A Project Report on

INVESTIGATIONS ON SPIRAL ANTENNAS

Submitted in partial fulfilment of the

requirements for the award of the degree

of

BACHELOR OF TECHNOLOGY

in

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by:

Parikshit Ramchandra Sahu (20116059)

Radha Chaurasiya (20116075)

Under the guidance of:

Prof. Utpal Dey

Department of Electronics and Communication Engineering

Indian Institute of Technology Roorkee

May 2024

DECLARATION

We hereby declare that the work which is being presented in this report entitled **“INVESTIGATIONS ON SPIRAL ANTENNAS”** in partial fulfilment of the requirements for the award of the degree of **BACHELOR OF TECHNOLOGY** in **Electronics and Communication Engineering** to the Department of Electronics and Communication Engineering, Indian Institute of Technology Roorkee is an authentic record of our own work carried out under the supervision of Prof. Utpal Dey, Department of Electronics and Communication Engineering, Indian Institute of Technology Roorkee. This work has been done from November 2023 to May 2024. We have not submitted the matter embodied in this report for the award of any other degree or diploma.

Date: 11 May 2024

Place: Roorkee

Parikshit Ramchandra Sahu	**Radha Chaurasiya**
(20116059)	(20116075)

CERTIFICATE

This is to certify that the project report entitled **"INVESTIGATIONS ON SPIRAL ANTENNAS"** submitted by *Parikshit Ramchandra Sahu* and *Radha Chaurasiya* to the Department of Electronics and Communication Engineering, Indian Institute of Technology Roorkee toward partial fulfilment of the requirements for the degree of **BACHELOR OF TECHNOLOGY** in **Electronics and Communication Engineering** is a record of bonafide work carried out under my supervision and guidance.

Date: 11 May 2024

Place: Roorkee

Prof. Utpal Dey
Assistant Professor
Department of Electronics and Communication Engineering
Indian Institute of Technology Roorkee

ACKNOWLEDGEMENT

We stretch out our genuine appreciation to every one of the people who have added to this B.Tech project on "Investigations on Spiral Antennas".

We, first and foremost, might want to communicate our most profound appreciation to our undertaking guide Prof. Utpal Dey and Suman Ma'am, whose direction, ability, and immovable help were instrumental in forming the course of this examination. The important experiences and valuable criticism gave all through the venture essentially enhanced its quality.

We are likewise appreciative to the employees of the Dept. of Electronics and Communications Engineering for their consolation and for encouraging a climate helpful for scholarly investigation.

Extraordinary thanks are because of Indian Institute of Technology Roorkee for giving admittance to fundamental assets, including the library, research centers, and recreation programming, which were essential for the fruitful execution of this venture.

This undertaking has been a huge opportunity for growth, and every individual referenced play had a significant impact in its effective fruition. Many thanks to you for being a piece of this scholastic undertaking.

ABSTRACT

The fast progression of correspondence frameworks requires the improvement of effective and flexible antennas. This B.Tech project centers around the plan and execution investigation of spiral antennas, investigating their appropriateness for different correspondence applications. Spiral antennas, described by their reduced size and broadband capabilities, offer huge benefits in present day remote communication. The task starts with a prologue to the basic standards of antennas and the one-of-a-kind elements of spiral antennas. A far-reaching writing survey gives experiences into the verifiable turn of events, various sorts, and past examination concentrates on connected with spiral antennas. The essential goals of the project incorporate designing spiral antennas for explicit frequency bands and directing a careful performance analysis.

Strategically, the project includes the utilization of advanced simulation tools for the design optimization of spiral antennas. Results got from simulations and estimations are introduced and investigated. Key execution measurements, for example, gain, radiation pattern, and impedance matching are examined, giving a premise to correlation between various spiral antenna models. The discussion section deciphers these outcomes, featuring the qualities and constraints of the designed antennas and contrasting discoveries and existing writing.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Introduction

1.1. Background and Significance

The advancement of correspondence and radar frameworks has prodded the requirement for antennas that can fulfill the needs of present-day applications. Spiral Antennas have acquired unmistakable quality because of their one-of-a-kind mathematical design and related electromagnetic properties. The winding design offers benefits like broadband qualities, smaller size, and omnidirectional radiation pattern, making them reasonable for a great many frequencies and applications.

The idea of spiral antennas goes back quite a few years, with introductory plans essentially centered around radar applications. After some time, their true capacity has been perceived for different correspondence frameworks, satellite correspondence, RFID (Radio Frequency Identification), and remote sensor organizations. The twisting shape considers a more productive utilization of space and is innately appropriate for applications requiring minimal and lightweight antennas.

Broadband Capabilities: One of the huge benefits of spiral antennas is their capacity to work over a wide frequency range. This makes them ideal for applications where a wide bandwidth is significant, like in current communication frameworks where numerous administrations work at the same time.

Compact Size: The small size of spiral antennas is especially important in circumstances where space is a restricting element. In satellite communication, for instance, where payload size and weight are basic, spiral antennas offer an answer for accomplishing proficient communication inside restricted spatial requirements.

