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A Broadband Printed Quadrifilar Helical Antenna with a Novel Compact Broadband Feeding Network

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Abstract—A broadband printed quadrifilar helical antenna (BPQHA) integrated with a broadband feeding network for satellite communications is proposed. Using a multiple arm technique, satisfactory antenna characteristics over a wide bandwidth are realized. To feed the antenna, a novel compact broadband feeding network composed of a frequency independent 180° out-of-phase power divider, two Wilkinson power dividers and two broadband 90° phase shifters is designed. The measured boresight gain remains positive with a reflection coefficient lower than −11 dB over a bandwidth of approximately 26%. The axial ratio is below 1.7 dB and the half-power beamwidth is more than 120° over the same bandwidth. Details of the proposed antenna design are provided and discussed, as well as the experimental results.

1. INTRODUCTION

Most satellite communication and navigation systems transmit signals adopting circularly polarized waves to benefit from better propagation characteristics through the atmosphere [1]. To overcome the problems of multipath fading and polarization mismatch between ground antenna receivers and satellites, circularly polarized (CP) antennas exhibiting an excellent axial ratio over the operating band and over a wide beamwidth are then required [1–7].

As their performances in terms of circular polarization, superior axial ratio over a wide beamwidth, and low cost, the printed quadrifilar helical antennas (PQHAs) have recently become a very attractive candidate for these systems. However, the relative bandwidth of a conventional PQHA with good performances is representatively of 5% to 8%, which is insufficient for some applications. Therefore, PQHAs with broadband properties is required. In the last two decades, to broaden the operating bandwidth, several techniques have been suggested in published works and several broadband PQHAs (BPQHAs) have been proposed [1, 4–6].

In consequence of the physical rotation of PQHA's four parallel arms, the feeding system needs to provide the four feeding ports with equal power and 90° phase shift between adjacent feeding ports. Nevertheless, conventional power dividers have large dimensions, and commercial 90° hybrids couplers are not practical for BPQHAs [1, 7]. Therefore, it is essential to design a simple and compact feeding network with a wide operating bandwidth for the BPQHA.

In this paper, a new design technique is utilized to obtain the BPQHA integrated with compact broadband feeding network. Using a multiple arm technique, the bandwidth can be increased. A novel dual-layer structure broadband feeding network is designed to obtain 90° of phase difference between adjacent feeding ports and equal division between the four feeding ports.

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2. ANTENNA GEOMETRY AND DESIGN

The geometry of the proposed BPQHA is shown in Figure 1, where the four parallel elements are printed on a thin FR4 substrate with a thickness of 0.2 mm, a relative dielectric constant of 4.5 and a loss tangent of 0.02. The four helix-shaped elements are rolled into a cylindrical structure and mounted on a small ground plane. The circumference of the helix-shaped element is taken as $C \approx 0.5\lambda_0$ (λ_0 is the free space wavelength at the center frequency), and each element consists of a wide radiating arm where two parallel narrow resonant arms are introduced at the wide arm's end. Each of the two resonant arms can resonate at an individual frequency, which is determined by the length of each narrow arm.

The wide arm with a width of W_a and number of turns of N_a is connected to the feeding point. The widths and numbers of turns of the narrow arms are W_b, W_c and N_b, N_c, respectively. Moreover, the three arms enjoy a same pitch of P. Then the length of arms can be given as follows:

$$L_a = N_a\sqrt{P^2 + \pi^2 D_1^2} \tag{1}$$

$$L_b = N_b\sqrt{P^2 + \pi^2 D_1^2} \tag{2}$$

$$L_c = N_c\sqrt{P^2 + \pi^2 D_1^2} \tag{3}$$

In fact, the narrow arms allow adjusting the resonance frequencies by varying the length of each narrow arm. With a proper length of the wide arm, the antenna can achieve a wide bandwidth with

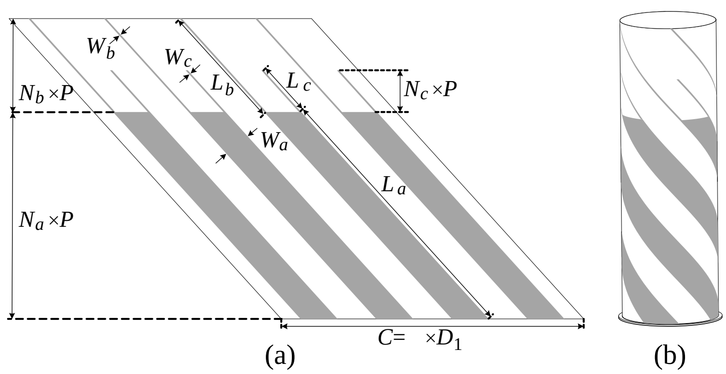

Figure 1. Geometry of the proposed antenna: (a) the unrolled antenna, (b) the proposed BPQHA. ($D_1 = 130$ mm, $P = 450$ mm, $W_a = 50$ mm, $W_b = 3$ mm, $W_c = 3$ mm; $N_a = 0.62$, $N_b = 0.28$, $N_c = 0.125$; $L_a \approx 416$ mm, $L_b \approx 170$ mm, $L_c \approx 76$ mm).

