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HFSS-Based Helix Antenna Design Optimization and Simulation

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Abstract

This project uses HFSS (High-Frequency Structure Simulator) to simulate, develop, and analyse the performance of a helix antenna for a particular purpose, such as broadband wireless or satellite communication. Because of their distinctive structural characteristics, helix antennas are well-suited for a variety of high-frequency applications by balancing compactness, high gain, and wide bandwidth. In this work, we parametrically analyse important design parameters including pitch, radius, number of turns, and wire diameter to create an optimum helix antenna model. To improve performance for certain performance target, such as circular polarization, wideband response etc., the antenna's radiation pattern, gain, and axial ratio will be assessed. Findings confirm the helix antenna's promise for target application by showing how well the optimized design achieved enhanced gain, effective polarization control, and expanded bandwidth. HFSS is demonstrated as a potent platform for iterative design and optimization in this work, which offers insights into helix antenna design for sophisticated RF applications. The ability of antenna to transform input power into radiated power is measured by its antenna efficiency. Typically, a percentage is used to represent it. A strong tool for designing and analysing high-frequency components, nsys HFSS (High-Frequency Structure Simulator) offers precise modelling and optimisation capabilities for intricate antenna systems. The concepts, design factors, and simulation procedure for helix antennas using HFSS are covered in this study, with an emphasis on maximising performance metrics like gain, axial ratio, and impedance matching.

Keywords: Circular polarization, high gain, parametric analysis, axial mode, antenna optimization, spiral structure, polarization control, antenna efficiency

INTRODUCTION

Helix antennas have emerged as a versatile and effective solution in modern RF (Radio Frequency) communication systems, valued for their unique geometry, which allows for circular polarization, high gain, and broadband performance. Due to these characteristics, helix antennas are widely used in applications such as satellite communication, wireless networks, IoT devices, and radar systems. Their distinctive spiral structure provides both axial and normal mode operation, offering designers the flexibility to tailor antenna characteristics based on application requirements.

This project will design and optimize a helix antenna using Ansys HFSS (High-Frequency Structure Simulator), a leading electromagnetic simulation tool renowned for its accuracy in modelling complex antenna structures. Through HFSS, we can perform parametric analyses on critical design factors, including pitch angle, radius, number of turns, and wire diameter, to study their impact on key performance metrics, such as gain,

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axial ratio, and radiation pattern. This approach allows for a thorough exploration of the trade-offs involved in helix antenna design, ensuring optimal performance for specific RF applications [1]. Polarization controllers can be operated without feedback, typically by manual adjustment or by electrical signals from a generator, or with automatic feedback. The latter allows for fast polarization tracking. A polarization controller can have the task of transforming a fixed, known polarization into an arbitrary one. Since polarization states are defined by two degrees of freedom, for example azimuth angle and ellipticity angle of the polarization state, such a polarization controller needs two degrees of freedom. The same holds for the task of transforming an arbitrary polarization into a fixed, known one.

In this study, a detailed simulation workflow is developed, where HFSS is used to model the helix antenna, simulate its performance, and refine its parameters iteratively. The results provide insights into achieving improved antenna efficiency, polarization control, and bandwidth, establishing the helix antenna as a viable candidate for advanced RF communication needs. The outcome of this project not only validates the effectiveness of HFSS in antenna design but also contributes valuable design guidelines for implementing high-performance helix antennas in diverse communication systems [2].

These are made up of waves reflecting between two opposite and parallel boundaries, like between the front and back wall, the floor and the ceiling, or the two side walls. Axial modes are the strongest modes and significantly impact the way low frequencies sound in a room.

LITERATURE SURVEY

Helix antennas have been extensively studied and applied in various high-frequency and broadband communication systems due to their inherent advantages of circular polarization, wide bandwidth, and high gain. The origins of the helix antenna date back to the 1940s when it was first proposed by Kraus (1948), who described its geometry and operational modes [1]. Kraus established that a helix antenna could operate in both axial and normal modes, with the former providing a directional, high-gain radiation pattern along the antenna's axis. This makes the axial mode particularly suitable for applications requiring strong, focused signals, such as satellite and deep-space communications.

