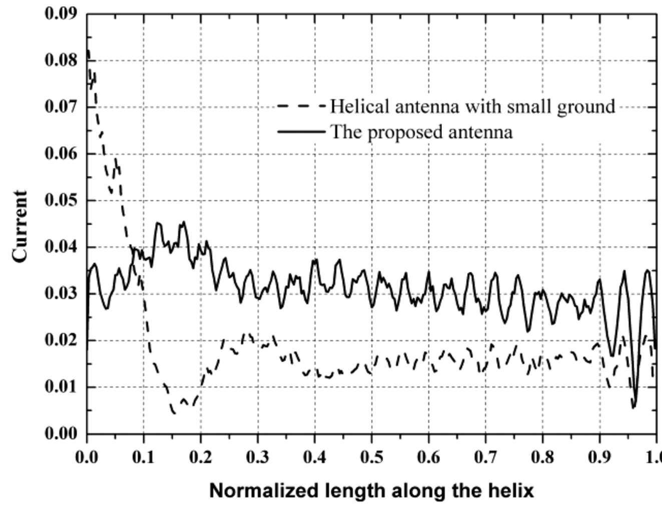

Fig. 2. Current distribution along the helix for a helix antenna with small ground and the proposed antenna.

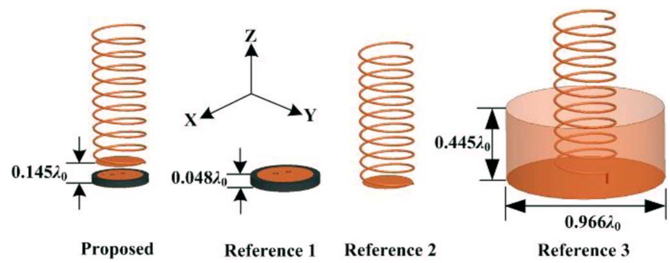

Fig. 3. Proposed antenna and references (not to scale).

To further verify the performance, a comparison between the proposed antenna and several reference antennas is given in Figs. 3 and 4. References 1 and 2 are the driven patch and the helix above the small ground used in proposed design, respectively, while Reference 3 is a helical antenna above a cylindrical cup ground as proposed in [6] and [8]. It can be noticed that the proposed design illustrates almost same gain, front-to-back ratio (FBR), and sidelobe level (SLL) as Reference 3.

The simulated xz- and yz-plane radiation patterns for the proposed antenna at 5.8 GHz are depicted in Fig. 5. The results demonstrate that the proposed antenna has unidirectional endfire LHCP patterns with peak gain of more than 13 dBic and FBR about 15 dB.

III. Results and Discussions

To demonstrate the validity of the presented design strategy, as depicted in Fig. 6, a prototype antenna was fabricated and measured. The helix was made of copper wire with a diameter of 1.2 mm and supported by foam substrate (ε_r is close to 1). The feed port, shown in Fig. 1, was connected to a semi-rigid coaxial cable, and the isolated port was terminated by a 50-Ω matching load. The reflection coefficients were measured by the vector network analyzer Agilent ENA E5071B, and the radiation patterns were performed in an anechoic chamber. Simulated and measured results are given in Figs. 7–9. Reasonable agreement between them could be observed.