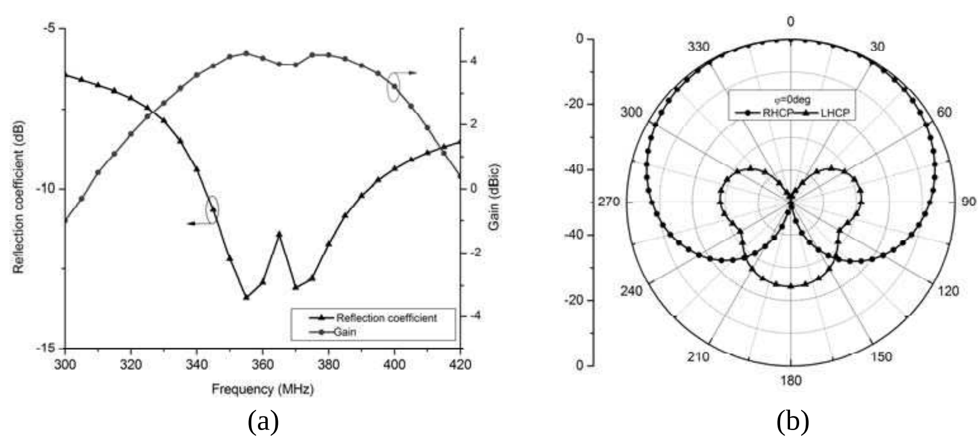

Figure 2. Simulated results of the proposed BPQHA fed with ideal amplitude and phase: (a) reflection coefficient and boresight gain, (b) normalized radiation patterns at F_0.

two closer frequency resonance points by optimizing the lengths of the narrow arms.

Figure 2 shows the simulated results of the proposed BPQHA fed with ideal amplitude and phase. It can be observed that $-10\,\mathrm{dB}$ reflection coefficient bandwidth with two distinct frequency resonance points covers 342–397 MHz (approximately 15%) from Figure 2(a). The boresight gain varies between 3.3 dBic and 4.3 dBic over the same frequency range. The two resonant frequency points are $F_1 = 355\,\mathrm{MHz}$ and $F_2 = 375\,\mathrm{MHz}$. Figure 2(b) presents the normalized radiation patterns at the center frequency ($F_0 = 365\,\mathrm{MHz}$). As is shown, a half-power beamwidth of approximately 130° can be achieved.

3. FEEDING NETWORK CONFIGURATION AND DESIGN

The configuration of the proposed compact broadband feeding network is presented in Figure 3. Using a frequency independent 180° out-of-phase power divider based on double-sided parallel-strip lines, two Wilkinson power dividers and two broadband 90° phase shifters, the novel feeding network provides an equal distribution of input power to the four helix elements and 90° of phase difference between adjacent elements over a wide bandwidth.

For the same strip width and dielectric constant, the characteristic impedance of a double-sided

