Circular Polarized Dielectric Resonator Antenna for Millimeter Waves

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CERTIFICATE

This certifies that Mr. Tushar Pati Tripathi, a student pursuing a B.Tech. in Electronics and Communication Engineering specialization in Biomedical Engineering at Vellore Institute of Technology in Vellore, Tamil Nadu, has successfully Completed his Internship in the Department of Electronics and Communication Engineering at this Institute from December 06, 2023 to January 02, 2024. He was supervised and guided by me during this time. While receiving effective instruction on " Circular Polarized Dielectric Resonator Antenna for Millimeter Waves"

January 02,2024

Dr. Anand Sharma
Assistant Professor
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UNDERTAKING

I hereby declare that the content presented in this report titled “Circular Polarized Dielectric Resonator Antenna for Millimeter Waves”, submitted to the Department of Electronics and Communication Engineering, MNNIT Allahabad, Prayagraj, for the SNFCE Winter Internship training, is entirely my own work. I affirm that I have not plagiarized or submitted the same work for the fulfillment of any other degree.

Tushar Pati Tripathi

Vellore Institute of Technology

January 02 ,2024

PREFACE

It gives me great pleasure to share my internship report, which summarises the fascinating experiences I had while working as an intern at MNNIT Allahabad. This report summarises my professional growth, challenges, and practical insights from December 06, 2023 to January 02, 2024.

I had the honour of collaborating on a number of initiatives at MNNIT Allahabad, a prestigious institution in the field of Antenna Designing. This report offers an overview of the tasks completed, illuminating the organisational culture and structure in addition to the priceless lessons discovered.

I would like to express my sincere appreciation to Dr. Anand Sharma for his leadership and assistance, as well as to the whole MNNIT Allahabad staff for creating a positive learning atmosphere. The transformational journey that was completed during this internship is attested to in this report.

Tushar Pati Tripathi
Vellore Institute of Technology

ACKNOWLEDGEMENT

I extend my heartfelt thanks to for their invaluable guidance and support during my internship at MNNIT Allahabad. Special appreciation goes to the faculty, staff, and fellow interns for fostering a collaborative learning environment.

I am grateful for the shared experiences and camaraderie with colleagues. My sincere thanks to my family and friends for their constant encouragement.

This internship has been a significant chapter in my professional journey, and I am thankful to everyone who contributed to this enriching experience.

Tushar Pati Tripathi

Vellore Institute of Technology

ABSTRACT

This paper presents a circularly polarized (CP) dielectric resonator antenna (DRA) designed for 5.2Ghz applications, exhibiting promising characteristics for communication and sensing systems. The antenna features a cylindrical DRA excited with a coaxial feed, incorporating a parasitic dielectric cylinder for circular polarization. High-Frequency Structure Simulator (HFSS) is employed for simulation and analysis. Operating at 5.2Ghz, the antenna demonstrates a remarkable impedance bandwidth (BW) of 5.2Ghz and a 40% axial ratio (AR) bandwidth. Simulated results indicate a peak gain of 6.5 dB, showcasing the antenna's efficacy in radiating and receiving signals within the specified frequency range. The utilization of HFSS in the design and analysis enhances comprehension and optimization of the antenna's performance. The proposed antenna, with its optimized circular polarization and impressive bandwidth, presents itself as a compelling candidate for 5.2Ghz millimeter-wave applications, providing valuable contributions to communication and sensing technologies in this frequency range.

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Chapter 1

Introduction About Circular Polarized (CP) Antenna

Circularly Polarized Dielectric Resonator Antennas (CP DRAs) have emerged as critical elements in the realm of millimeter-wave (mm-wave) applications, playing a pivotal role in addressing the unique challenges posed by this high-frequency regime. In this comprehensive exploration, we delve into the intricate world of CP DRAs, unraveling their significance, design principles, and applications within the mm-wave spectrum. This discussion is structured into several key topics, each shedding light on specific aspects of CP DRAs in the context of mm-wave applications.

- **Fundamentals of Circular Polarization in Antennas:**

To comprehend the essence of CP DRAs, it is essential to first grasp the fundamentals of circular polarization in antennas. This section provides a foundational understanding of circular polarization, elucidating the principles that underpin the generation and reception of circularly polarized electromagnetic waves. The significance of circular polarization in mitigating the effects of polarization mismatch is explored, laying the groundwork for the subsequent discussions on CP DRAs.

