



Université Mohamed Khider de Biskra  
Faculté des Sciences et de la Technologie  
Département de génie électrique

# MÉMOIRE DE MASTER

Sciences et Technologies  
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Présenté et soutenu par :  
**GACEM Mohamed Rami**

Le : [Click here to enter a date.](#)

## Study of Helical Antena: modeling, simulation

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## Study of Helical Antenna: modeling and simulation

Le : mardi 17 juin 2025

Présenté par :

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To everyone who contributed to this journey in any way, thank you.

## **Dedications**

I dedicate this to the memory that lives on in my heart — a journey shaped by love, support, and shared moments.

To my beloved parents, whose unwavering guidance and unconditional love have been the foundation of all I am and hope to become — thank you for every sacrifice, every lesson, and every embrace.

To my dear brothers, who have walked beside me through laughter and challenges — your presence has been a constant source of strength, joy, and inspiration.

This is for all the memories we've made together, and for the ones I will carry with me always.

## Abstract

This work presents the modeling and simulation of a helical antenna (HA), recognized for its ability to produce circular polarization (CP) and high directivity (D), making it ideal for RF, GPS, and satellite communication systems. The study covers both normal mode and axial mode operations, with a focus on the latter due to its superior gain and radiation efficiency.

The HA structure is analyzed through key parameters such as circumference (C), pitch (S), number of turns (N), and pitch angle ( $\alpha$ ). Simulations performed using MATLAB's Antenna Designer tool evaluate essential characteristics including return loss ( $S_{11}$ ), input impedance (Z), and radiation patterns (E, H) at an operating frequency  $f = 10$  GHz.

Results confirm that the antenna achieves optimal performance in axial mode, with  $S_{11} < -12$  dB and  $D \approx 9.41$  dBi, demonstrating efficient energy radiation and suitability for modern UHF/VHF systems. The design offers a good compromise between bandwidth, VSWR, and size, confirming its applicability in advanced wireless and aerospace communication.

### Keywords:

Helical antenna; Modeling; Simulation using Matlab.

## Résumé

Ce mémoire présente la modélisation et la simulation d'une antenne hélicoïdale (HA), reconnue pour sa capacité à générer une polarisation circulaire (CP) et une forte directivité (D), ce qui la rend idéale pour les systèmes de communication RF, GPS et par satellite. L'étude couvre les modes de rayonnement normal et axial, avec une attention particulière au mode axial en raison de son gain et de son efficacité de rayonnement supérieurs.

La structure de l'antenne est analysée à travers des paramètres clés tels que la circonférence (C), le pas (S), le nombre de spires (N) et l'angle d'inclinaison ( $\alpha$ ). Les simulations, réalisées avec l'outil Antenna Designer de MATLAB, évaluent des caractéristiques essentielles telles que la perte de retour ( $S_{11}$ ), l'impédance d'entrée (Z), et les diagrammes de rayonnement (E, H) à une fréquence de fonctionnement  $f = 10$  GHz.

Les résultats confirment que l'antenne fonctionne de manière optimale en mode axial, avec  $S_{11} < -12$  dB et une directivité  $D \approx 9.41$  dBi, prouvant une émission efficace et une adaptation idéale aux systèmes modernes UHF/VHF. Le design offre un bon compromis entre bande passante, VSWR, et taille, ce qui confirme son utilité dans les communications sans fil et aérospatiales avancées.

### Mots clés :

Antenne hélicoïdale ; Modélisation ; Simulation sous Matlab.

## ملخص

يقدم هذا البحث دراسة حول نمذجة ومحاكاة الهوائي الحلزوني (HA) ، المعروف بقدرته على توليد استقطاب دائري (CP) وتوجيه عالٍ (D) ، مما يجعله مثاليًا لأنظمة الاتصالات عبر RF وGPS والأقمار الصناعية. يغطي البحث وضعي التشغيل: الوضع العادي والوضع المحوري، مع التركيز على الوضع المحوري بسبب الربح العالي وكفاءة الإشعاع.

تم تحليل بنية الهوائي باستخدام معلمات رئيسية مثل المحيط (C) ، المسافة بين اللفات (S) ، عدد اللفات (N) وزاوية الميل ( $\alpha$ ). أُجريت المحاكاة باستخدام أداة Antenna Designer في برنامج MATLAB لتقييم خصائص مهمة مثل معامل الانعكاس ( $S_{11}$ ) ، معاوقة الدخل (Z) ، وأنماط الإشعاع (E, H) عند التردد  $f = 10 \text{ GHz}$ . أكدت النتائج فعالية الهوائي في الوضع المحوري، حيث كانت  $S_{11} < -12 \text{ dB}$  و  $D \approx 9.41 \text{ dBi}$ ، مما يدل على إشعاع فعال وملاءمة جيدة لأنظمة UHF/VHF الحديثة. ويُعد التصميم مزيًا مثاليًا بين عرض النطاق، VSWR والحجم، مما يثبت كفاءته في أنظمة الاتصالات اللاسلكية والفضائية المتقدمة.

## الكلمات المفتاحية

هوائي لولبي (أو هوائي حلزوني)؛ النمذجة؛ المحاكاة باستخدام ماتلاب

## List of Acronyms

- **Arconym full term**

<b>3D</b>	Three-Dimensional
<b>CCW</b>	Counter-Clockwise
<b>CEM</b>	Computational Electromagnetics
<b>CW</b>	Clockwise
<b>dB<sub>i</sub></b>	Decibels relative to isotropic antenna
<b>GHz</b>	Gigahertz
<b>GPS</b>	Global Positioning System
<b>HPBW</b>	Half Power Beamwidth
<b>HW</b>	Hansen–Woodyard
<b>MATLAB</b>	Matrix Laboratory (software)
<b>RF</b>	Radio Frequency
<b>S<sub>11</sub> (S11)</b>	Scattering Parameter (Return Loss)
<b>UHF</b>	Ultra-High Frequency
<b>VHF</b>	Very High Frequency
<b>VSWR</b>	Voltage Standing Wave Ratio

- **List of Symbols and Their Meanings**

<b>Symbol</b>	<b>Meaning / Description</b>	<b>Unit</b>
<b><math>\alpha</math></b>	Pitch angle	degrees (°)
<b>AR</b>	Axial ratio	dimensionless
<b><math>\beta</math></b>	Phase constant	radians/meter
<b>C</b>	Circumference of helix	meters (m)
<b>D</b>	Directivity	decibels (dBi)
<b>d</b>	Diameter of helix	meters (m)
<b>E</b>	Electric field	Volts/meter (V/m)
<b>f</b>	Frequency	Hertz (Hz) or GHz
<b>H</b>	Magnetic field	Amperes/meter (A/m)

<b>Symbol Meaning / Description</b>		<b>Unit</b>
<b>I</b>	Current	Amperes (A)
<b>Im(Z)</b>	Imaginary part of impedance	Ohms ( $\Omega$ )
<b>j</b>	Imaginary unit ( $\sqrt{-1}$ )	—
<b><math>\lambda</math></b>	Wavelength	meters (m)
<b>N</b>	Number of turns	dimensionless
<b>P</b>	Radiated power	Watts (W)
<b><math>\phi</math> (phi)</b>	Azimuth angle	degrees ( $^\circ$ )
<b>R</b>	Resistance	Ohms ( $\Omega$ )
<b>Re(Z)</b>	Real part of impedance	Ohms ( $\Omega$ )
<b>S</b>	Spacing between turns (pitch)	meters (m)
<b>S<sub>11</sub></b>	Return loss / reflection coefficient decibels (dB)	

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## General Introduction

Antennas are essential elements of modern communication systems, facilitating the transmission and reception of electromagnetic waves over long distances. Among the diverse array of antenna types, the **helical antenna** stands out for its distinctive geometry and adaptable performance. First introduced in the 1940s by American physicist and engineer **John D. Kraus**, the helical antenna has played a pivotal role in advancing wireless and space-based communication technologies. As a professor at **Ohio State University**, Kraus made significant contributions to antenna theory and radio astronomy, with his invention continuing to shape contemporary communication infrastructures.

