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A Novel Printed Helical Antenna for a Circularly Polarized Tilted Beam

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Abstract—A new printed helical antenna (PHA) for a circularly polarized (CP) titled beam is proposed. With the introduction of a multiple sections technique into the PHA's helical arm, the antenna radiates a CP titled beam. To feed the antenna, a matching network composed of a $50\,\Omega$ microstrip transmission line and two symmetrical $\lambda_0/8$ open stubs is designed. The simulated and measured results show that the PHA radiates a CP tilted beam with a maximum radiation direction of $(\theta_{\max}, \varphi_{\max}) = (32°, 135°)$ at $f_0 = 2.11\,\text{GHz}$. The measured bandwidth with a reflection coefficient lower than $-10\,\text{dB}$ is 11.8% (1.99–2.24 GHz), and the experimental results for the radiation pattern, gain, and axial ratio (AR) are also presented.

1. INTRODUCTION

Most satellite communication and navigation systems transmit signals adopting circularly polarized (CP) waves to benefit from better propagation characteristics through the atmosphere [1–4]. To overcome the problems of multipath fading and polarization mismatch between ground antenna receivers and satellites, CP antennas exhibiting satisfactory antenna characteristics are then required. Various antenna candidates have been proposed, such as the patch, gap loop, spiral antenna, and helical antennas [1–4].

An antenna that radiates a tilted beam is often required, for example, for mobile communication systems, satellite communication systems, or WLAN systems [5–7]. In response to this requirement, several methods have been suggested to form a tilted beam, such as the following three methods: by utilizing a novel concept of patterned slotted ground plane [5], by connecting a spiral antenna to the end of a truncated helical antenna [6], and by superposing radiation field F_1 on radiation field F_2, where F_1 and F_2 are the radiation fields from two different active regions on the spiral plane [7]. Note that the antenna with two portions (a spiral antenna and a truncated helical antenna) presented in [6] is suspended in the air, so it is unstable and complicated.

This paper presents a novel PHA for a CP titled beam with a simple and stable structure (supported by the substrate), compared with the one proposed in [6]. With the introduction of a multiple sections technique into the helical arm, the presented PHA radiates a CP titled beam. A matching network composed of a $50\,\Omega$ microstrip transmission line and two symmetrical $\lambda_0/8$ open stubs is also designed to feed the antenna.

2. ANTENNA GEOMETRY AND DESIGN

The configuration of the proposed PHA is shown in Figure 1. Figure 1(a) presents the geometry of the PHA's new helical arm with the matching network. The new helical arm is composed of five helix-shaped sections with different directions of rotation and printed on a thin Taconic TLY-5 substrate

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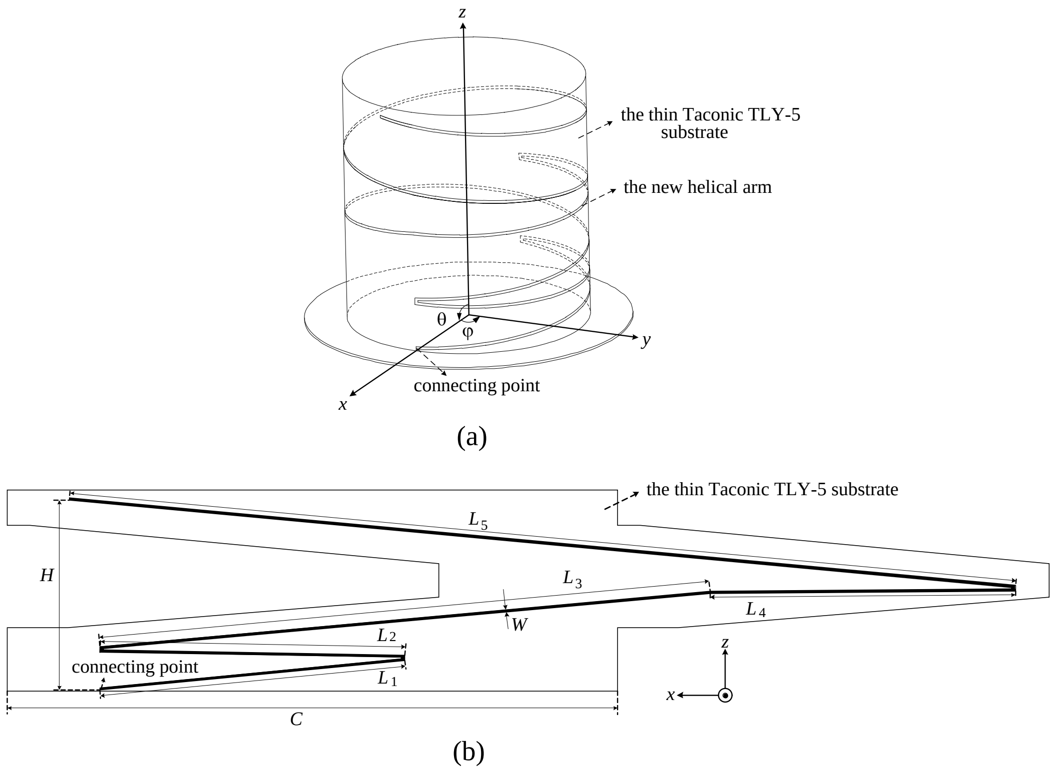