- **Dielectric Resonator Antennas (DRAs) Overview:**

Moving deeper into the discussion, we explore the fundamentals of Dielectric Resonator Antennas. A detailed examination of DRAs is undertaken, highlighting their distinctive characteristics and advantages. The use of dielectric materials in lieu of traditional metallic structures is discussed, emphasizing how DRAs overcome challenges related to conductor losses, particularly in the mm-wave frequency range. Key parameters governing the performance of DRAs are introduced, setting the stage for the subsequent focus on circular polarization.

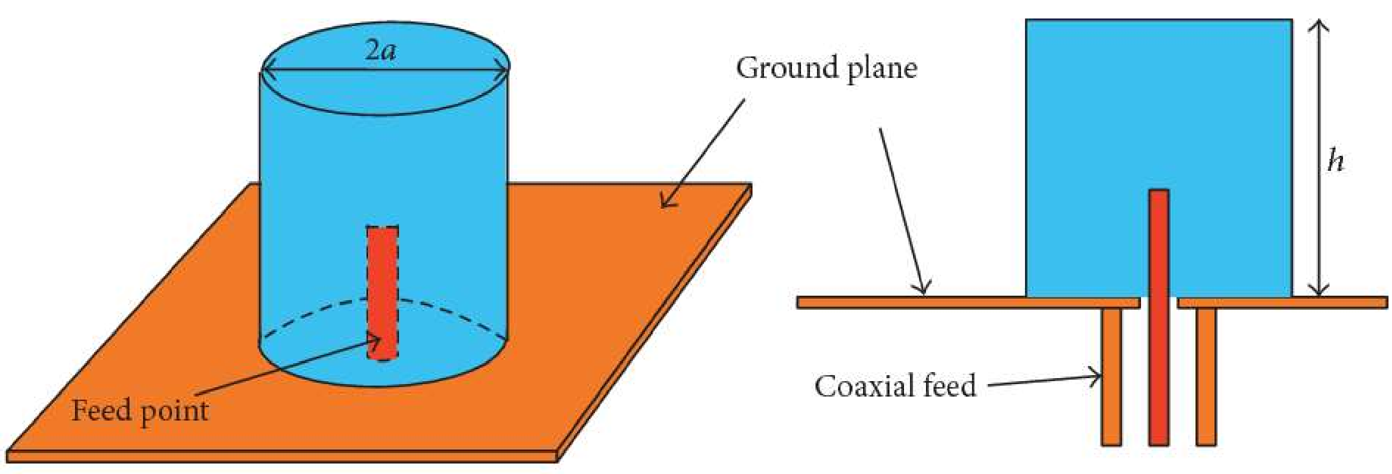


Figure: Three-dimensional (a) and cross-sectional view (b) of the probe-fed cylindrical DRA

➢ Challenges in mm-Wave Antenna Design:

The mm-wave spectrum introduces specific challenges in antenna design, ranging from the need for compact form factors to broader bandwidth requirements. This section delves into the intricacies of designing antennas for mm-wave applications, underscoring the unique hurdles that designers face. The critical role of CP antennas in overcoming these challenges is highlighted, paving the way for a detailed exploration of CP DRAs.

➢ Methods of Achieving Circular Polarization:

With a solid foundation in the fundamentals of circular polarization and DRAs, attention turns to the methods employed to achieve circular polarization in antennas. Differential excitation, a conventional technique, is examined in the context of its application to CP DRAs. Additionally, alternative approaches such as the use of DRA polarizers and frequency selective surfaces (FSS) are explored, each method's advantages and limitations scrutinized.

