A Printed Quadrifilar Helix Antenna (QHA) with Enhanced Bandwidth

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ABSTRACT: A circular polarized printed quadrifilar helix antenna (QHA) with enhanced bandwidth is proposed in this paper. The helix antenna offers a very compact size and comprises of four arms with varying width, four open stubs, a feeding network, and a metal ground plane. The different widths of the helix arms are employed to improve the impedance bandwidth while their varying pitches generates a cardioid radiation pattern. The antenna exhibits a VSWR$\leqslant$2 in the frequency range of 1.43 GHz to 1.63 GHz offering impedance bandwidth of 12%. Good radiation characteristics with high gain, a wide 3-dB axial ratio beamwidth of 180° along with small size make this antenna an excellent candidate for satellite communications and navigation systems.

Keywords: Helix antenna, Circular polarized, Enhanced bandwidth, Cardioid

radiation pattern.

1. INTRODUCTION

Massive growth of satellite communications and navigation and positioning systems necessitates novel solutions for the receiving antennas. These antennas are required to offer wide impedance bandwidth to support varying operating frequencies, circular polarization, good axial ratio beamwidth and compact size. A cardioid radiation pattern is also a critical requirement to mitigate multipath interference [1]. This area has attracted wide range of research due to its increasing demand. It is well known that many types of antennas could produce the cardioid radiation patterns, including microstrip array antennas, dipoles with orthogonal feed, equiangular spiral antennas and quadrifilar helix antennas (QHA) [1-14]. For microstrip array [2, 3] and orthogonal dipole antennas [4], the circularly polarized characteristics would be deteriorated when the antenna is away from the direction of maximum radiation. In [5], equiangular spiral antennas have been used to achieve the cardioid radiation pattern with a wide 3-dB axial ratio beamwidth. However, the gain in the broadside direction is difficult to control in this design. Besides generating the cardioid radiation pattern; the quadrifilar helix antennas also offer a compact size that makes them a very suitable choice for small satellite receivers and navigation devices [6-11]. The conventional quadrifilar helix antenna is a resonant antenna, and its impedance bandwidth is typically extremely narrow (i.e. only about 5%). Various designs to improve the bandwidth of these antennas have been presented in open literature [12-15]. Two similar antennas operating at different frequencies have been cascaded together constructing a whole new structure to widen the impedance bandwidth in [12] and [13]. Use of an LC circuit at the optimized position of the helix arms to generate another resonance has been proposed in [14]. Qin has used multi-arm spirals with different arm lengths to produce multiple closely located resonances [15]. By optimizing the resonant points, the antenna would achieve a wide impedance bandwidth. However, these designs suffer from a deteriorated circularly polarized performance limiting their usage in satellite based communication and navigation devices. It is therefore, pertinent to devise novel solutions for quadrifilar helix antennas.

In this paper, a printed QHA having helix arms of different widths have been proposed. The antenna has an enhanced bandwidth of 12% as compared to the conventional QHA, offers good cardioid radiation patterns, good 3-dB axial ratio over a wide angular range and a very compact size. Following the introduction in this section, the paper is organized in three sections. Section II presents the structural details of the antenna geometry. Section III discusses the performance of the antenna in terms of simulated and measured results. The paper is concluded in section IV.

2. ANTENNA DESIGN

The geometry of the proposed QHA is shown in Fig. 1(a). The antenna consists of four helix arms, four radial open stubs, the dielectric cylinder, ground plane and the feed network. The expanded view of the helix arms is illustrated in Fig.1 (b). The four helix arms with sectional width are key to improve the impedance and pattern bandwidth. Each arm has two turns. The first turn with an arm width W_1 and pitch P_1

is printed on the bottom side of the dielectric cylinder while the second turn having an arm width W_2 and pitch P_2 is on the top side of the cylinder. The two turns are connected with each other at point A. Point A is located at the step position. The dielectric cylinder has a relative permittivity of 4.4, radius of R_0 and height of H. H is a sum of P1, P2. It is placed at the center of the ground plane with a radius R_l. The radial open stub with dimensions S×T is connected to the end of the second turn of the helix arm. It effectively reduces the overall size of the antenna. There are four feed ports (ports B, C, D and E) at the bottom of the helix arms, which would be connected to the feed network. The feed network is printed on the FR4 substrate and consists of three Wilkinson power dividers with 90^o phase shifters as shown in Fig. 1(c). The feed network therefore provides four output ports (2, 3, 4 and 5) that have equal amplitude but a phase difference of 90^o. The antenna is connected to the excitation source at input port 1. The optimized dimensions of the antenna are summarized in Table I.

