

## **B. TECH. PROJECT ON**

### **Antenna Design for RFID Applications**

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Under the Guidance of

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B.Tech. in

Electronics & Communication Engineering



Department of Electronics & Communication Engineering

NETAJI SUBHAS UNIVERSITY OF TECHNOLOGY

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## CERTIFICATE OF DECLARATION



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Certified that Khushi Sahay(2020UEC2510), Aryan Gupta(2020UEC2513), Sonu Sharma(2020UEC2541), Ansh Makker(2020UEC2545) has carried out their project work presented in this project entitled “Antenna Design for RFID Applications” for the award of Bachelor of Technology, Department of Electronics and Communication, Netaji Subhas University of Technology, New Delhi, under my supervision. The project embodies results of original work, and studies are carried out by the students themselves and the contents of the project do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

Place: New Delhi

Prof. D. K. Upadhyay

Date:06/05/2024

SUPERVISOR

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## ABSTRACT

This report presents a comprehensive study on the development and performance evaluation of a novel circularly polarized cross dipole antenna designed on an FR-4 substrate. The antenna, with compact dimensions of  $26\text{ mm} \times 26\text{ mm} \times 1.6\text{ mm}$ , features strategically printed dipole elements on both the top and bottom surfaces of the substrate, each phased by  $180^\circ$  relative to its counterpart on the opposite side. A key aspect of the design involves the integration of a delay line, which effectively connects the perpendicular elements within each dipole pair to achieve right-hand circular polarization.

Operating at a resonant frequency of 2.45 GHz, the antenna exhibits an impressive impedance bandwidth spanning from 2.37 GHz to 2.60 GHz. Notably, it achieves a peak gain of 6.55 dB precisely at the resonant frequency, showcasing high efficiency and performance within the specified frequency range.

This report provides detailed insights into the antenna's construction methodology, including substrate selection, dipole element layout, and integration of the delay line for achieving circular polarization. The experimental section includes comprehensive measurements and analysis of the antenna's performance characteristics, emphasizing its compact form factor, wide impedance bandwidth, and peak gain at the target frequency.

The findings of this study contribute to the advancement of compact circularly polarized antenna designs suitable for applications requiring robust performance in the 2.45 GHz frequency band. The report concludes with recommendations for further optimization and potential applications based on the achieved results.

# **LIST OF CONTENTS**

	<b>Page no</b>
<b>CERTIFICATE</b>	1
<b>ACKNOWLEDGEMENT</b>	2
<b>PLAGIARISM REPORT</b>	3
<b>ABSTRACT</b>	4
<b>LIST OF CONTENTS</b>	5
<b>LIST OF FIGURES</b>	6
<b>LIST OF TABLES</b>	7
<b>CHAPTER ONE: INTRODUCTION</b>	8
1.1 RFID	9
1.1.1 WHY RFID?	10
1.1.2 APPLICATIONS OF RFID	11
1.1.3 COMPONENTS OF RFID	12
1.1.4 WORKING OF RFID SYSTEM	14
1.2 ANTENNA	17
1.2.1 OVERVIEW	18
1.2.2 CIRCULAR POLARIZATION IN ANTENNA	18
1.2.3 CROSS DIPOLE ANTENNA	19
<b>CHAPTER TWO: LITERARY REVIEW</b>	20
<b>CHAPTER THREE: GAPS IDENTIFIED</b>	23
3.1 ANTENNA GAIN	24
3.2 FREQUENCY BANDS	25
3.3 COMPACTNESS	26
<b>CHAPTER FOUR: DESIGN AND SIMULATIONS</b>	27
<b>CHAPTER FIVE - COMPARISON FROM OTHER PAPERS</b>	35
<b>CHAPTER SIX - CONCLUSION</b>	36
<b>REFERENCES</b>	38

## LIST OF FIGURES

Figure Number	Figure Name	Page Number
1	Applications of RFID	10
2	Components of RFID	11
3	Working of RFID system	14
4	Circular Polarization	19
5	Layout of the presented RFID antenna: top view	27
6	Layout of the presented RFID antenna: side view	28
7	Cross Dipole bottom view	29
8	Cross Dipole top view	29
9	Cross Dipole antenna with radiation box	30
10	Cross Dipole antenna Side view	30
11	Reflection Coefficient vs Frequency graph for L1	31
12	Reflection Coefficient vs Frequency graph for L2	31
13	Reflection Coefficient vs Frequency graph for L3	32
14	Gain curve of the proposed RFID antenna	33
15	Reflection coefficient of the presented antenna	33

## LIST OF TABLES

Table Number	Table Name	Page Number
1	Dimensions of proposed antenna	26
2	Comparison Table	34



## **CHAPTER 1 - INTRODUCTION**

In the realm of Radio-Frequency Identification (RFID), antennas play a pivotal role as the conduit for wireless communication between RFID tags and readers. These antennas serve as the critical link in transmitting and receiving radio frequency signals, thereby enabling the seamless exchange of data. This report delves into the multifaceted world of RFID antennas, offering an in-depth examination of their design principles, recent innovations, and practical applications across diverse industries.

At the core of RFID technology lies the RFID antenna, a component meticulously crafted to optimize performance metrics such as read range, accuracy, and reliability. Design considerations encompass a spectrum of factors including frequency range, polarization, gain, form factor, and environmental constraints. Engineers strive to strike a delicate balance between these parameters to ensure optimal functionality tailored to specific application requirements.

Recent technological advancements in RFID antenna design have propelled the field forward, promising enhanced capabilities and expanded possibilities. Innovations such as phased-array antennas, metamaterials, and beamforming technologies have emerged, offering solutions to address challenges such as electromagnetic interference, signal attenuation, and tag orientation sensitivity. These advancements not only improve the performance of RFID systems but also pave the way for new applications and deployment scenarios.

Despite significant progress, challenges persist in the development and deployment of RFID antenna systems. These challenges underscore the importance of ongoing research and innovation in addressing issues such as electromagnetic interference, signal propagation, and integration with existing infrastructure. By understanding the intricacies of RFID antenna technology, stakeholders can harness its potential to drive efficiency, productivity, and innovation across various sectors, shaping the future of RFID-enabled solutions.

## **1.1 RFID**

The rise of the Internet of Things (IoT) has ushered in a new era of connectivity, revolutionizing how devices and systems interact and communicate with each other. This interconnected network of physical objects, equipped with sensors and software, has transformed the digital landscape, creating unprecedented opportunities for innovation and efficiency gains across industries.

As IoT applications proliferate across sectors such as manufacturing, logistics, healthcare, and retail, there is a corresponding surge in demand for Automated Identification Data Capture (AIDC) systems. These systems serve as the backbone of IoT infrastructure, facilitating seamless data transfer and interactions among interconnected objects. By automating the capture, processing, and exchange of data, AIDC systems reduce reliance on manual intervention, streamline operations, and enable real-time decision-making.

At the forefront of AIDC technologies, Radio Frequency Identification (RFID) emerges as the preferred solution for high-speed data transmission and identification. RFID systems utilize electromagnetic fields to wirelessly identify and track tagged objects, offering unparalleled efficiency and accuracy in data capture. With RFID, objects can be uniquely identified and monitored in real-time, enabling seamless inventory management, asset tracking, and supply chain optimization.