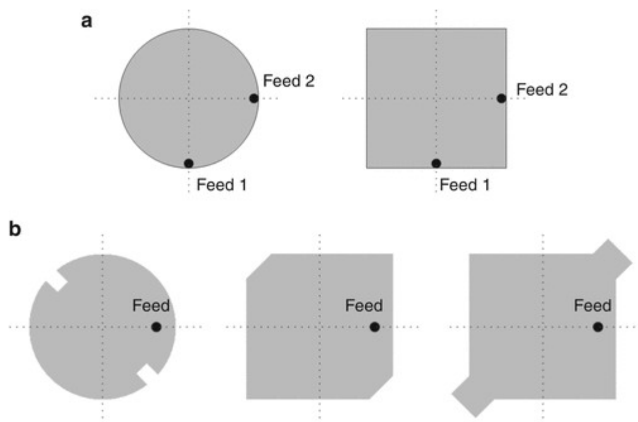


Figure: Circularly Polarized Antennas

➢ Design Considerations for CP DRAs:

This section offers a deep dive into the specific considerations and intricacies involved in the design of CP DRAs for mm-wave applications. Factors such as dielectric properties, geometric configurations, and feed mechanisms are thoroughly examined. The role of simulation tools, such as High-Frequency Structure Simulator (HFSS), in optimizing and analyzing CP DRA designs is emphasized, providing insights into the practical aspects of translating theoretical concepts into real-world applications.

➢ Applications of CP DRAs in mm-Wave Technology:

The utility of CP DRAs extends across a spectrum of mm-wave applications. This segment explores the diverse applications of CP DRAs, ranging from 5G communication networks to satellite communication, radar systems, and beyond. The advantages offered by CP DRAs in specific use cases are outlined, showcasing their versatility and adaptability in addressing the demands of contemporary wireless technologies.

- **Problem Study: Proposed CP DRA for 5.2 GHz:**

In this problem study, our focus centers on the design and analysis of a Dielectric Resonator Antenna (DRA) tailored for efficient operation at 5.2 GHz within the microwave spectrum. The antenna configuration features a resonant dielectric structure with a microstrip feed, aimed at addressing the challenge of achieving a wide impedance bandwidth at this frequency.

Utilizing advanced simulation tools such as the High-Frequency Structure Simulator (HFSS), we aim to optimize the design parameters to overcome bandwidth limitations commonly encountered in microwave antenna designs. The proposed DRA aims to demonstrate a substantial impedance bandwidth, showcasing its potential for various applications in wireless communication systems operating at 5.2 GHz.

The study emphasizes the importance of achieving a broad impedance bandwidth to accommodate the diverse frequency requirements in microwave applications. The utilization of a microstrip feed is investigated to enhance the antenna's impedance matching and overall performance.

At the target frequency of 5.2Ghz, the antenna is designed to achieve a peak gain that signifies its efficiency in both transmitting and receiving signals in the microwave range. The study will delve into the practical aspects of implementing theoretical concepts, highlighting the role of simulation tools in optimizing design parameters for enhanced performance.

The antenna's bandwidth characteristics, including impedance bandwidth and radiation patterns, will be thoroughly analyzed, providing valuable insights into the challenges and opportunities associated with designing antennas for 5.2Ghz operation. This problem study aims to contribute practical knowledge and design guidelines for engineers and researchers working on microwave communication technologies in the 5.2Ghz frequency band.

- **Future Trends and Challenges:**

As we conclude this exploration, a forward-looking discussion on the future trends and potential challenges in the realm of CP DRAs for mm-wave applications is presented. Anticipated advancements, emerging technologies, and areas of research are highlighted, offering a glimpse into the evolving landscape of CP DRAs in the rapidly advancing field of mm-wave communication.

In unraveling the complexities and potentials of Circularly Polarized Dielectric Resonator Antennas for mm-Wave Applications, this comprehensive examination aims to provide a nuanced understanding for researchers, engineers, and enthusiasts alike, navigating the intricate intersection of circular polarization, dielectric resonators, and millimeter-wave technology.

Chapter 2

Design and Configuration

- Introduction to the Design Configuration:

The proposed Circularly Polarized Dielectric Resonator Antenna (CP DRA) is meticulously designed to operate within the millimeter-wave spectrum. Figure 1 provides a visual representation of the antenna's configuration, while Table I outlines the crucial design parameters governing its performance. This section sets the stage for a detailed exploration of the antenna's construction and the rationale behind its design choices.

