Design of a Self-Phased Quadrifilar Helix Antenna for Satellite Communication

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Abstract—**The objective of this study is the design and implementation of a Quadrifilar Helix Antenna (QHA) for telemetry, tracking and control of a Low Earth Orbit (LEO) satellite. Because of its cardioid-shaped circularly polarized beam, QHA can satisfy requirements of satellite communications completely. In this paper, a variation of QHA referred to as "self-phased QHA" with a single feeding circuit, has been proposed to reduce implementation complexity. The designed antenna has been analyzed and the experimental results show that the radiation pattern provides good wide-beam in the desired frequency while the antenna's bandwidth is around 200MHz when VSWR is less than 2.**

Keywords-quadrifilar helix antenna; circular polarization; satellite communication

I. INTRODUCTION

There are many applications for the Quadrifilar Helix Antenna (QHA), because of its cardioid-shaped circularly polarized beam [1], such as global positioning systems [2, 3], mobile handsets and terminals [4-6] and space applications [7, 8] such as satellite payloads [9]. In the literature, there are several designs for dual-band QHAs [10-15]. The aim of this study is to design and implement a QHA for telemetry, tracking and control (TT&C) subsystem, which can be used as both receiver and transmitter. The designed antenna has a simple feeding circuit that makes the implementation easier. TT&C subsystem is one of the major parts of a Low Earth Orbit (LEO) satellite which is responsible for the communication between the satellite and the ground. The link between ground station and TT&C must always be fully operational. A connection loss would result in control loss of the satellite. For this reason the pattern of the antenna is a vital issue. In a LEO satellite with attitude determination and control subsystem, TT&C antenna radiation should be from both sides of the satellite because in both nadir and anti-nadir pointing situation the communication link should be stable. The desired radiation pattern can be achieved by using a single antenna or a combination of multiple antennas. Here, the antenna pattern has been achieved by using two separate S-Band self-phased QHAs described below.

II. ANTENNA DESIGN AND IMPLEMENTATION

A. *Self-Phased QHA*

The QHA was first introduced in [1] and further designed in [16, 17]. In order to reduce complexity of the feeding circuit, a variation of QHA referred to as "self-phased QHA" has been proposed. The self-phased QHA is composed of two bifilar loops, fed in parallel, designed with different resonant lengths, resulting 90° current phase shift with respect to one another. Optimizing the dimension of the bifilars, will improve the performance of the antenna. Since the input impedance of R+jR for longer loop and R-jR of shorter one is achieved, input impedance of R is obtained for the antenna when the two elements are excited by a single source [18]. We utilize the self-phased QHA in S-Band as both transmitter and receiver antenna for a LEO satellite.

B. *Simulation of The Designed Antenna*

Firstly, a self-phased QHA has been designed and simulated in S-Band frequency by CST software. Figure 1 shows the simulated antenna. The geometrical configuration of a helix consists usually of N turns, diameter D and spacing S between each turn. The total length of the antenna is L=NS, while the total length of the wire is $L_n=NL_0$, where L_0 is the length of the wire between each turn and C=πD is the circumference of the helix. Another important parameter is the pitch angle α which is the angle formed by a line tangent to the helix wire and a plane perpendicular to the helix axis. The pitch angle is defined by [19]:

$$\alpha=\tan^{-1}\left(\frac{S}{\pi D}\right) \quad (1)$$

Based on the proposed design, dimensions of the antenna are computed as follows. The larger loop is specified by: N=0.25, D = 24.2 mm, S=0.36λ, L=NS=0.25*0.36λ=0.09λ, F=2.25GHz→λ=0.133m and α = 32.2°. The smaller one is characterized as follows: N=0.25, D = 22.9 mm, S=0.34λ, L=NS=0.25*0.36λ=0.085λ, F=2.25GHz→ λ=0.133m and α = 32.16°. A semi-rigid coaxial cable can be used as balun and base of the antenna. The length of the cable used as balun is λ/4 of the minimum operating frequency. As such, it covers the highest frequency as well. This structure is a simple 1:1 current balun which causes 180° phase shift in the antenna's feed.

Fig. 1. Simulated antenna in CST.

