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DESIGN OF AN INNOVATIVE HELICAL ANTENNA FOR AERIAL PLATFORMS TO ENABLE JAM RESISTANT RECEPTION OF GNSS SIGNALS

[1]Inamullah, [2]Talha Farooq Hashmi, [3]Irfan Majid
[1 2 3]Department of Aeronautics and Astronautics
Institute of space technology, Islamabad
Email: inam8754@gmail.com

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ABSTRACT

This paper describes the design of a helical antenna at GPS upper L band frequency. Helical antennas are widely used in airborne and space borne applications to receive GNSS signals. One major concern in reception of GNSS signals is their susceptibility to jamming signals. To address this problem a novel antenna design is proposed in this paper. The proposed design provides lower side lobe levels than conventional helical antennas, without compromising efficiency of the antenna. The lower side lobe levels are the key feature in making the antenna less susceptible to jamming signals. Moreover, despite being smaller than classically designed helical antennas this design can handle relatively more power. To achieve these results the key parameters of helical antennas, namely, dimensions and shape of helix antenna i.e. height, radius, number of turns, thickness as well as pitch angle were optimized. In addition, the ground effect was used to supplement the desired results. Detailed simulation results using CST Microwave Studio software have been computed. These results are then compared with the results for standard helical antenna to validate and verify the advantage of using the proposed design.

Keywords: Helical antenna, polarization, GNSS, jamming resistant, side lobes level

1 INTRODUCTION

The signal strength of Global positioning system (GPS) satellite on reaching the earth is of the order of -130 dBs, consequently these signals are highly susceptible to intentional or unintentional interference resulting in jamming spoofing and possible spoofing [1]. All systems that use GPS for positioning or timing synchronization are rendered inoperable by such jamming [2]. Various types of Antennas have been designed for receiving the GPS signals.

At this stage it will be pertinent to review the basic characteristics of GPS antennas. The frequency range is from 1.1 GHz to 1.65 GHz. For GNSS reception applications the antenna should have maximum coverage of its upper hemisphere to receive maximum number of GNSS constellation satellites and polarization used is right hand circular polarization (RHCP). Airborne antennas entail further requirements. Namely, size, weight, ruggedness and the mounting plates should incorporate safety from possible lightning strike.

The properties of GPS antennas that effect functioning and performance are gain, pattern, frequency range, polarization, phase center variation, suppression of multi paths, thus ensuring better sensitivity of the receiver [3]. Its placement should ascertain that there is no interference from other transmitting antennas in relatively close vicinity i.e. aircraft airframe. The prime antenna position must not be "dappled" by any assembly or by other antennas [4][5]. GPS receiver antennas include monopole, dipole, quadrifilar helix, slot and microstrip patch antennas. The most commonly used GPS receiver antenna in airborne application are microstrip and helical antenna. Both of these have pros and cons, keeping these pros and cons in mind selection of the antenna for subject purpose was made [6]. Microstrip type antennas are used due to their ease of fabrication and low cost. Their low profile makes them valuable in many applications of satellite. But they are best suited for such applications where size is a paramount concern such as in mobile phones where very small size is required and its positional orientations can degrade performance. Its performance is greatly dependent on the size of ground plane. Helical antennas are known for their simplicity and good axial ratio. On the basis of these parameters they are divided into two modes one is known as axial mode while the other is called normal mode.

Helical antennas shown in Figure 1 constitute a wire curled from a cylinder-shape usually made from copper, brass or steel. Signal is fed using a coaxial cable at the base end [7]. The helical antenna has some distinct desirable properties like inherent circular polarization, matured construction techniques, and high-power handling capability, wide bandwidth and greater directivity [8]. In airborne applications helical antenna is the primary choice for receiving GNSS signals [9][10]

In more recent times interference and jamming has become a major problem in reception of GPS signals. Therefore, significant research effort has been focused on design of GPS antenna with high level of immunity to jamming signals [11]. To avoid jamming first step is to detect jamming signals. Psiaki et al propose detecting jamming signals by the method of moving single antenna and the method of double antenna. In double antenna method jamming of signals are sensed from differences between the two antennas' carrier phases while in single moving antenna jamming can be determined from the coupled evidence of navigation signals received in different times *[4]*. Montgomery et al address the issue by measuring difference between expected and observed results of the carrier phase difference of double antennas [12]. Daneshmand et al recommend anti jamming of GPS signal by using antenna arrays and adjusting weight of the received signal in each array channel [13]. After direction of jamming signals has been determined the gain is adjusted so that it is minimized in the direction of jamming. However, the techniques used for determining the jamming signals are not 100% accurate.