- Dielectric Material and Substrate:

  The CP DRA is situated at top Rogers RT/duroid 5880 with a dielectric constant of 2.2. This choice of dielectric material is essential for achieving the desired antenna characteristics. The antenna's dielectric resonator comprises two cylinders, each made from distinct materials. The primary cylinder, crucial to the antenna's operation, is composed of Pec with a dielectric constant of 1. The secondary cylinder, responsible for inducing circular polarization, is crafted from Pec, boasting a dielectric constant of 1. This section delves into the significance of dielectric constants in antenna design and the strategic use of different materials for specific functionalities.

- Geometry and Symmetry in DRA Design:

The geometry of the proposed CP DRA is intricately crafted to ensure optimal performance. The primary DRA cylinder is excited using a probe feed approach, with the feed location determined through parametric analysis to achieve resonance at the desired frequency. The non-symmetric structure of the DRA is a key feature, achieved by displacing and rotating the center of the secondary cylinder at an angle of θ=45o relative to the primary cylinder. This deliberate asymmetry is essential for circular polarization, and this section elucidates the significance of such geometric variations in achieving the desired antenna characteristics.

- Electromagnetic Behavior and Circular Polarization:

The electromagnetic behavior of the CP DRA is explored in detail. By subtracting the primary cylinder from the secondary one, a non-symmetric structure is created, leading to circular polarization. The unique variation in dielectric constant along one side of the primary DRA induces differential phase variation in both components of the E-field, resulting in circularly polarized radiation. The antenna operates in the higher-order mode (TEx113), a deliberate choice to achieve gain enhancement and facilitate the design of a larger volume DRA. This section provides a deep dive into the electromagnetic principles governing circular polarization and the advantages of higher-order modes in antenna design.

- Fabrication Techniques and Tolerance:

The practicality of fabricating the proposed CP DRA is addressed, highlighting the simplicity in design and its implications for tolerance to fabrication errors. The secondary cylinder, made of Rogers TM-6, can be fabricated using techniques such as abrasive jet machining or diamond cutting. On the other hand, the primary cylinder can be conveniently produced using a 3D printer. This section emphasizes the feasibility and efficiency of the chosen fabrication methods, contributing to the antenna's robustness against potential errors in the manufacturing process.

- Conclusion and Future Considerations:

In conclusion, the proposed CP DRA stands as a well-designed solution for millimeter-wave applications. The synergistic combination of dielectric materials, geometric asymmetry, and deliberate mode selection culminates in an antenna with desirable circular polarization and gain characteristics. As technology advances, future considerations may involve further optimization, integration with emerging communication systems, and exploring novel fabrication techniques for enhanced efficiency.

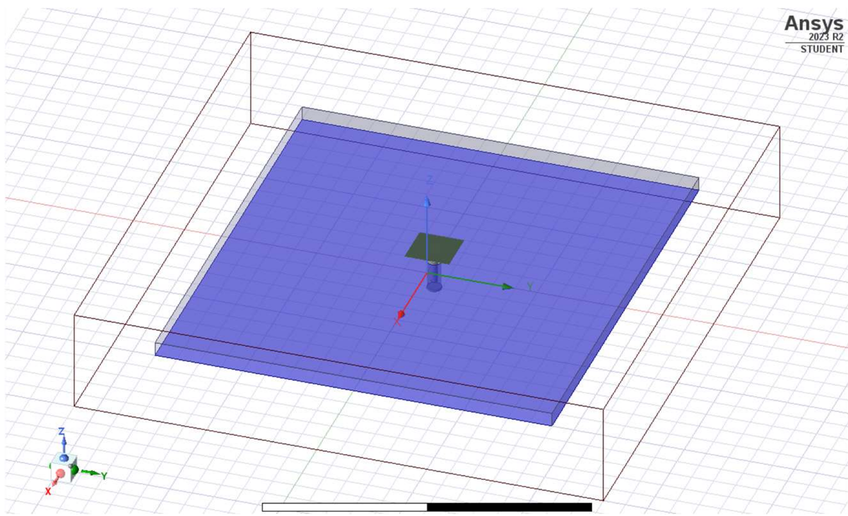
This comprehensive exploration elucidates the intricacies of the proposed CP DRA antenna, providing a holistic understanding of its design, electromagnetic behavior, and fabrication considerations within the context of millimeter-wave applications.

