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DESIGN AND ANALYSIS OF QUADRIFILAR HELICAL ANTENNA FOR CUBE-SATS USING C-BAND FREQUENCY RANGE FOR SATELLITE COMMUNICATION

Pinku Ranjan[1], Mihir Patil[2], Amit Bage[3], Brajesh Kumar[2], Sandeep Kumar P.[2]

[1]Department of Computer Science & Engineering, ABV-Indian Institute of Information Technology and Management, Gwalior, Madhya Pradesh–474015, India
[2]Department of Electronics and Communication Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai, Tamil Nadu– 603203, India
[3]Department of Electronics and Communication Engineering, National Institute of Technology, Hamirpur, Himachal Pradesh – 177005, India

Abstract. *Design and analysis of Quadrifilar helical antenna are presented in this paper. The proposed antenna is designed for Cube-Sats in the low earth and medium earth orbits. It is a combination of four helical antennas, each separated by 90°, and excited separately at the feeding point. The antenna is designed for operation at 4.5 GHz with an impedance bandwidth of 11.11 %. Design of the antenna is done in two steps. The first step being the design of a ground plane, which can make the antenna operate at 4.5 GHz. The second step is to analyze the antenna's performance for different helix angles using the best ground plane dimensions obtained in the first step. The gain versus frequency curve has been obtained and the designed antenna is having a gain of more than 4 dB at the resonant frequency of 4.5 GHz.*

Key words: *Quadrifilar Antenna, Satellite Communication, Coaxial Probe feed*

1. INTRODUCTION

Due to a huge building, assembling and launching costs of large satellites, many of the private institutions who are willing to contribute even a bit of chunk to the space exploration department are having a cube and microsatellites as their priority. In modern microwave and millimeter wave communication systems, the use of quadrifilar helical antenna is increasing day by day. This is due to the very large beam-width and high gain provided by the antenna [1-4]. It has become a major pillar for antenna design of satellite communication. Even due to the evolution of electronics and VLSI technology, it is possible for small satellites to perform pretty difficult space exploration task. And thus, there is a need

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Corresponding author: Amit Bage
Department of ECE, SRM Institute of Science and Technology, Kattankulathur, Chennai, India, 603203
(e-mail: bageism@gmail.com)

felt to design small antennas suitable to fit on Cube-Sats. In [5] the deployable helical antennas antenna is presented for Cube-Sats. The deployment mechanism is used for the antenna to take as less space as possible. Thus, it would require a ground plane which is also deployable to reflect out the back lobes. In some cases, this might help but, because it requires a deploying mechanism. It becomes very hard for small satellites to carry out the job with perfection. Even, it could worsen the radiation pattern if not deployed properly and would thus be prone to a lot of errors. The dual-band quadrifilar helix antenna using stepped widths arms has been demonstrated in [6]. In [7] an omnidirectional antenna, sending circularly polarized waves is presented.

C-band is selected for the antenna operations. Because the antenna's dimensions are very small in this band. It becomes very suitable to fit on 1U, 2U, 3U Cube-Sats. Also, very less free space loss is incurred as compared to the X and the Ku-band. Adding to that going towards higher frequencies leads to more atmospheric losses. The S-band is rejected because it would require an antenna of about 14 cm in height. Which, the C band is providing at about half the height. The low earth orbits have much less time for a direct line of sight communication. Thus, they need to be properly oriented when the line of sight communication can be established. As one QFH antenna could serve only 180°, 2 QFH antennae are required to serve the whole 360^o view of the satellite. The antenna helices require a phase difference of 90^o between two helices. In [8] a very cost efficient and very small sized circuit is designed to give phase differenced signal, which could help to lower the burden of generating and sending out phase differenced signal. The basic design of the quadrifilar helical antenna has been demonstrated in [9]. On basis of that, an antenna is proposed and further optimized. The gain enhancement techniques have been presented in [10]. In [11] printed circuits discontinuities have been taken into account. This works as a resonating structure and thus allows only certain frequency to be received by the antenna. In 2011[12], B. Pawan. K et.al. presented circularly polarized (CP) Quadrifilar Helix antenna (QFH)..