Table I Dimensions of the proposed antenna

Antenna Structural Parameter	R_0	H	R_1	W_1	W_2
Dimension (mm)	*18*	*195*	*80*	*12*	*5*
Antenna Structural Parameter	P_1	P_2	S	T	W_3
Dimension (mm)	*58*	*120*	*6*	*10*	*5.5*

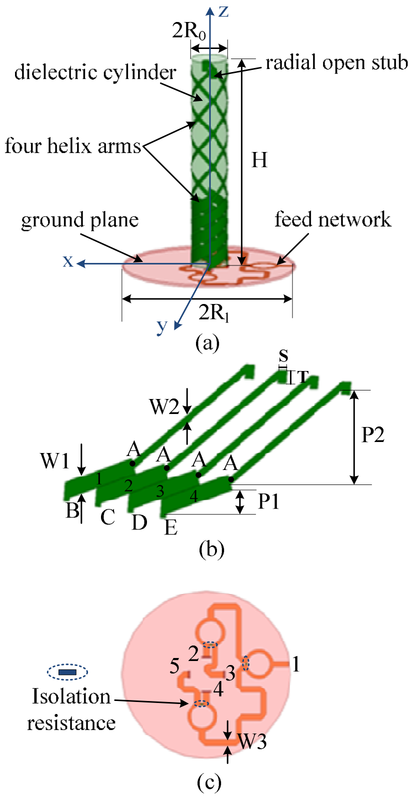


Fig.1 Geometry of the proposed antenna:（a）3D view, (b) expanded view, (c) feed network

3. RESULTS AND DISCUSSION

The antenna has been designed and analyzed numerically using Ansoft High Frequency Structure Simulator (HFSS 14.0). To highlight the advantages of the proposed structure, three antenna configurations are considered in simulation; the QHA with unequal pitch and arm width (Ant. 1 – proposed), the QHA with equal pitch and arm width (Ant. 2 – conventional QHA), and the QHA with unequal pitch and without radial open stubs (Ant. 3). The simulated results for Ant. 1 have been validated through measurements.

Fig. 2 shows the comparison of simulated VSWR response for the three QHA configurations. It can be observed that the conventional QHA (Ant. 2) has a height of 235 mm and exhibits a narrow impedance bandwidth of 5% for VSWR≤2. The impedance bandwidth of Ant. 1 on the other hand is 12% ranging from 1.43 GHz to 1.63 GHz. For Ant. 3, the resonant frequency is shifted to higher band, which indicates that the use of the open stubs has reduced the size of the QHA resulting in a resonance at lower frequency. The enhanced impedance bandwidth is primarily due to the helix arms with different widths. The effects of the arm width on the impedance characteristics of the proposed antenna (Ant. 1) have been studied in detail. Fig. 3 shows the simulated VSWR for the arm width of the first helix turn (W_1) varied from 3 to 15 mm while keeping the other parameters constant. It is observed that the VSWR is affected by the changing value of W_1 dramatically. An increasing W_1 has enhanced the VSWR≤2 impedance bandwidth of the QHA. However, when W_1 reaches to 15 mm, the VSWR is deteriorated. The simulated VSWR for the arm width of the second helix turn (W_2) varied from 3 to 14 mm is presented in Fig. 4. It can be seen that the VSWR≤2 impedance bandwidth of the antenna is decreased with an increase in W_2. The optimal impedance bandwidth for the proposed QHA is achieved with W_1 = 12 mm and W_2 = 5 mm. These results clearly indicate that compared to the conventional QHA, the impedance bandwidth of the proposed antenna is enhanced by using the helix arms with different widths.