The helical antenna features a spiral-shaped conductive wire wound into a helix, typically positioned above a ground plane. This unique configuration enables the emission of **circularly polarized electromagnetic waves**, making the antenna particularly suitable for scenarios where transmitter and receiver orientations vary—such as in satellite communications, spacecraft telemetry, weather monitoring, GPS, and RFID systems. Its capability to function effectively in both **normal (broadside)** and **axial (end-fire)** radiation modes adds to its versatility across a range of frequency bands and design needs.

Performance-wise, the antenna's effectiveness is highly influenced by its geometric parameters, including the **number of turns, pitch angle, wire diameter**, and overall dimensions relative to the operating wavelength. In axial mode, it exhibits **high gain, directional radiation**, and **broadband** characteristics, while in normal mode, it offers a **more compact**, omnidirectional design suitable for mobile applications. These features make the helical antenna a compelling choice for systems requiring **high reliability, precision, and robust signal propagation**, particularly in **dynamic or challenging environments**.

This report aims to provide a **comprehensive exploration** of the helical antenna, combining **theoretical insights, mathematical modeling, and practical simulations**. It is structured into three main chapters.

- **Chapter 1** introduces the basic principles, structural configuration, and radiation mechanisms of helical antennas, highlighting their key features, advantages, and limitations.
- **Chapter 2** focuses on the analytical modeling of the antenna, discussing how its electromagnetic behavior is derived from classical antenna theory and how its operational modes are influenced by physical design.

## Study of Helical Antenna: modeling, simulation

- **Chapter 3** presents a detailed simulation-based analysis using MATLAB's Antenna Designer tool, evaluating the antenna's performance through return loss, gain, directivity, current distribution, and impedance plots.

Through this multidisciplinary approach, the document seeks to bridge the gap between fundamental theory and practical implementation, offering valuable insights into the design and optimization of helical antennas for current and future communication systems. It underscores the enduring relevance of Kraus's innovation in the face of rapidly evolving wireless technologies and highlights the antenna's potential in supporting the next generation of aerospace and telecommunications infrastructures.

# **Chapter 1: General considerations on the helical antenna**

# 1 Chapter 1: General considerations on the helical antenna

## 1.1 Introduction

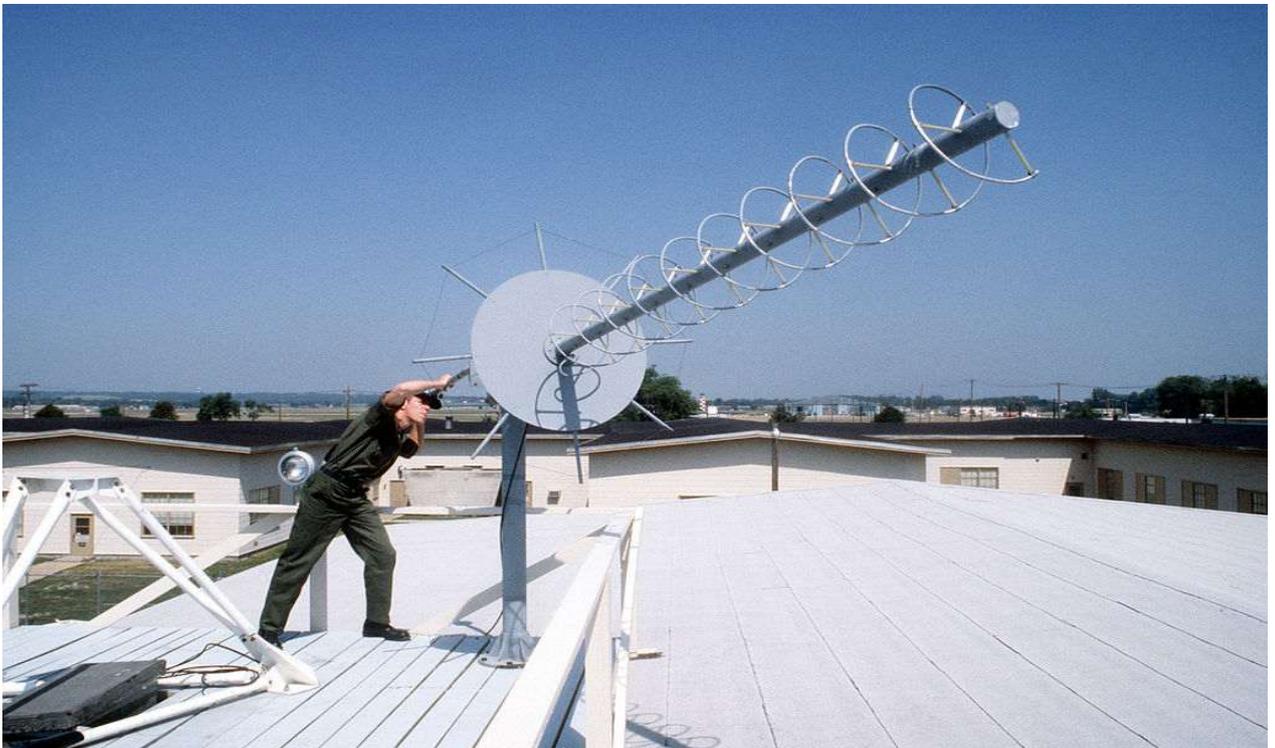
The helical antenna was invented by *John D. Kraus*, an American physicist and engineer, in the 1940s. *John D. Kraus* was a professor at Ohio State University. He is known for major contributions to antenna theory and radio astronomy. He also authored the influential textbook "Antennas", widely used in engineering education.

The helical antenna is one of his most significant innovations, particularly valued for its circular polarization, wide bandwidth, and high directivity, especially in satellite and space communication applications.

A helical antenna (or helix antenna) is a type of antenna made of a conductive wire wound into a spiral (helix) shape, typically mounted above a ground plane.

The main characteristics of this antenna are:

- Structure: A metallic wire wound in a spiral around an axis, often with multiple turns.
- Polarization: It generates circularly polarized waves (either right-hand or left-hand circular, depending on the winding direction).



*Figure 1.1: Helical antenna axial[1]*

## 1.2 Radiation modes

Helical antennas operate primarily in two radiation modes: [2]

- Normal Mode (Broadside Radiation)
  - o Radiates perpendicular to the axis of the helix.
  - o Used when the antenna dimensions are small compared to the wavelength.
  - o Common in mobile and compact devices.
- Axial Mode (End-Fire Radiation)
  - o Radiates along the axis of the helix.
  - o Occurs when the helix dimensions are comparable to or larger than the wavelength.
  - o Provides circular polarization and directional radiation.
  - o Widely used in satellite and space communications.