This paper describes research carried out to develop a relatively low-cost solution to GPS jamming faced by aerial platforms. The design is innovative in the sense that it offers a simple solution to reduce the level of received jamming signals without any associated complex signal processing. The Achilles Heel of airborne GPS antennas, as regards to ground based jammers, is their side lobes. The planned design provides higher gain and lower side lobe levels than conventional helical antennas. The lower side lobe levels are the key feature in making the antenna less susceptible to jamming signals without compromising antenna gain thus maintaining good "signal to jammer"ratio.

1.1 Research Problem

Axial-mode helical antennas are considered as the most appropriate antennas for GPS as their large volume permits sufficient coverage of the complete skyline. It has typical gain of 5 to 7 dB at zenith while -3 to -6 at horizon. Helical antennas are widely used in airborne and space borne applications to receive GNSS signals. One major concern in reception of GNSS signals is their susceptibility to jamming signals. The design parameters of helical antennas have matured over the years and closed form expressions are readily available. Furthermore, relationship of these design parameters to side lobe levels has not been investigated [14]. Thus, an empirical or experimental approach has been adopted. The achieved results have been tabulated here to serve as a reference for any future researcher interested in finding dependence of helical antenna side lobe levels on basic design parameters [9].

1.2 Research objective

The advantages of the research conducted on Helical antenna indicates lower side lobe levels making it more resistant to antenna jamming rather than conventional antenna that is not preferable to be used. Secondly, the small size of the helical antenna is more suitable to be used in the aerial platforms. Furthermore, Baseline work is carried out to conduct parametric analysis of design parameters and side lobe levels.

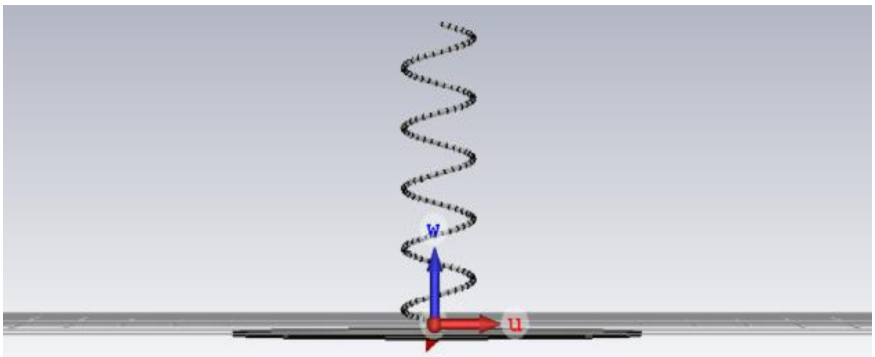

Figure 1: Basic geometry of helical antenna

2 RESEARCH METHOD

2.1 Simulation Model

The designed helical antennas were simulated using industry standard CST Microwave Studio Software. The simulations were used to calculate the far field characteristics, S11 parameters, reflected power of the antenna (VSWR), gain, efficiencies and side lobe levels of the desired antenna. In this paper the basic geometry of axial mode helical antenna has been considered at 1.5 GHz. First a standard axial mode helical antenna was designed with parameters as shown in Table 1, to serve as a reference antenna. The axial mode helical antenna designed from the parameter given in Table 2 is shown in Figure 2.