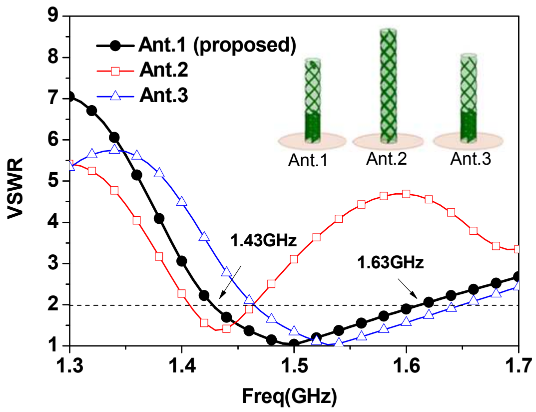


Fig.2 Simulated VSWR of Ant. 1, Ant. 2 and Ant. 3 (Ant. 1: proposed QHA; Ant. 2: conventional QHA; Ant. 3: QHA without the radial open stubs)

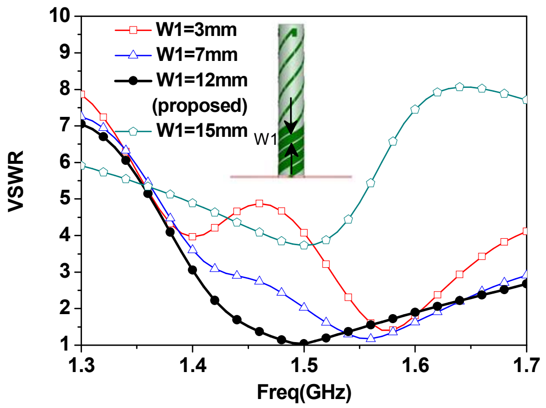


Fig.3 The simulated VSWR for different values of the arm width for the first helix turn (W_1)

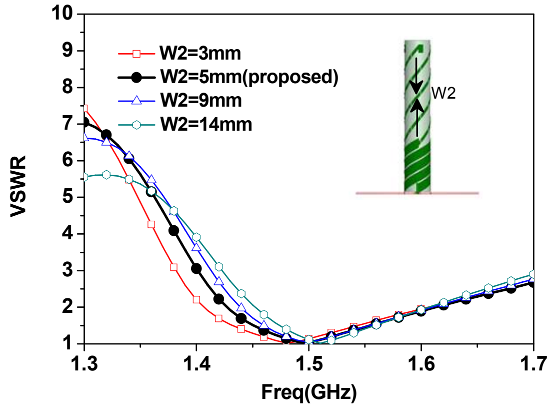
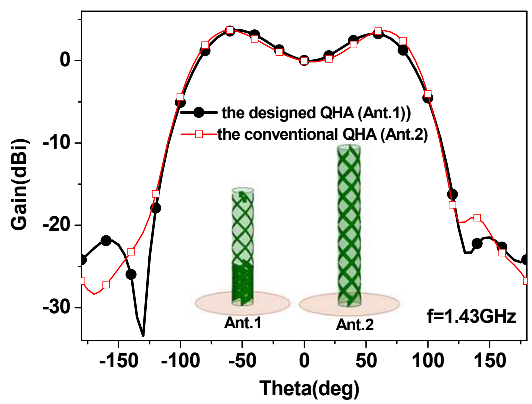
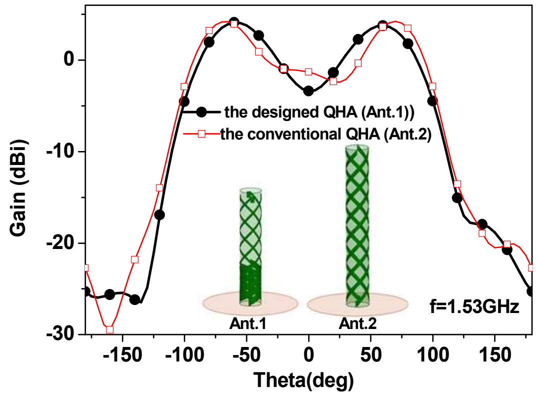