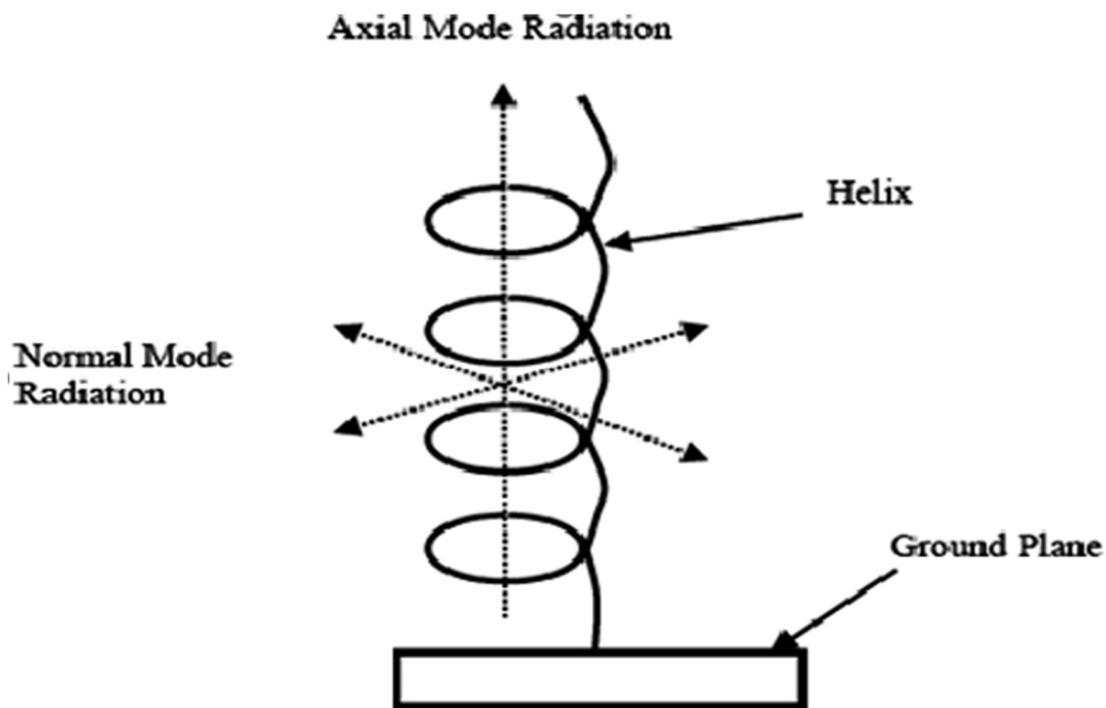


Figure 1.2: Normal and axial mode of radiation[3]

## 1.3 Helical antenna applications

- Satellite communication (GPS, weather, and communication satellites);
- Spacecraft antennas;
- Telemetry and tracking systems;

## General consideration on the helical antenna

- UHF and VHF systems;
- RFID and wireless communication where circular polarization is beneficial. [4]

### 1.4 Helical antennas advantages

- Circular polarization: Less sensitive to orientation between transmitting and receiving antennas;
- Wide bandwidth;
- High gain in axial mode;
- Simple construction;
- Low sensitivity to mechanical tolerances (e.g., spacing or wire thickness). [5]

### 1.5 Helical antennas limitations

- Larger physical size in axial mode;
- Can be less efficient in normal mode;
- Gain and polarization depend on precise geometric design. [6]

### 1.6 Conclusion

The helical antenna stands out as a versatile and effective antenna design, particularly suited for applications requiring circular polarization and high directivity. Its ability to operate in both normal and axial modes allows it to serve a range of uses, from compact mobile devices to high-gain satellite communication systems. With advantages such as wide bandwidth, simple construction, and mechanical robustness, it remains a popular choice in modern wireless and aerospace technologies. However, trade-offs such as its larger size in axial mode and the dependency of performance on precise geometric parameters must be considered during design and deployment. Overall, the helical antenna represents a key innovation in antenna engineering, combining practical functionality with reliable performance.

# **Chapter 2: Helical antenna modeling**

## 2 Chapter 2: Helical antenna modeling

### 2.1 Introduction

The helical antenna can be viewed as an evolution of the loop antenna. In this section, we introduce this unique type of antenna, known for its remarkable characteristics. Professor *Kraus* made a notable contribution to its development. The helical antenna offers a nearly constant resistive input across a broad frequency range and functions as a high-gain end-fire array within that same range. Additionally, it is tolerant to variations in conductor size and spacing between turns. Its minimal mutual impedance makes it particularly well-suited for use in antenna arrays.

### 2.2 Helical antenna modeling

As illustrated in figure 2.1, a helical antenna is formed by winding a conductor into a spiral or helical shape. This type of antenna produces circular or elliptical polarization. A helix wound in a right-hand (clockwise) direction emits or receives right-hand circularly polarized waves, while one wound in a left-hand (counterclockwise) direction emits or receives left-hand circularly polarized waves. Although the helical antenna is capable of radiating in multiple modes, the most commonly utilized are the axial (end-fire) mode and the normal (broadside) mode.



*Figure 2.1 : Helical antenna [7]*

### 2.2.1 Loop Antenna: Small loops

For small loops (circumference  $C = 2\pi a < \frac{\lambda}{3}$ ), the current can be considered as constant. It has been found that a magnetic current  $I_m \Delta l$  is equivalent to a small loop of radius  $a$  and constant electric current  $I_0$  provided that:

$$I_m \Delta l = j\omega\mu S I_0 \quad (2.1)$$

Where  $S = \pi a^2$  is the area of the loop.

It is well known that the far fields of an electrically small loop are given by:

$$\begin{cases} H_\theta = \frac{jI_m \Delta l}{4\pi r \eta} \beta \sin(\theta) e^{-j\beta r} \\ E_\phi = -\frac{jI_m \Delta l}{4\pi r} \beta \sin(\theta) e^{-j\beta r} \\ H_r = H_\phi = 0 \\ E_r = E_\theta = 0 \end{cases} \quad (2.2)$$

The far field of a small loop is given in (2.2) as:

$$E_\phi = \eta \frac{k^2 (D/2)^2 I_0}{4r} \sin(\theta) e^{-jk} \quad (2.3)$$

$$E_r = E_\theta = 0$$

The far field of a short dipole is shown as:

$$E_\theta \approx j\eta \frac{kI_0 S e^{-jkr}}{4\pi r} \sin(\theta) \quad (2.4)$$

The  $E_\theta$  and  $E_\phi$  components of dipoles and loops are 90 degrees out of phase. The combination of them gives a circularly or elliptically polarized wave. The axial ratio is:

$$AR = \frac{\|E_\theta\|}{\|E_\phi\|} = \frac{\left\| j\eta \frac{kI_0 S e^{-jkr}}{4\pi r} \sin(\theta) \right\|}{\left\| \eta \frac{k^2 (D/2)^2 I_0 e^{-jkr}}{4r} \sin(\theta) \right\|} = \frac{4s}{\pi k D^2} = \frac{4s}{\pi \frac{2\pi}{\lambda} D^2} = \frac{2\lambda s}{(\pi D)^2} \quad (2.5)$$

When the circumference is equal to:

$$C = \pi d = \sqrt{2\lambda s} \quad (2.6)$$

the axial ratio becomes unity and the radiation is circularly polarized. Otherwise, the radiation is elliptically polarized. From expressions (2.3) and (2.4), we know that the radiation pattern is as shown in **figures 2.2** and **2.3**, and omnidirectional in the horizontal plane. The directivity is again about 1.5 and the *HPBW* is 90 degrees, similar to that of a short dipole or small loop. The input impedance is very sensitive to changes of frequency; the bandwidth is therefore very narrow. In practice, the helix is normally used with a ground plane, the polarization is predominantly vertical and the radiation pattern is similar to that of a monopole. In this case, the radiation resistance can be approximately given by

$(25.3 Ns/\lambda)^2$ . These antennas tend to be inefficient radiators (depending on size and materials) and are typically used for mobile communications where reduced size is a critical factor.