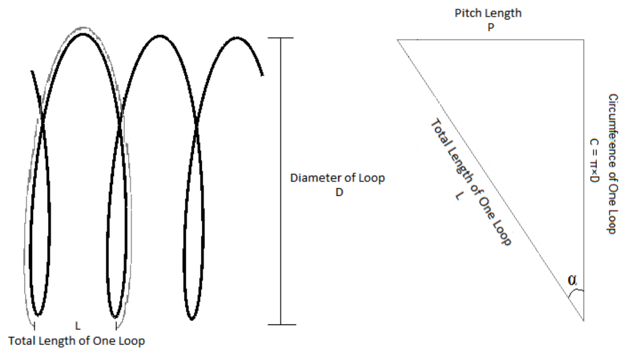

Fig. 2. Helix geometry.

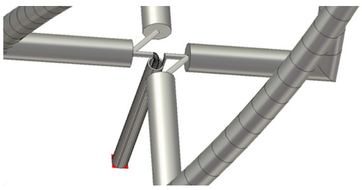

Fig. 3. Feeding Circuit.

We assume the following case study to use the designed antenna as TT&C antenna of a LEO satellite, in which, the ground station communicates with a the satellite in 500 km orbit beginning from 10° elevation angles. Antenna pattern should be measured in a corresponding boresight angle which is computed by the following formula:

$$\text{boresight}=2\sin^{-1}\left(\frac{R_e}{R_e+h}\cos e\right) \qquad (2)$$

where R_e is Earth radius, h denotes the orbit of the satellite, and e is the elevation angle. Based on above assumptions, boresight angle is calculated as 120 which corresponds to θ=60°. As shown in Figure 4 antenna gain is always higher than 1.5dBi. Thickness of the wire used to simulate the antenna, will put the VSWR of the antenna in its proper range, making the antenna applicable in both uplink and downlink frequencies. VSWR is shown in Figure 5.

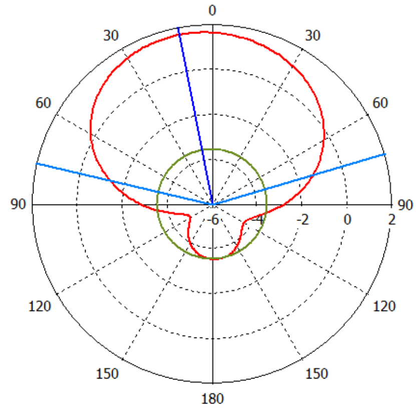

Fig. 4. Simulated Antenna Pattern.

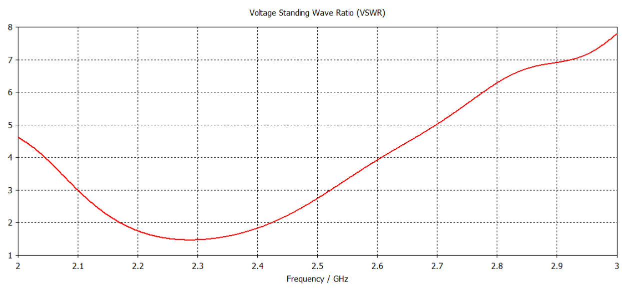

Fig. 5. VSWR of the Simulated Antenna.

C. Implementation and Using as TT&C Antenna

Based on antenna simulation described in the previous session, a self-phased antenna has been implemented in laboratory (Figure 6). Figure 7 illustrate antenna pattern and VSWR for the implemented antenna which is measured in a far field antenna chamber. The measurement results are in close agreement with simulation. As mentioned earlier, the implemented antenna has been designed to be used as transmitter and receiver antenna individually in TT&C subsystem. In order to make this antenna applicable to this usage, it is required to position two separate antennas, each in one side of the satellite (in nadir and anti-nadir side) in order to have acceptable radiation coverage. Because of the size of the satellite, shown in Figure 9 we run the simulation using the MLFMM solver method in CST software. The result of impedance simulation within frequency range is shown in Figure 10. For a satellite with attitude determination and control subsystem, in nadir pointing situation, antenna radiation should be calculated in θ=120°. For this θ the antenna pattern is shown in Figure 10. In anti-nadir satellite pointing, antenna radiation should be calculated in θ=60° and the antenna pattern is shown in Figure 11. Since there is not considerable difference between the simulated antenna and the one built in laboratory, it can be induced that in a similar way the simulation of the antennas and a real situation would produce the similar results with negligible error. Based on the numerical results, the antenna designed in this paper, can be used as TT&C antenna.