Fig. 4 The simulated VSWR for different values of the arm width for the second helix turn (W_2)

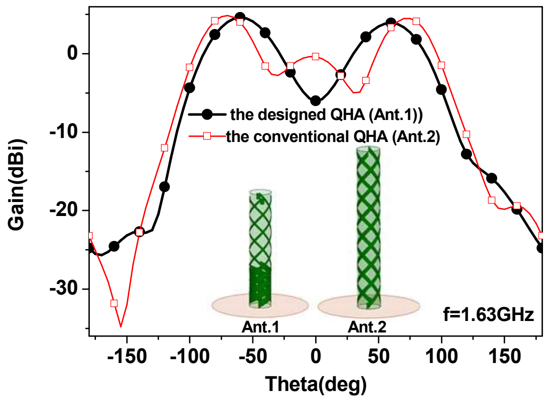
To achieve a better cardioid radiation pattern, different pitch sizes for the four helix arms have been employed in the proposed antenna design. Fig. 5 presents a comparison of the simulated Left Hand Circular Polarization (LHCP) radiation patterns in the XZ plane ($\phi = 0^o$) at 1.43 GHz, 1.53 GHz and 1.63 GHz for the conventional and the proposed QHA. The results show that the radiation pattern of the conventional QHA (Ant. 2) is distorted in the axial direction at high frequency whereas the proposed QHA (Ant. 1) exhibits good cardioid radiation patterns at all three frequencies.



(a)



(b)



(c)

Fig. 5 Simulated Left Hand Circular Polarization (LHCP) radiation patterns in the XZ plane ($\Phi=0^{o}$) for the conventional QHA and the proposed QHA at: (a) 1.43 GHz, (b) 1.53 GHz, (c) 1.63 GHz.

The effects of the pitch of the two turns of the helix arms (P_1 and P_2) on the antenna's radiation characteristics are investigated further at the center frequency of 1.53 GHz. Fig. 6 shows that varying values of P_1 and P_2 brings drastic changes in the antenna radiation pattern. An increasing value of P_1 and decreasing value of P_2

deteriorates the otherwise cardioid radiation pattern. When P_1 is greater than 89 mm and P_2 is smaller than 89 mm, the maximal radiation direction returns back to the axial direction (θ=0°). Hence, to obtain a good cardioid radiation pattern, P_1 should be kept smaller than P_2. The optimal radiation pattern is achieved with P_1 = 58 mm and P_2 = 120 mm.

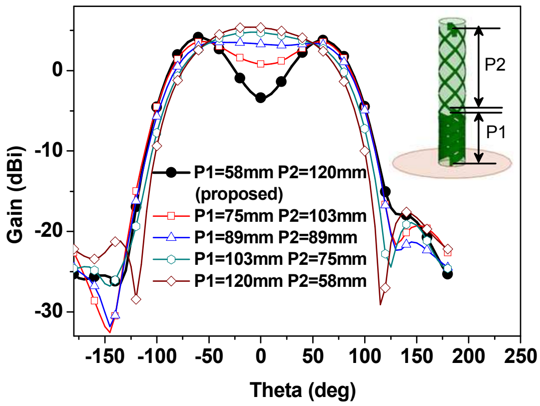


Fig. 6 Simulated LHCP radiation patterns for different values of the helix pitch (P_1 and P_2) at.1.53 GHz.

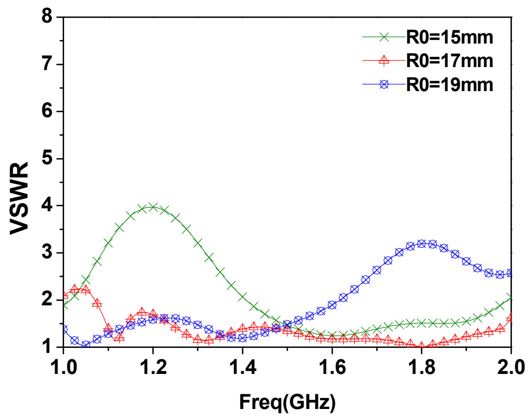


Fig.7 The simulated VSWR for different values of the helix radius (R_0)