### 2.2.2 Normal Mode Helix

The main design parameters are:

$D$ : diameter of the helix;

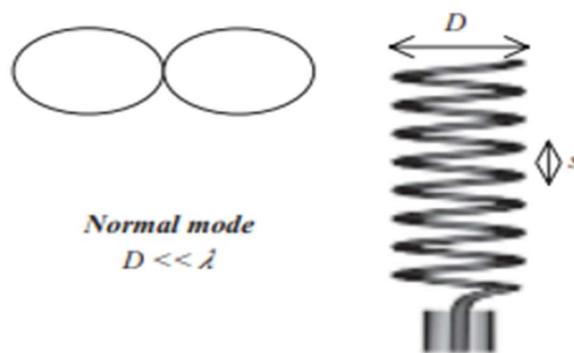
$s$ : spacing between turns;

$N$ : number of turns;

$C = \pi D$ : circumference of helix;

$L = \sqrt{C^2 + s^2}$ : length of one turn.

The normal (broadside) mode occurs when the diameter of the helix is much smaller than the wavelength ( $D \ll \lambda$ ) and the total length is also smaller than the wavelength. It behaves more like a dipole (or monopole with a ground plane) antenna.

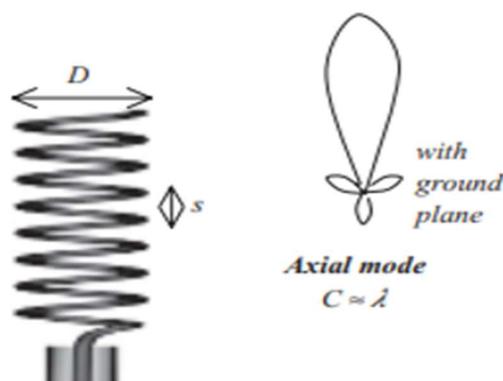


**Figure 2.2:** Normal helical antenna mode of radiation[14]

The radiation pattern is broadside to the helix axis. In this case, the helix may be treated as the superposition of  $N$  elements, each consisting of a small loop of diameter  $D$  and a short dipole of length  $S$ . The axes of the loop and dipoles coincide with the axis of the helix.

### 2.2.3 Axial Mode Helix

The axial (end-fire) mode occurs when the circumference of the helix is comparable with the wavelength ( $C = \pi D \approx \lambda$ ) and the total length is much greater than the wavelength. This has made the helix an extremely popular circularly polarized broadband antenna at the VHF and UHF band frequencies. [15]



*Figure 2.3: Axial helical antenna mode of radiation[16]*

In this mode of operation, there is only one main lobe and its maximum is along the axis of the helix and, as shown in **figures 2.2 and 2.3** (with a ground plane), there may be some side lobes. The recommended parameters for an optimum design to achieve circular polarization are:

- Normalized circumference:  $3/4 < C/\lambda < 4/3$ ;
- Spacing:  $s \approx \lambda/4$ ;
- Pitch angle:  $12^\circ \leq \alpha = \arctg\left(\frac{s}{C}\right) \leq 15^\circ$ ;
- Number of turns:  $N > 3$ .

In contrast to the normal mode helix, which has a current almost uniform in phase over the antenna, the phase of the axial mode helix current shifts continuously along the helix like a traveling wave. Because the circumference is about one wavelength, the currents at opposite points on a turn are about 180degrees out of phase. This cancels out the current direction reversal introduced by the half turn. Thus, the radiation from opposite points on the helix is nearly in phase. This is essentially the same as the one-wavelength loop. It is therefore not surprising to have the maximum radiation along the axis. The radiation pattern of the axial mode helix can be modeled using antenna array theory, to be discussed later in this chapter. Basically, each turn can be considered an element of the array with a radiation pattern of  $\cos \theta$ . The normalized total radiation pattern is:

$$E = A \cos(\theta) \frac{\sin\left[\left(\frac{N}{2}\right)\psi\right]}{\sin\left(\frac{\psi}{2}\right)} \quad (2.6)$$

where the first term is the normalization factor:  $A = 1/N$  for ordinary end-fire radiation and  $A = \sin\left(\frac{\pi}{2N}\right)$  for *Hansen–Woodyard (HW)* end-fire radiation (the axial mode helix was found to approximately satisfy the *Hansen–Woodyard* condition, which is larger than  $1/N$  to reflect the increased directivity – it is achieved by increasing the phase change between element sources. The second term in the equation ( $\cos \theta$ ) is the element radiation pattern and the last term represents the array factor of a uniform array of  $n$  elements.  $\psi = k_0 \left( S \cos(\theta) - \frac{L_0}{p} \right)$  and  $p$  is the relative phase velocity given by:

$$p = \frac{v}{c} = \frac{\frac{L_0}{\lambda}}{\frac{S}{\lambda} + 1} \quad ; \text{ for ordinary end-fire radiation, } \psi = -2\pi$$

$$p = \frac{v}{c} = \frac{\frac{L_0}{\lambda}}{\frac{S}{\lambda} + \left(\frac{2N+1}{2N}\right)} \quad ; \text{ for } \textit{Hansen–Woodyard} \text{ end-fire radiation, } \psi = -2\pi - \pi/N \quad (2.7)$$

It has been found that the half-power beamwidth is roughly:

$$HPBW(^\circ) = \frac{K_B}{\frac{C}{\lambda}} \sqrt{\frac{Ns}{\lambda}} \approx \frac{52^\circ}{\frac{C}{\lambda} \sqrt{N \frac{S}{\lambda}}} \quad (2.8)$$

It is inversely proportional to  $C$  and  $\sqrt{Ns}$ .

Using the link between the directivity and *HPBW*, we obtain the directivity:

$$D \approx 12C^2Ns/\lambda^3 \quad (2.9)$$

The axial ratio is found to be:

$$AR = \frac{2N+1}{2N} \quad (2.10)$$

The input impedance of an axial mode helix with a ground, which is greater than one wavelength, is almost resistive, with values between 100 and 200. The estimated value within 20% accuracy is expressed by:

$$R_{in} = 140 \frac{C}{\lambda} \quad (2.11)$$

### 2.3 Conclusion

In this chapter, the helical antenna was modeled and analyzed in both normal and axial modes. The fundamental design principles, radiation characteristics, and performance metrics were explored. Notably, the axial mode offers circular polarization and higher directivity, making it ideal for broadband and satellite communication applications. Through theoretical modeling and design optimization, the helical antenna proves to be a versatile and efficient solution for various modern wireless systems.

# **Chapter 3: Helical antenna simulation**

## 3 Chapter 3: Helical antenna simulation

### 3.1 Introduction

Designing and evaluating antenna performance requires a balanced integration of theoretical analysis and simulation. This chapter centers on the simulation of a helical antenna, valued for its directional radiation and circular polarization—attributes well-suited for wireless communication applications.

