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Miniature Folded Printed Quadrifilar Helical Antenna with Integrated Compact Feeding Network

Ping Xu*, Zehong Yan, Xiaoqiang Yang, Tianling Zhang, and Geng Yuan

Abstract—A miniature folded printed quadrifilar helical antenna (FPQHA) using a novel compact feeding network is proposed. Folding and meandering techniques are used to obtain 66% of size reduction for the axial length of the printed quadrifilar helical antenna. A compact feeding network using an out-of-phase power divider based on double-sided parallel-strip lines and a Wilkinson power divider is designed. A fabricated prototype of the FPQHA employing the compact feeding network is presented. The measured positive gain bandwidth is from 380 MHz to 425 MHz with a reflection coefficient less than −20 dB and an axial ratio below 2 dB. The measured maximum gain is 3.08 dBic at 395 MHz with a half-power beamwidth of 150°. With good radiation performance and integrated feeding network, the proposed antenna can become a better candidate in satellite and mobile communications.

1. INTRODUCTION

With the rapid development in wireless technology, circularly polarized (CP) antenna has been generally used in satellite and mobile communication systems to overcome the problems of polarization mismatch and multipath fading [1]. To obtain better propagation characteristics between the ground antenna receivers and satellite transmitters, the system requires antennas exhibiting a good axial ratio and hemispherical radiation patterns over the operating band. Various antenna candidates have been proposed, such as the cross printed dipole [2], the printed stacked patch antenna [3], and the quadrifilar helical antenna [4–9].

Recently, the folded printed quadrifilar helical antennas (FPQHA) have become an attractive choice owing to their performances of low profile, circular polarization, good axial ratio, and wide beamwidth. Due to the physical rotation of FPQHA's four arms, the feeding network needs to provide 4 ports with equal power and 90° of phase shifting between adjacent ports. Several FPQHAs have been suggested for application in satellite system [4–9]. However, most of them either have large dimensions or require an external feeding system. In [5, 6], two integrated feeding networks were proposed but they used commercial 90° hybrids coupler to reduce the size of the feeding system. The external or commercial feeding system providing almost ideal magnitude and phase shifting is not practical for antenna system. Therefore, FPQHAs with a compact size employing a simple and integrated feeding network are then required.

In this letter, a miniature FPQHA with integrated compact feeding network is presented. Using folding and meandering techniques, the axial length of FPQHA can be reduced by 66%. The feeding network consists of an out-of-phase power divider based on double-sided parallel-strip lines and two Wilkinson power dividers. It is utilized to realize the equal division and 90° phase shifting.

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* Corresponding author: Ping Xu (pingxu@mail.xidian.edu.cn).
The authors are with the National Key Laboratory of Science and Technology on Antennas and Microwaves, Xidian University, Xi'an, Shaanxi 710071, China.

2. ANTENNA CONFIGURATION AND DESIGN

Figure 1 shows the configuration of the proposed FPQHA, which is printed on a thin Taconic TLY-5 substrate with thickness of 0.254 mm, a relative permittivity of 2.2 and a loss tangent of 0.0009. The four helix elements are wrapped around a cylindrical support and mounted on a small ground plane. Each helix element is composed of two arms, shorted at the top of the helix. One is a conventional helix arm connected to the feed point with a width of W_a, pitch of P and number of turns of N_1, while the other is a folding and meandering helix arm consisting of four segments which is opened to the ground. Each segment contains a strip and a helix arm with a width of W_b, pitch of P and number of turns of N_2.

By properly folding and meandering the helix arm, the antenna can resonate at a much lower frequency than the conventional PQHA consisting of four single helix elements of equal length. The axial length of proposed PQHA has been reduced by 66% from a conventional PQHA, which is about 530 mm with the same radius. Commercial simulation software HFSS V13 has been used in the design process.