The widespread adoption of RFID technology across diverse industries underscores its versatility and reliability in addressing a myriad of operational challenges. In manufacturing, RFID enables automated inventory control and production monitoring, enhancing productivity and quality assurance. In logistics and transportation, RFID facilitates efficient tracking and tracing of goods, reducing errors and delays in delivery. In retail, RFID enables seamless inventory visibility and personalized customer experiences, driving sales and loyalty.

In conclusion, as the IoT ecosystem continues to expand, the importance of AIDC systems, particularly RFID technology, cannot be overstated. By enabling seamless

data transfer and interactions among interconnected objects, AIDC systems pave the way for smarter, more efficient, and more responsive operations, ultimately driving business growth and innovation in the digital age.

### **1.1.1 WHY RFID?**

RFID readers boast the remarkable capability to concurrently read hundreds of RFID tags, facilitating rapid and efficient data collection in diverse environments. Unlike traditional optical technologies such as barcodes, passive RFID tags possess an extended lifespan, lasting for years without the need for maintenance or replacement. Moreover, the non-line-of-sight reading feature of RFID technology eliminates the constraints imposed by line-of-sight requirements inherent in barcode scanning, offering unparalleled flexibility in data capture scenarios.

In comparison to optical technologies like barcodes, RFID technology boasts significantly longer reading ranges, enabling tags to be detected and identified from considerable distances. This extended range enhances operational efficiency and enables seamless tracking and monitoring across expansive environments.

Furthermore, RFID tags surpass barcodes and QR codes in data storage capacity, offering ample space to store diverse information, including product details, manufacturing dates, and batch numbers. This enhanced data storage capability empowers organizations with comprehensive insights into their inventory, assets, and processes.

One of the most compelling features of RFID tags is their reusability and rewritability, allowing for dynamic adaptation to changing requirements and applications. This versatility enables the same RFID tag to be reprogrammed multiple times throughout its lifespan, accommodating diverse items or purposes without the need for physical replacement. This adaptability not only streamlines inventory management and asset tracking but also contributes to sustainability efforts by minimizing waste and resource consumption.

In essence, the myriad advantages of RFID technology, including its multi-tag reading capabilities, extended lifespan, non-line-of-sight reading capabilities, long-range operation, expansive data storage capacity, and reusability, position it as a transformative solution for diverse industries seeking efficient, flexible, and scalable data capture and identification solutions.

### 1.1.2 APPLICATIONS OF RFID

Radio Frequency Identification (RFID) technology serves a multitude of purposes across industries, enhancing efficiency and streamlining operations. In retail and inventory management, RFID automates inventory tracking processes, mitigating stockouts and bolstering supply chain visibility. Likewise, in logistics and supply chain management, RFID tags facilitate real-time tracking of goods, optimizing inventory levels and minimizing errors. Asset tracking benefits from RFID

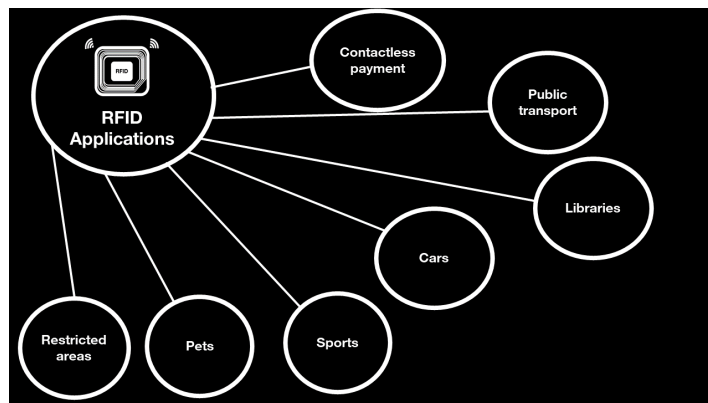


Figure 1 Applications of RFID

technology as well, enabling organizations to monitor equipment and vehicles, thus improving utilization rates and ensuring safety compliance. Access control systems benefit from RFID, enhancing security through streamlined authentication processes. In agriculture, RFID tags aid in animal tracking, contributing to health monitoring and breeding records. Healthcare settings leverage RFID for patient safety and medication management, reducing errors and improving overall care quality. Additionally, RFID streamlines waste management and recycling processes by enabling efficient tracking

and sorting of waste streams, thereby promoting sustainability efforts. Overall, RFID technology offers versatile solutions that empower organizations to enhance efficiency and deliver superior experiences across various sectors.

### 1.1.3 COMPONENTS OF RFID

RFID antennas consist of several key components, each playing a crucial role in facilitating wireless communication between RFID tags and readers. These components include:

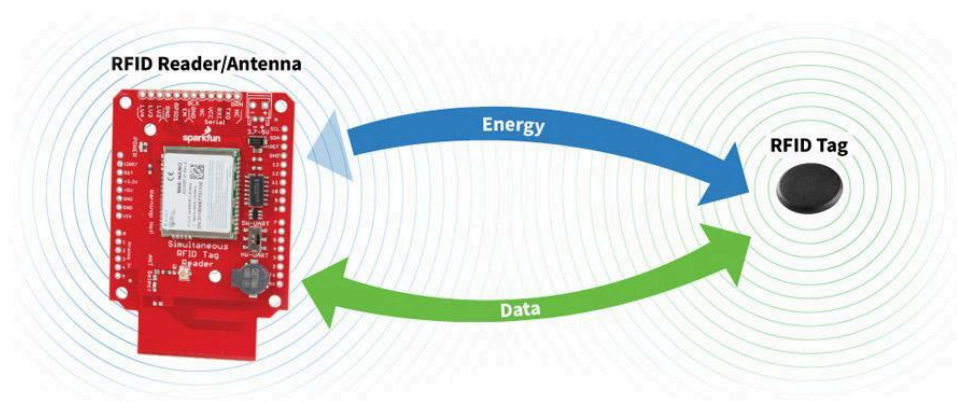


Figure 2 Components of RFID

1. **Radiating Element:** At the core of an RFID antenna is the radiating element, which generates and radiates electromagnetic waves. The radiating element can take various forms, such as a coil, dipole, patch, or loop, depending on the specific application requirements and frequency range of the RFID system.
2. **Feed Network:** The feed network is responsible for delivering RF energy to the radiating element from the RFID reader. It ensures efficient transfer of power to the radiating element, optimizing the antenna's performance in terms of read range and sensitivity.
3. **Matching Network:** The matching network is essential for impedance matching between the RFID reader and the antenna. It adjusts the impedance of the antenna to match that of the RFID reader, minimizing signal reflections and maximizing power transfer, which is critical for reliable communication.

4. **Ground Plane:** The ground plane serves as a reference point for the radiating element and helps to establish the antenna's radiation pattern. It also aids in reducing electromagnetic interference and improving the antenna's efficiency by providing a stable electrical reference.

5. **Housing or Enclosure:** The housing or enclosure of an RFID antenna provides mechanical support and protection for the internal components. It shields the antenna from environmental factors such as moisture, dust, and physical damage, ensuring long-term reliability and durability.

6. **Connector:** The connector facilitates the connection between the RFID antenna and the RFID reader or associated electronics. It allows for easy installation and replacement of antennas, as well as flexibility in system integration.