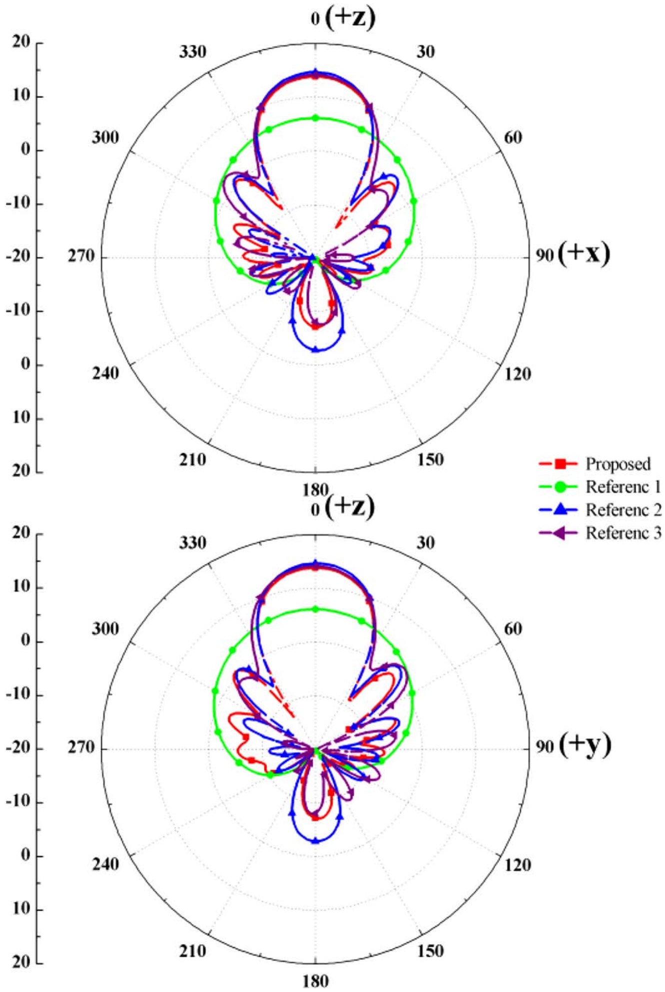

Fig. 4. Simulated radiation patterns for the proposed antenna and references.

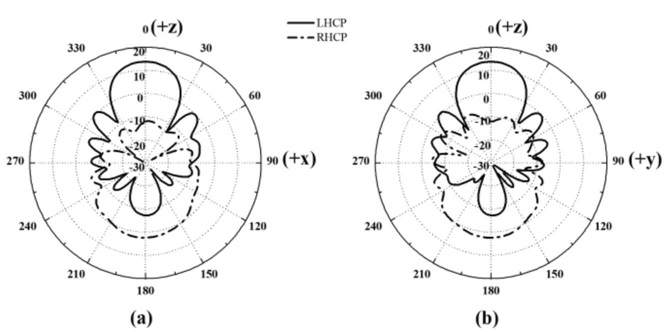

Fig. 5. Simulated radiation patterns for the proposed antenna at 5.8 GHz. (a) xz-plane. (b) yz-plane.

A. Reflection Coefficient

Both the simulated and measured reflection coefficients are shown in Fig. 7. The simulated impedance bandwidth for $S_{11} \leq -10$ dB was 22% (5.05–6.30 GHz) at the center frequency of 5.675 GHz, while the measured was 19% (5.22–6.30 GHz) at the center frequency of 5.760 GHz.

B. Axial Ratio and Gain

Fig. 8 depicts the simulated and measured AR and gain of the proposed antenna against frequency. Both the simulated and measured results demonstrate that the peak gains are higher than 9 dBic and AR is better than 3 dB over the bandwidth of 5–6.3 GHz.

Fig. 6. Photograph of the proposed antenna.

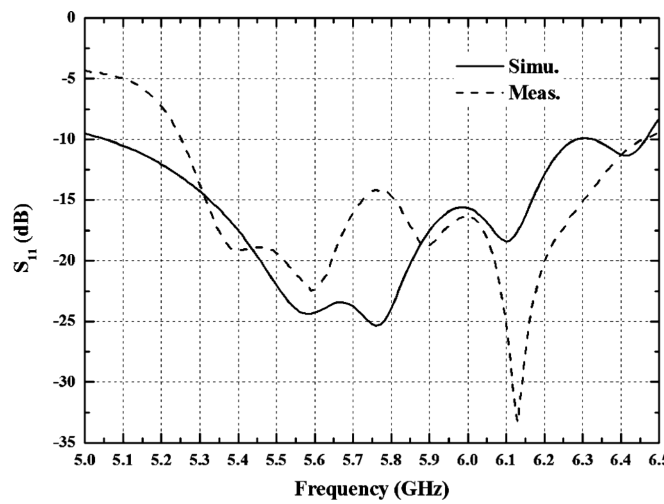

Fig. 7. Simulated and measured S_{11}.