Omnidirectional Radiation: The omnidirectional radiation patterns of spiral antennas make them reasonable for applications requiring 360-degree inclusion. This trademark is fundamental in situations where signal receiving or transmission should be autonomous of the antenna’s orientation, like in portable specialized gadgets.

Versatility in Design: Specialists can investigate different plan boundaries of spiral antennas, including the quantity of turns, pitch angle, and diameter, to tailor their presentation for explicit applications. This flexibility is urgent in gathering the assorted necessities of various communication and detecting frameworks.

Integration with Advanced Technologies: Examinations on spiral antennas additionally include their integration with cutting edge materials and advances, for example, metamaterials and frequency selective surfaces. This coordination intends to upgrade antenna execution, giving open doors to advancement and beating restrictions related with traditional antenna designs.

Challenges and Solutions: The examination concerning spiral antennas incorporates addressing difficulties connected with impedance matching, radiation efficiency, and polarization attributes. Specialists try to overcome these difficulties through hypothetical demonstrations, simulations, and practical trials, adding to the progression of antenna innovation.

1.2 Objectives of Study

The goals concentrating on spiral antennas can be different, contingent upon the objectives, applications, and difficulties designated by the exploration. Here are a few normal goals that scientists could seek after in a concentrate on spiral antennas:

Characterization of Electromagnetic Properties: Direct a comprehensive investigation to comprehend the electromagnetic properties of spiral antennas, including impedance, radiation pattern, polarization, and gain, across various frequency bands.

Optimization of Design Parameters: Examine the effect of design parameters, for example, the quantity of turns, pitch angle, and measurement on the exhibition of spiral antennas. Upgrade these boundaries to accomplish wanted qualities, like improved bandwidth, further developed radiation efficiency, and explicit polarization.

Broadband Performance Assessment: Assess the broadband capacities of spiral antennas and recognize techniques to upgrade their bandwidth. Examine methods for accomplishing steady execution over a wide range of frequencies to satisfy the needs of present-day communication frameworks.

Integration with Advanced Materials: Investigate the reconciliation of spiral antennas with cutting edge materials, for example, metamaterials or frequency selective surfaces, to work on their exhibition. Research how these materials can add to scaling down, gain upgrade, and other helpful antenna qualities.

Comparison with Traditional Antennas: Lead a near examination between spiral antennas and conventional antennae designs to feature the benefits and impediments of spiral antennas in various situations. This could include evaluating factors like size, weight, and execution measurements.

Practical Prototyping and Testing: Manufacture models of spiral antennas in light of enhanced plans and lead viable testing. Approve hypothetical models and reenactment results through simulations, guaranteeing that the antennas proceed true to form in reasonable applications.

Application-specific Investigations: Investigate the appropriateness of spiral antennas for explicit applications like communication, radar frameworks, satellite communication, RFID, or remote sensor organizations. Tailor the examinations to address the interesting prerequisites of every application and propose design alterations as needs be.

Environmental Considerations: Explore the effect of natural elements, like temperature, stickiness, and encompassing designs, on the exhibition of spiral antennas. Comprehend how these antennas act in certifiable circumstances to guarantee their dependability and stability.

Development of Design Guidelines: Infer plan rules and proposals in light of the review's discoveries. Give viable experiences to specialists and analysts chipping away at the execution of spiral antennas in different applications.

Future Trends and Innovations: Investigate arising patterns and likely developments in the field of spiral antennas. Recognize regions for future innovative work, taking into account mechanical headways and advancing prerequisites in communication and detecting frameworks.

1.3 Limitations

Size Constraints: Notwithstanding being small compared with some traditional antennas, spiral antennas might in any case have constraints concerning size, particularly for applications where space is very limited.

Bandwidth Limitation: While spiral antennas are known for their broadband abilities, there might be difficulties in accomplishing ideal execution across very wide frequency ranges. Designing spiral antennas with reliable and high gain over a broad bandwidth is in fact a challenge.

Directional Characteristics: While spiral antennas for the most part show omnidirectional radiation designs, in certain designs, there may be limits in accomplishing perfect symmetry.

Complex Design Optimization: Accomplishing the ideal plan for a spiral antenna can be many-sided, including different boundaries, for example, the quantity of turns, pitch angle, and diameter. Design optimization may require progressed computational apparatuses and might time-consume.

Susceptibility to Environmental Factors: The exhibition of spiral antennas can be impacted by ecological factors like temperature, mugginess, and close by structures. Changes in natural circumstances might affect the antenna's impedance matching, radiation pattern, and in general efficiency.

Integration Challenges: Integrating spiral antennas with other electronic components or devices can pose challenges. Achieving seamless integration, especially in compact electronic systems, may require additional engineering efforts and considerations.

Limited Power Handling Capacity: Spiral antennas might have impediments as far as power handling capacity, especially when contrasted with specific kinds of directional antennas. This impediment can affect their stability for high-power applications.

Manufacturing Complexity: Creating spiral antennas with accuracy and consistency might be more complicated than assembling some traditional antennas. This complexity can bring about expanded creation expenses and expected difficulties in large scale manufacturing.