7. **Mounting Hardware:** Mounting hardware, such as brackets, screws, and mounting plates, enables secure attachment of the RFID antenna to various surfaces or structures. Proper mounting ensures optimal antenna placement for optimal performance and coverage.

These components work together harmoniously to form a functional RFID antenna system capable of reliable and efficient wireless communication for a wide range of applications, from inventory management and asset tracking to access control and vehicle identification.

### 1.1.4 WORKING OF RFID SYSTEM

RFID (Radio Frequency Identification) technology operates on the principle of wireless communication between RFID tags attached to objects and RFID readers equipped with antennas. Here's how the process works:

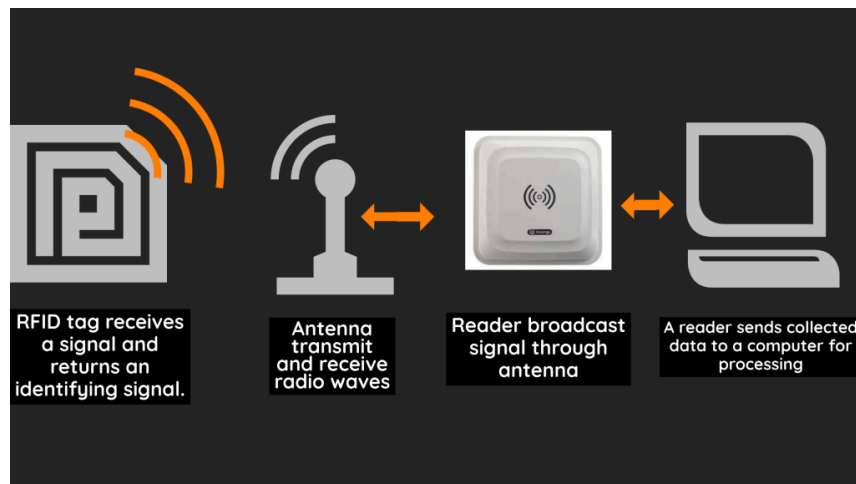


Figure 3 Working of RFID system

- 1. RFID tags attachment:** RFID tags are affixed to objects to uniquely identify them. These tags contain a unique identifier and may also store additional information about the object, such as its manufacturer, product type, or serial number.
- 2. RFID reader emission:** RFID readers emit radio frequency (RF) waves through their antennas, creating an electromagnetic field in their vicinity.
- 3. Tag activation:** When RFID tags with antennas come into the vicinity of the RF waves emitted by the reader, they absorb energy from the waves and become activated. This energy powers the tag's circuitry, allowing it to respond to the reader's signal.
- 4. Data transmission:** Once activated, RFID tags transmit data back to the RFID reader using RF waves. This data typically includes the unique identifier stored in the tag's memory, along with any additional information programmed into the tag.

**5. Data reception:** The RFID reader, equipped with antennas, receives the transmitted data from the activated tags within its read range. The reader's antennas capture the RF signals emitted by the tags and convert them into digital data for processing.

**6. Communication with backend system:** The RFID reader communicates with a backend system, which could be a computer, server, or database, depending on the application. The reader sends the received data, including the unique identifiers and any other relevant information, to the backend system for further processing and analysis.

Overall, RFID technology enables seamless identification, tracking, and management of objects by leveraging the interaction between RFID tags and readers through radio frequency waves. This process facilitates a wide range of applications across industries, including inventory management, asset tracking, access control, and supply chain optimization.



## 1.2 ANTENNA

An antenna is a fundamental component in radio frequency (RF) communication systems, including RFID technology. Its primary function is to transmit or receive electromagnetic waves, enabling wireless communication between devices. In the context of RFID, antennas play a crucial role in facilitating the exchange of data between RFID tags and readers.

Antennas consist of conductive materials, such as metal wires or printed circuits, arranged in specific configurations to efficiently radiate or receive electromagnetic energy. When used for transmission, the antenna converts electrical signals into electromagnetic waves, propagating them through the surrounding space. Conversely, during reception, the antenna captures incoming electromagnetic waves and converts them back into electrical signals.

In RFID systems, antennas are typically integrated into RFID readers and tags. The reader's antenna emits radio frequency waves, creating an electromagnetic field within its vicinity. When an RFID tag with its own antenna enters this field, it absorbs energy from the waves, powering its circuitry and enabling it to transmit data back to the reader. The reader's antenna then receives the transmitted data from the tag for further processing.

The design of an RFID antenna is critical for optimizing communication performance, read range, and reliability. Various factors, including antenna geometry, size, shape, and orientation, as well as the frequency of operation, must be carefully considered to achieve desired performance metrics. Additionally, environmental factors such as nearby metal objects or electromagnetic interference can impact antenna performance and effectiveness.

In summary, antennas are essential components in RFID systems, enabling wireless communication between RFID tags and readers. Their design and configuration are carefully engineered to ensure efficient transmission and reception of electromagnetic waves, facilitating seamless data exchange in various applications across industries.

### **1.2.1 OVERVIEW**

An antenna serves as the intermediary for transmitting and receiving electromagnetic waves in communication systems. In the realm of Radio Frequency Identification (RFID), antennas play a critical role in enabling wireless communication between RFID tags and readers.

RFID antennas are designed to emit radio frequency waves in specific patterns and directions, creating an electromagnetic field within their range. When an RFID tag enters this field, it absorbs energy from the waves and becomes activated, allowing it to transmit data back to the RFID reader.

Key aspects of RFID antennas include their design, frequency range, polarization, gain, and form factor. Engineers carefully engineer these antennas to optimize performance metrics such as read range, accuracy, and reliability while considering practical constraints like size, cost, and deployment scenarios.

Recent advancements in RFID antenna technology include innovations such as phased-array antennas, metamaterials, and beamforming techniques. These advancements promise to enhance the capabilities of RFID systems, enabling new applications and overcoming existing limitations.

Overall, RFID antennas are essential components in RFID systems, facilitating efficient wireless communication and enabling a wide range of applications across industries such as retail, logistics, healthcare, and manufacturing.

### **1.2.2 CIRCULAR POLARIZATION IN ANTENNA**

Circular polarization in antennas refers to the orientation of electromagnetic waves as they propagate through space. Unlike linear polarization, where the electromagnetic waves oscillate in a single plane, circular polarization involves the rotation of the wave's electric field vector as it travels. This rotation can be clockwise (right-hand circular polarization) or counterclockwise (left-hand circular polarization), depending on the antenna's design.

Circular polarization offers several advantages in wireless communication systems, including:

1. Improved signal reception: Circularly polarized antennas can receive signals regardless of the orientation of the transmitting antenna. This makes them ideal for applications where the relative orientation between antennas may vary, such as mobile or dynamic environments.
2. Reduced multipath interference: Circular polarization helps mitigate the effects of multipath interference, where signals reflect off surfaces and arrive at the receiver with slight delays and phase shifts. By rotating the polarization of the transmitted signal, circularly polarized antennas can minimize the impact of reflections and improve signal reliability.
3. Enhanced coverage: Circular polarization allows for more uniform coverage in three-dimensional space compared to linear polarization. This makes circularly polarized antennas well-suited for applications requiring omnidirectional or hemispherical coverage, such as satellite communications or RFID systems.