Simulations are performed using MATLAB's Antenna Designer, selected for its user-friendly interface and seamless integration with the Antenna Toolbox. This environment facilitates efficient tuning of critical parameters such as helix diameter, pitch, number of turns, and operating frequency to optimize antenna performance.

The chapter outlines the simulation methodology and a comparative analysis of results, underscoring the effectiveness of the design strategy and the antenna's real-world performance.

### 3.2 Antenna Designer Tool

Antenna Designer is an interactive design tool available in MATLAB that allows users to create, analyze, and visualize a wide range of antenna types using a graphical interface. It is part of the Antenna Toolbox, which provides built-in functions and customizable options for simulating antenna behavior in different environments and frequency ranges.

The tool simplifies the design process by enabling users to adjust key parameters—such as dimensions, materials, and frequency—while instantly visualizing the effects on antenna performance. Parameters like gain, directivity, input impedance, and radiation patterns can be easily analyzed without complex coding.

In this project, Antenna Designer is used to model and simulate a helical antenna, which is known for its circular polarization and high directivity. The tool allows precise control over structural features such as helix diameter, pitch, number of turns, and ground plane size, making it ideal for optimizing the antenna before physical implementation.

### 3.3 Simulation

The geometric and physical characteristics of the helix antenna element are defined by key design parameters, which are listed below for reference:

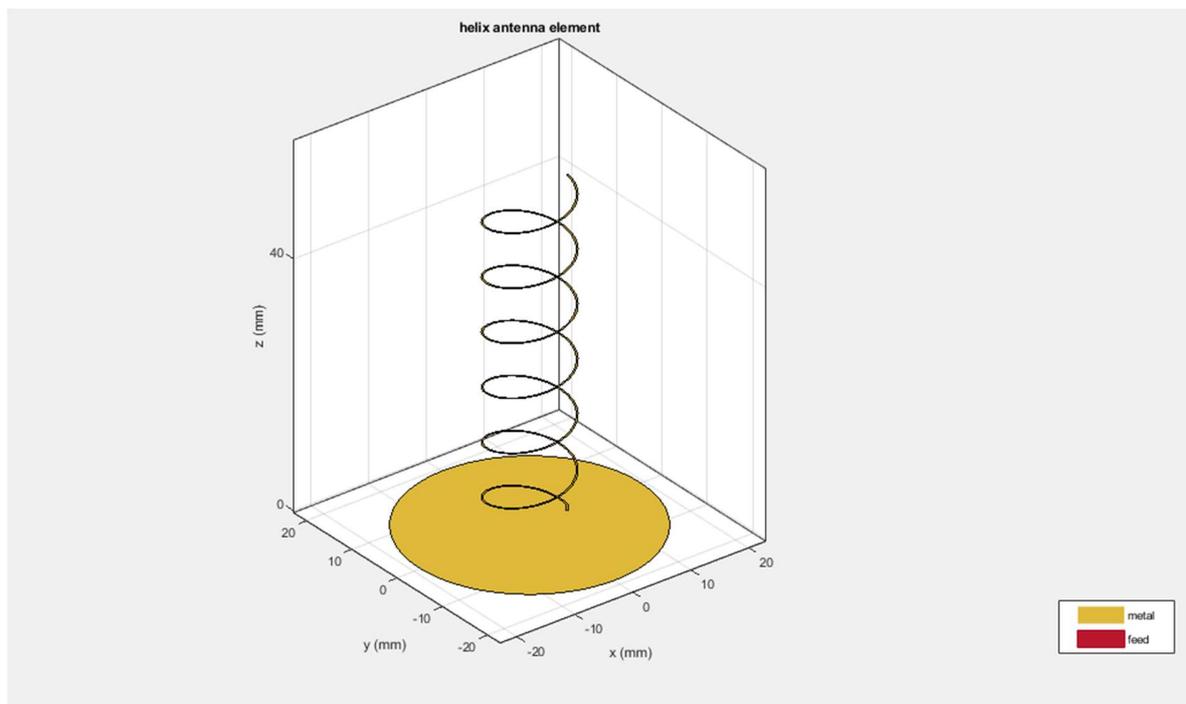
- Frequency: **10 GHz**

- Radius of the helix : **0.0064 m**
- Width of the wire: **2.5437e-04 m**
- Turns of the helix : **6**
- Spacing between turns: **0.0088 m**
- Winding Direction: **counter-clockwise 'CCW' around the Z-axis**
- Feed Stub Height for connection with the RF source: **1.0000e-03 m**
- Ground Plane Radius : **0.0191 m**

Analysis of the simulation data reveals the following.

### 3.3.1 Three-dimensional (3D) model of a helical antenna

This figure illustrates the 3D structural model of a helical antenna, designed and visualized for operation at 10 GHz. The antenna is constructed on a circular ground plane. Operating at 10 GHz, this antenna is optimized for axial-mode radiation, which produces a circularly polarized wave radiating along the axis of the helix.

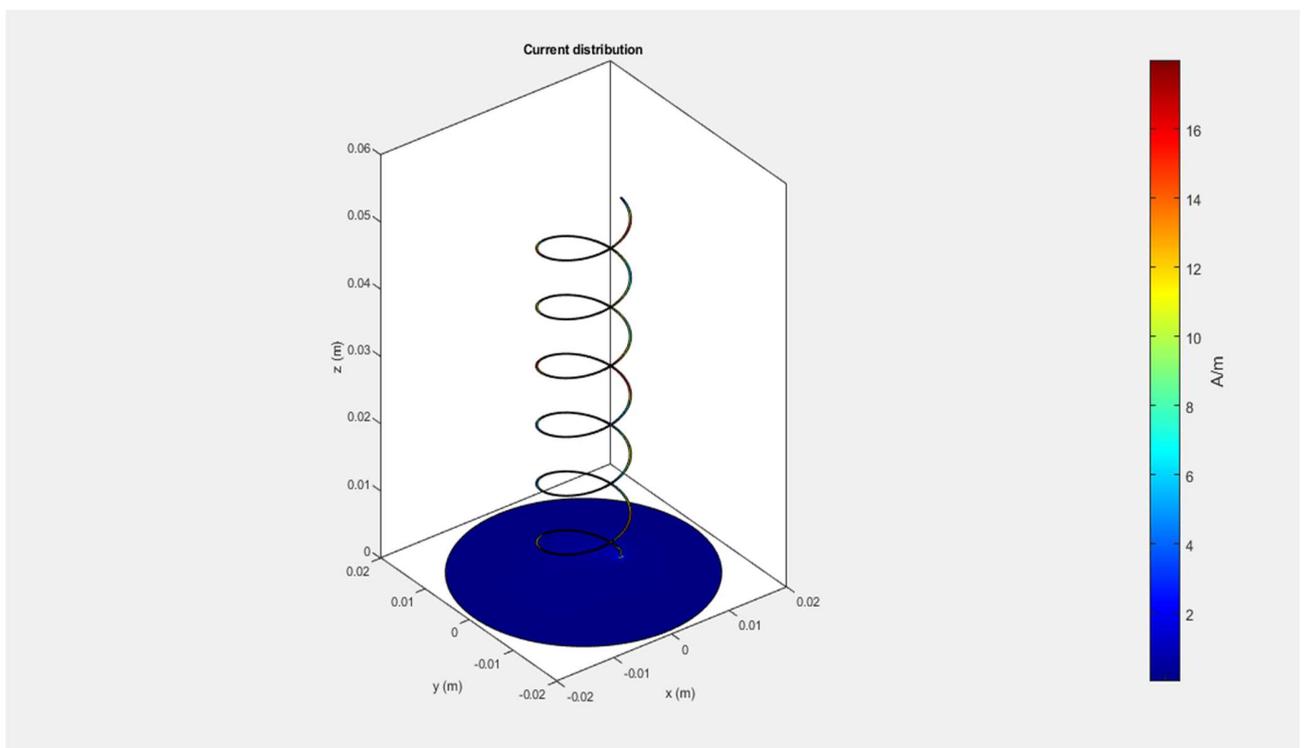


**Figure 3.1:** 3D structural model of a helical antenna

### 3.3.2 Current distribution on a helical antenna above a ground plane

**Figure 3.2** shows the current distribution on a helical antenna structure at an operating frequency of **10 GHz**. The visual representation illustrates how current flows along the helical wire, which is crucial for understanding the radiation characteristics and performance of the antenna.