Table 1: DETAILED DIMENSIONS OF HELICAL ANTENNA

Frequency	**F**	**1.5GHz**
Wavelength	λ= c/F	200mm
Number of turns	N	5
Height	H = N*S	250mm
Diameter of helix	D	68mm
Pitch angle	α= tan-1(S/C)	13degree
Thickness of helix	d	4mm
Input impedance	Z	150ohm

2.2 Specification

For our research axial mode helical antenna has been selected as the preferred option. Typical structure of axial mode helical antenna is shown in Figure 1. For GPS type application the best choice is axial mode which is achieved with following parameters: -

Circumference of antenna C≈ λ
Height of the antenna H=N x S
Pitch angle α= tan-1(S/C), usually 12 < α < 14 degrees Ground plane diameter approximately = λ
λ= wavelength of the antenna
N= number of turns
S= spacing between two consecutive turns

After designing the standard reference antenna and verifying the results as canonical cases, numerous simulations were carried out to develop a database for sensitivity analysis. The effects of different variations in results were analyzed. As elucidated in the introduction, focus here is to design an antenna least prone to jamming. Suppressing the side lobes will achieve the objective to a great extent, however, if gain of the main lobe can also be maintained or increased it will give a better "signal to jammer ratio" and aid in better signal processing of received signals.

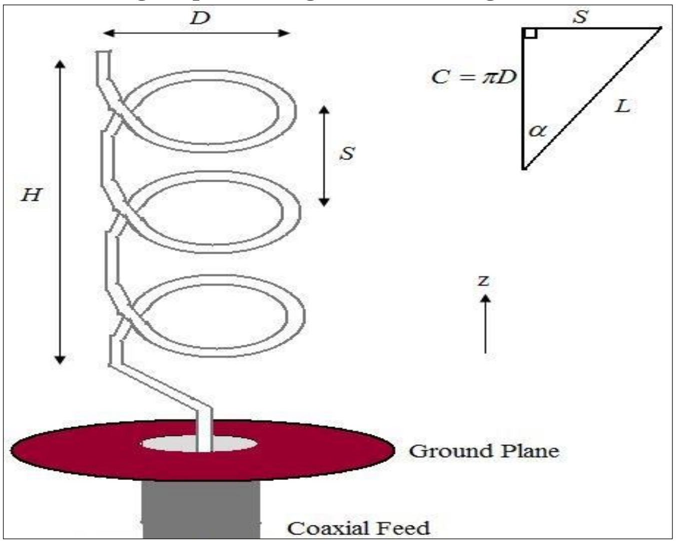

Figure 2: Basic geometry of helical antenna with labeled parameters

3 Results and findings

3.1 Simulation results achieved by iterative sweep of design parameters

Different iterations were performed on the standard helical antenna parameters to achieve the desired results. The strategy adopted was to vary one parameter at a time and keep the rest of the parameters of standard antenna constant, subsequently extracting and storing results from each simulation.

From **Table 2** it is deduced that as we increase height of the antenna the side lobes also increase, while gain decreases. On the other hand, if we decrease length of the antenna up to 100mm the side lobes decrease, however, there is no significant effect on gain of the antenna. When the height is decreased beyond 100mm then all the parameters of antenna start to degrade.

From **Table 3** it is concluded that there is no significant effect of pitch angle on gain and side and VSWR while side lobes results got better nevertheless after decreasing to more than 10 radian it starts to vary abruptly.

From **Table 4** it is inferred that by decreasing circumference of the helix, gain of the antenna increase but there is noteworthy reduction in side lobes level up to 62mm but by decreasing more and more it start decreasing side lobes up to 2 dB

From **Table 5** it can be seen that by increasing the diameter of the ground plane, directivity of standard antenna is increases while side lobes decrease.

Additionally, some experimentation was carried out to see the effects of variation in thickness of the helix, thickness of the ground plane, number of turns and position of the ground plane. Due to variation in thickness of the ground plane the results of the antenna deteriorated. But on increasing the thickness of the helix up to 6mm, results got better nevertheless after decreasing to more than 6.2mm it starts to vary abruptly and same is observed in the case for position of the ground plane. These dependencies can be investigated in future research.

Table 2: Variation of parameters W.R.T height of the antenna

Height (mm)	Directivity (dB)	Beamwidth (degree)	VSWR	Side lobes (dB)
325	10.5	46.7°	1.67	-9.8
300	10.6	46.9°	1.69	-10
275	10.9	47°	1.72	-10.9
250	11.2	47°	1.61	-12.3
225	11.2	47.7°	1.53	-13.3
200	11.2	48.7°	1.68	-13.5
175	11.2	49.5°	1.91	-14.0
150	11.2	50.2°	1.93	-14.3
125	11.1	51.3°	1.64	-14.4
100	10.5	54.2°	1.18	-13.6
75	9.9	61.2°	2.11	-13.0