Figure 1. Configuration of the proposed antenna: (a) the proposed PHA, (b) the unrolled helical arm in plane view. ($C = 270\,\text{mm}$, $P_1 = 26\,\text{mm}$, $P_2 = 4.5\,\text{mm}$, $P_3 = 24.5\,\text{mm}$, $P_4 = 2\,\text{mm}$, $P_5 = 25\,\text{mm}$, $N_1 = 0.5$, $N_2 = 0.5$, $N_3 = 1$, $N_4 = 0.5\,\text{mm}$, $N_5 = 1.55\,\text{mm}$, $W = 1\,\text{mm}$, $L_1 \approx 135.6\,\text{mm}$, $L_2 \approx 135\,\text{mm}$, $L_3 \approx 271.1\,\text{mm}$, $L_4 \approx 135\,\text{mm}$, $L_5 \approx 420.3\,\text{mm}$, $H \approx 79.5\,\text{mm}$).

with a thickness of 0.381 mm, relative dielectric constant of 2.2 and loss tangent of 0.0009, as shown in Figure 1(b). The novel helical arm printed on the thin Taconic TLY-5 substrate is rolled into a cylindrical structure with a circumference of C and connected to the latter matching network.

The directions of rotation of the five helix-shaped sections (the first, second, third, fourth, and fifth sections) are right-hand (RH) rotation, left-hand (LH) rotation, RH rotation, RH rotation, and LH rotation, respectively. The pitches and numbers of turns of the five helical sections are P_1, P_2, P_3, P_4, P_5, and N_1, N_2, N_3, N_4, N_5, respectively. Moreover, the five sections enjoy a same width of W. Then the lengths of the five sections and height of the designed antenna can be given as follows:

$$L_1 = N_1\sqrt{P_1^2 + C^2} \tag{1}$$

$$L_2 = N_2\sqrt{P_2^2 + C^2} \tag{2}$$

$$L_3 = N_3\sqrt{P_3^2 + C^2} \tag{3}$$

$$L_4 = N_4\sqrt{P_4^2 + C^2} \tag{4}$$

$$L_5 = N_5\sqrt{P_5^2 + C^2} \tag{5}$$

$$H = N_1 \times P_1 + N_2 \times P_2 + N_3 \times P_3 + N_4 \times P_4 + N_5 \times P_5 \tag{6}$$

In fact, the lengths for each element are chosen as an integer number of λ (140.8 mm at 2.13 GHz) by optimizing the pitches and numbers of turns of the five helical elements, and then the antenna can achieve a good radiation pattern.

For the conventional helical antenna with a fixed direction of rotation of the arm (namely, a conventional arm), the radiation beam becomes a CP conical beam when the circumference of the antenna is greater than $4\lambda_0/3$ (λ_0: wavelength in free space at the centre frequency) [6]. This phenomenon is used for designing the novel PHA with a CP tilted beam.

When the circumference of the new PHA is greater than $4\lambda_0/3$, the antenna can obtain a CP tilted beam with good pattern by optimizing the pitches and numbers of turns of the five helix-shaped sections.

It is worth investigating how each of the currents distributed along the five helical sections contributes to the formation of the CP tilted beam. In fact, when excited by high-frequency signal, the phase relevant to the three right-hand circularly polarized (RHCP) wave components radiated from the currents on the three helical sections with the RH rotating direction (namely, the first section, the third section, and the fourth section) is constructive for forming a RHCP tilted beam. And it is noticed that when the number of turns of the first section, N_1, equals around 0.5, the RHCP tilted beam tilts on the side of the first section of the proposed antenna. The second section is a transmission section and allows the current flowing from the first section to the third section. In addition, the left-hand circularly polarized (LHCP) wave component radiated from the currents on the first four sections (namely, the first section, the second section, the third section, and the fourth section) is an undesired component in the design procedure. Then the fifth helical section is introduced to radiate a LHCP wave component. With appropriate pitches and numbers of turns of the five helical sections, the phases of the two previous LHCP wave components (radiated from the currents on the first four sections and the fifth helical section, respectively) are approximately out-of-phase in the tilted direction. Thus a lower radiation field intensity $|E_L|$ of the LHCP wave component is obtained. Note that the ANSYS HFSS software has been utilized in the design procedure.