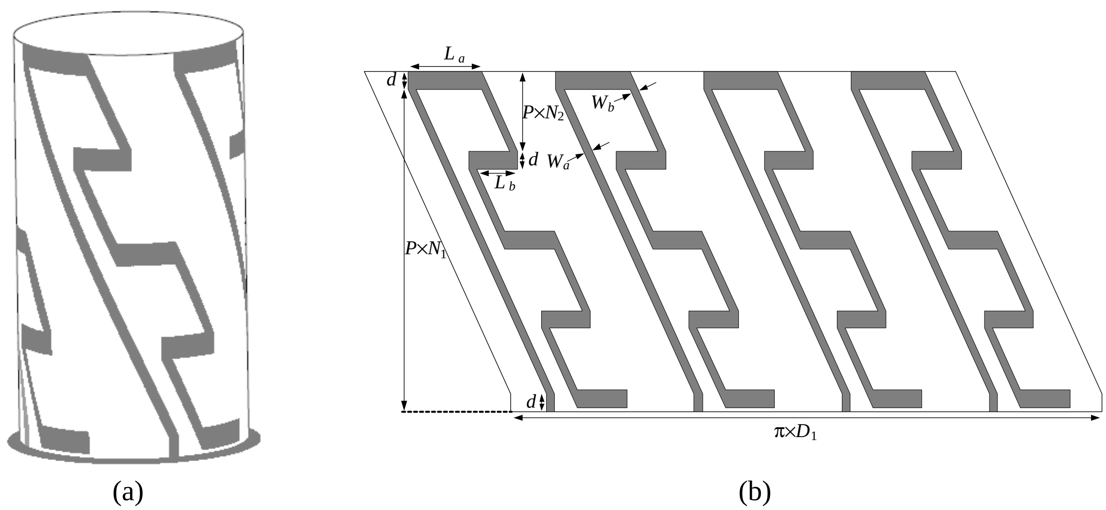

Figure 1. Configuration of the proposed antenna: (a) the proposed FPQHA, (b) the unwrapped FPQHA. (D_1 = 100 mm, d = 9.5 mm, P = 690 mm, W_a = 4.3 mm, W_b = 4.3 mm, L_a = 39 mm, L_b = 21.8 mm, N_1 = 0.25, N_2 = 0.06).

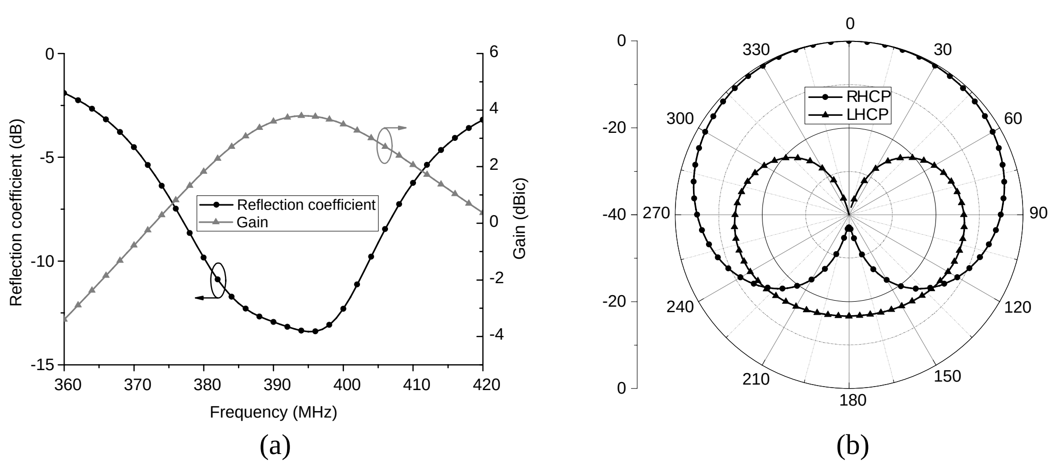

Figure 2. Simulated results of the proposed FPQHA fed with ideal amplitude and phase: (a) reflection coefficient and gain, (b) normalized radiation patterns at 395 MHz and $\varphi = 0$ deg.

Figure 2 shows the simulated results of the proposed FPQHA. It can be seen that the impedance bandwidth with reflection coefficient below −10 dB covers 380–404 MHz (about 6.1%). And the maximum antenna gain varies between 1.83 dBic and 3.8 dBic over the same impedance band. Simulated normalized radiation patterns at 395 MHz are presented in Figure 2(b). As can be found, a large beamwidth of about 150° can be obtained.

3. THE COMPACT FEEDING NETWORK

The geometry of proposed compact feeding network is presented in Figure 3. The novel feeding network is composed of a 180° out of phase power divider and a Wilkinson power divider.