Circular polarization can be achieved using various antenna designs, including helical antennas, crossed-dipole antennas, and microstrip antennas with specific feeding techniques. By carefully engineering the geometry and feeding configuration of the antenna, engineers can generate circularly polarized electromagnetic fields suitable for a wide range of applications.

In summary, circular polarization in antennas offers advantages such as improved signal reception, reduced multipath interference, and enhanced coverage. These benefits make circularly polarized antennas valuable components in wireless communication systems, enabling reliable and efficient data transmission in diverse environments.

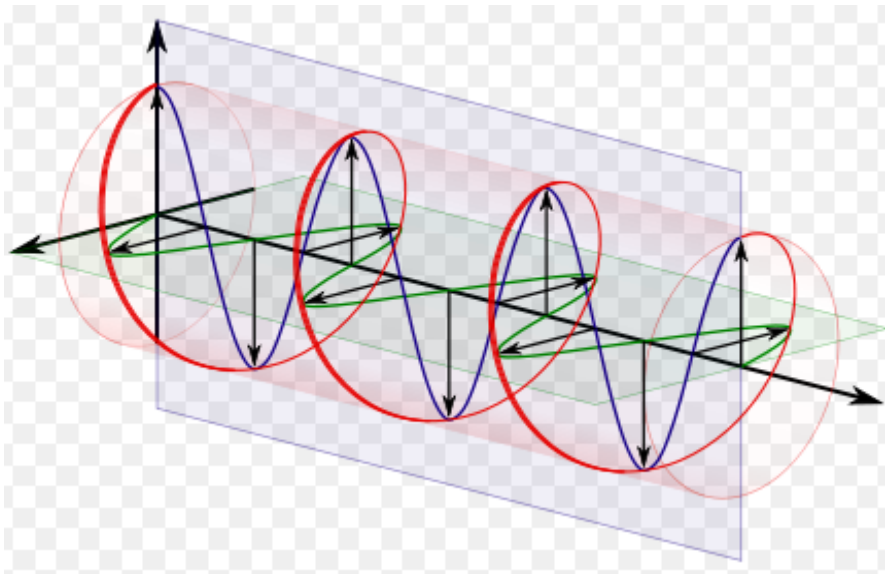


Figure 4 Circular Polarization

### **1.2.3 CROSS DIPOLE ANTENNA**

A Cross Dipole Antenna consists of two perpendicular dipole elements arranged in an "X" configuration. This design allows the antenna to transmit and receive signals with both horizontal and vertical polarizations simultaneously, making it ideal for applications where polarization may vary. The antenna offers omnidirectional coverage, compact size, and wideband operation, making it suitable for wireless communication, radio astronomy, radar systems, and satellite communication.

## CHAPTER 2 - LITERARY REVIEW

In [8], a stacked parasitic patch was employed to generate additional resonance, achieving wide impedance and axial ratio bandwidths. However, this configuration increased the antenna's size and profile.

On the other hand, [9] introduced a low-profile antenna with a slotted conducting plane as the reflector, fed by a two-port branch-line coupler. Although this design reduced the antenna's size, it resulted in a more complex geometry and larger cross-section compared to [8].

Both [8] and [9] antennas were initially designed to operate within the RFID UHF band. However, expanding coverage to additional RFID bands offers potential benefits such as improved data rates and extended detection range. To address this, various dual-band RFID antenna designs have been proposed, as documented in references [10–14]. These designs predominantly utilize circular polarization, with the exception of the approach described in [8], which employs a linearly polarized  $1 \times 2$  aperture coupled patch array.

In references [11–12], the design strategy emphasized aperture-coupled antenna configurations, utilizing a stacked arrangement to meet dual-band requirements. This involved implementing dual feed networks to achieve circular polarization across both frequency bands. While effective in achieving the desired polarization characteristics, this approach inherently introduced complexity to the antenna structure due to the necessity for precise alignment and control of multiple feeding mechanisms.

In contrast, the antenna configuration presented in [13] offered a simpler alternative. It featured a cross-slot circular patch antenna design with strategically placed slits in the ground plane. This design choice aimed to streamline the antenna structure while maintaining adequate performance, emphasizing ease of fabrication and deployment.

Meanwhile, [14] explored yet another approach by utilizing a dipole pair configuration to cover both the UHF and 2.45 GHz bands. Although this design

provided versatility in frequency coverage, it maintained a linear polarization scheme, deviating from the circular polarization focus of previous designs.

Despite efforts to achieve multi-band capabilities, reported antennas in [15–19] remained linearly polarized. While these designs expanded the frequency coverage to include triple-band operation, they did not address the circular polarization requirement typically sought after in RFID applications.

Switching gears, GPS technology stands out for its ability to precisely locate objects in outdoor environments by leveraging data from satellites [20]. Its widespread use in navigation and positioning systems underscores its reliability and accuracy. Combining RFID with GPS enhances the capabilities of such systems, offering improved versatility and accuracy by integrating real-time object identification and tracking capabilities with precise location data provided by GPS. This synergy opens up new possibilities for applications requiring precise positioning and tracking, such as asset management, logistics, and vehicle tracking systems.

In [21], researchers explored a modified Sierpinski fractal antenna configuration aiming to cover the UHF RFID and GPS L1 bands. Despite its innovative design, the antenna fell short in certain aspects. While it successfully addressed the UHF RFID band requirement, it only covered a single RFID band and exhibited a narrow impedance bandwidth. Additionally, the antenna operated with linear polarization, limiting its suitability for certain applications requiring circular polarization.

Similarly, [22] introduced a UHF RFID and GPS antenna with broad impedance and axial ratio bandwidths. However, like its predecessor, this antenna also covered only a single RFID band, failing to meet the demand for multi-band RFID functionality. Despite its improved impedance and axial ratio bandwidths, its limitation to a single RFID band posed a constraint on its versatility in multi-band RFID applications.

In a departure from the single-band focus, [23] adopted a trident-shaped dipole element arrangement to achieve coverage across the 2.4 GHz, 5.2 GHz, and 5.8 GHz bands. This approach offered broader frequency coverage compared to previous

designs, catering to the growing demand for multi-band antennas in wireless communication systems.

Expanding on the multi-band concept, [27] utilized dual-band LC resonators as dipole elements to achieve coverage across three bands at 1.61 GHz, 2.2 GHz, and 2.81 GHz. This innovative approach further broadened the antenna's frequency coverage, demonstrating the potential for multi-band antennas to support diverse communication requirements.

Meanwhile, [29] presented a complex antenna configuration featuring two crossed dipoles, eight parasitic shorted patches, a square ground plane, and a feeding coaxial cable. This design aimed to achieve a broad bandwidth ranging from 0.66 GHz to 1.25 GHz, catering to a wide range of frequency-dependent applications.

In summary, while advancements have been made in achieving multi-band functionality and broadening impedance bandwidths in RFID and GPS antennas, challenges remain in addressing the need for circular polarization, covering multiple RFID bands, and achieving compact, low-profile designs suitable for various real-world applications. Continued research and innovation in antenna design are essential to address these challenges and unlock the full potential of RFID and GPS technologies in diverse applications.