More recent studies have focused on optimizing helix antenna designs for specific applications, such as high-frequency (HF) and ultra-high frequency (UHF) systems [3]. For instance, Botella C et al. (2017) conducted an in-depth study on the effect of various design parameters (e.g., pitch angle, helix diameter, and number of turns) on gain and radiation pattern, demonstrating that a higher pitch angle and greater number of turns could significantly improve gain in axial mode operation. This research has paved the way for more robust parameter optimization techniques aimed at balancing antenna performance with design constraints, such as size and weight [4]. Parametric analysis is a data analysis method that uses a sample from a population to estimate population parameters and study the relationships between those parameters. It is a branch of inferential statistics that relies on certain assumptions to ensure that the sample, sampling distribution, and population are compatible. Circular polarization is a state of electromagnetic radiation where the electric field vector rotates in a circle at a constant rate in a plane perpendicular to the direction of the wave. It is one of three types of polarization, along with linear and elliptical polarization.

METHODOLOGY

To design a helix antenna in HFSS, start by defining the key parameters: frequency, wavelength, diameter, spacing between turns, number of turns, and pitch angle. Create the helical geometry by extruding or sweeping a circular cross-section along a helical path that meets these dimensions. Add a ground panel at the base of the helix and configure the setup accordingly. This section includes a theoretical study of the helix antenna based on perturbation theory, considering a large number of turns. It consists of a series of equations that outline the theoretical framework and fundamental aspects of the antenna's behavior [5]. The collected data was analysed to reach a set of conclusions about the validity of the research hypothesis by clarifying and explaining the results according to the mechanism and importance of the helix parameters This part starts with demonstrating the resonant frequency as shown in Eq. (1):

$$\frac{f-f_0}{f_0}=\frac{\int_{\Delta v}(\mu\|Ho\|^2-\in\|Eo\|^2)dv}{\int_{vo}(\mu\|Ho\|^2+\in\|Eo\|^2)dv} \tag{1}$$

Where:
ε: the relative dielectric,
μ: the magnetic permeability,
ΔV: difference of shape disturbance,
V0: resonant medium resonator,
f0: initial frequency, and
f: resonant frequency.

However, the electromagnetic field along the cylindrical direction z is almost constant in the helical coil, as shown in Eq. (2). In addition, Eq. (3). Represents the corresponding electric field distribution, demonstrating the field variations in the x, y plane.

$$\|Ho\|=H(x,y) \tag{2}$$

$$\|Eo\|=E(x,y) \tag{3}$$

Substituting both Eqs. (2) and (3) in Eq. (1) according to the height for the non-conductor material where the height will be from h0 to h, where h results in the formula shown in Eq. (4).

$$\frac{f-f_0}{f_0}=\frac{\int_{\Delta v}\left[\int_s\left(\mu H^2(x,y)-\epsilon E^2(x,y)\right)dxdy\right]dz}{\int_{ho}\left[\int_s\left(\mu H^2(x,y)+\epsilon E^2(x,y)\right)dxdy\right]dz} \tag{4}$$

According to the above, Eq. (5) will be:

$$\frac{f-f_0}{f_0}=C\,\frac{h-h_0}{h_0} \tag{5}$$

Where the last equation is excellent for the helix antennas with a big number of helical turns, according to the obtained uniform magnetic and electric fields. Figure 1 shows the helix antenna before adding AOS, which is designed by using MATLAB software program [6].

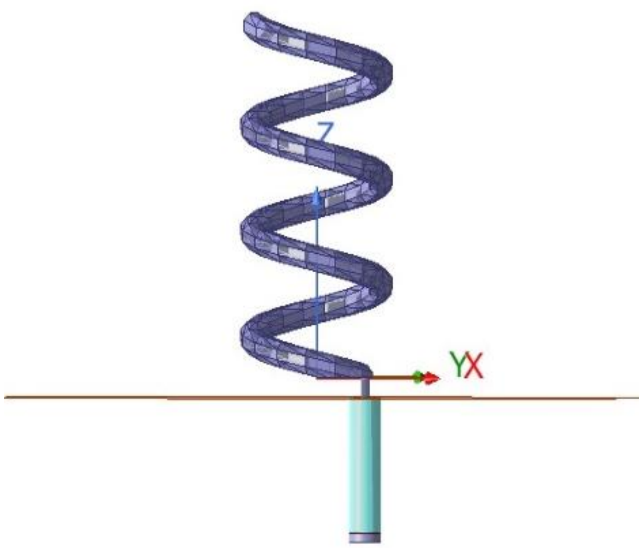

Figure 1. Helix antenna design.