Chapter 2

Literature Review

2.1 Historical Development of Spiral Antennas

The authentic improvement of Spiral Antennas has been set apart by both numerical headways and hypothetical bits of knowledge. Here are brief subtleties illustrating the key achievements:

1940s: Early Concepts and Mathematical Foundations- The idea of Spiral Antennas can be followed back to the early 1940s with crafted by John Kraus, who investigated the radiation properties of helical antennas. Kraus' work established the numerical starting point for grasping the way of behaving of spiral antennas.

1950s and 1960s: Theoretical Advancements and Experimental Studies- The 1950s and 1960s saw huge progressions in the hypothetical comprehension of spiral antennas, especially as far as their electromagnetic properties and radiation designs. Analysts like Eikichi Yamashita, Edward Hallen, and Robert Harrington made huge commitments to this field.

Close by hypothetical turns of events, trial studies were directed to approve the hypothetical expectations and explore the reasonable exhibition of spiral antennas. These examinations uncovered the wideband qualities and polarization adaptability of spiral antennas, making them allure for different applications.

1990s and Beyond: Numerical Simulations and Advanced Optimization- The advent of powerful computers and advanced numerical simulation tools during the 1990s changed the investigation and plan of spiral antennas. These apparatuses empowered designers to mimic the way of behaving of mind-blowing aperiodic designs and advance antenna execution all the more successfully.

This era likewise saw further advancements in hypothetical comprehension and experimental studies of spiral antennas. Researchers explored new design concepts, investigated novel applications, and delved further into the electromagnetic properties of these antennas. Today, spiral antennas continue to play a vital role in various fields, and research is still ongoing to further enhance their performance and expand their applicability.

2.2 Basic Parameters

2.2.1 Geometric Parameters:

Number of Turns: The number of turns in a spiral antenna affects its size, directivity, and impedance. Understanding how variations in the number of turns affect the antenna's performance is crucial for design enhancement.

Arm Length: The size of each arm in the spiral structure affects the overall dimensions of the antenna. Exploring the effects of non-uniform arm lengths is crucial for understanding how variations in this parameter affect the antenna's radiation pattern.

Spacing Between Turns: The distance between successive turns plays a vital role in determining the spatial distribution of the antenna. Investigating irregular spacing between turns can give insights into the impact on radiation patterns and impedance.

2.2.2 Electromagnetic Parameters:

Radiation Pattern: The radiation pattern of a spiral antenna depicts the distribution of radiated energy in space. Looking at how varieties in mathematical boundaries impact the shape and characteristics of the radiation pattern is fundamental for enhancing execution.

Impedance Matching: Accomplishing impedance matching guarantees proficient power move between the antenna and the transmission line. Researching what different mathematical arrangements mean for impedance matching is vital for improving the antenna's exhibition.

Frequency Response: Understanding the recurrence reaction of a spiral antenna includes investigating its conduct across a scope of frequencies. Varieties in mathematical boundaries can influence the antenna's reverberation and data transmission, influencing its reasonableness for various applications.

These subtopics dig into the principal geometric and electromagnetic parameters of spiral antennas, providing an establishment for understanding how varieties in these parameters influence the antenna's performance and behavior.

2.3 Current State of Spiral Antenna Research

5G and Beyond:

Millimeter-Wave Frequency Optimization: Current research in spiral antennas for 5G and beyond includes enhancing plans for millimeter-wave frequencies, tending to the novel difficulties presented by these higher recurrence groups. Specialists are investigating novel spiral antenna setups and materials to accomplish proficient and dependable correspondence in millimeter-wave 5G applications.

Integration in Massive MIMO and Beamforming: spiral antennas are being researched for their reasonableness in Massive Multiple Input Multiple Output (MIMO) frameworks and beamforming applications inside 5G organizations. Scientists might be investigating the way in which the unique radiation patterns of spiral antennas can be utilized for directional correspondence and worked on ghastly proficiency in the developing scene of 5G and beyond.

IoT and Wireless Sensor Networks:

Miniaturization and Integration for IoT Devices: Current research in spiral antennas for IoT and wireless Sensor Networks (WSNs) centers around miniaturization and integration strategies. Researchers are investigating ways of designing compact and energy-efficient spiral antennas reasonable for small IoT devices and wireless sensors, empowering consistent reconciliation into different IoT form factors.

Adaptation to Environmental Constraints: Exploring how spiral antennas can adjust to the natural limitations frequently experienced in IoT and WSN organizations. This includes designing antennas that are versatile to ecological factors like temperature varieties and impedance, guaranteeing dependable and stable activity in different and testing conditions.

Metamaterial Integration:

Researchers are investigating the integration of metamaterial structures to accomplish further developed gain, bandwidth, and radiation qualities. Metamaterials offer remarkable electromagnetic properties not tracked down in regular materials, and their consolidation into spiral antennas could prompt upgraded functionalities.

Areas of interest include accomplishing frequency-selective behavior, decreasing common coupling in antenna arrays, and making custom-made electromagnetic responses for explicit applications. Analysts may likewise be investigating the viable execution of metamaterial-coordinated spiral antennas in genuine situations, addressing difficulties connected with creation, versatility, and natural heartiness.