## **CHAPTER 3 - GAPS IDENTIFIED**

### **3.1 ANTENNA GAIN**

High gain in an antenna is paramount for applications necessitating an extended communication range. A high-gain antenna achieves this by concentrating its radiated power in a specific direction, thereby augmenting the signal strength in that particular direction and facilitating communication over extended distances. This capability proves especially vital in scenarios characterized by obstacles or challenging environments, where the signal must traverse through or around barriers to reach its intended destination. By focusing the radiated power, high-gain antennas enhance the signal's resilience against attenuation and interference, thereby bolstering overall system performance and reliability. Whether it's in remote sensing, long-range communication, or satellite communication, the deployment of high-gain antennas ensures robust and dependable communication links, even in adverse conditions. In essence, the ability of high-gain antennas to amplify signal strength in specific directions plays a pivotal role in overcoming communication challenges and extending the reach of wireless communication systems.

Antennas capable of supporting multiple frequency bands play a crucial role in modern wireless communication systems by enabling devices to operate seamlessly across a wide range of communication standards. By accommodating multiple frequency bands, these antennas ensure compatibility with diverse networks, services, and technologies, regardless of the specific frequency bands used by different communication systems.

The versatility provided by antennas designed to operate in multiple frequency bands is particularly valuable in today's interconnected world, where devices need to connect to various networks and services to access a multitude of applications and services. Whether it's for cellular communication, Wi-Fi connectivity, Bluetooth pairing, or satellite navigation, devices equipped with multi-band antennas can effortlessly switch between different frequency bands to maintain connectivity and adapt to changing environmental conditions.

### **3.2 FREQUENCY BANDS**

Moreover, antennas that support multiple frequency bands contribute to efficient spectrum utilization, a critical aspect of modern communication systems. By leveraging available frequencies across different bands, these antennas enable devices to optimize their performance by selecting the most suitable frequency band for a given application or communication task. This dynamic spectrum utilization helps mitigate congestion in crowded frequency bands, improve overall network capacity, and enhance the reliability and quality of wireless communication services.

In summary, antennas designed to operate in multiple frequency bands play a pivotal role in enabling seamless connectivity, ensuring compatibility with diverse communication standards, and promoting efficient spectrum utilization. Their ability to support a wide range of frequencies empowers devices to deliver reliable, high-performance wireless communication across various networks and technologies, ultimately enhancing the user experience and driving innovation in the telecommunications industry.

In urban environments, consumer electronics, and wearable devices, the size of the antenna plays a critical role in shaping the overall design and form factor of the product. This is particularly evident in devices such as smartphones, smartwatches, fitness trackers, and other portable gadgets where space is limited, and sleek aesthetics are highly valued.

### **3.3 COMPACTNESS**

A more compact antenna design offers several advantages in such applications. Firstly, it allows for seamless integration into smaller devices without sacrificing performance. By minimizing the physical footprint of the antenna, manufacturers can optimize internal space utilization, enabling the inclusion of additional features, components, or functionalities within the device.

Furthermore, a compact antenna design enhances the portability and usability of the product, making it more convenient for users to carry, handle, and interact with. Whether it's a smartphone that fits comfortably in a pocket or a wearable device that blends seamlessly into everyday attire, the smaller form factor afforded by a compact antenna contributes to a more streamlined and user-friendly experience.

Additionally, compact antennas offer greater flexibility in product design and aesthetics, allowing designers to explore innovative form factors and creative solutions without being constrained by bulky or obtrusive antenna configurations. This freedom to experiment with design elements can lead to the development of more visually appealing and marketable products that resonate with consumers' preferences and lifestyles.

Overall, the size of the antenna directly influences the overall design, functionality, and user experience of electronic devices in urban environments, consumer electronics, and wearable technology. By prioritizing compactness and integration without compromising performance, manufacturers can create products that not only meet the demands of modern consumers but also seamlessly blend into their daily lives.

## CHAPTER 4 - DESIGN AND SIMULATIONS

The primary objective of this project is to design and develop an advanced antenna configuration for RFID systems, with the goal of achieving increased accuracy, broader RFID band coverage, higher gain, and a more compact form factor compared to existing antennas in the market that will enhance the overall performance and adaptability of RFID technology.

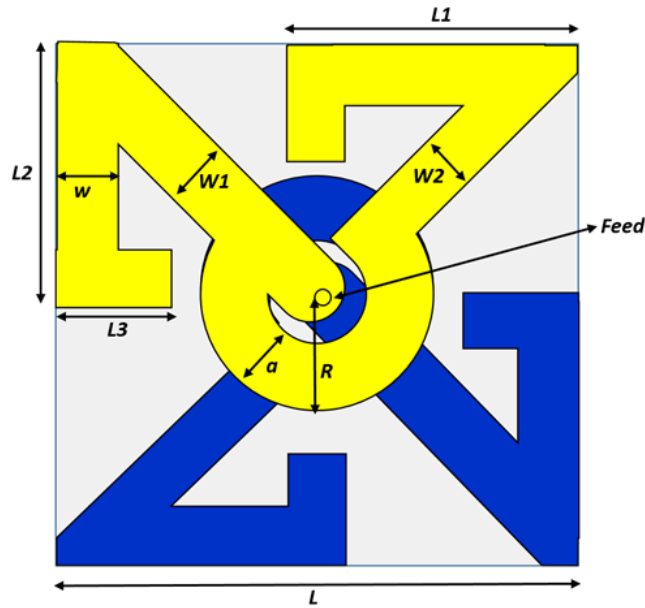


Fig 5. Layout of the presented RFID antenna: top view

TABLE I. DIMENSIONS OF THE PROPOSED ANTENNA

Parameter	(mm)	Parameter	(mm)
$L$	26	$W1$	3.48
$L1$	12	$W2$	2.63
$L2$	11.3	$a$	3.45
$L3$	2.7	$R$	6.08

The antenna configuration comprises two dipole elements, each meticulously crafted with arrow-shaped components. These elements are meticulously printed on both sides of an FR-4 substrate, known for its commendable dielectric properties. The substrate boasts a relative permittivity ( $\epsilon_r$ ) of 4.4 and a negligible loss tangent ( $\tan \delta$ ) of 0.02, ensuring minimal signal loss and superior performance. With a slender thickness of 1.6 mm, the substrate strikes a balance between structural integrity and compactness.

Crucially, the top and bottom dipoles are strategically engineered to operate  $180^\circ$  out of phase, a fundamental aspect of their design aimed at optimizing antenna performance. This phase difference ensures constructive interference between the two elements, maximizing radiation efficiency and pattern control.

To achieve circular polarization—a desirable characteristic in many communication applications—a delay line is skillfully integrated into the antenna design. This delay line introduces a precise  $90^\circ$  phase shift between the elements of the dipole pair, effectively aligning their polarization orientations orthogonal to each other. This meticulous arrangement imparts circular polarization to the emitted electromagnetic waves, enhancing signal robustness and resilience to polarization mismatch.