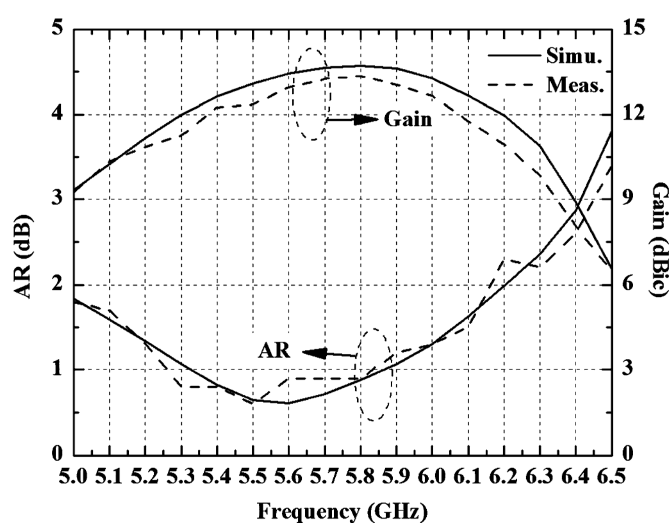

Fig. 8. Simulated and measured AR and gain.

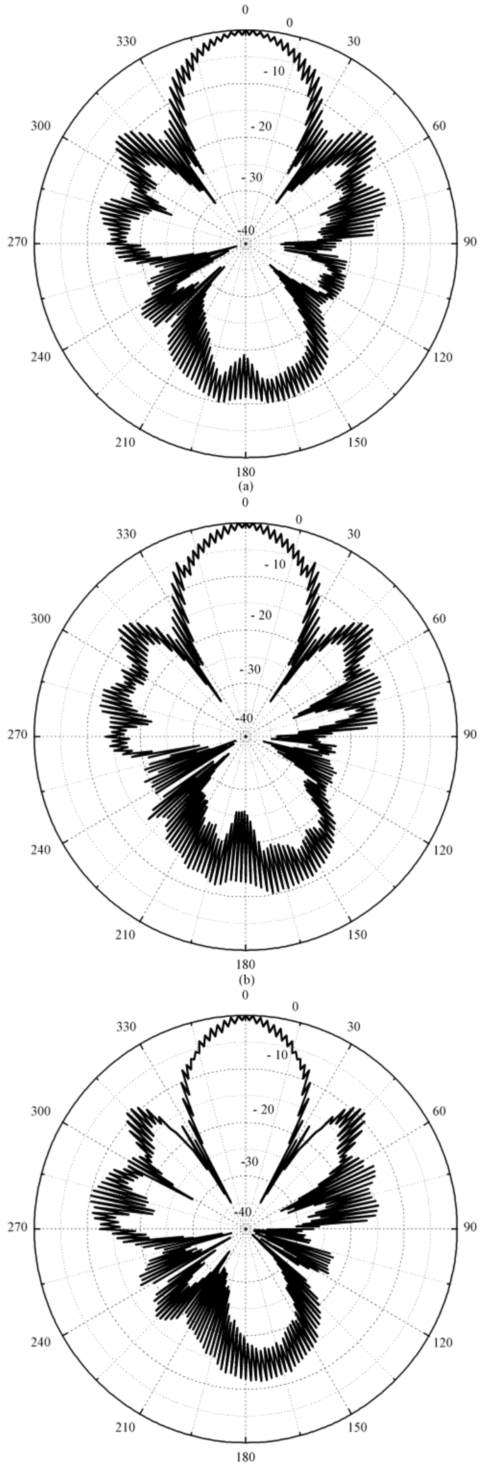

Fig. 9. Measured normalized spinning linear far-field radiation patterns in xz-plane at (a) 5.6, (b) 5.8, and (c) 6.0 GHz.

C. Radiation Pattern

Fig. 9 shows the measured normalized radiation patterns by spinning linear method or rotating-source method [9] at 5.6, 5.8, and 6.0 GHz in xz-plane. The difference between two adjacent values of the measured zigzag patterns represents the corresponding axial ratio. Because the structure is rotationally symmetric, only results in xz-plane are given. The measured 3-dB AR beamwidths are about 45° for 5.6 and 5.8 GHz, and 60° for 6.0 GHz, respectively. All the measured front-to-back ratios are better than 10 dB. Since the circular ground of the proposed antenna is very small, measured back-radiations are higher than the simulated results, which may be caused by the fabrication error and radiation from the feed semi-rigid coaxial cable.

IV. Conclusion

A patch-helix hybrid CP antenna with small ground was presented. The measured impedance bandwidth was enhanced to 19% (5.22–6.30 GHz) by adjusting capacitive coupling between the driven patch and parasitic patch. In addition, excellent LHCP radiation patterns were observed in the endfire direction over 5.0–6.45 GHz. The peak gain was found to have a measured maximum value of 13.35 dBic with a small ground due to relatively uniform current along the helix.

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