The effects of the parameter of the helix radius on the impedance characteristics are also presented. Fig.7 shows the simulated VSWR for the radius of the helix (R_0) varied from 15 to 17 mm. It can be seen that the radius of the helix has a large impact on the working frequency, which the optimal results are obtained for the proposed antenna for R_0=17mm. With the decrease of the radius, the upper resonant frequency shifts towards upper frequency and the impedance matching has been deteriorated at the lower frequency. With the increase of the radius, the lower resonant frequency shifts towards lower frequency and the impedance matching has been deteriorated at the upper frequency.

The proposed QHA with the feed network has been fabricated and the antenna performance has been validated through a comparison of the simulated results with experimental measurements. The measurements have been carried out using an Agilent E8363B Network Analyzer.

The simulated and measured VSWR results are compared in Fig. 8. The two results have got good agreement and the antenna also acquires 12% impedance bandwidth in the measurement. Slight discrepancies present are due to the fabrication errors and SMA connector. It has also been observed that due to the isolation resistances added in the feed network, a good impendence match (VSWR≤2) is also obtained in a wide non-resonant band beyond 1.63 GHz. However, this band is useless because of the very low gain.

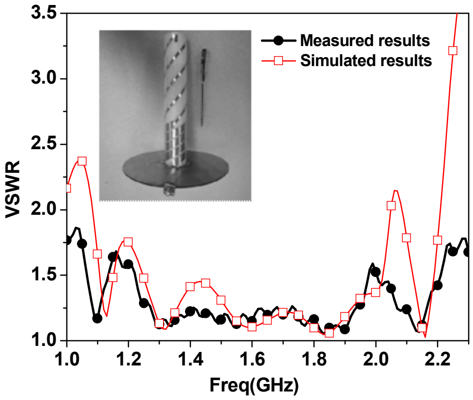
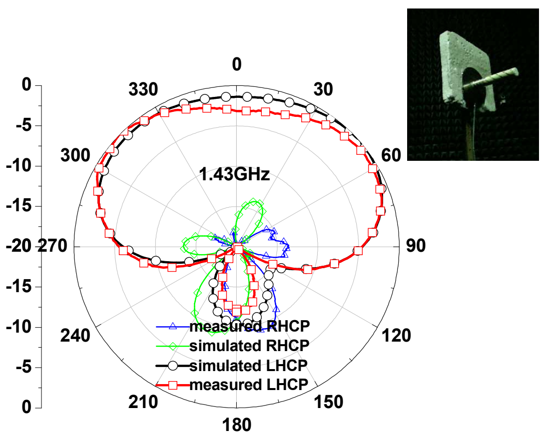
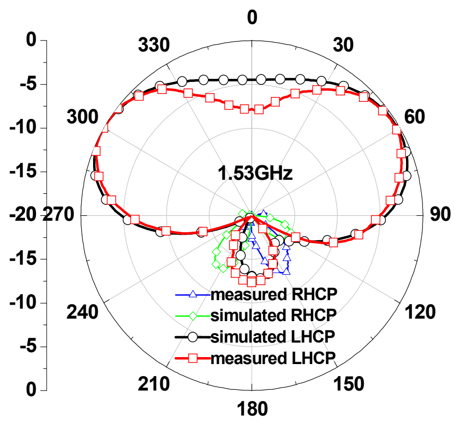


Fig. 8 Simulated and measured VSWR of the proposed quadrifilar helix antenna

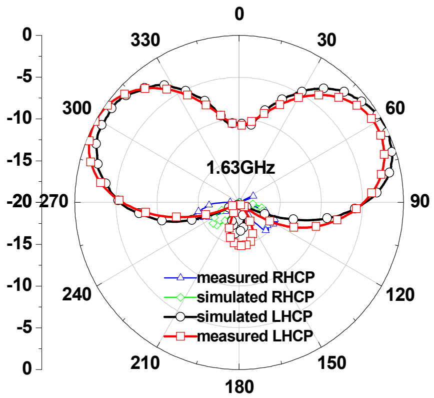
The simulated and measured LHCP and RHCP radiation patterns (co- and cross-polarization) in the XZ plane ($\phi = 0^o$) at 1.43 GHz, 1.53 GHz and 1.63 GHz are plotted in Fig.9. The measured results agree very well with the simulations. The results indicate that the co-polarization is Left Hand Circularly Polarized (LHCP), and the cross-polarization is Right Hand Circularly Polarized (RHCP). Due to the varying pitch of the helix arms, good cardioid radiation patterns are achieved in the required band. The maximum radiation direction is at 30^o of elevation.