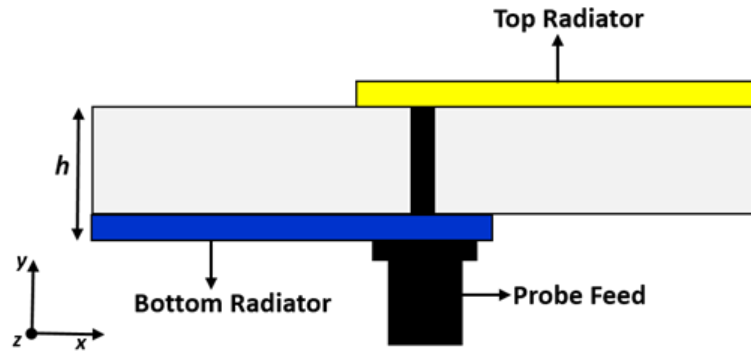


Fig 6. Layout of the presented RFID antenna: side view

A centrally positioned 50-ohm probe serves as the feeding mechanism for both dipoles, imbuing the antenna with compatibility for seamless integration into standard communication systems. This standardized impedance ensures efficient power

transfer and facilitates straightforward interfacing with transmission lines and radio frequency circuits.

In summary, the antenna's intricate architecture, characterized by arrow-shaped dipole elements, a carefully selected dielectric substrate, and precise phase control mechanisms, culminates in a high-performance antenna solution primed for a multitude of communication applications. Its circular polarization capability, in conjunction with a standardized feeding mechanism, renders it a versatile and reliable component within modern communication networks.

This research contributes to the development of compact yet efficient antennas suitable for various wireless communication systems. The demonstrated performance characteristics and compact form factor highlight the potential of this design for practical implementation in modern communication technologies. Moving forward, further optimization and exploration of applications in wireless communication systems are recommended based on the achieved results. The promising performance and compact nature of this antenna design open avenues for advancements in miniaturized antenna technologies.