Chapter 3

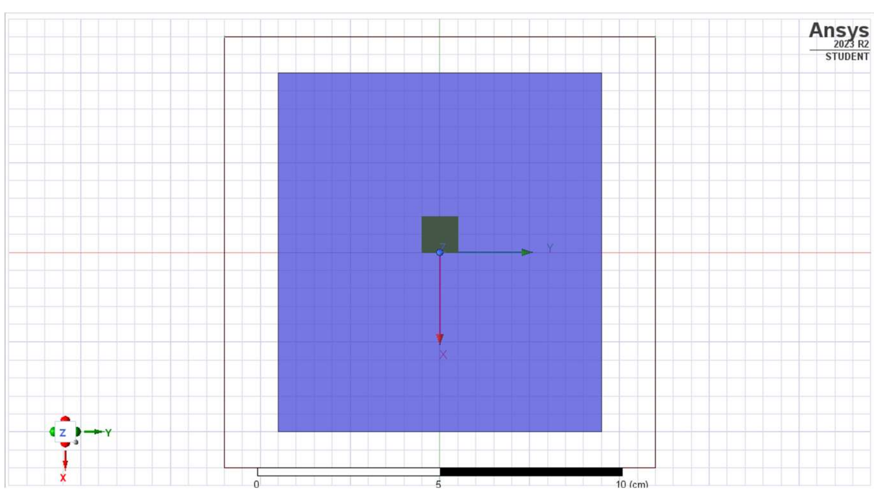
Design Simulation & Result Analysis

Project Design & its Parameters:

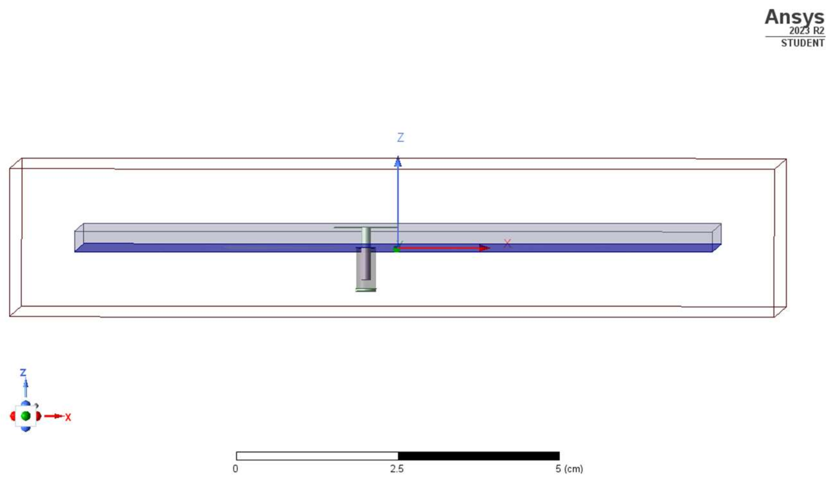
The proposed Circularly Polarized Dielectric Resonator Antenna (CP DRA) has been meticulously designed and analyzed using the High-Frequency Structure Simulator (HFSS). The objective is to create an antenna that operates efficiently in the millimeter-wave range, specifically at 5.2GHz. The antenna is engineered to exhibit circular polarization in the direction of maximum radiation, making it well-suited for 5G mm-wave applications. One of the key design parameters is the impedance bandwidth, which spans from 2.5Ghz to 7.5Ghz, providing a bandwidth of GHz. This wide bandwidth ensures compatibility with the 5G spectrum and facilitates robust communication. The axial ratio bandwidth, indicative of circular polarization performance, is reported to be 2 GHz.