Table 3: Variation of parameters W.R.T pitch angle of the antenna

Pitch angle (degree)	Directivity (dB)	Beamwidth (degree)	VSWR	Side lobes (dB)
16	11.1	47.2°	1.65	-12.0
15	11.1	47.5°	1.62	-12.6
14	11.2	46.9°	1.66	-11.8
13	11.2	47°	1.61	-12.3
12	11.2	46.9°	1.58	-12.1
11	11.2	46.8°	1.62	-12.8
10	11.2	46.9°	1.61	-13.0
9	10.9	46.8°	4.20	-11.8

Table 4: Variation of parameters W.R.T circumference of the antenna

Circumference (mm)	Directivity (dB)	Beamwidth (degree)	VSWR	Side lobes (dB)
70	11.5	45.8°	1.68	-12.1
68	11.2	47°	1.61	-12.3
66	11.0	48.3°	1.57	-12.5
64	10.8	49.5°	1.55	-12.7
62	10.4	50.6°	1.48	-11.7
58	10.7	50.8°	1.8	-13.0
54	10.8	52°	1.9	-13.3
50	10.1	55°	2.1	-12.2

Table 5: Variation of parameters W.R.T diameter of ground plane of the antenna

Diameter (mm)	Directivity (dB)	Beamwidth (degree)	VSWR	Side lobes (dB)
0				
50	4	137°	2.2	-3.8
100	8.3	50.9°	1.15	-4.1
150	9.9	50.5°	1.39	-8.3
200	11.2	47°	1.61	-12.3
250	11.5	45.7°	1.5	-13.6
300	12.1	43.3°	1.55	-14.2
350	12	43.8°	1.4	-14.8
400	11.6	43.4°	2.5	-11.7

3.2 Comparison of Results

A number of experiments for the proposed helical antenna were conducted and the effects of each parameter variation were analyzed. After reviewing the results from all possible parameter variations, the best fit for maximum gain and minimum side lobes level was selected. Far-field patterns, gain, directivity, 3D characteristics, VSWR characteristics of reference and proposed antenna have been calculated for a number of cases. A helical antenna with parameters listed in Table V was found to have maximum gain and minimum side lobes level characteristics.

Table 6: DETAILED DIMENSIONS OF PROPOSED HELICAL ANTENNA

Frequency	**F**	**1.5GHz**
Wavelength	λ= c/F	200mm
Number of turns	N	5
Height	H	110mm
Diameter of helix	D	52mm
Pitch angle	α	10degree
Thickness of helix	d	6mm
Input impedance	Z	140ohm