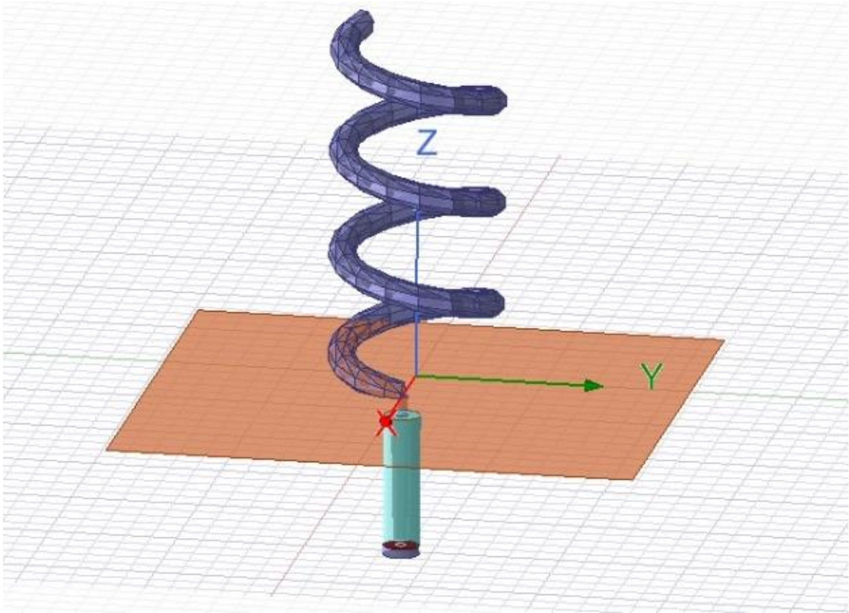

Figure 2. The analysing photo for the helix antenna by adding an aluminium oxide strip (AOS).

A helix antenna design starts by determining the operating frequency and wavelength, as these dictate the overall dimensions and characteristics. Given a frequency, the wavelength (λ) is calculated using the formula λ=c/f, lambda =\frac{c}{f} λ=fc, where ccc is the speed of light. Key parameters include the helix diameter (D), typically chosen as D=λπD \frac{\lambda} {\pi} D for axial-mode operations, providing a directional radiation pattern ideal for applications like satellite communication. The pitch angle (α), or the angle between the helix wire and a perpendicular plane, usually ranges from circ12∘ to circ14∘, which enhances directional gain. The spacing between turns (S) is generally set at λ4\frac{\lambda}{4}4λ for optimal performance in axial mode [7]. The analysing photo for the helix antenna by adding an aluminium oxide strip (AOS) is shown in Figure 2.

To fine-tune the antenna's performance, designers choose a suitable number of turns (N), with more turns generally offering higher gain but at the expense of a larger structure. The circumference (C) of the helix, calculated as C=πDC=\pi DC=πD, is ideally close to one wavelength to achieve the desired directivity. A ground plane, typically about 1.5 times the helix diameter, can also be added beneath the helix for enhanced gain in a particular direction. The input impedance for a helix antenna is approximately 140–150 Ω, though this varies depending on the spacing and number of turns, and impedance matching methods like a tapered line or balun may be required for efficient power transfer [8].

PARAMETERS

The Table 1 is showing the parameter description of the antenna and their values.

Table 1. Component description of Antenna.

S. No.	Name	Description	Value
1.	t_g	Thickness of the ground plane	2 mm
2.	a	Radius of helix	0.5 mm
3.	Di_c	Diameter of inner coaxial feed	1.3 mm
4.	Do_c	Diameter of outer coaxial feed	4.35 mm
5.	C	Circumference of helix	100 mm
6.	t_oc	A thickness of the outer coaxial layer	0.5 mm
7.	Dh	Helix diameter	31.8309 mm
8.	Lf	Length of coaxial feed	10 mm

SIMULATION RESULT

This study aims to provide a new design for a passive wireless displacement sensor. The sensor consists of an external helix antenna and an AOS, which means aluminium oxide strip. There is a nearly linear relation strip between the moving of AOS in the space gap and in the vibrating frequency of helix antenna authority of the perturbation theory, which designs the helix antenna by using HFSS (high-frequency structure simulator) according to the study of the analyzation of the helix antenna. Jaf SF, HFSS is defined as a simulation software based on the Finite Element Method (FEM) for analyzing electromagnetic characteristics. It was used to simulate the radiation properties of the helix antenna sensor. Figures 3(a) and 3(b) illustrate the helix antenna design simulated using HFSS without any modifications. This comparison allows for an analysis of parameter differences between the antenna without AOS and with AOS [9].

