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Quadrifilar Helix Antenna Using Compact Low-Cost Planar Feeding Circuit in Array Configuration

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Abstract—A wideband printed quadrifilar helical antenna (PQHA) using a novel single layer compact feeding circuit is proposed in this paper. A low-cost single-layer feeding circuit which consists of a 180° compact rat race coupler and two 3 dB hybrid commercial couplers is incorporated at the bottom of the quadrifilar antenna. The antenna arms are tapered at the feeding point to improve impedance matching between the antenna and feeding circuit. The operating frequency band ranges from 1.9 to 2.3 GHz which shows that the proposed antenna is a good candidate for various applications such as satellite communication and broadcasting satellite systems. Therefore, the array of the proposed antenna on the simple cube satellite mock-up is investigated. By this antenna array configuration, a fully spherical radiation coverage is obtained around the structure. The bandwidth of the axial ratio (AR) with a wide beamwidth (160^o) is 20% in operating frequency band. The measured peak gain of the proposed antenna varies between 2.6 and 3.2 dBic in the frequency band of interest. The measured 3 dB AR half-power beamwidth is 160°.

1. INTRODUCTION

Circular polarization (CP) antennas are mostly used in satellite communication, broadcasting and global poisoning systems. Circular polarization link is well suited for transmit and receive data due to insensitivity to polarization rotation. For precise and efficient communication between ground station and satellites in telemetry, tracking and command (TT&C) satellite communication and global positioning systems, the hemispherical radiation patterns with good axial ratio in the operating frequency bandwidth is needed [1]. Some practical antennas such as wire helix [2], cross dipole [3] and turnstile or printed microstrip type such as stacked patch antenna [4] or wire [5] and printed quadrifilar helix antenna (PQHA) [6–11] are a good choice to be employed in mentioned systems. In [5], a method of designing CP omnidirectional helix antenna with low profile is presented. It is shown that the saddle pattern of TT&C antenna is required to compensate the free-space losses from horizon to nadir angle. The PQHA antenna is a type of CP antennas, which accomplishes required wide hemispherical beamwidth coverage and CP radiation characteristics over a broad frequency bandwidth. This characteristic is very attractive in a small Low Earth Orbit (LEO) satellite TT&C communication. By using meander line techniques, a compact PQHA antenna is proposed in [7]. The four ports of helical antenna should be fed with 90° of phase difference between them. A common power divider and directional coupler circuits were applied to the feeding system of the PQHA in [8]. The feeding circuit with this method provides narrow frequency bandwidth, and therefore, the size of the structure could be increased. In [9], a folded PQHA is proposed with a double-layer feeding structure based on an aperture-coupled transition and including two 90° SMT hybrids. In [10], feeding networks for three operating

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frequencies of the proposed antennas are presented. These networks are based on compact single-layer Wilkinson power dividers with meandered lines. The bandwidths of these circuits are narrow.

The communication specifications vary considerably in the LEO satellite applications. As the satellite orbits the Earth, the TT&C communication links between satellite and ground station constantly change with regard to the relative distance between a fixed ground station and the fast moving satellite. Also, sometimes the satellite attitude determination and control system (ADCS) is missing, and the satellite rotates around itself. Therefore, if the satellite TT&C antenna does not have semi-omni radiation pattern and coverage, then the radio link between satellite and ground station could not be established. One useful solution to achieve fully spherical radiation pattern coverage is to exploit two hemispherical antennas on the opposite sides of the cube satellite platform. By using this method, the antenna array composed of the two wide beam width antennas is created, which makes a stable communication link.