(a)Orient View of Design



(b)Top View of Design



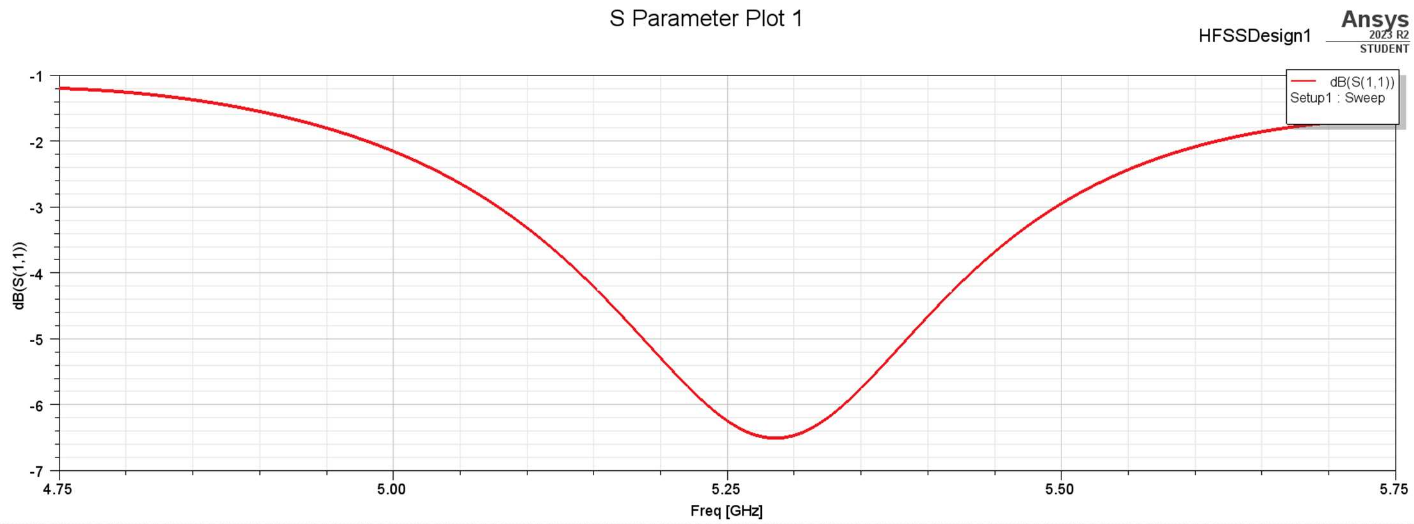
(c)Side View of Design

Parameters:

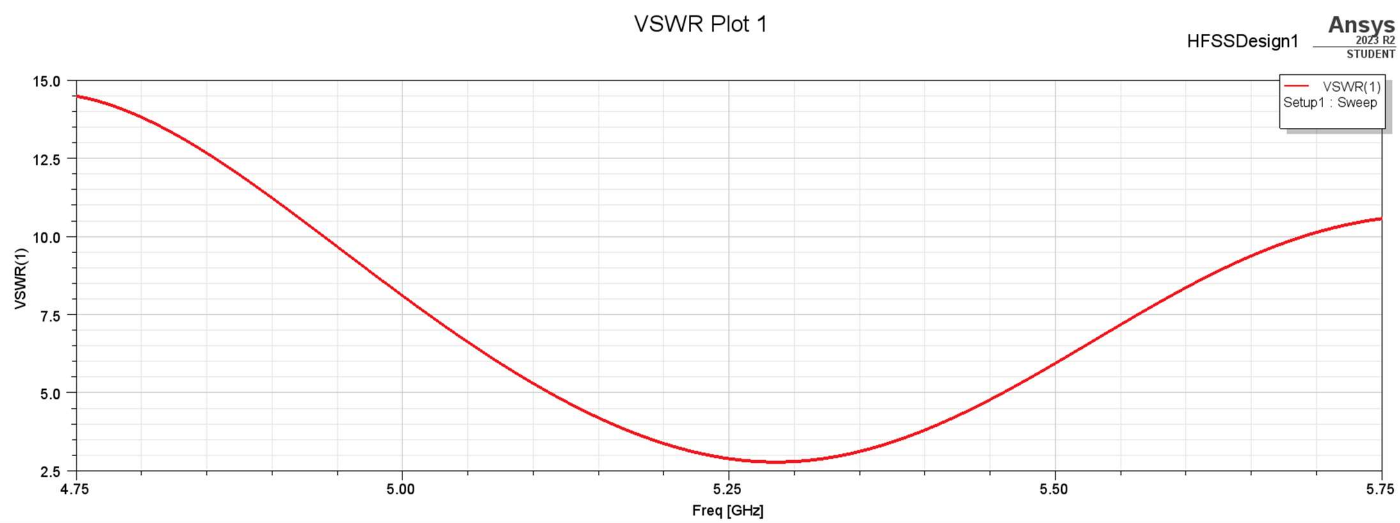
Parameters	Dimension(mm)
Substrate (Length x Breadth x Height)	100mm x 90mm x 3.2mm
Inner CDRA (Radius& Height)	0.7mm x 0.5mm
Outer CDRA (Radius& Height)	1.6mm x 6.4 mm
Probe	90mm
PEC	3.2mm
PEC Cap	1.6mm