Machine Learning and Optimization:

The present state of spiral antenna research with an emphasis on machine learning and optimization includes the use of cutting-edge computational strategies to enhance the plan, execution, and organization of spiral antennas. Researchers might be investigating the way that machine learning algorithms can help with automating the antenna design process, fine-tuning parameters, and anticipating the predicting the performance of complex designs.

Streamlining techniques in light of machine learning might be utilized to upgrade the proficiency, bandwidth, and other key characteristics of spiral antennas. Moreover, machine learning calculations could support the examination of huge datasets connected with antenna execution, ecological circumstances, and client prerequisites, directing the advancement of versatile and clever antenna systems.

Environmental Considerations:

Impact Analysis and Mitigation Strategies: Current research on spiral antennas and environmental considerations includes a point-by-point investigation of the effect of temperature, dampness, and other natural variables on antenna performance. Researchers are creating relief techniques, like the utilization of specific materials or coatings, to upgrade the antennas' resilience and reliability in fluctuating environmental conditions.

Real-World Testing and Simulation: Researchers are directing broad certifiable testing and reenactments to comprehend how spiral antennas act in various natural situations. This reminds them to assess their presentation for outside arrangements and guaranteeing that the antennas meet the functional necessities under changing ecological circumstances. The objective is to give commonsense bits of knowledge to the organization of spiral antennas in diverse ecological settings.

Chapter 3

Simulation in CST Studio Suite

3.1. Proposed System Design

In the proposed antenna design, the Archimedean spiral antenna with two-arm structure is proposed. Rogers with dielectric constant $\varepsilon_r = 3$ was chosen as substrate. The antenna operation covers the frequency range from 10.1 GHz to 11.75 GHz. In this antenna, the polarization, radiation pattern and impedance remain unchanged over large bandwidth.

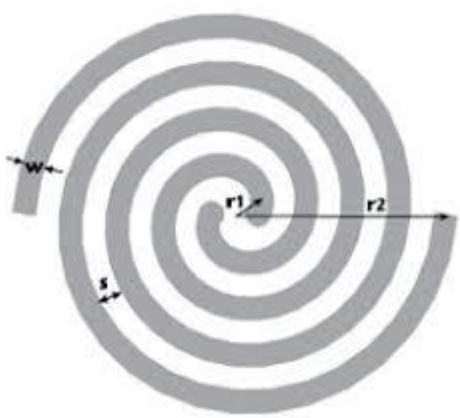

Figure 1 Geometry of Archimedean Spiral Antenna

In Archimedean spiral antenna, each arm is linearly proportional to the angle, and is described by the following relationships.

$$r = r_0\varphi + r_1$$

$$r = r_0(\varphi - \pi) + r_1$$

The proportionality constant of the Archimedean spiral is determined by,

$$r_0 = \frac{s + \pi}{2}$$

In the previous model, we had made an antenna with a rectangular cross section, which gave satisfactory results but could not be improved any further. This time for our own unique antenna we decided to make it with a circular cross section, and upon simulation for various combinations these were the values we ended up with:

Design parameters for spiral arms:

Parameter	Value
Inner Radius	4.5 mm
Cross section radius	3 mm
Number of Turns	1.5
Spacing width	8.5 mm
Winding Progress	25.5 mm

The substrate has a radius of 55mm and height 1mm.

Feeding mechanism: Carrying out a differential feed for an antenna utilizing SMA connectors includes providing equivalent size however oppositely phased transmissions to the antenna components, a design decided to upgrade performance by limiting common mode noise and working on signal integrity. SMA connectors act as the point of interaction between the transmission lines and the antenna, giving a small and reliable association reasonable for high-frequency applications. The plan integrates impedance matching considerations, likely utilization of baluns for conversion, and cautious design to protect the differential sign integrity.

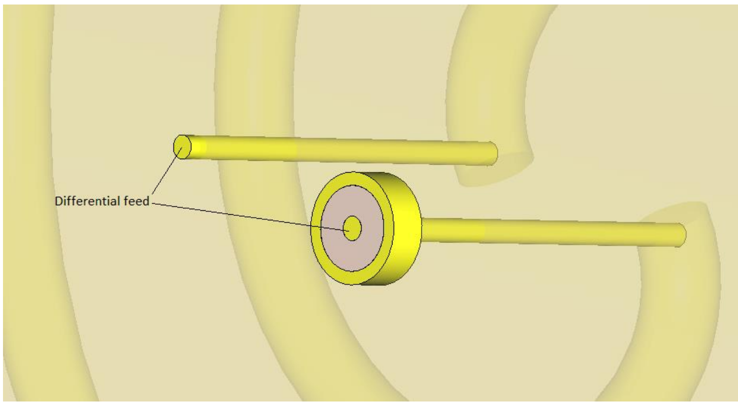

Figure 2: Coaxial cable in CST

3.2. Investigations and Key Findings

Here are the key findings on how the radius and width of a spiral antenna affect its performance, as well as the effects of the substrate and ground plane:

Inner Radius: Expanding the range of a spiral antenna for the most part builds its directivity and gain, yet it likewise diminishes its bandwidth. A bigger radius brings about a more drawn-out radiation way, prompting a more engaged radiation design and higher directivity. Nonetheless, an expanded span additionally increases the antenna's inductance, which can bring down its resonant frequency and lessen its working data transfer capacity. Hence, there is a compromise among directivity and bandwidth while planning a spiral antenna concerning its inner radius.