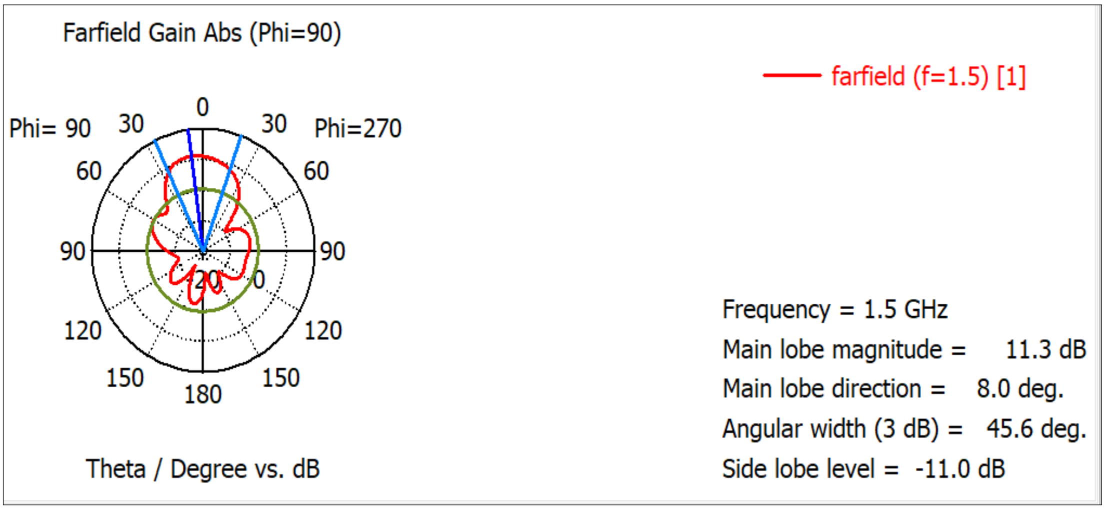

Figure 3: Gain of reference helical antenna

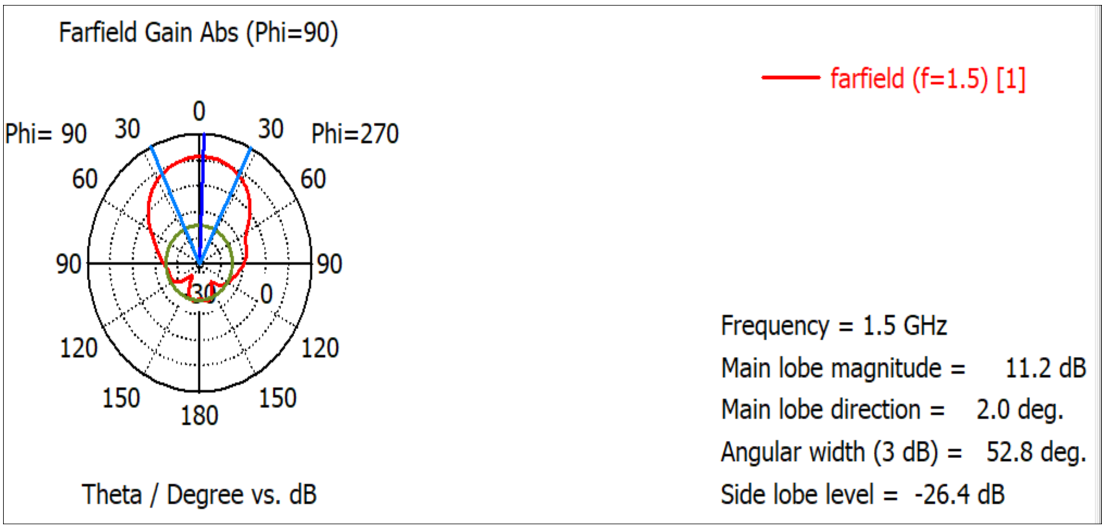

Figure 4: Gain of proposed helical antenna