This manuscript presents the design and analysis of the quadrifilar helical antenna. It is a combination of four helical antennas, each separated by 90^o, and excited separately at the feeding point. The antenna is operated at 4.5 GHz, with 11.11 % of impedance bandwidth. The antenna works as a circularly polarized antenna in 4.28 – 4,64 GHz. The length of the antenna is 7.5 cm and the bottom cylinder which is below the ground plane is 1 cm. while the length of the feed cylinder (above the ground plane) is 3.6 mm. The numerical simulation analysis has been carried out using Ansys High-Frequency Structure Simulator (version 15). The organization of the manuscript is as follows. In the first section, the quadrifilar helical antenna's geometry is presented. In the second section results and discussion are presented. In the last section final conclusion has been presented.

2. ANTENNA GEOMETRY

The pitch of the helices is 15 cm and has half a turn and thus making a total length of 7.5 cm, which is 1.125λ. The helix radius is 1.15 cm. And the radius of the wire is 0.5 mm. In [13] the maximum antenna characteristics are achieved using an angle of 73°. While in this design the antenna has a helix angle of 81.28°, to attain a better radiation pattern. All the four helices are of the same dimensions. Each of the helices is rotated by 90° with respect to the previous helix. The number of segments per turn is taken as 36, which is the default value. The top part of the antenna is having four cylinders, which have their axis perpendicular to the z-axis. This is to support the antenna structure from the top. These cylinders are called as top cylinders. The total height of these cylinders is 11.5 mm, and a radius of 1 mm. These values are taken such that cylinder can easily accommodate the helix into itself. The top cylinders are made up of copper. And thus, no losses are incurred into the design. Four metallic rods are placed above the ground plane to support the antenna structure from down. These cylinders are called bottom cylinders. All the four rods are having a radius of 0.9 mm and height of 7.5 mm, such that it could easily accommodate the incoming helix. The four helices, the top four supporting cylinders and the bottom four supporting cylinders are united to make one antenna radiating structure. Copper is assigned as the material to the structure. It is assigned a perfect E boundary condition. Then below these cylindrical rods, there is a ground plane which is square shaped. Below the ground plane, there are four copper rods of 0.9 mm. These cylinders are called as feed cylinders. The feed cylinders are made up of copper. The feed cylinder rods are surrounded by a Teflon tube of an inner radius of 0.9 mm and outer radius of 3.018 mm. The radius is taken such that it makes a total impedance of 50 ohms. This makes any wire suitable to attach to the antenna with 50 ohms of impedance. The impedance matching plays a major role for power transmission through the antenna. The height of the feed cylinder is 3.6 mm. The height is selected so that the antenna can be easily mounted on any structure. On the bottom face of these feed cylinders, excitation is given to the ports. Separate excitation is given to all the four ports. The four ports are feed with a 90° of phase shifted signal with respect to the simultaneous port. All the ports are fed in clockwise direction. The dielectric constant of Teflon is 2.1. The inner copper tube is responsible for transferring the electrical signal from the wave-port to the antenna structure. The cross sections are taken as minimum as possible such that they can easily accommodate the incoming helices, to avoid losses. There are four holes subtracted from the cross-section of the ground plane of radius 0.9 mm, so as to allow the passing of the electric signals through the ground plane. Fig. 1 shows the side view of the proposed antenna. Fig. 2 shows only the bottom view of the ground plane. Fig. 3 shows the cross-sectional view of the whole antenna. Fig. 4 shows the direction of alignment for the feeds of the 4 ports of the antenna.

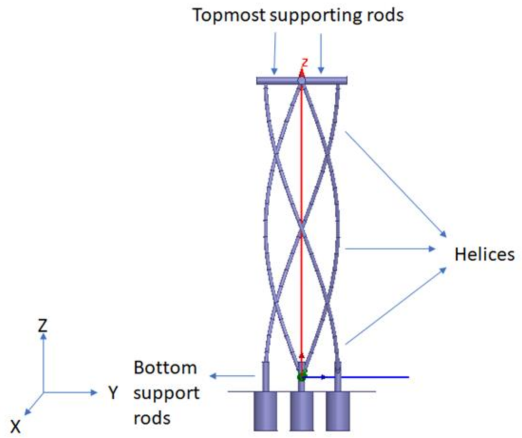

Fig. 1 Side view of QFH antenna

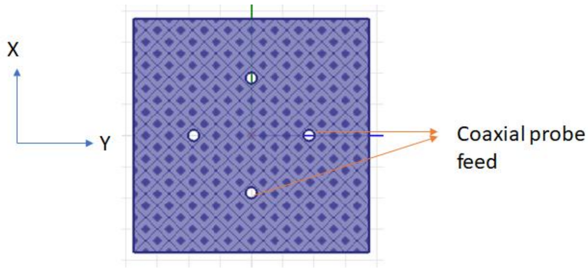

Fig. 2 Bottom view of the ground plane.