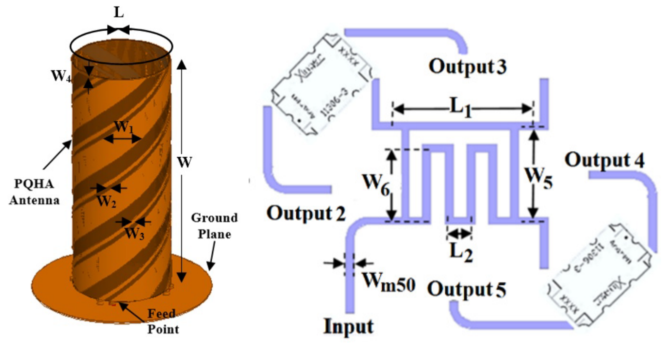
This paper presents a broadband printed quadrifilar helix antenna integrated with a novel compact single-layer low-cost feeding circuit. Our proposed antenna in [11] is expanded with details in functionality, and the array of the designed antennas is studied briefly on the platform of an LEO satellite. The structure of the designed antenna consists of a wideband compact 180° phase shift rat-race coupler and two commercial 3 dB 90° hybrid couplers. The whole feeding structure is fabricated on a single-layer microstrip board and integrated at bottom of the PQHA antenna. The novelty of the proposed antenna is in the compactness of the feeding circuit and analysis of the configuration of antenna array to accomplish omni-spherical radiation coverage without missing communication with ground stations. The antenna array exhibits a good CP radiation characteristic over a wide beamwidth in 1.9–2.3 GHz frequency band.

2. ANTENNA AND FEEDING CIRCUIT CONFIGURATION AND DESIGN

The geometry of the designed PQHA is shown in Fig. 1(a). The 4 helix-shaped radiating arms are printed on a Rogers RT/duriod 5880 microstrip substrate board with $\varepsilon_r = 2.2$ and thickness of 8 mil. After printing radiating element on the PCB, the antenna board is folded around a cylindrical foam holder. The conductor strip of width W_1 is soldered to the exciting point, and the other parasitic element of width W_3 is grounded. The optimized number of helix turns N, pitch angle ϕ, antenna radius and other antenna parameters are mentioned in Table 1.

The initial antenna parameters are calculated by using design procedure of the helix antenna mentioned in [9]. Then the commercial High Frequency Structure Simulator (HFSS) software has been used to improve the design. By using two parallel strips and altering the width of these radiating elements, the broadband characteristics of the folded PQHA are obtained [11]. The conductor strip is tapered at the feeding point (junction between feeding circuit and antenna) to improve impedance matching (Fig. 1(a)).

The designed feeding circuit should represent 90° differential phase shift among the four arms of

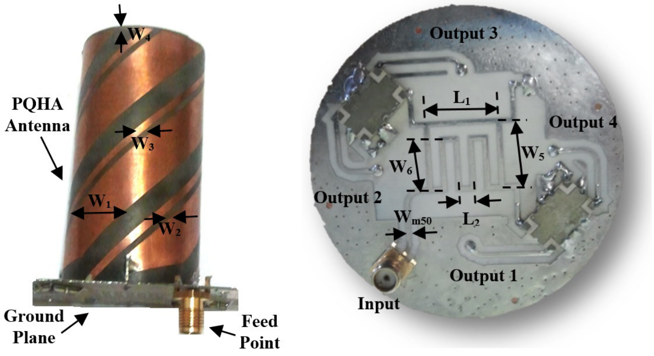


(a) (b)

Figure 1. Geometry of proposed antenna. (a) Schematic of PQHA antenna and (b) Schematic of feeding circuit.

the antenna over the frequency band of interest with low insertion loss. A conventional four-arm helix antenna has a feeding structure with a common power divider and hybrid couplers to generate 90° phase difference. This structure has low frequency band, and its dimension is relatively massive in size. To overcome this problem, broadband hybrid and rat-race couplers are proposed in [12–15]. Caillet et al. in [9] employ dual-layer aperture coupled transition to provide 180° power divider with 29% bandwidth. Also we could accomplish feeding network with the combination of broadband 180° phase shifter [16] and wideband coupler structure proposed in [15].

Geometry of the proposed novel compact feeding structure is shown in Fig. 1(b). This circuit consists of a compact rat-race 180° coupler and two commercial Anaren 3 dB hybrid SMT couplers integrated on a single-layer RO4003 microstrip substrate board [Fig. 2(b)]. The outputs of feeding structure are connected to the PQHA via holes and connecting pins [Fig. 1(a)]. The optimal values of the proposed feeding circuit are tabulated in Table 2.



(a) (b)

Figure 2. Fabricated proposed antenna. (a) PQHA antenna and (b) Feeding circuit.