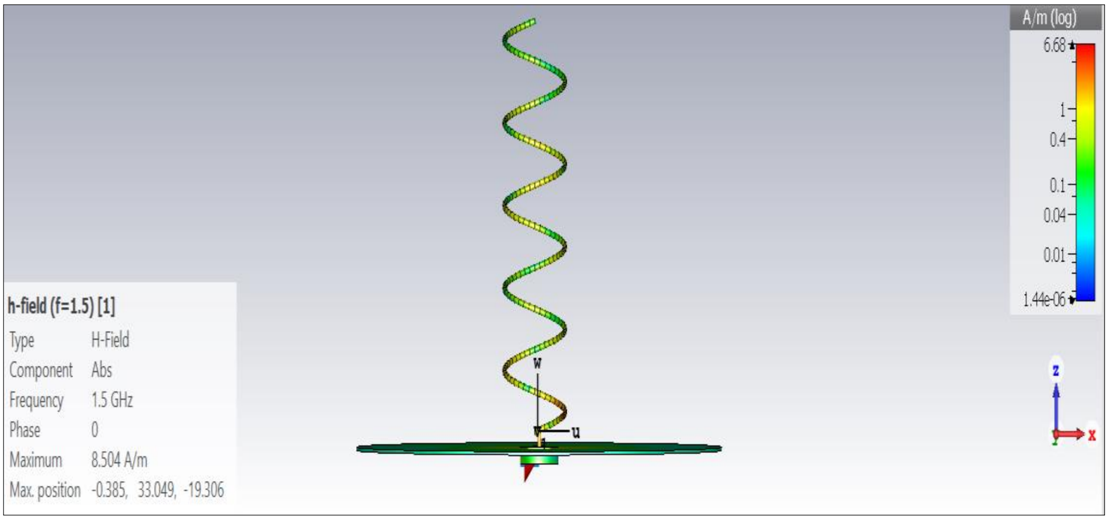

Figure 5: Magnetic field plot of reference helical antenna

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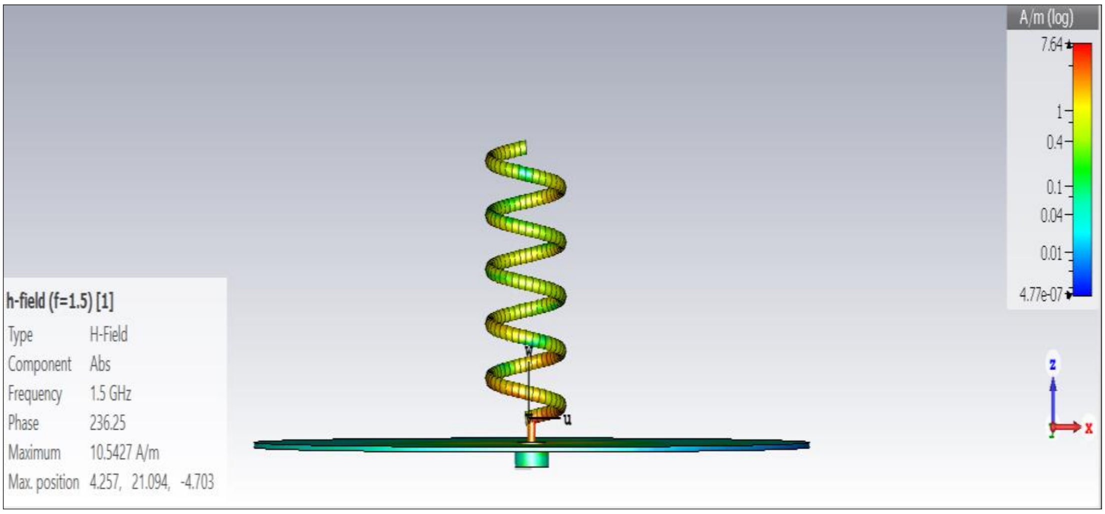