Figure 2 presents the simulated results of the radiation field intensity $|E_L|$ of the LHCP wave component in the $\varphi_{\max} = 135^\circ$ plane at f_0. Figure 2(a) shows the result of the first four sections, and Figure 2(b) presents the result of the five sections. It is found that in the maximum tilted direction of ($\theta_{\max} = 30^\circ$, $\varphi_{\max} = 135^\circ$), a lower radiation field intensity $|E_L|$ of the LHCP wave component is obtained when the fifth section is added to the first four sections. Then the overall radiation forms a RHCP tilted beam with good pattern and low AR, as shown by the radiation pattern in Figure 5(c).

To feed the designed PHA, a matching network is designed as shown in Figure 3. The matching network consisting of a $50\,\Omega$ microstrip transmission line and two symmetrical $\lambda_0/8$ open stubs is printed on an FR4 substrate with a thickness of 1 mm, relative dielectric constant of 4.4 and loss tangent of 0.02. The antenna is excited by connecting a coaxial line to the $50\,\Omega$ microstrip transmission line with a length of L_m and a width of W_m by an SMA connector. The two open stubs with a length of L_s and width of W_s are introduced to adjust the imaginary part of the input impedance of the antenna, thus the impedance bandwidth is enhanced. The dimensions of stubs are determined by the input impedance of the antenna (simulated by the ANSYS HFSS software) and the Smith Chart.

3. CHARACTERIZATION OF THE ANTENNA

A prototype of the designed PHA is presented in Figure 4. The reflection coefficient is measured using the Agilent E8363B vector network analyser, and the radiation performances are obtained in a far-field

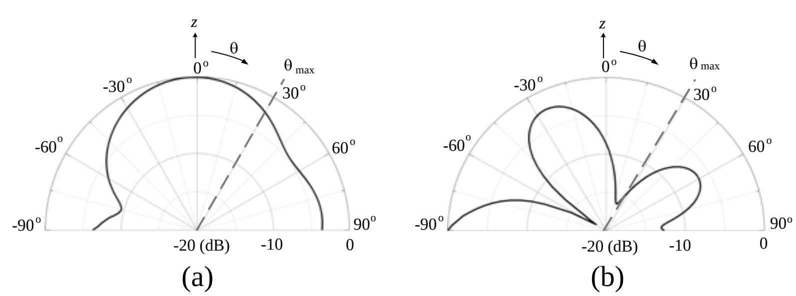

Figure 2. The simulated results of $|E_L|$ of the LHCP wave component in the $\varphi_{\max} = 135^\circ$ plane at f_0: (a) the result of the first four sections, (b) the result of the five sections.

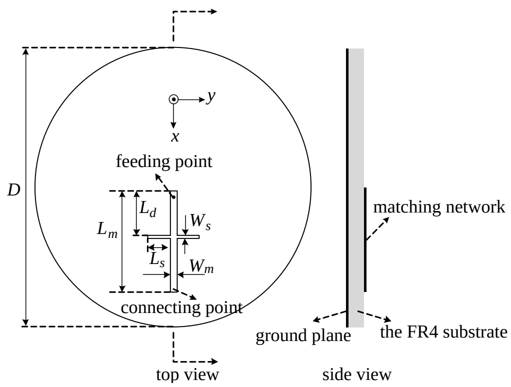

Figure 3. Geometry of the matching network ($D = 116\,\mathrm{mm}$, $L_m = 39\,\mathrm{mm}$, $W_m = 1.9\,\mathrm{mm}$, $L_s = 10\,\mathrm{mm}$, $W_s = 0.7\,\mathrm{mm}$, $L_d = 17.5\,\mathrm{mm}$).

Figure 4. Fabricated antenna model.