Cross-section Radius: A bigger span for the most part upgrades gain, limits the beamwidth, and widens the bandwidth. This adds to further developed directivity and resonance frequency. Notwithstanding, cautious thought is expected to stay away from unnecessary side curves and keep up with impedance matching. Then again, smaller radii might offer benefits in compactness and simplicity of creation however may restrict bandwidth.

Substrate: The substrate material and thickness can fundamentally influence the exhibition of a spiral antenna, especially at lower frequencies. A thicker substrate with a higher permittivity can bring down the antenna's resonant frequency and lessen its bandwidth. Moreover, the substrate's dielectric losses can present extra attenuation, diminishing the antenna's efficiency.

Ground Plane: The presence of a ground plane can essentially impact the radiation pattern and impedance of a spiral antenna. A ground plane can give a reflective surface to the antenna's radiation, expanding its directivity and gain in the forward heading. Moreover, the ground plane can go about as an impedance-matching component, working on the antenna's efficiency and information power handling ability.

3.3. Simulation Results for second model

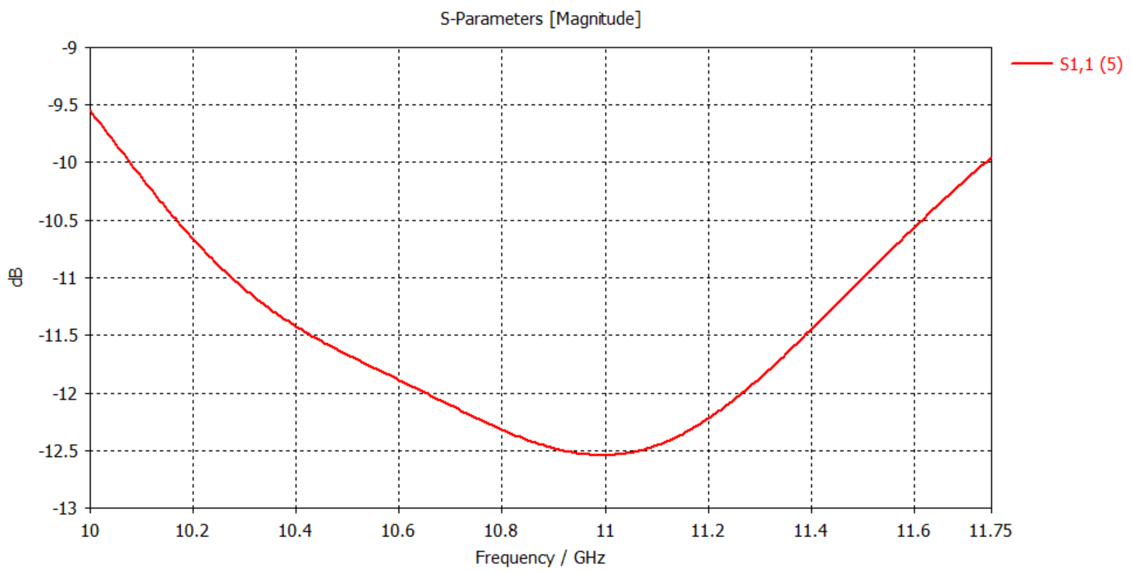

Figure 3: Input reflection coefficient

As can be seen from the figure, the input reflection coefficient of the antenna is below -10 dB over the entire frequency range. This indicates that the antenna is well-matched to the transmission line and that there is minimal reflection of power.