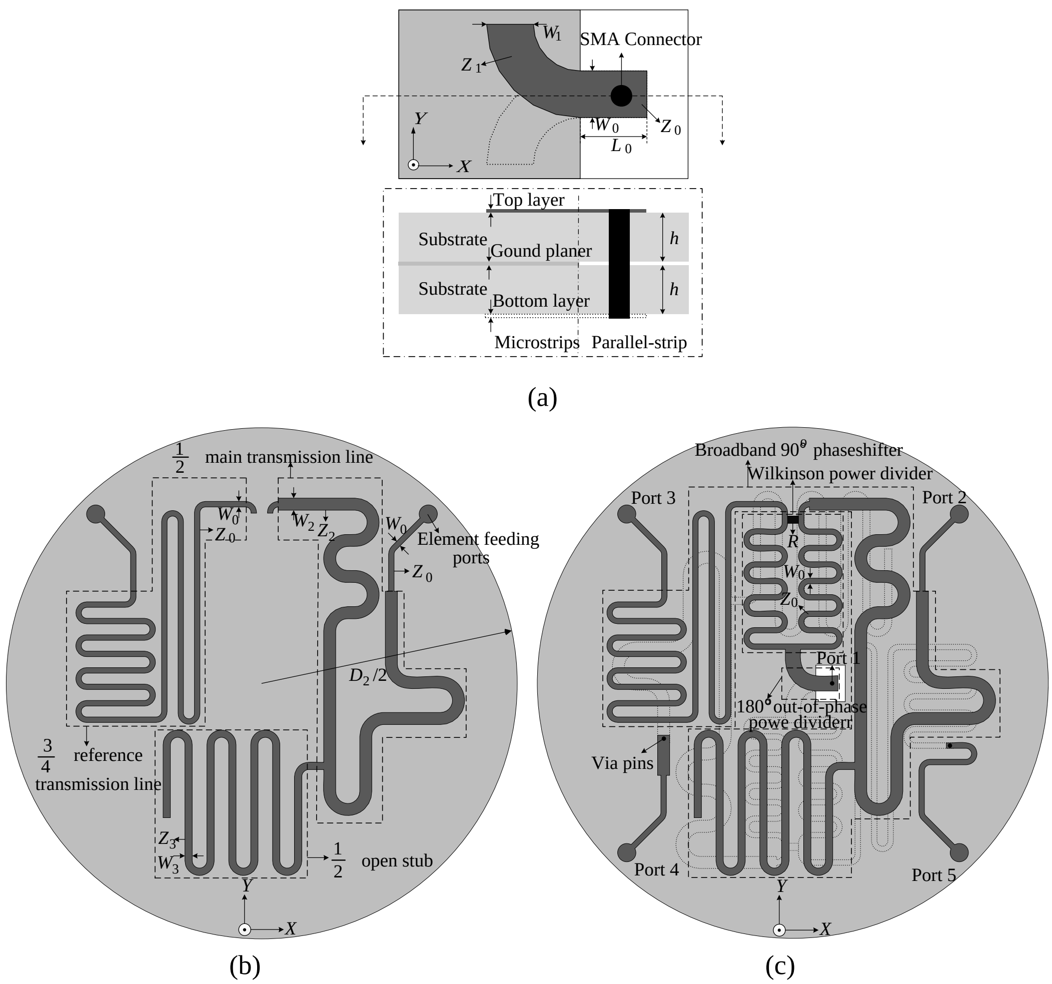

Figure 3. Configuration of the novel compact broadband feeding network: (a) the 180° out-of-phase power divider, (b) the broadband 90° phase shifter, (c) the overall configuration of the feeding network. ($Z_0 = 50\,\Omega$, $Z_1 = 25\,\Omega$, $Z_2 = 30\,\Omega$, $Z_3 = 45\,\Omega$, $R = 50\,\Omega$; $D_2 = 140\,\mathrm{mm}$ $W_0 = 4.2\,\mathrm{mm}$, $W_1 = 4.2\,\mathrm{mm}$, $W_2 = 3.3\,\mathrm{mm}$, $W_3 = 2\,\mathrm{mm}$, $L_0 = 6\,\mathrm{mm}$, $h = 0.8\,\mathrm{mm}$).

parallel-strip line with dielectric separation h is twice the characteristic impedance of a microstrip line with dielectric thickness $h/2$ [9]. By inserting a ground plane at the center of a dual-layer structure with a parallel-strip line and paralleling it to the parallel-strip line, the double-sided parallel-strip line is transformed into two identical microstrip lines placed back to back as shown in Figure 3(a). The two identical microstrip lines are 180° out-of-phase and equal in magnitude, which is frequency independent. From the previous analysis, we can obtain

$$Z_0 = 2Z_1 \tag{4}$$

Then two broadband 90° phase shifters are realized at the top and bottom layers, respectively. As presented in Figure 3(b), the broadband 90° phase shifter has two portions: a three-quarters wavelength reference transmission line and a half wavelength main transmission line with a half wavelength open stub loaded at the middle. Characteristic impedances of the main line and the reference line are Z_2 and Z_0, respectively, and for the stub is Z_3. When Z_2 equals $30\,\Omega$ and Z_3 equals $45\,\Omega$, it presents a 90° phase difference over a wide bandwidth with a small variation between the main transmission line and the reference transmission line [10]. To feed the helix elements expediently, via pins are introduced to