For the same strip width and dielectric constant, the characteristic impedance of a double-sided parallel-strip line with dielectric separation h is twice the characteristic impedance of a microstrip line with dielectric thickness $h/2$ [10, 11]. Then a ground plane is inserted into a dual-layer structure with a parallel-strip line as shown in Figure 3(a). The ground plane converts the parallel-strip into two identical microstrip lines placed back-to-back. So we can obtain

$$Z_0 = 2Z_1. \tag{1}$$

To transform Z_1 to the input impedance Z_0, a quarter-wave impedance transformer with the characteristic impedance of Z_2 is inserted. So the equations are given as

$$Z_2 = \sqrt{Z_1 Z_0}. \tag{2}$$

Using (1), (2) is simplified to

$$Z_2 = \frac{\sqrt{2}}{2} Z_0. \tag{3}$$

It is observed that the two identical microstrip lines are equal in magnitude and opposite in phase.

Then two Wilkinson power dividers are connected to the outputs of out of phase power divider at the top and bottom layers, respectively. The 90° phase shifting between the two outputs of the Wilkinson power divider is realized by adjusting the length of microstrip lines. Using via pins, the signal at the bottom layer can be transmitted to the top layer, which is convenient for feeding the helix elements.

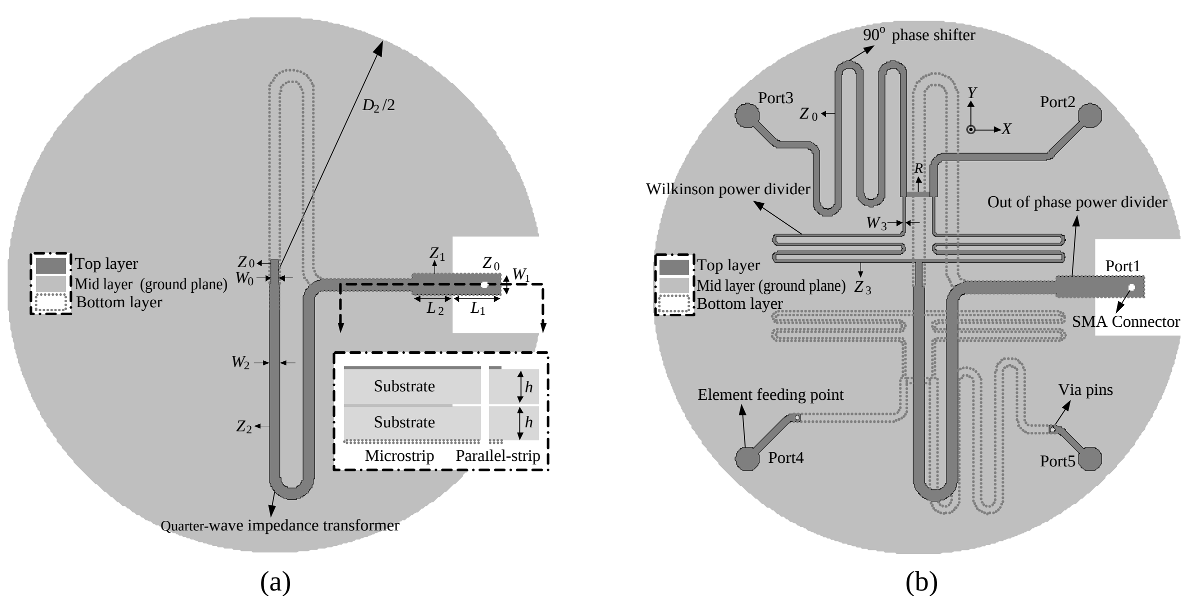

Figure 3. Geometry of the compact feeding network: (a) the out of phase power divider, (b) the feeding network. ($Z_0 = 50\,\Omega$, $Z_1 = 25\,\Omega$, $Z_2 = 35.35\,\Omega$, $Z_3 = 70.7\,\Omega$, $R = 100\,\Omega$; $D_2 = 110$ mm, $W_0 = 1.5$ mm, $W_1 = 4.2$ mm, $W_2 = 2.3$ mm, $W_3 = 0.6$ mm, $L_1 = 10$ mm, $L_2 = 8$ mm, $h = 0.8$ mm).