Figure 6: Magnetic field plot of proposed helical antenna

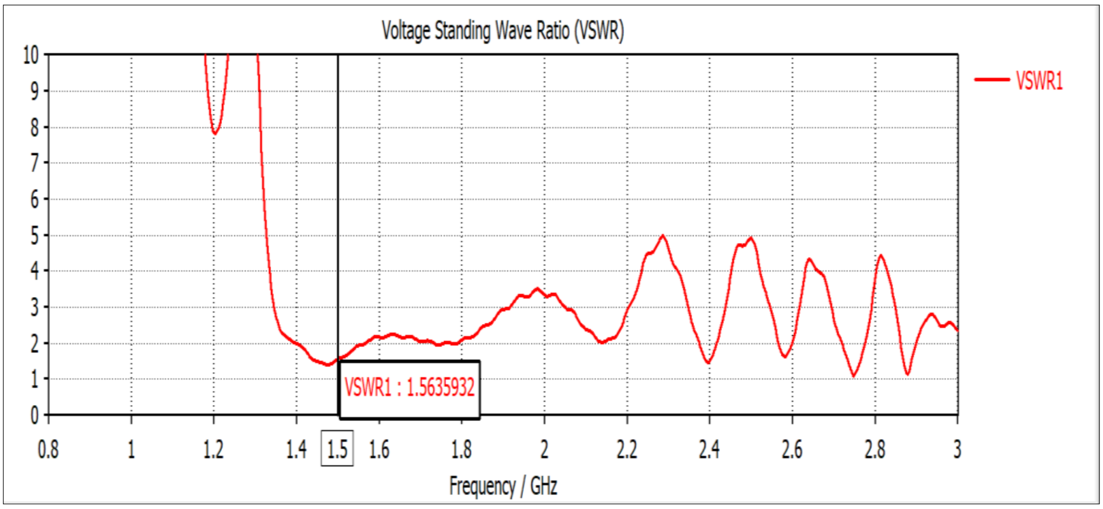

Figure 7: VSWR results of reference helical antenna

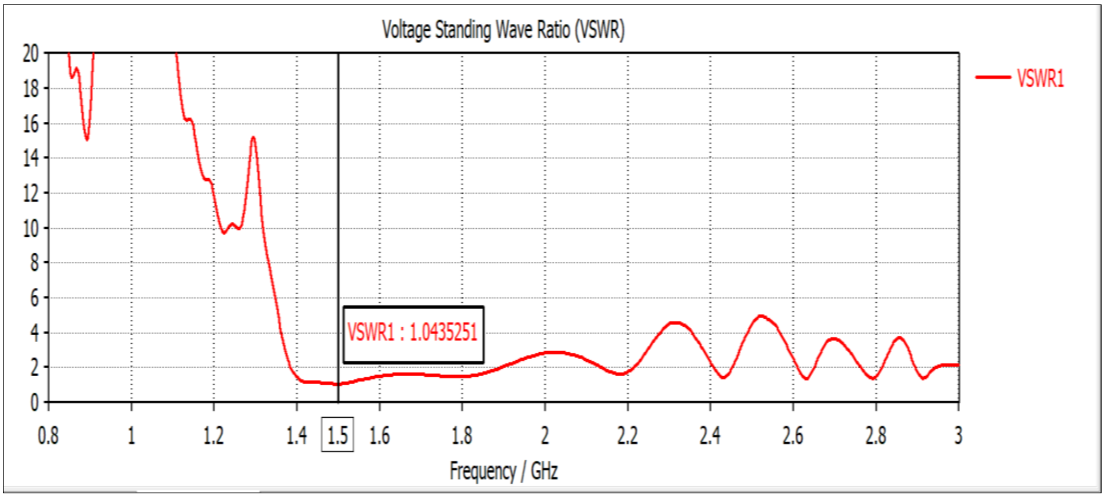

Figure 8: VSWR results of proposed helical antenna

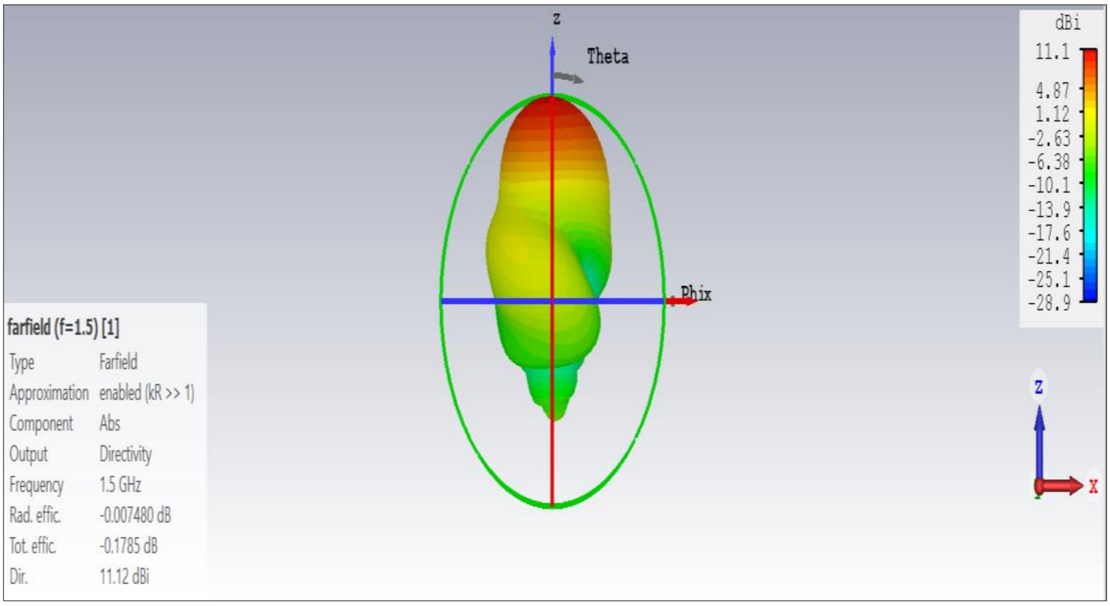

Figure 9: Far field plot of reference antenna

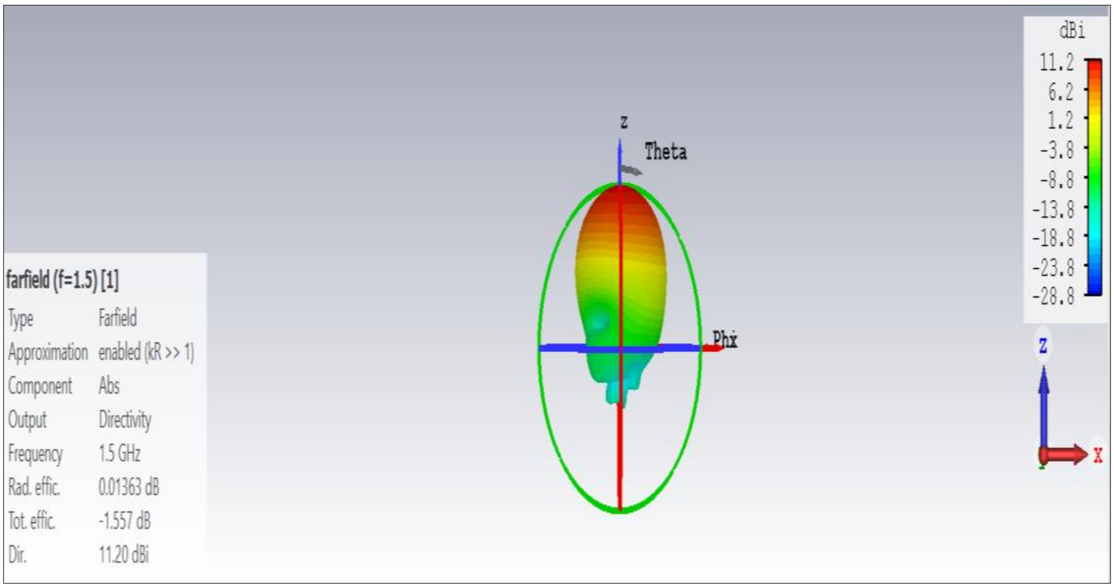

Figure 10: Far field plot of proposed antenna

From the polar plots of reference antenna and proposed antenna shown in **Figure 3 and 4**, it is shown that the gain and directivity have not been changed by altering the standard helical antenna, however, it can be observed from these polar plots that in the proposed design the side lobes level has reduced by 15.4 dB.

The magnetic field plot in **Figure 5 and 6** affirms greater current handling of the proposed antenna as compared to reference antenna. From the **Figure 7 and 8** it can be observed that VSWR of proposed designed is much better than reference design. By comparing the **Figure 9 and 10**, we can explicitly observe that side lobes of the antenna have reduced by 14 to 15 dB while gain of the proposed antenna has reduced by 0.1 dB which is attributable to increase in S11 but is anyway negligible.

4 DISCUSSION

UAVs heavily rely on GNSS signals to carry out their navigation however inherently GNSS signals are below noise floor level and highly susceptible to jamming. Installing special anti-jamming antennas or processing modules is an expensive option. This paper presents a novel method to make GNSS more immune to jamming signals by employing an antenna that has very low side lobe levels. As jamming signals are generally transmitted from ground, it is very difficult for any intentional or unintentional signals to enter the receiver without side lobes pointing towards ground. The design methodology used was to select a reference antenna and iteratively vary its design parameters to see the effects on the side lobe levels. CST Microwave studio was used to carry out the simulations which is an industry standard 3D Electromagnetic solver. Although helical antennas have been around for decades and generally all design equations and related design aids are readily available no reported study has been carried out to determine the effects of these design parameters on antenna side lobes levels. It would have involved a very extensive effort to develop analytical equations. So, we decided to take advantage of 3D Electromagnetic solvers available and carry out the process empirically. After optimizing the results obtained by individually varying the parameters the best possible parameter was picked and then a combined iterative process of refinement of results was used. The best results were obtained when parameter values were shown in **Table 6.**

5 CONSLUSION

A novel approach to reducing the susceptibility of airborne GPS antennas to ground based jammers has been presented. The novelty lies in mitigating the back door access of jamming signals to the receiver rather than resorting to multiple antennas and complex signal processing. The results have been successfully verified as regards to achieving the desired antenna parameters. Future work will focus on fabricating the antenna and observing its "anti-jam" characteristics on an actual aerial platform. Moreover, with some further mathematical work closed form expressions can be formed for determining relationship between key antenna design parameters and side lobe levels of helix antennas.

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