The circular disk at the base represents the metallic ground plane with a radius of 19.1 mm. It provides a reflective surface, improving impedance matching and directing radiation along the positive Z-axis. This distribution confirms axial-mode operation, where radiation is emitted along the helix axis (Z-axis) with circular polarization.



*Figure 3.2: Current distribution on a helical antenna structure*

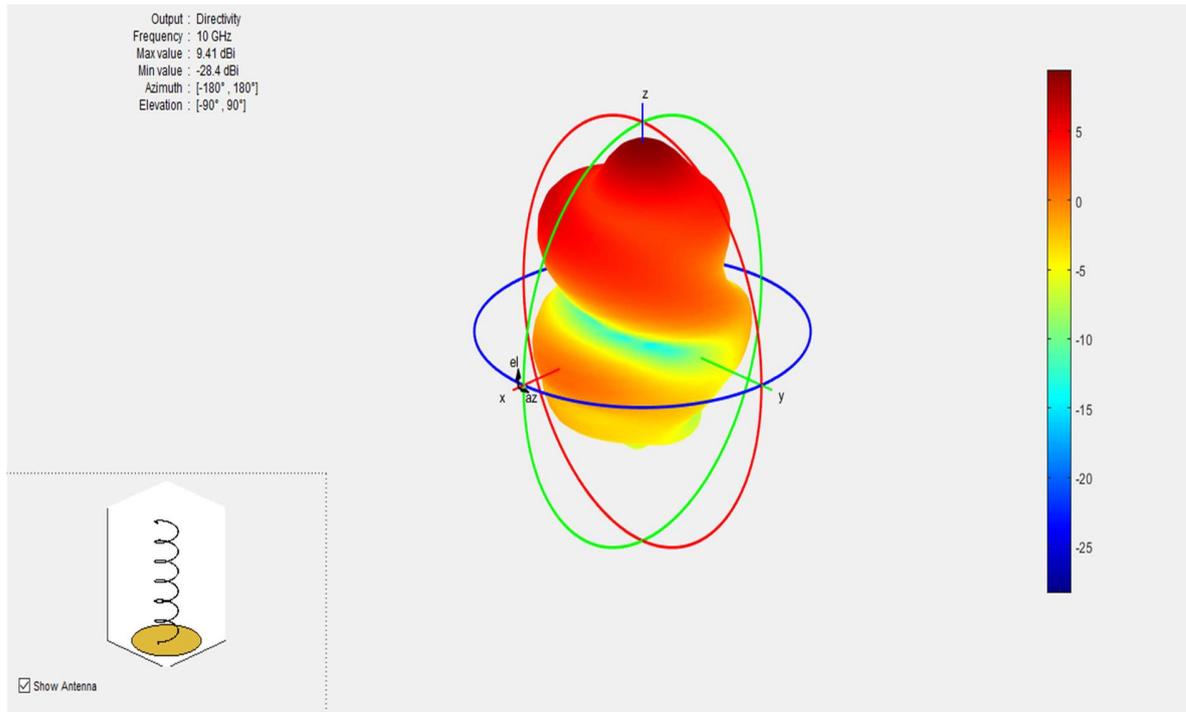
### 3.3.3 3D Radiation pattern of a helical antenna

**Figure 3.3** illustrates the 3D directivity radiation pattern of a helical antenna operating at **10 GHz**, displaying the spatial distribution of radiated power.

#### A- Simulation Parameters

- Output : **Directivity**
- Operating Frequency : **10 GHz**
- Maximum Directivity : **9.41 dBi**

- Minimum Value : **-28.4 dBi**
- Azimut Range : **-180° to 180°**
- Elevation Range : **-90° to 90°**



*Figure 3.3: 3D directivity radiation pattern of a helical antenna*

### B- Radiation pattern analysis

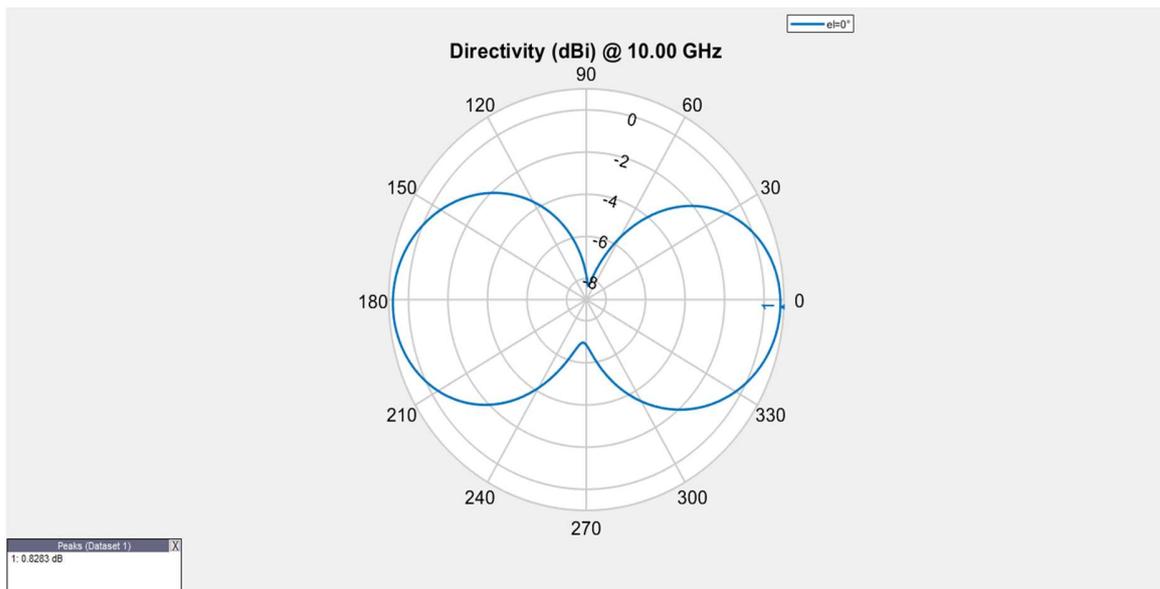
- The radiation pattern is shown in a spherical 3D plot, where the color scale indicates directivity in dBi.
- The main radiation lobe is directed along the Z-axis (upward), indicating that the antenna operates in axial mode, typical of helical antennas designed for circular polarization.
- The pattern is relatively symmetrical around the Z-axis, further confirming good axial-mode behavior and directional radiation properties.

#### 3.3.4 Directivity pattern of an antenna

**Figure 3.4** shows a polar plot of the radiation pattern (directivity in dBi) of an antenna at **10 GHz**.

- The plot shows the azimuthal radiation pattern (horizontal cut, elevation = 0°) of the helical antenna at 10 GHz.