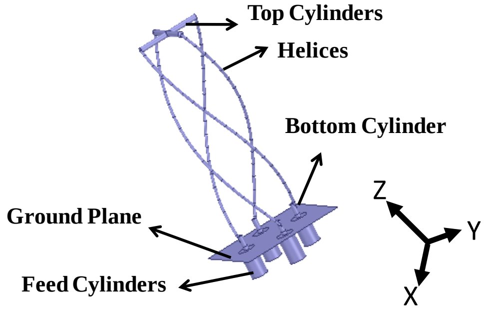

Fig. 3 Cross-section view of QFH antenna

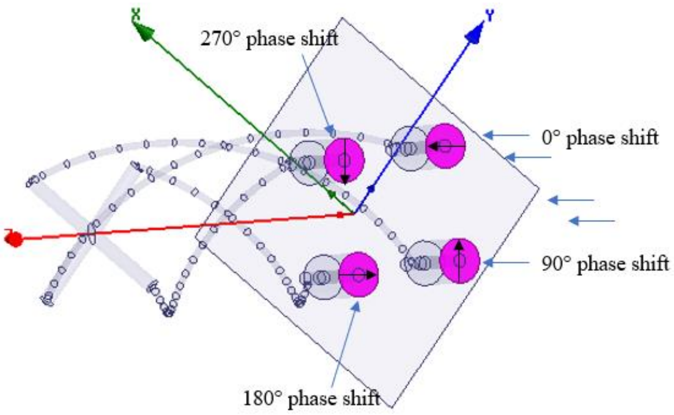

Fig. 4 Feed alignment of the 4 ports.

3. Result and Discussion

The antenna's input characteristics have been analyzed for the desired operating frequency. The ground plane dimension has been analyzed for the lowest reflection coefficient. From the simulations, as shown in Fig. 5, it is found that the reflection coefficient is least for the ground plane of length 3.75 cm. It is half of the total height of the antenna. The antenna is simulated in HFSS with the following design constraints. The maximum no. of passes taken is 6 and the maximum delta S is 0.02.The step size is kept as 0.01 so as to depict the most accurate antenna parameters.

The minimum length of the ground plane for which the simulation is evaluated is 3 cm. below 3 cm the ground plane would not be able to support the helix structure. The lowest value of the reflection coefficient is -12 dB at 3 cm of the ground plane, which then further decreases until the length of 3.75 cm. The lowest value at 3.75 cm ground plane is about -28.8 dB. But after that, the value increases until 5 cm. The value goes up to -16.7 dB and then further decreases. The value at 6 cm ground plane is about -21.4 dB. But, after 6 cm of ground plane length, the resonating frequency starts to move towards 4.4 GHz. Then further at 7, 8, 9, 10 cm the lowest reflection coefficient stays in between -19.5 and -20.5 dB but resonating at 4.4 GHz.

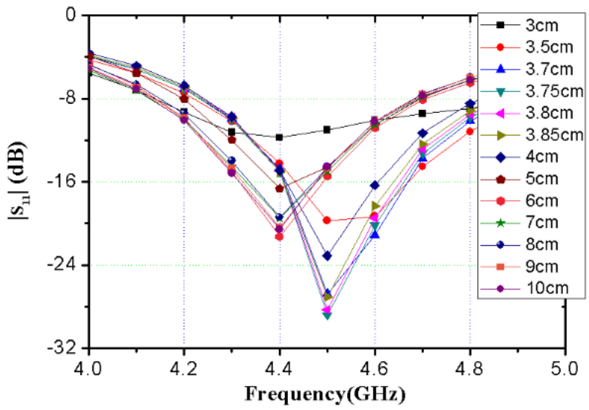

Fig. 5 Plot for reflection coefficient against frequency for the different lengths of the ground plane.

After this, by keeping the length of the ground plane as 3.75 cm, further optimization is tried by calibrating its results against different helix angles.

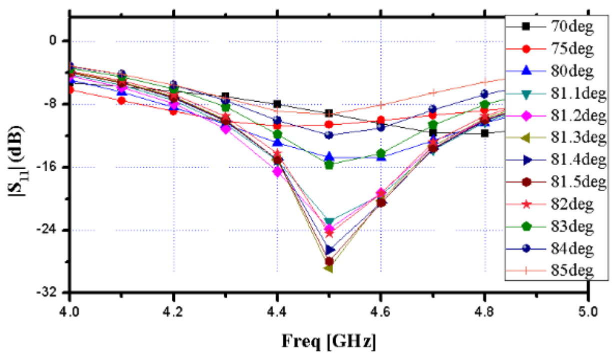

Fig. 6 Reflection coefficients for different helix angle with the constant ground plane of 3.75 cm.