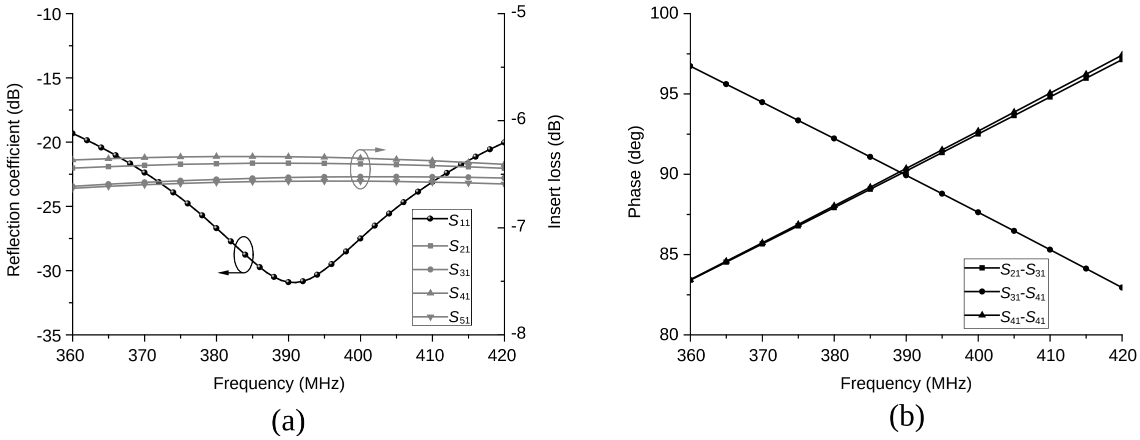

Figure 4. Simulated results of the proposed feeding network: (a) S-parameters in magnitude, (b) phase differences between the adjacent ports.

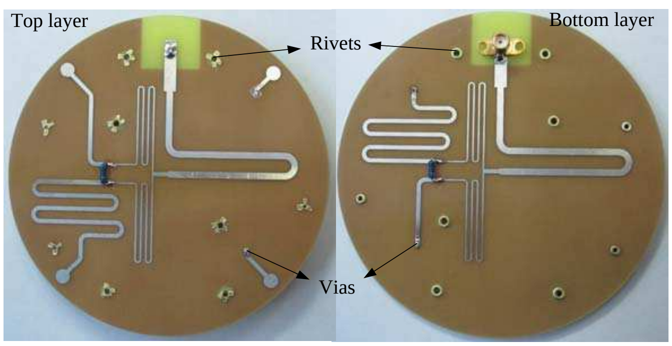

Figure 5. The compact feeding network prototype.

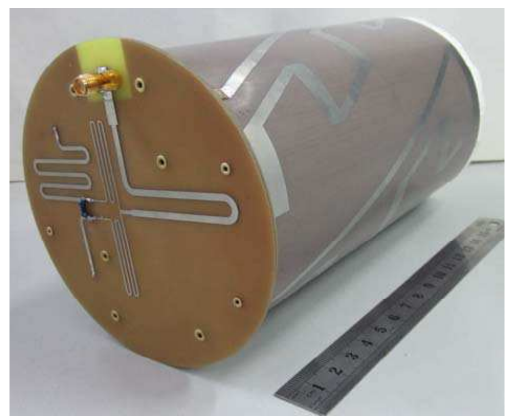

Figure 6. Fabricated antenna prototype.

Figure 4 presents the simulated reflection coefficient, magnitudes and phase differences of the outputs. It is indicated that the performance of the network is sufficient for feeding the proposed FPQHA. The feeding network is printed on two inexpensive FR4 substrates with a relative permittivity of 4.5 and a loss tangent of 0.02. A fabricated prototype is realized as shown in Figure 5. During the fabrication, rivets were used to reinforce the dual-layer structure in case binding.

4. CHARACTERIZATION OF THE ANTENNA

Figure 6 presents the fabricated prototype of the FPQHA with the proposed feeding network. The reflection coefficient was obtained using an Agilent E5071B vector network analyzer and the far-field performances were measured in a far-field anechoic chamber.

Measured results of the proposed antenna fed by the compact feeding network are shown in Figure 7. As can be found, the positive gain bandwidth is from 380 MHz to 425 MHz with a reflection coefficient lower than -20 dB and an axial ratio below 2 dB. The measured maximum gain is 3.08 dBic at 395 MHz. Normalized radiation patterns at 395 MHz of the proposed antenna are shown in Figure 7(c). It is noted that a half-power beamwidth of about 150° can be obtained.