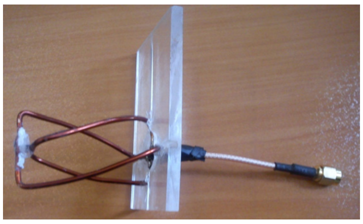

Fig. 6. Implemented Antenna.

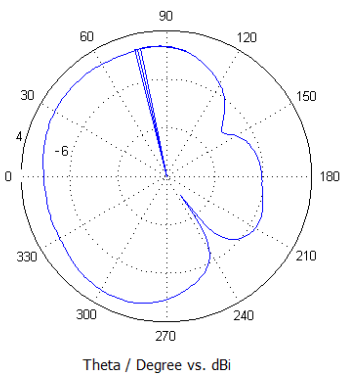

Fig. 7. Implemented Antenna Pattern (phi=0).

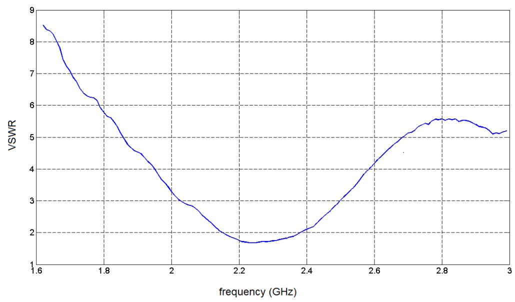

Fig. 8. VSWR of the Implemented Antenna.

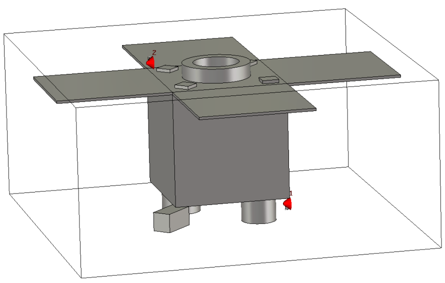

Fig. 9. Satellite model with two antennas.

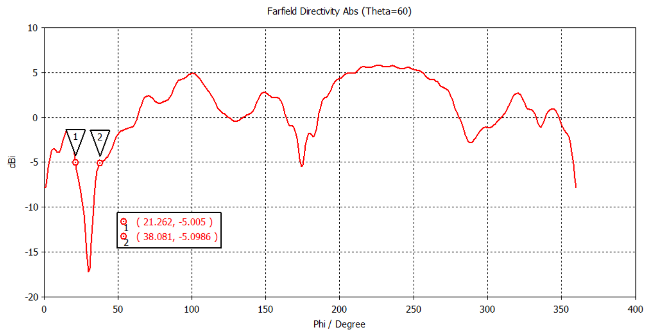

Fig. 10. Radiation pattern in nadir.

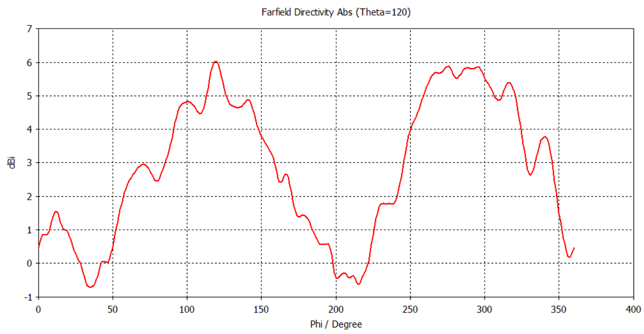

Fig. 11. Radiation pattern in zenith.

III. CONCLUSION

In this paper, a comparison of the VSWR and radiation pattern properties of a self-phased quadrifilar helix antenna is presented. The simulated and measured results show that the bandwidth of the antenna is around 200MHz when VSWR ≤ 2. Using single feeding circuit reduces the complexity of fabrication and the weight of the antenna. As reliability is a main concern in satellite communication, lower complexity leads to reducing the number of failures of the system.

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