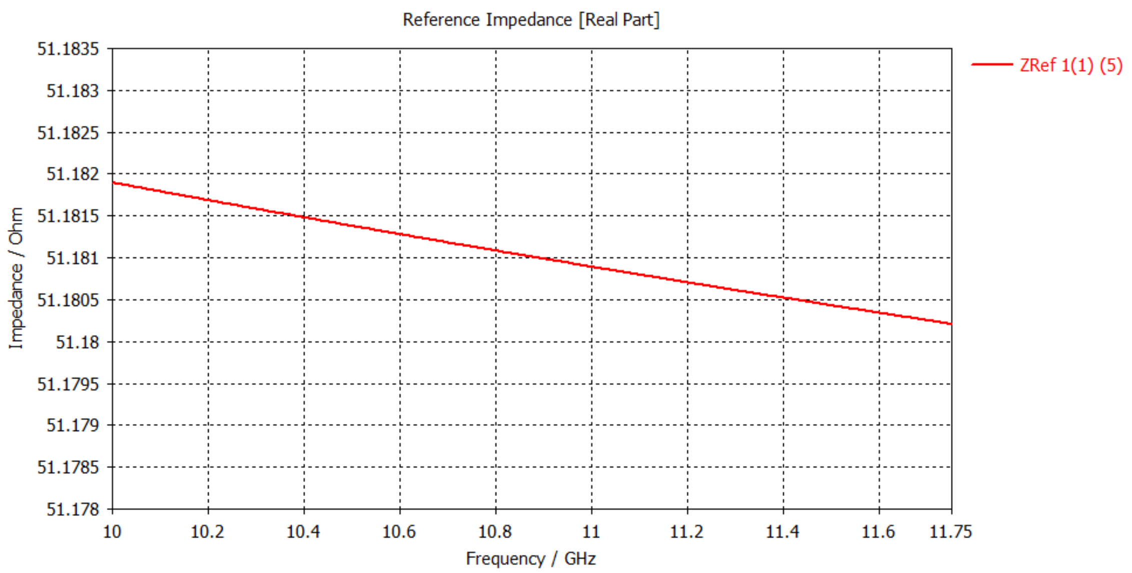

Figure 4: Reference Impedance

The reference impedance of the spiral antenna was matched to 50 ohms over the frequency range of 10.1 GHz to 11.75 GHz. The results are shown in Figure 3.

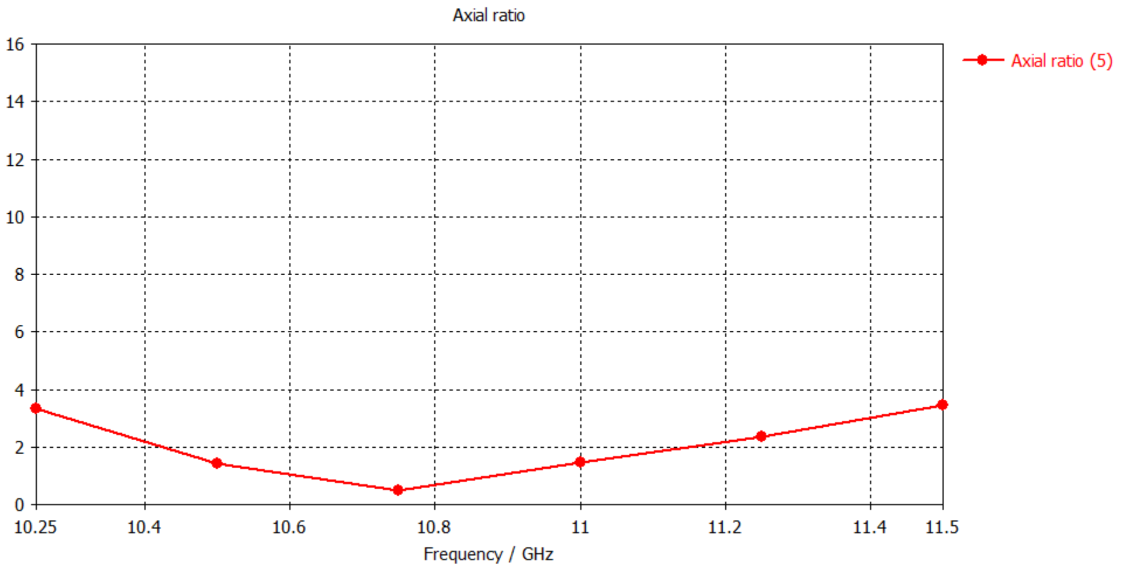

Figure 5: Axial Ratio

As can be seen from the figure, the Axial Ratio of the antenna is below 3dB for the range of 800 MHz. This indicates that the antenna can maintain a near circular polarization over this bandwidth.

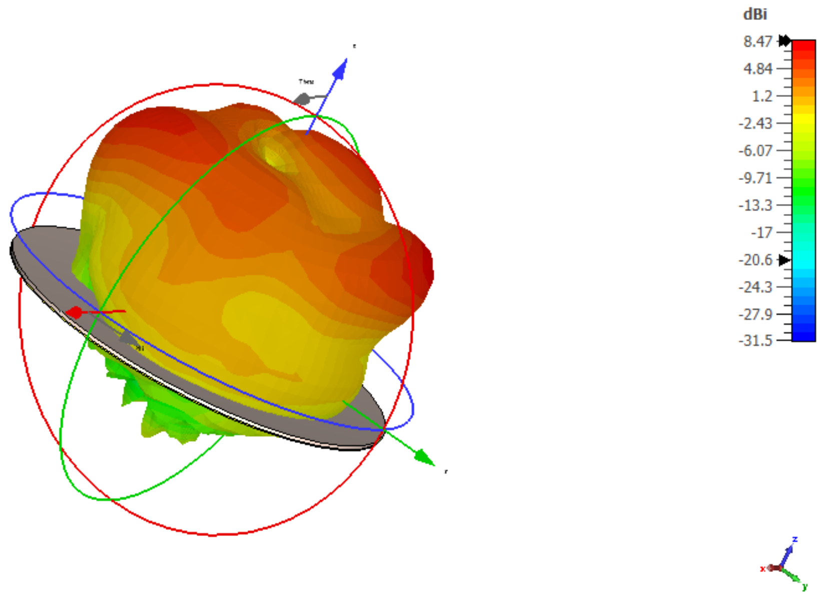

Figure 6: Farfield radiation pattern

3.4. Simulation Results for final model

There were two small issues with our previous model. First was that it was producing too many side lobes, and second that it had circular cross section which was not easy to fabricate. Thus we went on with our third and last model for this project, a log spiral antenna.