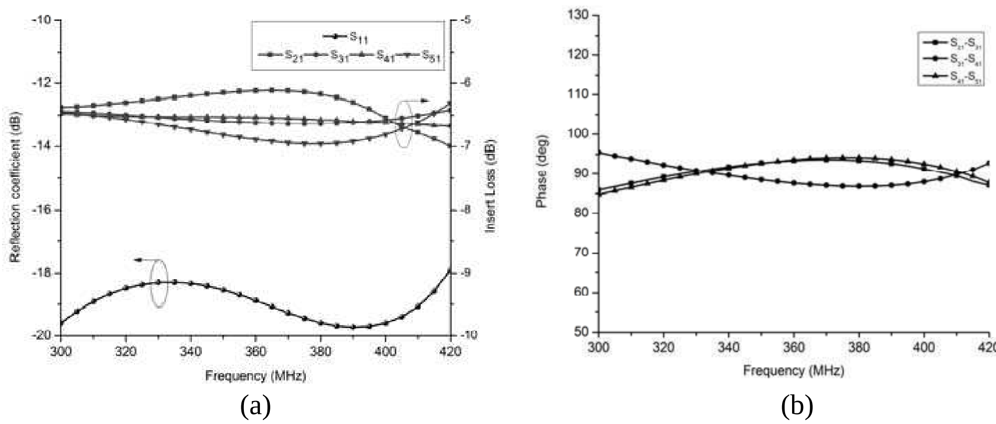

Figure 4. Simulated results of the proposed feeding network: (a) S-parameters in magnitude, (b) phase differences between adjacent outputs.

Figure 5. Fabricated antenna model.

transmit the signal from the bottom layer to the top layer.

In addition, two Wilkinson power dividers are introduced to connect the 180° out-of-phase power divider and the two 90° phase shifters at the top and bottom layers, respectively. Characteristic impedances of the input and the output of the Wilkinson power divider are Z_1 and Z_0, respectively.

The overall configuration of the feeding network is shown in Figure 3(c). When the signal is excited at the input (port 1), the feeding network provides an equal distribution of the signal power and a 90° phase sequential rotation to the four outputs (port 2, port 3, port 4, and port 5).

The feeding network is printed on two FR4 substrates with a thickness of 0.8 mm, a relative dielectric constant of 4.5 and a loss tangent of 0.02. Figure 4 presents the S-parameters of the feeding network. The reflection coefficient is lower than −18 dB over the operating bandwidth of the proposed antenna. It exhibits a 90° phase difference with a maximum ripple of 4° between adjacent outputs and