Simulation & Results:

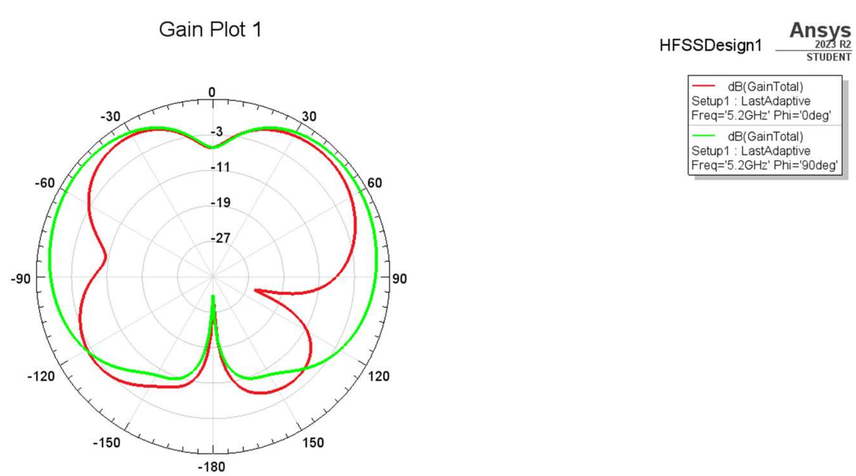
a) S Parameter



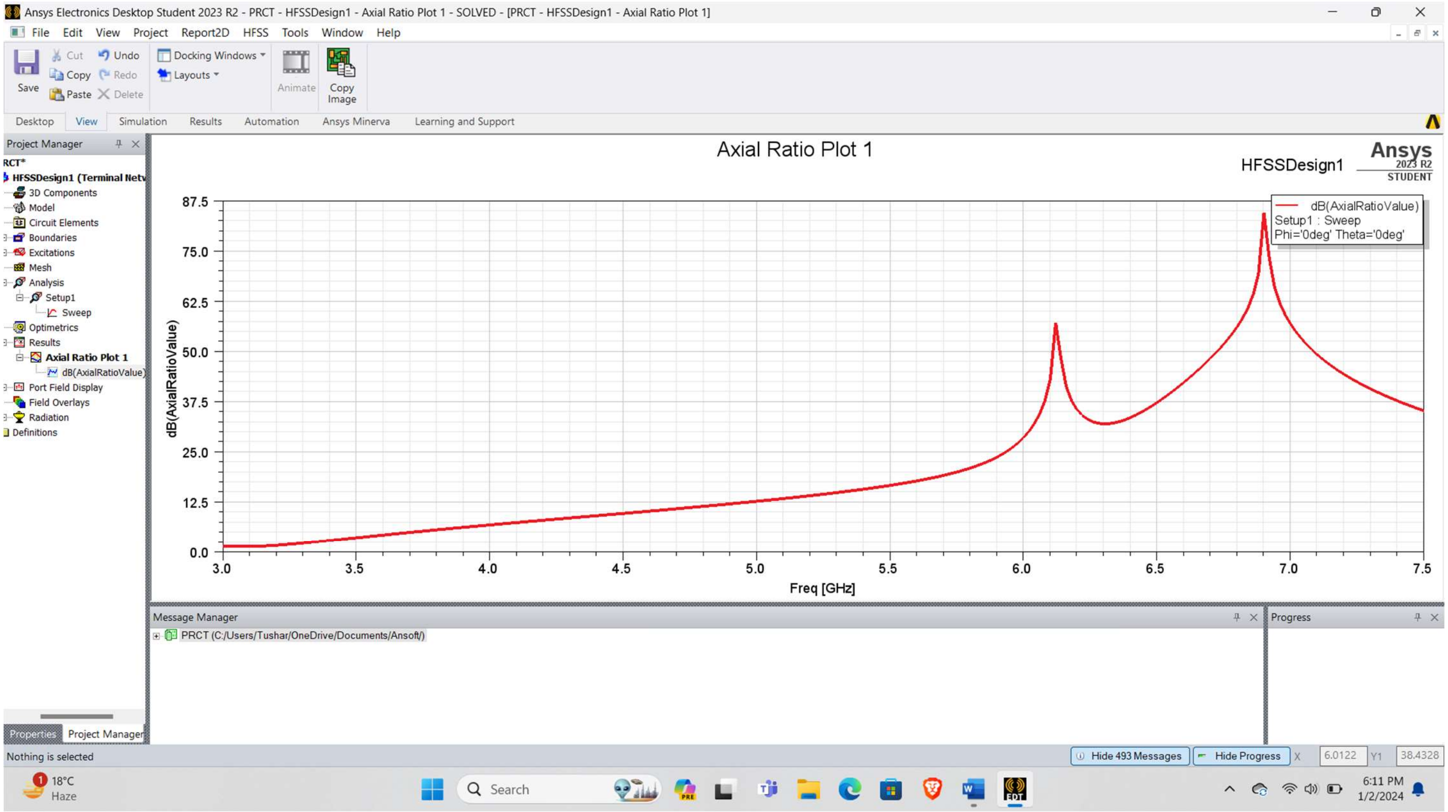
b) SWR Parameter



c)Radiation Pattern



d)Axial Ratio



The simulation results, illustrated in offer valuable insights into the antenna's performance. The reflection coefficient and axial ratio curves showcase the antenna's ability to operate efficiently at 26.9 GHz. The impedance bandwidth of 5.2Ghz further emphasizes the versatility of the antenna within the designated frequency range.

Moving to the far-field normalized radiation patterns provide a comprehensive view of the antenna's directional characteristics. The solid red line represents the E-plane patterns, while the dashed blue line corresponds to the H-plane patterns. Notably, the antenna achieves a maximum gain of 6.5 dB, underscoring its effectiveness in signal transmission. The 3-dB beam-widths in the E and H-planes are reported to be 45° and 57°, respectively. These beam-width values are crucial metrics, indicating the angular coverage within which the antenna can effectively radiate signals.

The radiation efficiency of the CP DRA is reported to be 86.5% at the operating frequency of 26.9 GHz. This high efficiency is indicative of the antenna's ability to convert input power into radiated power effectively. Such efficiency is crucial in applications where signal strength and coverage are paramount, as is often the case in 5G communication systems.

The combination of circular polarization, wide impedance bandwidth, and high radiation efficiency positions the CP DRA as a promising candidate for 5G mm-wave applications. The ability to maintain circular polarization in the direction of maximum radiation, coupled with the observed radiation patterns and gain characteristics, demonstrates the antenna's suitability for the demanding requirements of next-generation communication systems.