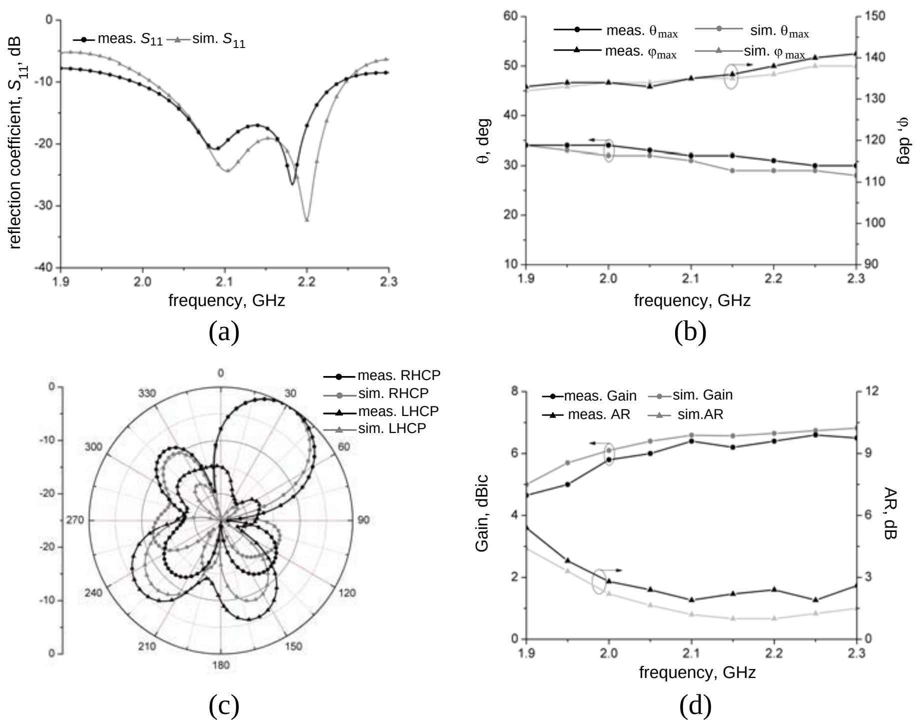

Figure 5. The simulated and measured results: (a) the reflection coefficient of the designed antenna, (b) the variations of maximum tilted directions with frequency, (c) the radiation patterns in the $\varphi_{\max} = 135°$ plane at f_0, (d) the gain and axial ratio characteristics at maximum beam pointing angle ($\theta_{\max}$, $\varphi_{\max}$) over the working frequency band.

measurement system.

The simulated and measured results are depicted in Figure 5. The simulated 10 dB return loss bandwidth is 11.2% (2.01–2.25 GHz), and the measured one is 11.8% (1.99–2.24 GHz), as shown in Figure 5(a). Figure 5(b) shows the variations of the simulated and measured maximum tilted directions of the tilted beam with frequency. It is observed that the measured maximum tilted direction at f_0 occurs in a direction of $(\theta, \varphi) = (32° \equiv \theta_{\max}, 135° \equiv \varphi_{\max})$. The simulated and measured radiation patterns in $\varphi_{\max} = 135°$ plane at f_0 are depicted in Figure 5(c). The gain and AR characteristics at maximum beam pointing angle ($\theta_{\max}$, $\varphi_{\max}$) over the working frequency band are plotted in Figure 5(d).

Table 1. Comparison of the structure and the range variations of the maximum tilted directions with frequency between the proposed antenna and antenna in the previous wor.

Ref.	Structure	$\Delta\theta_{\max}$ with frequency	$\Delta\varphi_{\max}$ with frequency
[6]	unstable and complicated	6°	52°
Proposed	simple and stable	5°	7°

The measured gain varies between 5.8 and 6.6 dBic, and the corresponding axial ratio is less than 2.9 dB. It is noticed that the discrepancy between simulated and measured results is mainly due to the instability of the substrate and the test environment.

A comparison between the proposed antenna and the antenna presented in [6] is shown in Table 1. It is observed that the proposed antenna has a good stability in structure and the maximum tilted direction.

4. CONCLUSION

A novel PHA with a matching network is proposed. With the introduction of a multiple sections technique into the PHA's helical arm, the presented antenna radiates a CP titled beam with a maximum radiation direction of $(\theta_{\max}, \varphi_{\max}) = (32°, 135°)$ at f_0. The measured bandwidth with a reflection coefficient lower than -10 dB is 11.8% (1.99–2.24 GHz). The gain at maximum beam pointing angle ($\theta_{\max}$, $\varphi_{\max}$) varies between 5.8 and 6.6 dBic, and the corresponding axial ratio is below 2.9 dB over the same bandwidth.

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