In a helix (helical) antenna, radiation is characterized by its unique circular polarization and directional radiation pattern, making it suitable for applications like satellite communication and radio astronomy. The radiation pattern and behaviour of a helical antenna depend on its geometry and the operational mode: normal mode or axial mode [10, 11].

Normal Mode

In this mode, the antenna radiates perpendicular to the axis of the helix. It produces an omnidirectional pattern, somewhat like a dipole antenna, with linear polarization. This mode is common for shorter helices relative to the wavelength. Return loss is shown in Figure 4.

Axial Mode

In this mode, the helix radiates along its axis, resulting in a directional beam with circular polarization, making it highly effective for long-distance and satellite communications. This mode occurs when the circumference of the helix is about the size of the wavelength. The radiation pattern has a narrow beamwidth and high gain along the axis of the helix [12].

The helical antenna is favoured for its simplicity in design and its ability to produce circularly polarized waves, which reduce the effects of signal fading due to orientation mismatch between the transmitting and receiving antennas.

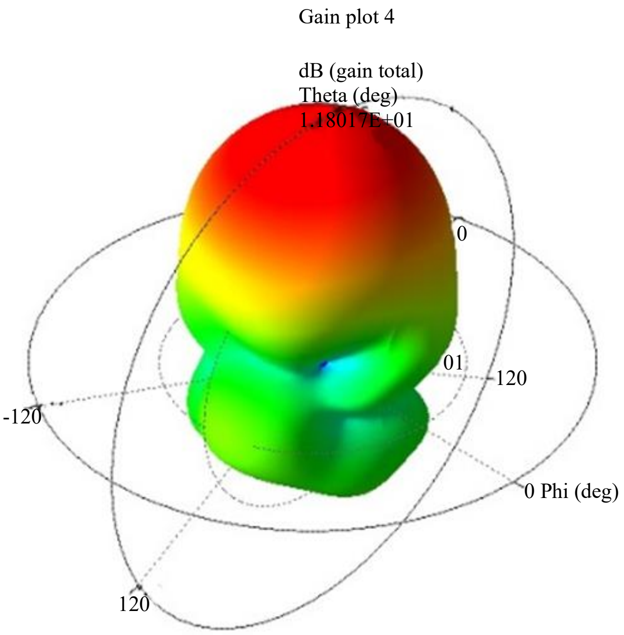

Figure 3a. Gain plot (A).

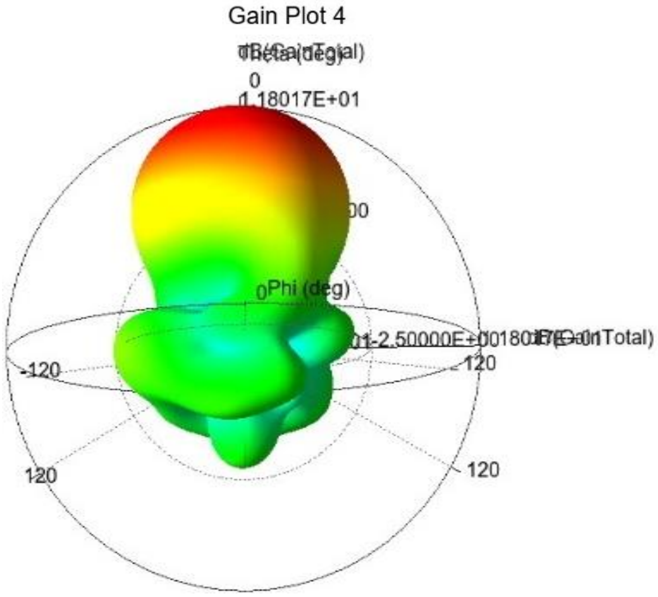

Figure 3b. Gain plot (B).