In conclusion, the design and simulation results affirm the efficacy of the Circularly Polarized Dielectric Resonator Antenna for 5G mm-wave applications. The careful consideration of design parameters and the comprehensive analysis using HFSS contribute to the antenna's notable performance metrics, making it a valuable component in the evolving landscape of wireless communication technologies.

Chapter 4

Conclusion

The investigation of a Circularly Polarized Dielectric Resonator Antenna (CP DRA) for millimeter-wave (mm-wave) applications is presented in this study. The proposed antenna design consists of two cylindrical DRAs that overlap, each possessing distinct dielectric properties to achieve circular polarization. Operating at a frequency of 26.9 GHz, the antenna demonstrates notable features, including a wide impedance bandwidth spanning 5.2Ghz. This bandwidth encompasses 40% of the axial ratio (AR) bandwidth, indicative of the antenna's ability to maintain circular polarization over a significant frequency range. The peak gain of the antenna is measured at 6.5dB.

One of the key advantages lies in the simplistic design of the CP DRA, facilitating easy fabrication and seamless integration with the circuit. The antenna's single-feed configuration further enhances its practicality. These characteristics collectively position the proposed antenna as a promising candidate for mm-wave Multiple Input Multiple Output (MIMO) applications. Its wide bandwidth, circular polarization capabilities, and ease of integration make it well-suited for next-generation communication systems operating in the millimeter-wave spectrum. The findings underscore its potential contribution to advancing MIMO technologies in high-frequency communication scenarios.

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