Table 1. Optimized dimensions of the designed coupler.

Dimension of antenna	**Parameters (mm)**										
	L	**W**	**N**	**W_1**	**W_2**	**W_3**	**W_4**	**W_{S1}**	**Ant. Rad**	**Φ**	**Gnd Rad**
Values	140	65	1	16.3	2	2.7	140	0.5	9	60°	25

Table 2. Optimized dimensions characteristics of the feeding circuit.

Characteristics of feeding circuit	**Parameters (mm)**						
	L_1	**L_2**	**W_5**	**W_6**	**W_{m50}**	**h (sub. thickness)**	**ε_r**
Values	20	4.2	15.4	12.25	1.1	0.508	3.38

3. SIMULATED AND MEASURED RESULTS OF SINGLE ANTENNA

The simulated main features of the PQHA are investigated without feeding circuit. The height and diameter of the antenna are 65 and 35 mm, respectively. Fig. 3 shows the simulated VSWR of the PQHA which is equal to or lower than 2, from 1.9 to 2.3 GHz. The assembly of the feeding board is fabricated and measured to investigate its features over the operating frequency band. The measured S-parameters amplitude and phase difference responses of the feeding network are shown in Figs. 4(a) and (b). The return loss between the input and outputs of the circuit is better than 15 dB, and the

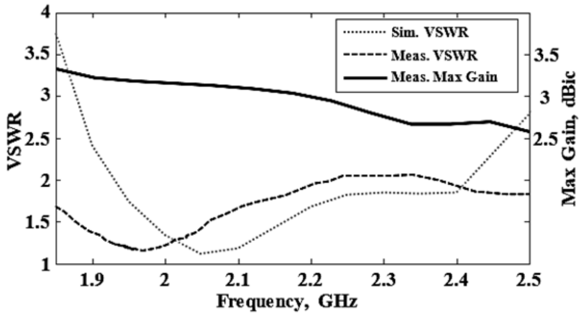
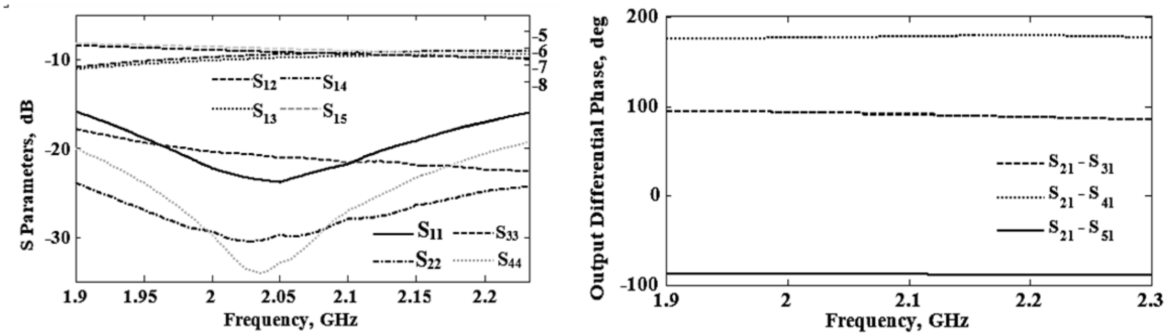
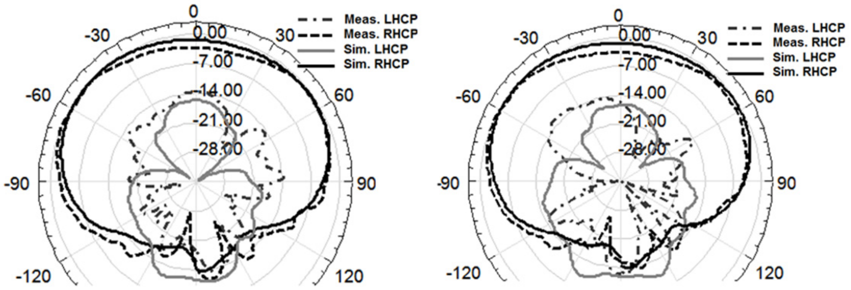


Figure 3. Measured VSWR and peak gain of the PQHA.