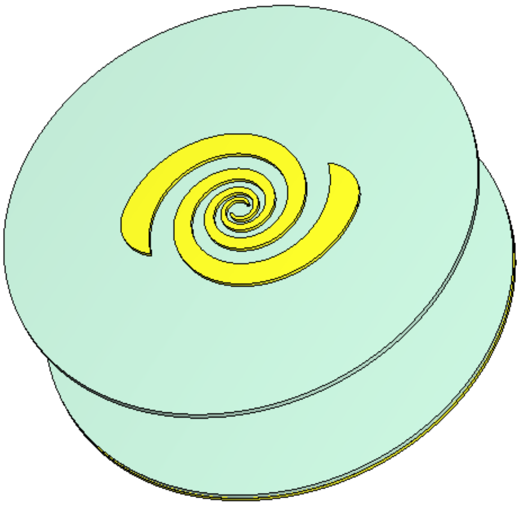

Figure 7: Logarithmic Spiral Antenna in CST

The input reflection coefficient were satisfactory for around 18% bandwidth.

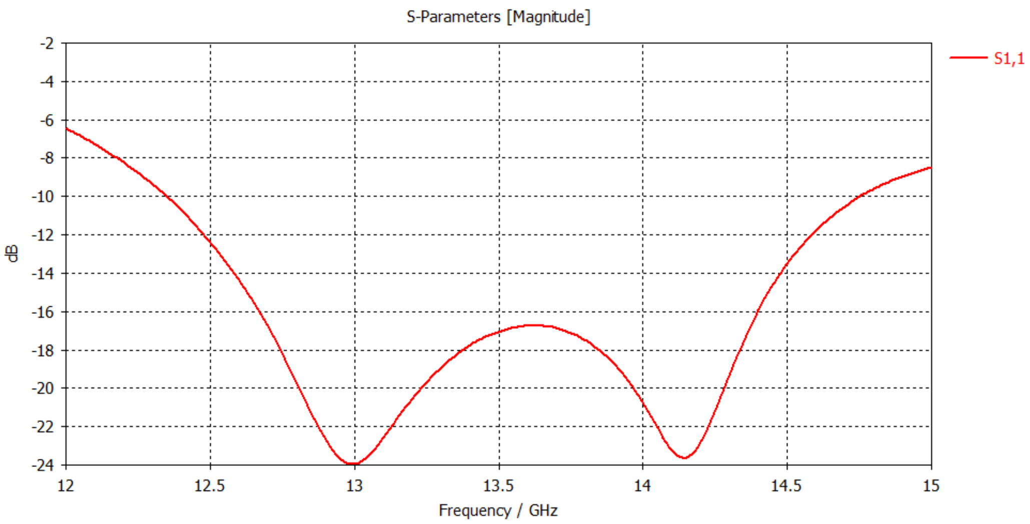

Figure 8: Input Reflection coefficient

The axial ratio results were good for around 12% bandwidth, which is the best one we've got until now.

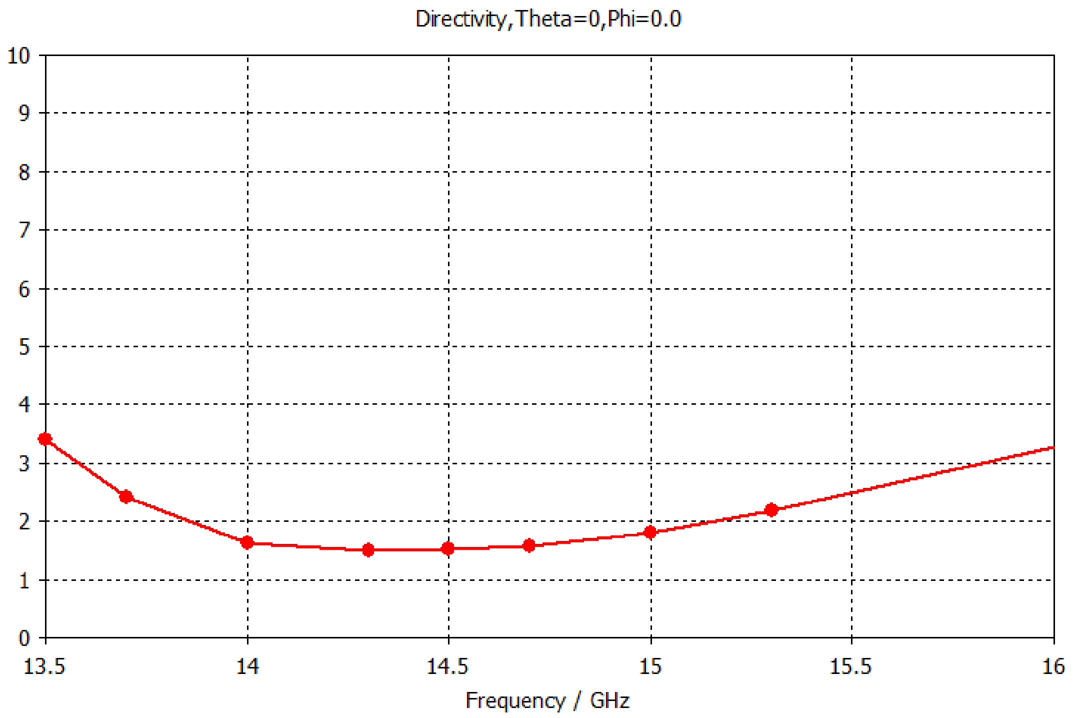

Figure 9: Axial Ratio

And finally, the radiation pattern was smooth without producing too many side lobes.