Thus, from Fig. 6, it can be inferred that the antenna at the helix angle of 70º resonates at the frequency of 4.8 GHz. And at 75º the antenna resonates at the frequency of 4.4 GHz. But, after that from 80º until 85º, the resonating frequency stays at 4.5 GHz. The antenna performs best at the helix angle of 81.3º, with minimum reflection coefficient of -28.8041. The antenna helix angles are evaluated until 85º. Because, above 85º it becomes impossible to mount the coaxial feed as they intersect with other feeds. The final $|S_{11}|$ versus frequency curve has been extracted and it is shown in Fig. 7. From Fig. 7, it can be inferred that it has a resonant frequency of 4.5 GHz with 11.11 % impedance bandwidth.

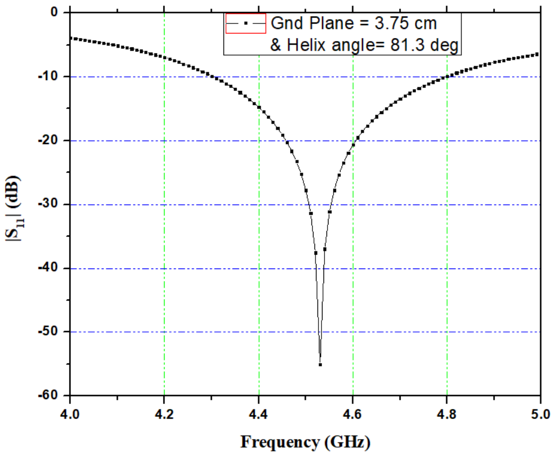

Fig. 7 Reflection coefficient for the ground plane of dimension 3.75 cm and helix angle of 81.3º.

The far-field analysis has been done for the proposed antenna at their resonant frequency (4.5 GHz). The radiation pattern for xz-plane and xy-plane has been shown in Fig. 8 and Fig. 9 respectively. The difference between co and cross-polarized is more than 15 dB. The E-plane view has the maximum value of E field radiation in that cross-sectional plane, which is shown in Fig. 8. Similarly, H-plane has the maximum value of H field radiation in that cross-sectional plane, which is shown in Fig. 9. Thus, the antenna assures very promising radiation pattern.

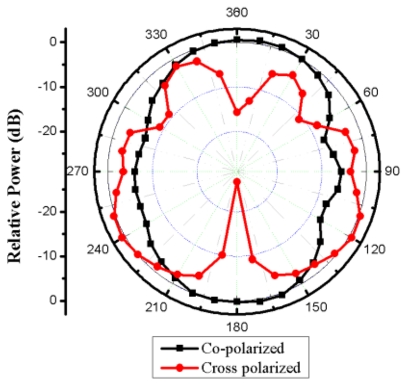

Fig. 8 Radiation pattern for the optimum antenna dimension for xz-plane (E-plane).

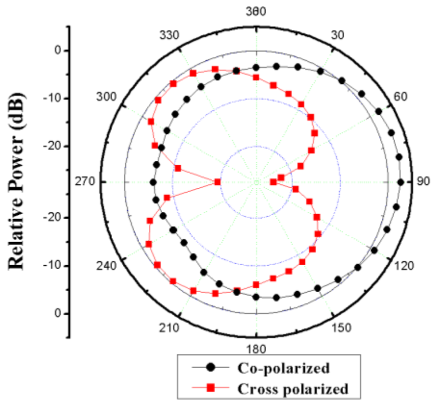

Fig. 9 Radiation pattern for optimum antenna dimension for xy-plane (H-plane).

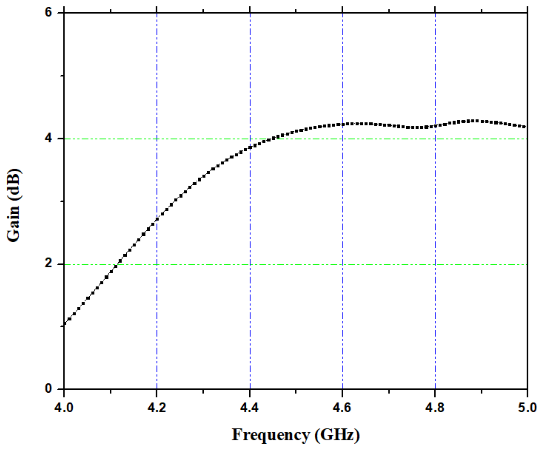

Fig. 10 Gain (dB) vs. Frequency (GHz) for Phi=80º and Theta=110º.