- The shape of the plot is figure-eight (or two-lobed), typical of normal mode radiation where the radiation is strongest perpendicular to the helix axis.

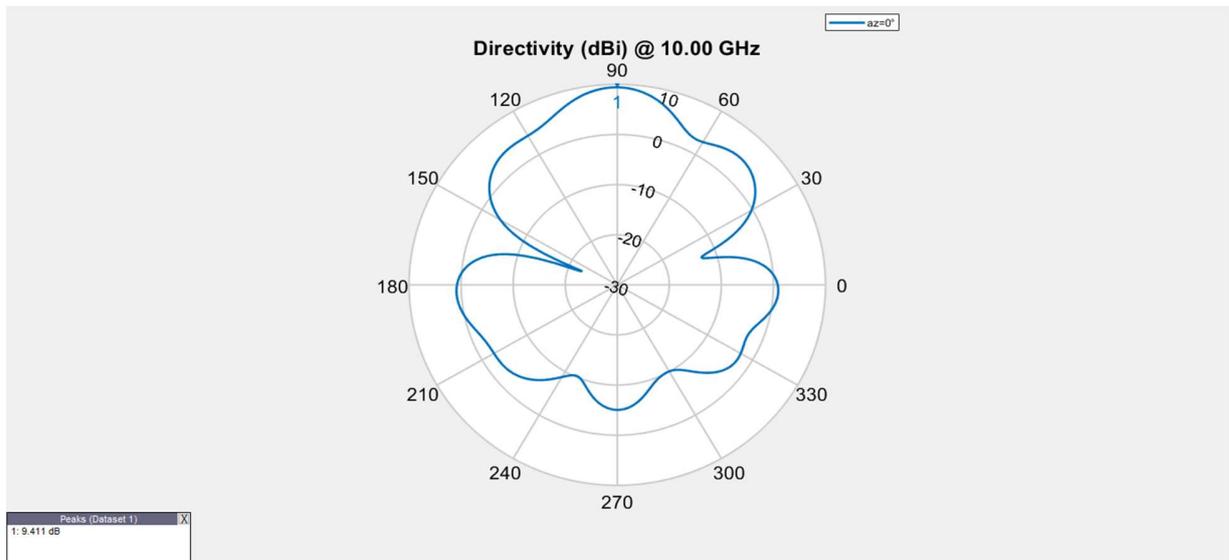


*Figure 3.4: polar plot of the radiation pattern*

- The antenna exhibits bidirectional radiation, which is typical for dipoles or similarly symmetric antennas in free space or simple environments.
- The relatively low maximum directivity (0.8283 dBi) suggests this is not a highly directional antenna, but rather one with broad coverage in the horizontal plane.
- This kind of pattern may be suitable for applications like broad-area coverage, indoor antennas, or omnidirectional systems in 3D when combined with vertical patterns.

### 3.3.5 Antenna directivity plot (azimuth)

- The peak radiation occurs along the axis of the helix, which is typical of axial mode operation.
- The directivity of 9.41 dBi confirms this — axial mode helices usually provide 7–15 dBi gain.
- The main lobe is well-formed and relatively narrow, consistent with directional radiation.

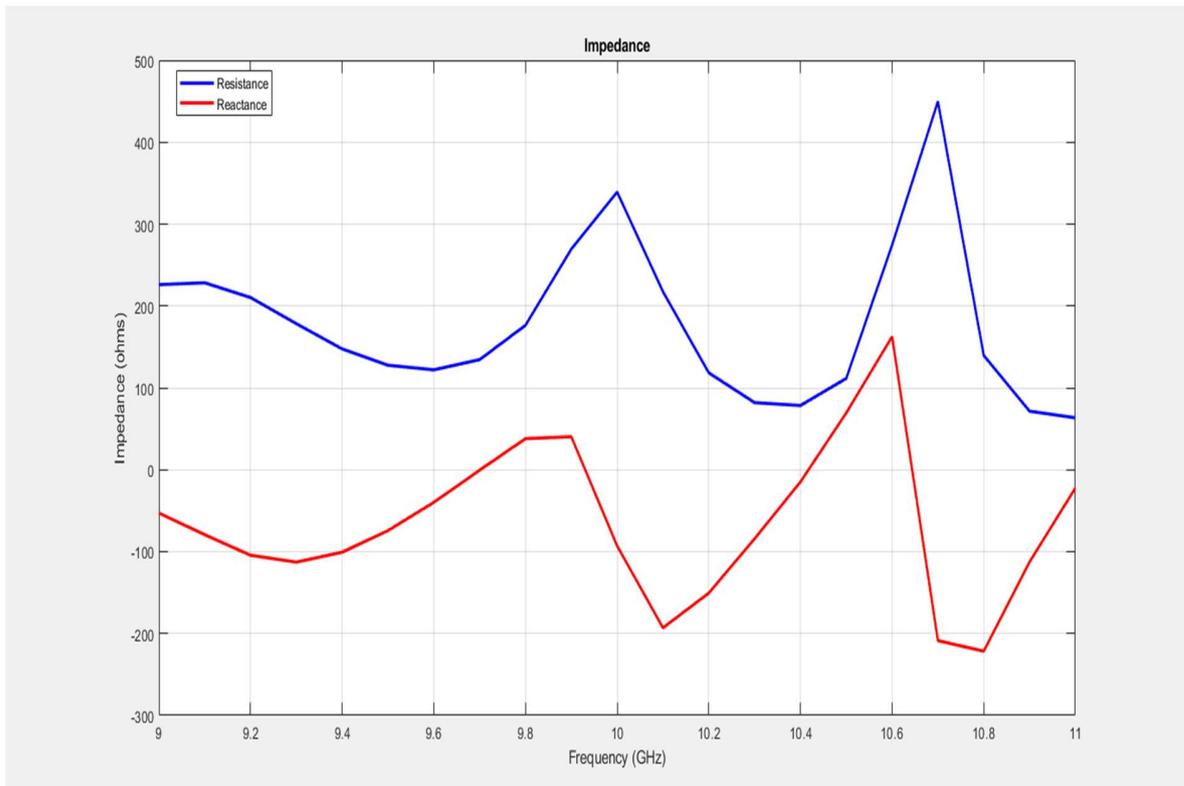


*Figure 3.5: Antenna directivity plot (azimuth)*

### 3.3.6 The Impedance plot

**Figure 3.6** plot shows how the input impedance (both resistance and reactance) of helical antenna varies over a frequency range from 9 GHz to 11 GHz.

This means the antenna is not yet matched to 50  $\Omega$  at 10 GHz. The real part is high, and the negative reactance indicates capacitive behavior at this frequency.