A comparison between the proposed antenna and the antennas presented in [4, 5] is shown in Table 1. It is observed that the proposed antenna with integrated feeding network has a miniature dimension. And the radiation performances are comparable with the previous works.

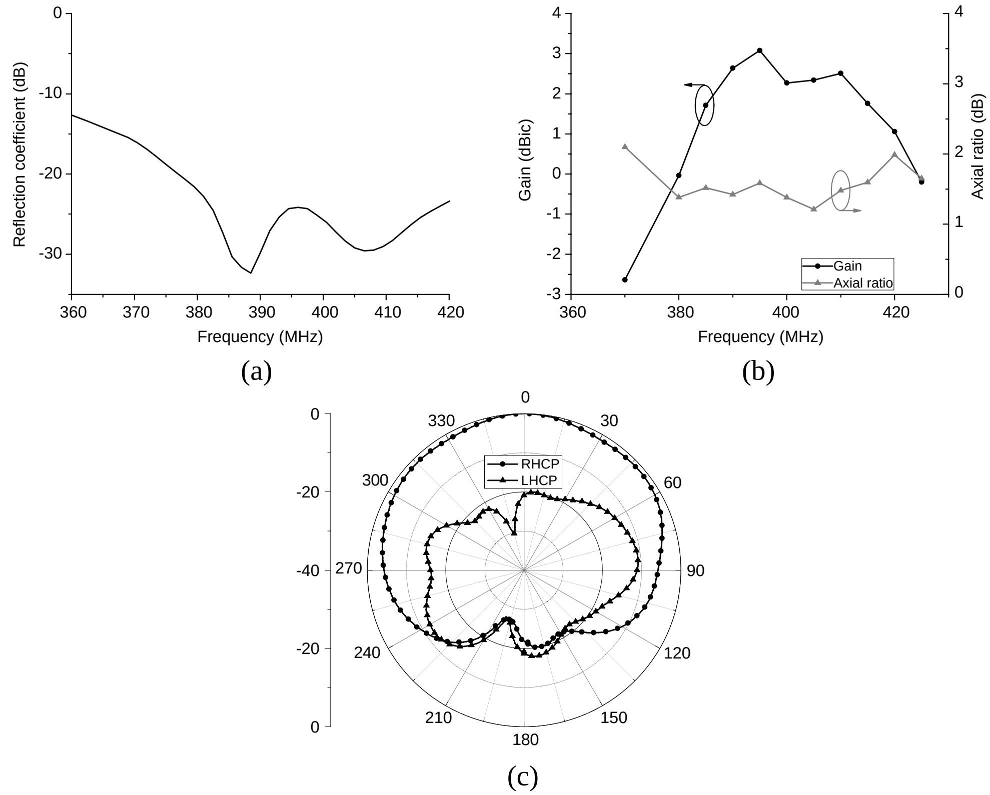

Figure 7. Measured results of the FPQHA fed by the proposed feeding network: (a) reflection coefficient, (b) gains and axial ratios, (c) normalized radiation patterns at 395 MHz and $\varphi = 0$ deg.

Table 1. Comparison of the dimensions and radiation performances between the proposed antenna and antennas in the previous works.

Ref.	Axial length	Impedance bandwidth	Peak gain (dBic)	3-dB beamwidth (deg)	Feeding network
[4]	$0.574\lambda_0$	30% ($S_{11} < -10$ dB)	∼3.2	150	External
[5]	$0.574\lambda_0$	29% ($S_{11} < -12$ dB)	∼2.7	150	Integrated
Proposed	$0.227\lambda_0$	12.9% ($S_{11} < -20$ dB)	3.08	150	Integrated

5. CONCLUSION

A miniature folded printed quadrifilar helical antenna employing a compact feeding network is presented. Using folding and meandering techniques, the axial length of the antenna can be reduced by 66%. The feeding network is a combination of an out of phase power divider with a Wilkinson power divider. With compact size and simple structure, the feeding network can be well integrated with the proposed antenna. Measured gain with positive value covers from 380 MHz to 425 MHz with a reflection coefficient less than −20 dB and an axial ratio below 2 dB. The maximum gain is 3.08 dBic at 395 MHz with a half-power beamwidth of 150°. Good performance over a wide beamwidth and ease of integration make the proposed antenna a better candidate for satellite and mobile communications.

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