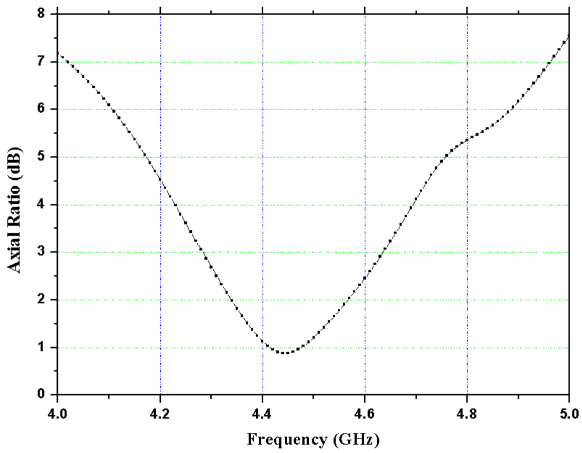

Fig. 11 Axial Ratio of the antenna.

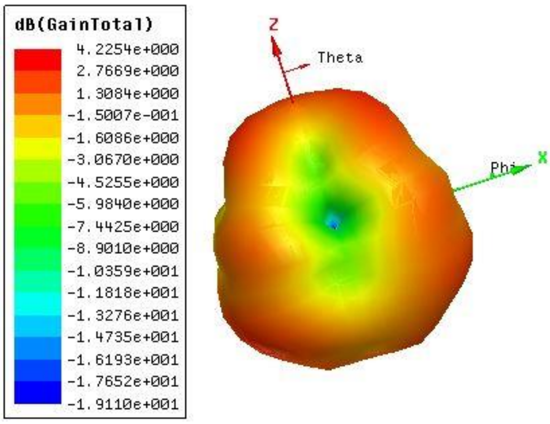

Fig. 12 3-D Radiation pattern of the proposed antenna.

The gain versus frequency curve has been analyzed for the proposed antenna and it is shown in Fig. 10. Thus, it can be inferred that the antenna gives a maximum gain of 4.2254 dB at Phi=80º and Theta=110º at resonant frequency 4.5 GHz. The antenna gain is constant throughout the operating frequency band. In Fig. 11, the axial ratio of the antenna is shown. The antenna works as circular polarized antenna from 4.28-4.64 GHz.In Fig. 12, 3-D radiation pattern of the proposed antenna is shown, in that the maximum gain is 4.22 dBi. The radiation efficiency of the antenna is 79 % is obtained at 4.5 GHz.

The proposed antenna is compared with other quadrifilar helical antennas in Table-1. It can be inferred from the data that the antenna has a very high bandwidth of 500 MHz, as compared to other designs. Also, the proposed antenna has a moderate gain as compared to other designs presented in Table-1. Linearity in gain over the bandwidth proves very helpful. Thus, the novelty in this design is the impedance bandwidth and gain of the antenna. It supports 500 MHz of bandwidth, with a linear gain of 4.22 dB. This is the major advantage of the design. The design is a result of intense optimization in the antenna's height, ground plane size and the diameter of the cylindrical rod. All this is possible with the very simple design of the antenna using the metallic rods.

Table 1 comparison of the proposed antenna with other antenna designs**.**

Ref.	Resonating frequency (GHz)	Bandwidth (MHz)	Gain (dB)	Length of the antenna (cm)	% impedance
[1]	2.51	20	2.32	4183	0.0079
[11]	0.86	95	6.4	16.1	0.110
[12]	4.2	500	3.5	4.6	0.1190
[13]	1.53	200	6.2	19.5	0.1307
Our Work	4.5	500	4.22	7.5	0.1111

4. CONCLUSION

The Quadrifilar helical antenna has been designed at 4.53 GHz resonant frequency with 11.11% impedance bandwidth (4.3 GHz to 4.8 GHz). The optimized antenna dimension has a total height of 7.5 cm with half a turn, and it performs the best at 3.75 cm x 3.75 cm of the ground plane with a helix angle of 81.3º. It gives a gain of about 4.2 dB at resonant frequency 4.5 GHz at Phi=80º and Theta=110º. This paper shows that the QFH antenna is a very good candidate for omnidirectional on Cube-Sats application with a good gain.

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