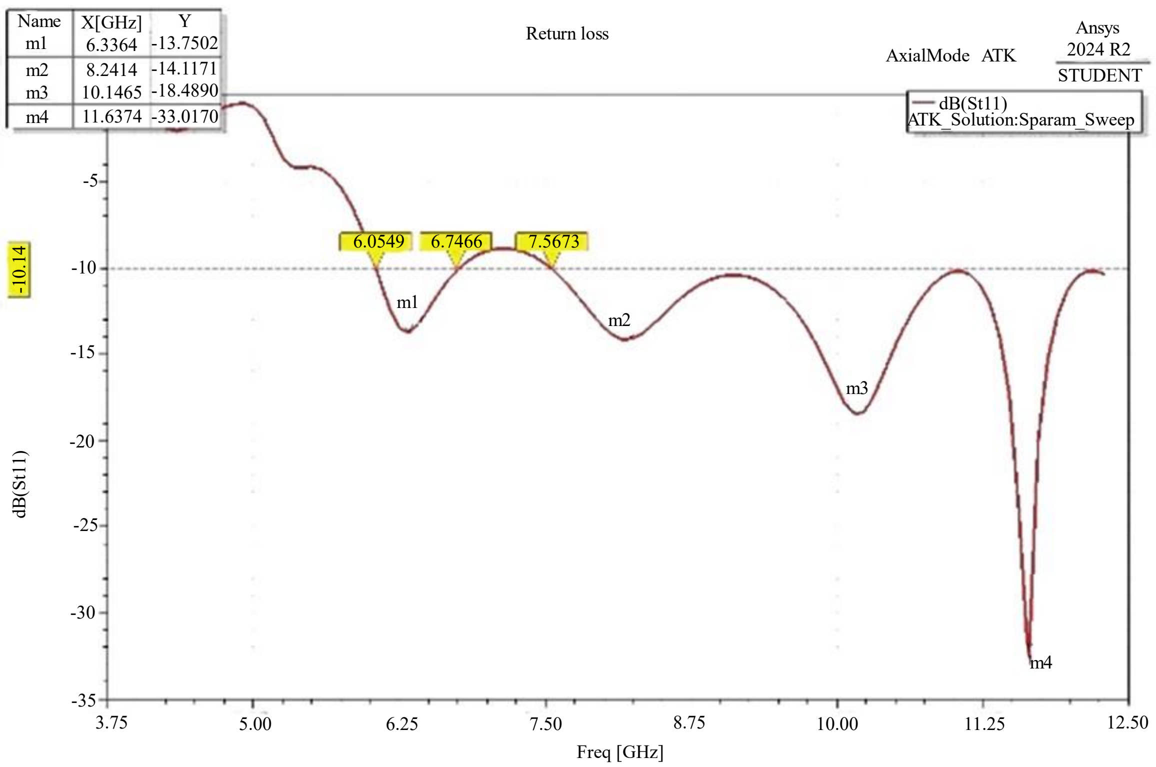

Figure 4. Return loss.

Graphical Representation

The graphical representation of the gain plot and return loss are presented in Figures 3 and 4.

CONCLUSION

In summary, designing a helix antenna using HFSS (High-Frequency Structure Simulator) provides a clear and detailed understanding of how the antenna will perform in real-world applications. HFSS allows engineers to adjust key design parameters, such as the spacing between coils, number of turns, pitch angle, and size of the ground plane. This flexibility helps achieve specific performance goals, like high gain (signal strength), circular polarization, and wider bandwidth to support multiple frequencies.

Using HFSS, engineers can also simulate the antenna's impedance matching to minimize signal loss and ensure efficient power transfer, which is crucial for consistent performance across the operating frequency range. By examining the radiation pattern, they can analyse it. How the antenna directs energy, allowing for focused signal coverage ideal for applications like satellite communications. HFSS also supports parametric sweeps that test various design changes quickly, making it easier to find the best configuration.

Finally, HFSS enables realistic modelling by including materials, wire gauges, and environmental factors in simulations, which is essential for creating durable antennas that work reliably in practical conditions. In essence, HFSS provides the insights needed to design efficient, high-performance helix antennas suitable for demanding applications, ensuring reliable communication and optimized signal quality.

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