(a) (b)

Figure 4. Measured results of feeding circuit. (a) *S*-parameters magnitude of the feeding circuit. (b) Differential phase shift between outputs of the feeding circuit compared to those of the output port 2.



(a) (b)

Figure 5. Simulated and measured LHCP and RHCP radiation pattern of the PQHA with feeding structure at (a) 2 GHz, (b) 2.2 GHz.

transmission coefficients indicate a maximum imbalance of 0.8 dB over 1.9–2.3 GHz frequency band. Measured differential phase shift between outputs of the feeding circuit compared to the output port 2 is shown in Fig. 4(b). The maximum phase ripple is 3.5° over bandwidth.

The measured VSWR of the PQHA and feeding circuit is illustrated in Fig. 3. It is lower than 2.1 at 1.7–2.4 GHz frequency band which meets the desired frequency band requirements. The radiation patterns of the PQHA with the compact broadband feeding system were measured in a far-field anechoic chamber.

Figure 3 shows simulated and measured right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) radiation patterns in *xoz* cut-plane at 2 [Fig. 5(a)] and 2.2 [Fig. 5(b)] GHz frequencies. The measured half-power beamwidth (HPBW) is almost 160° at 2.2 GHz and 170° at 2 GHz, and the cross polarization rejection is greater than 15 dB over the HPBW.

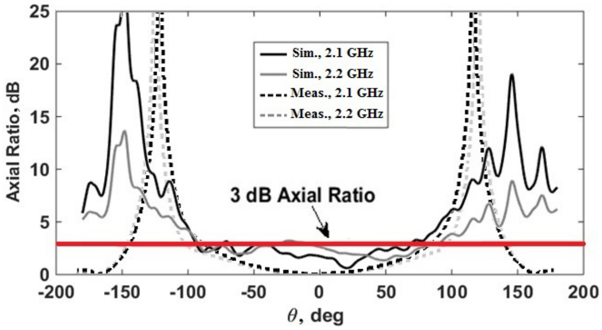


Figure 6. Simulated and measured axial ratio of the PQHA antenna.

Figure 6 shows simulated and measured axial ratios at 2 and 2.2 GHz frequencies. The 3 dB AR beamwidth is about 170° at 2 and 2.2 GHz frequencies. The maximum gain of the proposed antenna varies between 2.6 and 3.3 dBic. The gain of the antenna is lower than that of simulation results due to the loss of implementation.

4. SIMULATED AND MEASURED RESULTS OF ANTENNA ARRAY

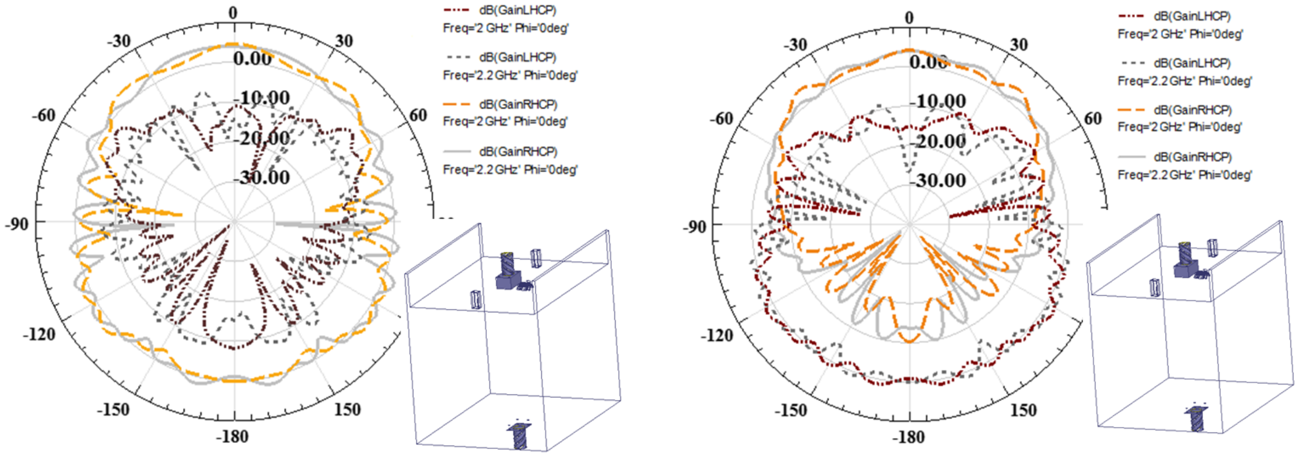
The antenna array configuration of the proposed PQHA antennas is shown in Fig. 7. Because of demand on the fully spherical performance on the satellite communication link, the two designed antennas are placed on the opposite sides of cube platform. Based on the proposed antenna, two antennas with RH and LH circular polarizations are designed. An antenna array with two different configurations is designed. In the first approach, the same polarization antenna (RHCP) is placed on the opposite sides of the mock-up. At the second one, the polarizations of the antennas are different.