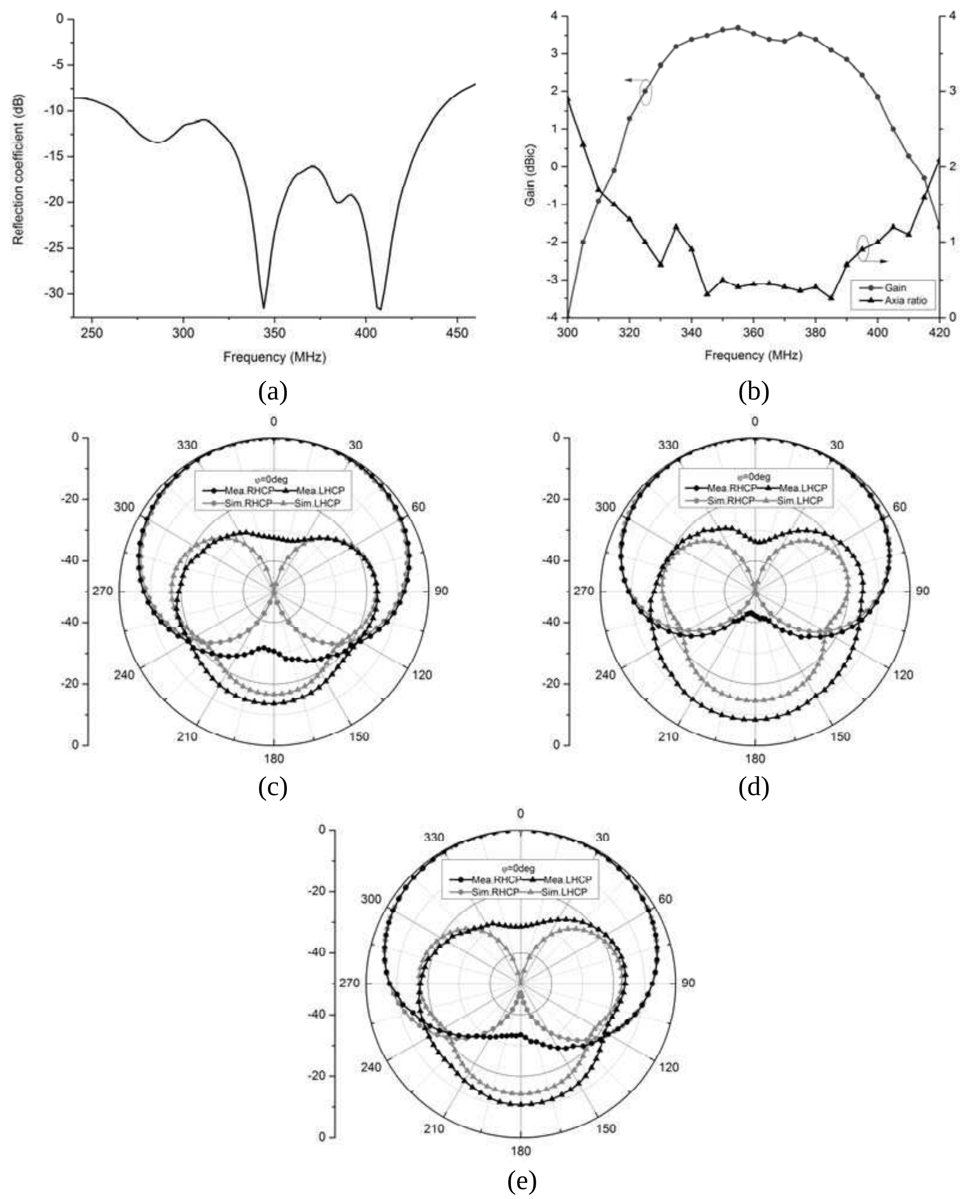

Figure 6. Measured results of the BPQHA fed by the proposed broadband feeding network: (a) reflection coefficient; (b) gain and axial ratio at boresight; measured and simulated normalized radiation patterns at (c) F_1, (d) F_2 and (e) F_0.

the magnitudes of the four outputs presents a maximum imbalance of 0.8 dB over the same frequency range. The simulated results indicate that the behaviors of the network is sufficient to feed the proposed BPQHA.

4. CHARACTERIZATION OF THE ANTENNA

The fabricated model of the BPQHA with the proposed compact broadband feeding network is presented in Figure 5. Ansoft HFSS software has been utilized in the design and simulation process. The reflection coefficient was measured using an Agilent E5071B vector network analyzer and the radiation performances were obtained in a far-field measurement system.

Figure 6 shows the measured results of the BPQHA fed by the proposed broadband feeding network. The measured boresight gain varies between 0 and 3.7 dBic over a bandwidth of 26% (from 315 MHz to 410 MHz) with an axial ratio below 1.7 dB and a reflection coefficient lower than −11 dB. Figures 6(c), (d), and (e) show the measured and simulated normalized radiation patterns at F_1, F_2 and F_0, respectively. It can be seen that the half-power beamwidth is more than 120° over the operating bandwidth.

Table 1 presents a comparison of the sizes and operating characteristics between the proposed BPQHA in this paper and antennas in the previous literatures. It is observed that the proposed BPQHA with the broadband feeding network has a wider relative bandwidth and a compact dimension.

Table 1. Comparison of the dimensions and radiation performances between the proposed BPQHA in this paper and antennas in the previous literatures.

Ref.	Axial length	Impedance bandwidth	Positive gain bandwidth	Feeding network
[6]	0.574 λ_0	25% ($S_{11} < -12$ dB)	25%	Integrated
[8]	0.312 λ_0	16.4% ($S_{11} < -20$ dB)	12.3%	Integrated
Proposed	0.493 λ_0	47% ($S_{11} < -11$ dB)	26%	Integrated

5. CONCLUSION

A broadband printed quadrifilar helical antenna (BPQHA) fed by a novel compact broadband feeding network is presented. By adjusting the lengths of the two narrow arms, satisfactory antenna behaviors over a wide bandwidth can be obtained. The proposed novel compact broadband feeding network exhibits a phase difference of 90° (±4°) between adjacent outputs over the operating bandwidth. With simple structure and compact size, the broadband feeding network can be expediently integrated with the proposed BPQHA. The measured boresight gain with positive value covers from 315 MHz to 410 MHz (approximately 26%) with a reflection coefficient less than −11 dB and an axial ratio below 1.7 dB. And the half-power beamwidth is more than 120° over the same frequency band. With these properties, the proposed antenna can be a better candidate for satellite communication and navigation systems.

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