**Figure 3.6:** Input impedance of helical antenna

### A- Impedance Matching

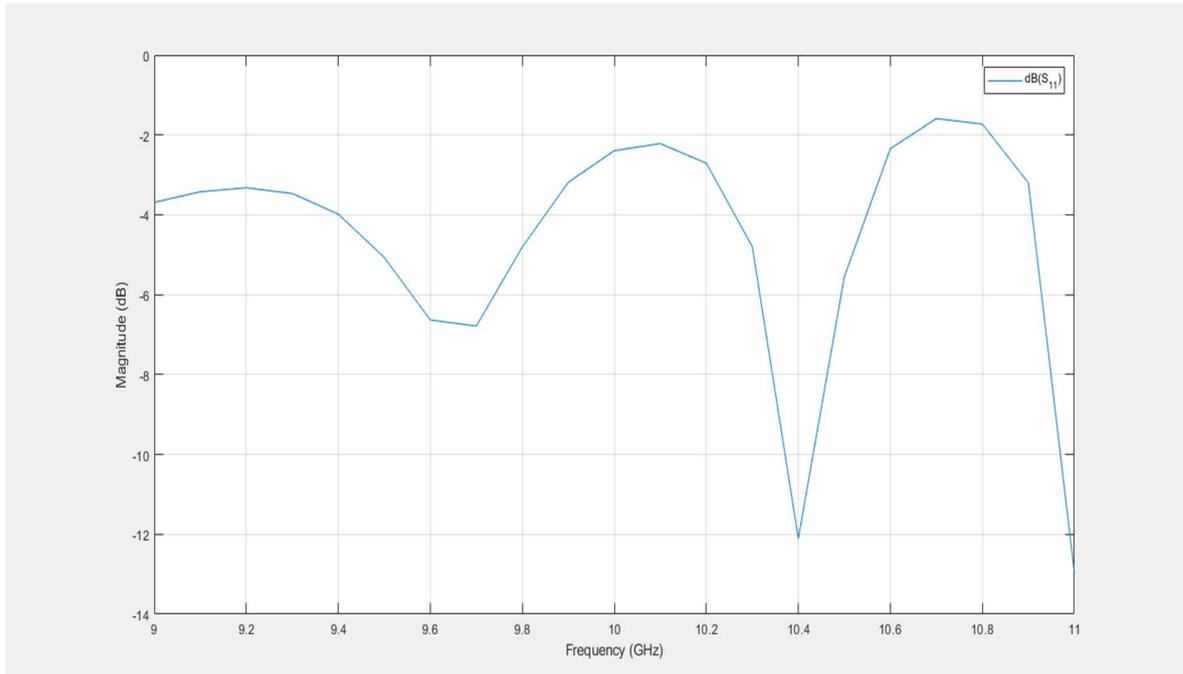
- For efficient power transfer, the input impedance of the antenna should be close to the system impedance (commonly  $50 \Omega$ ).
- At 10 GHz :
  - The mismatch is significant ( $Z \approx 340 - j120 \Omega$ )
  - This would result in high reflection (S11) and poor matching unless a matching network is used

### B- Resonance Behavior

- The impedance trace shows multiple resonant points, particularly:
  - Around 9.9 GHz and 10.6 GHz, where the reactance crosses zero
  - These are candidate frequencies for resonance
- At  $\sim 10.6$  GHz, the resistance peaks and the reactance flips sign quickly — likely a series resonance.

### 3.3.7 $S_{11}$ parameter plot

Figure 3.7 represents the  $S_{11}$  parameter (return loss) in dB versus frequency (GHz).



*Figure 3.7 :  $S_{11}$  Parameter Plot*

#### A-Description

- Y-Axis (Magnitude in dB): This shows the reflection coefficient  $S_{11}$ , which indicates how much power is reflected back from the antenna input.
  - Lower (more negative) values mean better impedance matching and more power being radiated or transmitted.
- X-Axis (Frequency in GHz): Ranges from 9 GHz to 11 GHz, covering a typical X-band range.

The plot shows multiple dips in the  $S_{11}$  curve, with two significant resonances:

- Around 10.4 GHz and 11 GHz, where the  $S_{11}$  drops to below -12 dB, indicating strong resonance and good matching at these frequencies.
- Other dips are shallower but still relevant, indicating potential harmonic or weaker resonances.

### B-Interpretation

- The antenna shows good performance around 10.4 GHz and 11 GHz, as evidenced by  $S_{11}$  values less than -10 dB.
- The presence of multiple dips in  $S_{11}$  suggests multi-resonant behavior, which can be typical for spiral or helical antennas due to the multiple current paths and self-resonance characteristics.
- Slight mismatch at 10 GHz implies further tuning might be needed if the goal is optimal performance precisely at 10 GHz.

### 3.4 Conclusion

This chapter has presented a simulation-based analysis of a helical antenna designed for operation at 10 GHz using MATLAB's Antenna Designer tool. The simulations gave the antenna's directional behavior, circular polarization, and performance under different configurations.

Key results include the visualization of the 3D current distribution, which confirms axial-mode operation with radiation directed along the helix axis. The 3D radiation pattern, with a maximum directivity of 9.41 dBi, further supports this, highlighting the antenna's suitability for applications requiring high gain and focused radiation, such as satellite and wireless communication systems.

The impedance analysis revealed some mismatch at 10 GHz ( $Z \approx 340 - j120 \Omega$ ), suggesting that an appropriate matching network would be required for optimal performance. However, multiple resonances were observed in the  $S_{11}$  plot, especially around 10.4 GHz and 11 GHz, where return loss values dropped below -12 dB, indicating efficient energy transmission.

The polar plots and azimuthal directivity confirmed both axial and normal mode behavior, depending on the observed cross-sections, and illustrated the antenna's ability to cover different radiation profiles. This dual-mode versatility further validates the adaptability of the helical antenna in diverse practical environments.

Overall, the simulation results are in strong agreement with theoretical expectations and demonstrate the helical antenna's potential as a robust and efficient solution in high-frequency and circularly polarized systems.

# **General Conclusion**

## General Conclusion

In this final-year project, a study into the design, modeling, and simulation of the **helical antenna** has been carried out, with the objective of understanding its theoretical foundation, practical behavior, and applicability in modern wireless communication systems.

The helical antenna, introduced by John D. Kraus, remains a cornerstone in antenna engineering due to its unique capability to **generate circular polarization**, support **broadband operations**, and offer **high gain**, particularly in **axial mode**. These characteristics make it exceptionally suitable for demanding applications such as **satellite communication, aerospace systems, telemetry, GPS, RFID, and UHF/VHF systems** where polarization diversity, reliability, and signal integrity are essential.

Throughout this work, we first explored the **general characteristics** of the helical antenna, including its structure, operation modes, and practical uses. The **dual radiation modes**—normal and axial—were discussed, showcasing the antenna's flexibility across different operating environments. A clear understanding of the advantages and limitations of the helical design was established, providing a balanced view of its performance capabilities.

In the modeling phase, theoretical formulations were introduced to describe the antenna's **electromagnetic behavior**, based on classical antenna theory. The analysis considered small loop approximations, radiation patterns, directivity, impedance, and polarization properties in both operating modes. This provided the necessary analytical framework to support simulation and design optimization.

The simulation phase, conducted using **MATLAB's Antenna Designer Toolbox**, enabled validation of theoretical principles. Detailed 3D models were created, and key performance parameters such as **return loss ( $S_{11}$ ), impedance characteristics, current distribution, and radiation patterns** were obtained. The simulation results confirmed that the helical antenna, when carefully designed, performs optimally in the desired frequency range (10 GHz in this case), particularly in **axial mode**, where it exhibited a **maximum directivity of 9.41 dBi** and a well-focused radiation pattern along the helix axis.

**Future perspectives** include the integration of advanced optimization algorithms for automatic tuning, exploration of **multi-band or dual-polarized helical designs**, and experimental validation through **prototyping and measurement in anechoic chambers**. Additionally, the use of other

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simulation platforms or full-wave solvers such as CST or HFSS could provide more detailed electromagnetic analysis.

# References

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