(a)



(b)



(c)

Fig. 9 Comparison of simulated and measured radiation patterns in the XZ plane (ϕ = 0°) at (a) 1.43 GHz, (b) 1.53 GHz, (c) 1.63GHz.

The simulated and measured AR and peak gain of the antenna are shown in Fig. 10. The two results have again found a good agreement between them. The antenna has shown a wide AR bandwidth with the AR below 3 dB in the whole frequency range of interest. The antenna has also exhibited good peak gain values ranging from 1.5 dBi to 5 dBi in the frequencies of 1.43 GHz to 1.63 GHz.

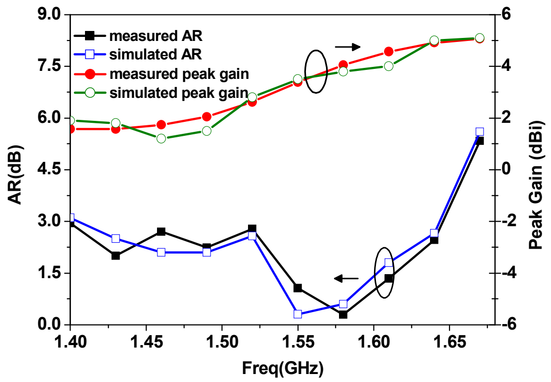


Fig. 10 Comparison of simulated and measured frequency responses of AR and peak gain for the proposed QHA.

The measured results for the AR in Fig. 11 also show that the antenna can efficiently acquire good circular polarization in the angular range of -104^{o} to 60^{o} at 1.43 GHz, -90^{o} to 114^{o} at 1.53 GHz and -87^{o} to 97^{o} at 1.63 GHz, respectively.

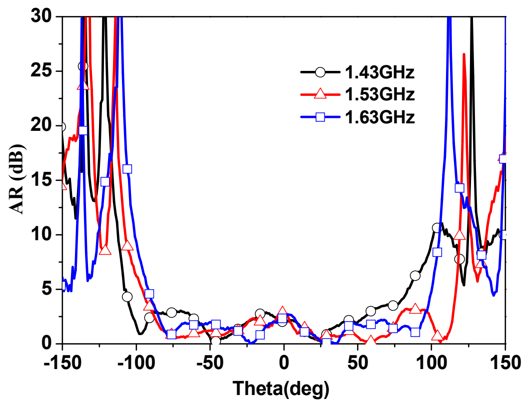


Fig. 11 Measured AR at 1.43 GHz, 1.53 GHz and 1.63 GHz for the proposed QHA.

The simulated and measured results clearly indicate that this compact QHA exhibits a very good performance in terms of impedance bandwidth, radiation pattern and circular polarization.

4. CONCLUSION

A printed quadriflar helix antenna with enhanced bandwidth has been proposed. The performance of the antenna has been analyzed in terms of impedance matching, impedance bandwidth, radiation pattern, axial ratio and peak gain. The simulated results have been verified through measurements and a good agreement has been achieved between the two. The antenna has made use of a novel arrangement of varying widths and pitch of the four axial arms to attain an improved impedance bandwidth and consistent radiation characteristics in terms of cardioid shape and axial ratio. The size of the antenna has been reduced by using four radial open stubs. The results has shown that the proposed antenna exhibits an impedance bandwidth of 12% as compared to 5% offered by the conventional QHA and effectively covers the frequency range of 1.43 GHz to 1.63 GHz. These features make this antenna a good potential candidate for satellite communication devices and navigation system applications.

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