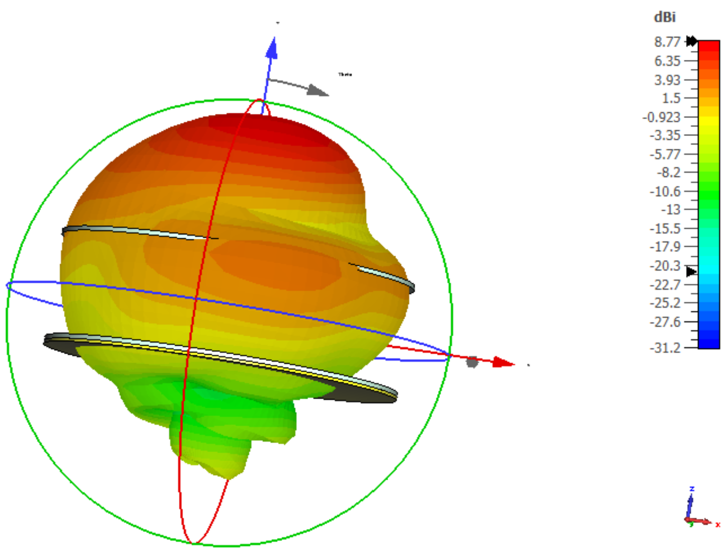

Figure 10: Radiation pattern

Chapter 4

Conclusion and Future Work

4.1. Summary and conclusion

The designed antenna was simulated over the frequency range 10.1 GHz to 11.75 GHz, and it is seen to give good outcomes for Input reflection coefficient, and Axial ratio. The performance of spiral antennas is impacted by different elements, including their mathematical geometry, substrate, ground plane, and feed system. Cautious enhancement of these boundaries is necessary for planning spiral antennas that meet explicit application prerequisites, adjusting aspects like directivity, gain, bandwidth, efficiency, and impedance.

Mathematical modelling techniques, like CST Studio Suite and HFSS, have become important instruments for upgrading the design and execution of spiral antennas. These product bundles empower engineers to simulate the antenna's radiation design, impedance, efficiency, and other execution parameters, working with the identification and solution of likely issues before creation.

4.2. Future Work

1. Developing new spiral antenna geometries: Investigations of novel spiral antenna geometries, such as fractal-based or multi-arm designs, could prompt upgraded performance characteristics, such as wider bandwidth, higher directivity, and improved polarization purity.

2. Improving the efficiency of spiral antennas: Investigation of strategies to upgrade the radiation efficiency of spiral antennas, such as optimizing conductor materials and substrate properties, could lead to more energy-proficient antenna systems.

3. Developing adaptive spiral antennas: Exploration of versatile spiral antenna designs that can progressively change their radiation pattern and polarization in light of environmental conditions or user requirements could enhance their flexibility and adaptability.

References

[1] Balanis, C.A. (2005) Antenna Theory: Analysis and Design. 3rd Edition, John Wiley & Sons, Hoboken.

[2] H. Nakano, K. Nogami, S. Arai, H. Mimaki and J. Yamauchi, "A spiral antenna backed by a conducting plane reflector," in IEEE Transactions on Antennas and Propagation, vol. 34, no. 6, pp. 791-796, June 1986, doi: 10.1109/TAP.1986.1143893.

[3] https://vtechworks.lib.vt.edu/bitstream/handle/10919/25963/Caswell_etd_Ch2.pdf

[4] https://apps.dtic.mil/sti/citations/ADA434995

[5] Mustafa, Ahmad & Mohamad, Sarah & Abdul Malek, Norun & Mohd Isa, Farah & Islam, Md. (2017). A wideband circularly-polarized spiral antenna for CubeSat application.

[6] https://www.researchgate.net/profile/Smrity-Dwivedi/post/Growing_Spiral_design_in_CST/attachment/5fbca279c4a92300010498b7/AS%3A961277740453889%401606197881305/download/2411.pdf

[7] S. Wang et al., "3-D Printed Zirconia Ceramic Archimedean Spiral Antenna: Theory and Performance in Comparison With Its Metal Counterpart," in IEEE Antennas and Wireless Propagation Letters, vol. 21, no. 6, pp. 1173-1177, June 2022, doi: 10.1109/LAWP.2022.3161004.

[8] A. A. Althuwayb, “Enhanced radiation gain and efficiency of a metamaterial-inspired wideband microstrip antenna using substrate integrated waveguide technology for sub-6 GHz wireless communication systems,” Microw., Opt. Technol. Lett., vol. 63, no. 7, pp. 1892–1898, Jul. 2021.