(a) (b)

Figure 7. Configuration of antenna array on the satellite platform. (a) Top view and (b) bottom view.

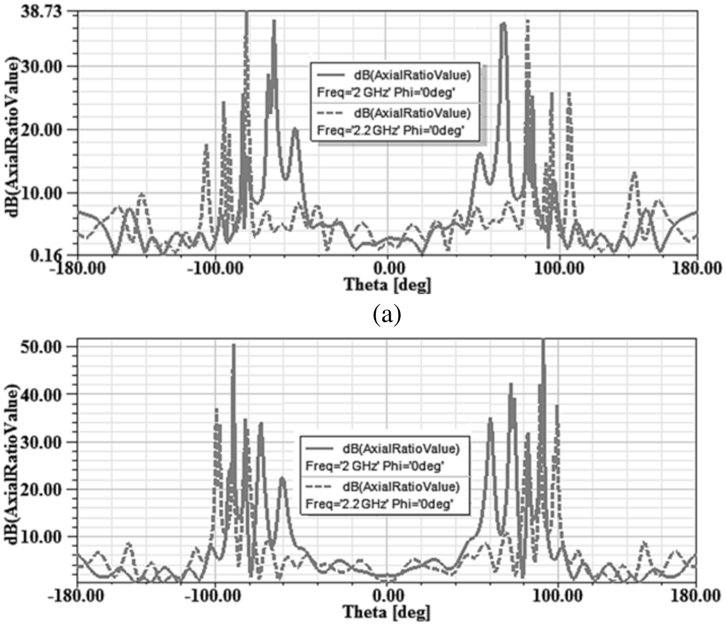
Figure 8 shows simulated right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) radiation patterns in Phi = 0° plane at 2 and 2.2 GHz frequencies. As shown in Fig. 7, at the top plate of platform, two metal plates are placed near the antenna. These plates cause the antenna beamwidth at this face to decrease, and ripple of radiation pattern in this hemispherical is increased. But as seen in Fig. 9, the simulated axial ratio of the antenna array with two different polarizations has wider beamwidth than antennas with the same polarization. As can be observed, the antenna array has almost full coverage with CP characteristics around the satellite. The 3 dB axial beamwidths with the same and different polarizations are 48° in 2 GHz (20° in 2.2 GHz) and 38° in 2 GHz (18° in 2.2 GHz), respectively.

The radiation characteristics of the proposed CP PQHA antennas on the mock-up structure were



(a) (b)

Figure 8. Simulated LHCP and RHCP radiation pattern of the PQHA with feeding structure at 2 and 2.2 GHz. (a) Two RLCP antenna (b) RLCP and LHCP antennas on the top and bottom side of platform.



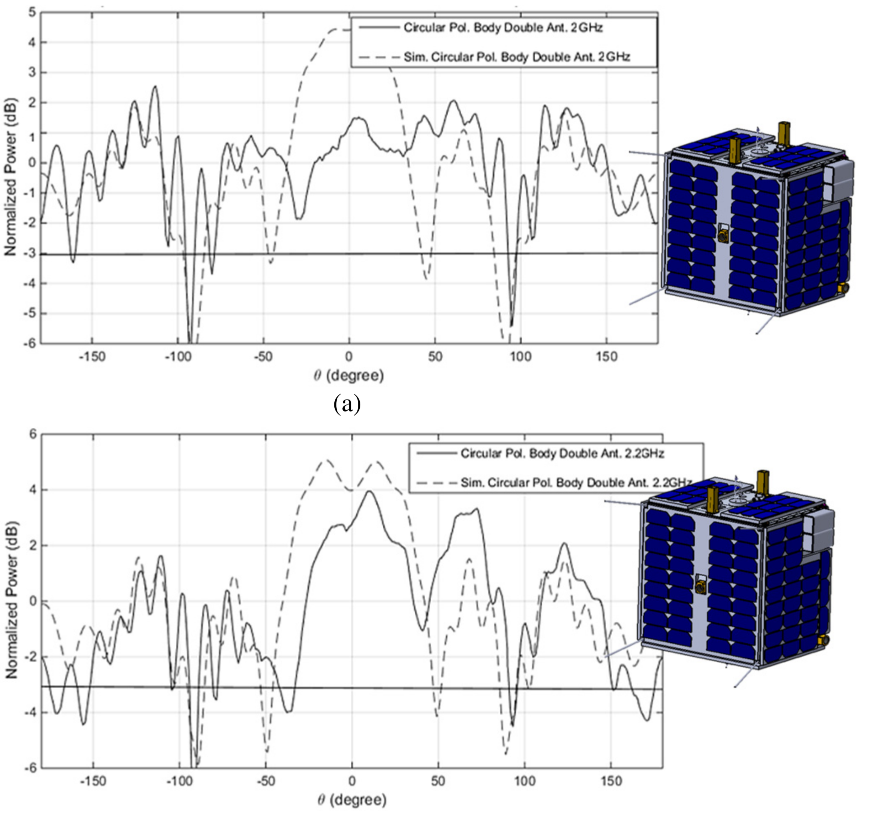
(a)

(b)

Figure 9. Simulated axial ratio of the PQHA antenna array at 2 and 2.2 GHz. (a) Two RLCP antenna (b) RLCP and LHCP antennas on the top and bottom side of platform.

measured in a far-field anechoic chamber. Fig. 10 indicates simulated and measured RHCP and LHCP radiation patterns in Phi = 0° cut-plane. The proposed antenna array has omni radiation pattern. The radiation patterns are measured at 2 and 2.2 GHz in the practical frequency band. The 3 dB AR beamwidth, 10 dB return loss bandwidth and size of the antennas are tabulated in Table 3 for comparison. It is clearly seen that the proposed antenna with low cost and compact structure in a single-layer configuration has wider beamwidth and simple fabrication processes.

Finally, the appropriate circular polarization radiation characteristics achieved make the proposed broad beamwidth PQHA antenna in array configuration suitable for creating fully spherical coverage in TT&C satellite communication system applications.



(a)

(b)

Figure 10. Measured LHCP and RHCP radiation pattern of the PQHA antenna array when two RHCP and LHCP antenna placed on the mock-up (Fig. 6), (a) 2 GHz and (b) 2.2 GHz.

Table 3. Comparison of characteristics for various PQHA antennas.

Antenna Ref.	Feeding circuit	3 dB Axial Beam Width (deg)	10 dB RL BW (%)	Dimension (λ_0^3)
[8]	Commercial hybrid coupler	150	30	$0.66 \times 0.2 \times 0.2$ @ 1.2 GHz
[9]	Two layer (aperture coupled)	150	29	$0.68 \times 0.3 \times 0.3$ @ 1.2 GHz
[10]	Single layer	100	11	1×1 @ 3 GHz
Proposed	Single layer	**160**	**19.5**	$\mathbf{0.38 \times 0.3 \times 0.3}$ @ **2.1 GHz**

5. CONCLUSION

In this paper, a broadband printed quadrifilar helical antenna (PQHA) using a novel single-layer compact feeding circuit is proposed. The bandwidth of the axial ratio with wide beamwidth (160°) is 20% in operating frequency band ranging from 1.9 to 2.3 GHz. By using the proposed antenna in array configuration, semi omni radiation characteristics are achieved. The proposed antenna has good CP radiation characteristics which show that the proposed antenna is a good candidate for various applications in TT&C and satellite communication systems.

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