## 4.1 ANTENNA DESIGN

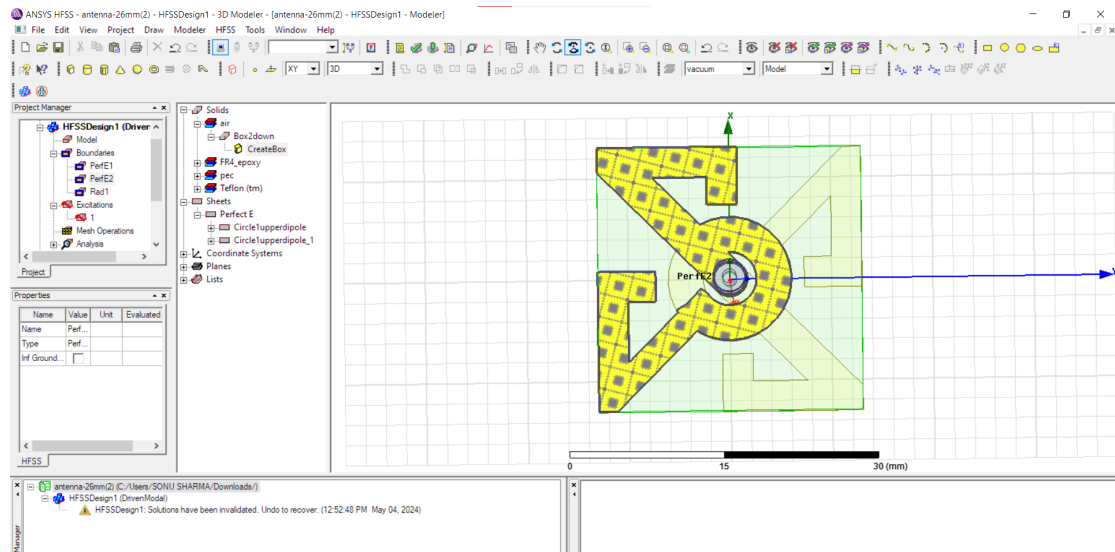


Figure 7 Cross Dipole bottom view

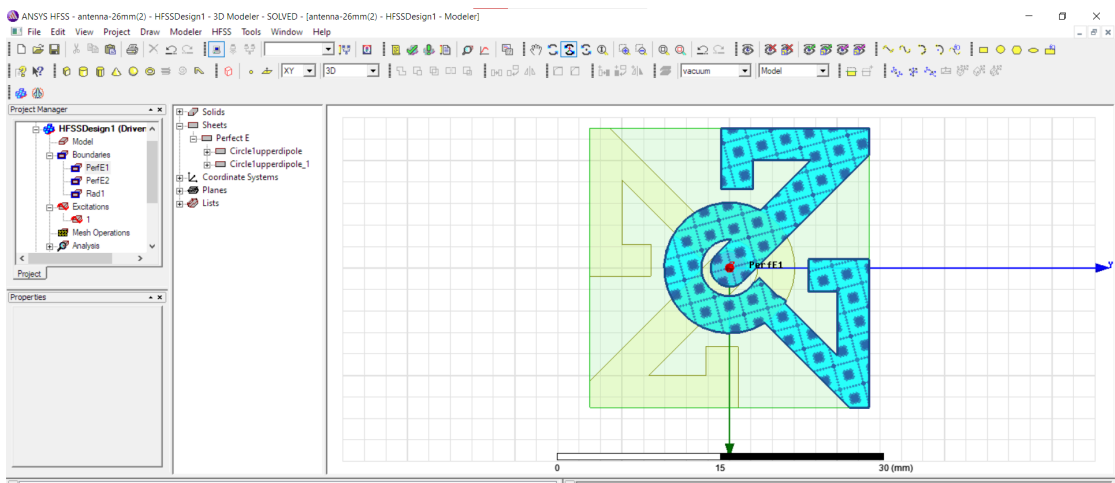


Figure 8 Cross Dipole top view

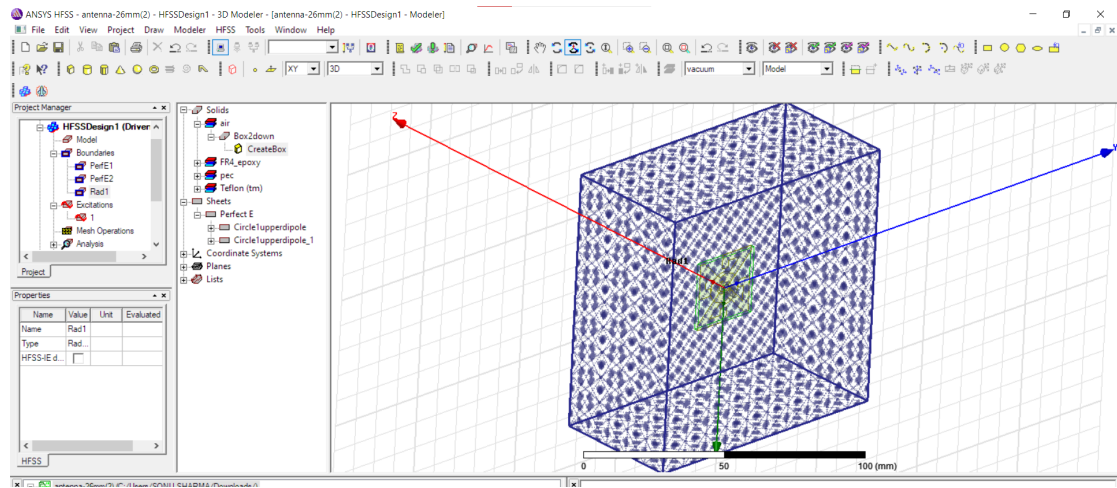


Figure 9 Cross Dipole antenna with radiation box

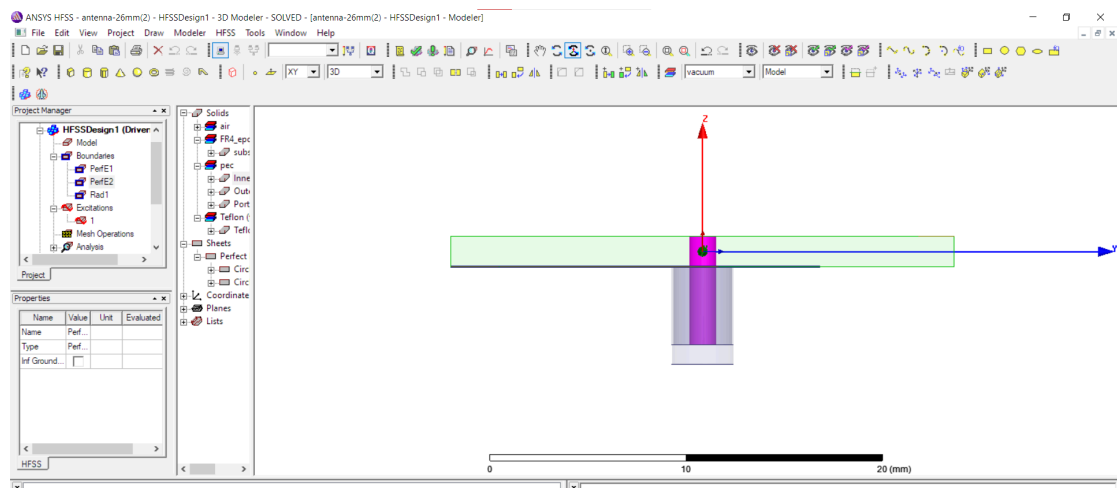


Figure 10 Cross Dipole antenna Side view



## 4.2 RESULTS AND SIMULATIONS

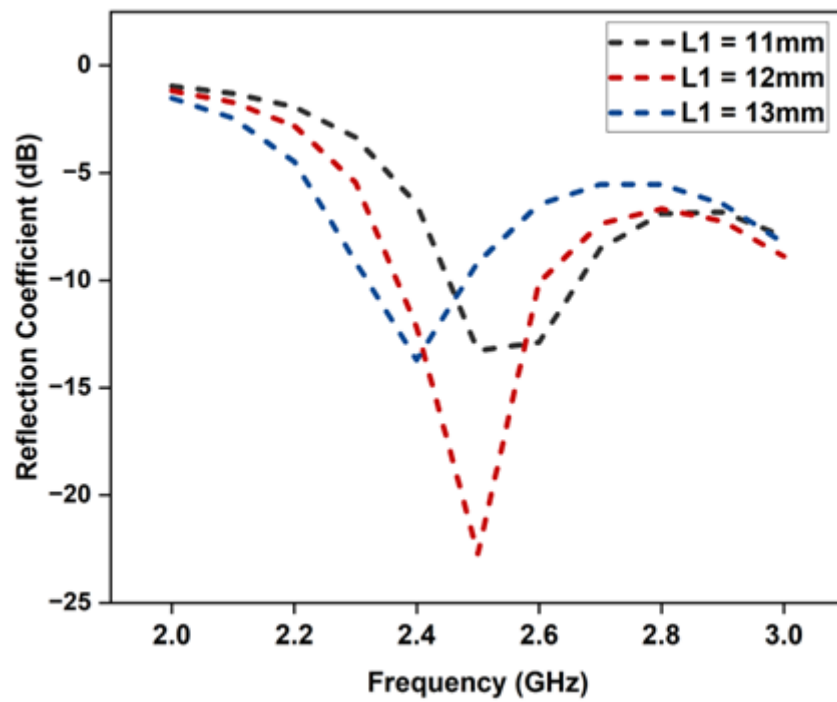


Figure 11 Reflection Coefficient vs Frequency graph for L1

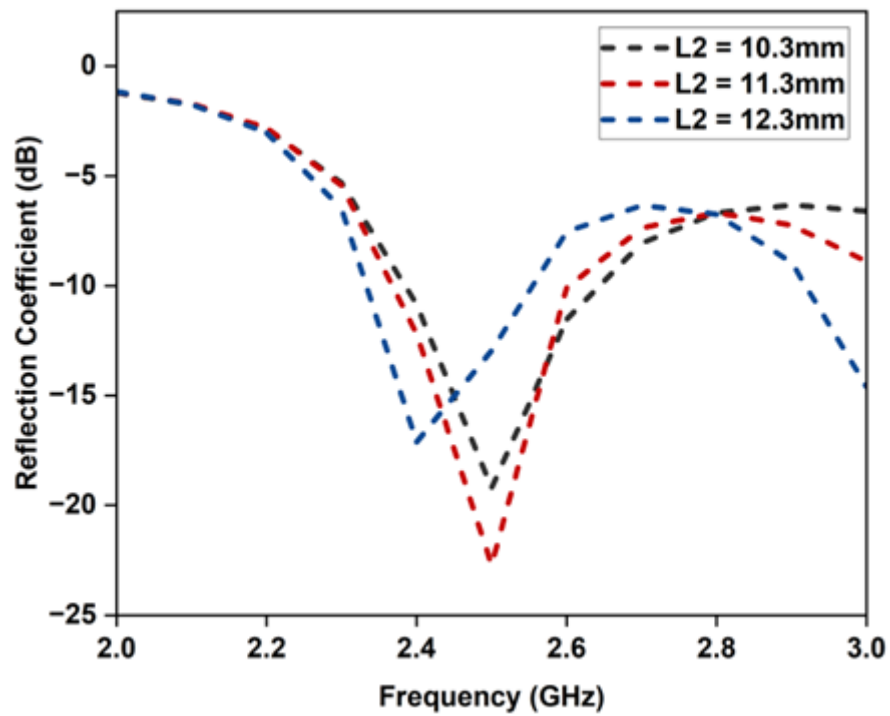


Figure 12 Reflection Coefficient vs Frequency graph for L2

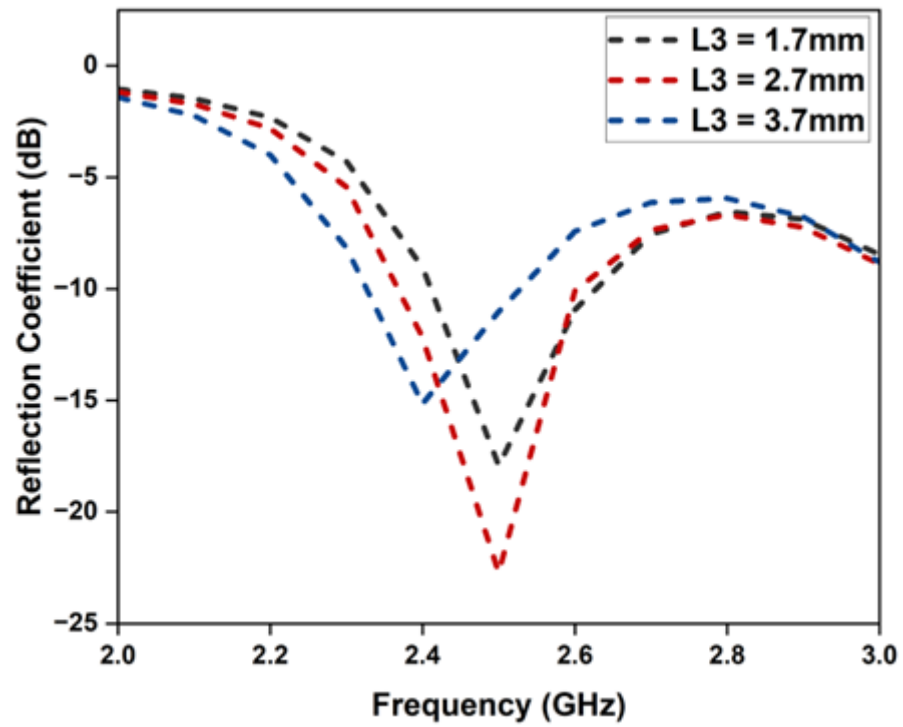


Figure 13 Reflection Coefficient vs Frequency graph for L3

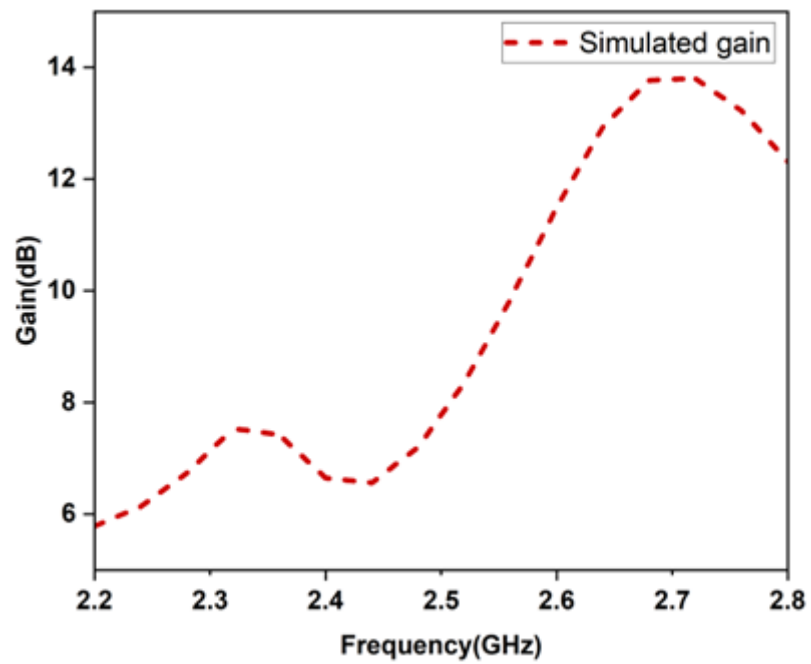


Figure 14 Gain curve of the proposed RFID antenna

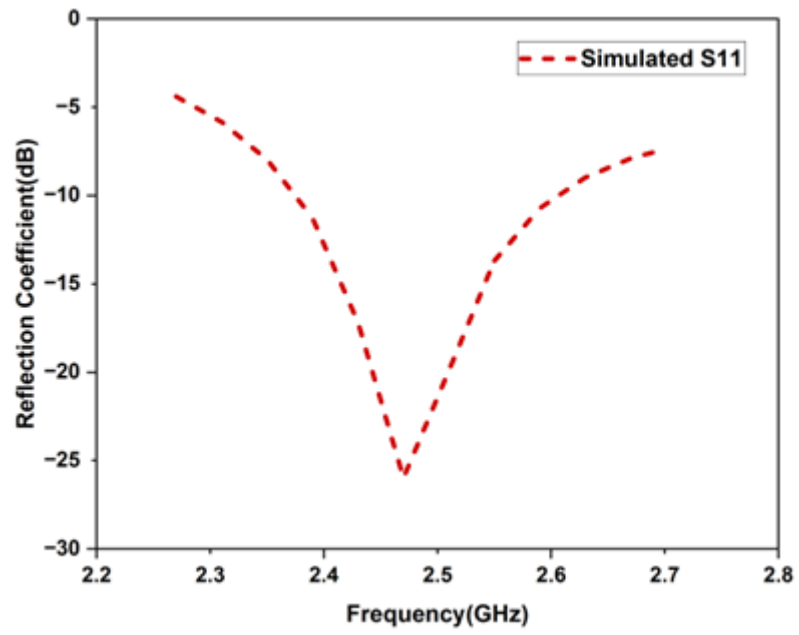


Figure 15. Reflection coefficient of the presented RFID antenna

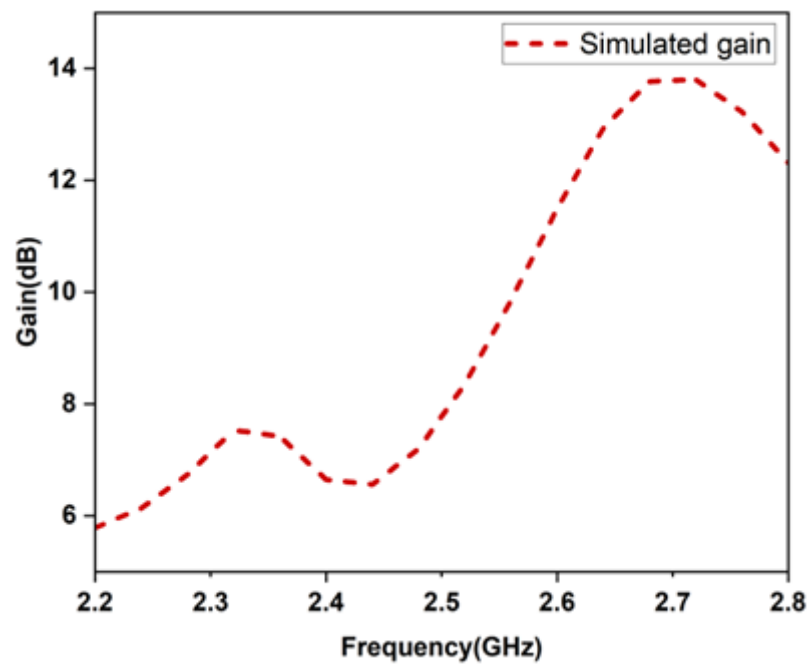


Figure 16 3-dB axial ratio of the presented antenna

## CHAPTER 5 - COMPARISON FROM OTHER PAPERS

As shown in Table II, compared to previous antennas studied, the antenna presented in this paper is the most concise and exhibits a high gain when compared to the cross dipole antennas given in [6–9]. The antenna presented in [6] has significantly larger cross-section, yet it achieves a subpar gain at the operating frequency of 2.45 GHz. In [7] the antenna mentioned is bulkier while delivering a suboptimal peak gain at 2.45 GHz. Additionally, the design referenced in [8], despite employing a specific slot for impedance matching, suffers from a relatively low gain and a substantial size. Furthermore, the design in [9] relying on an artificial magnetic conductor (AMC) to achieve unidirectional radiation results in a moderate gain at 2.45 GHz but at the cost of a bulky structure.

TABLE II. COMPARISON TABLE

Ref	Antenna Gain (dB)	Antenna Size ( $\lambda_o \times \lambda_o$ )	Impedance bandwidth (MHz)	Axial Ratio Bandwidth (MHz)
[6]	4	$0.23 \times 0.23$	220 (2.3 – 2.52 GHz)	170
[7]	1.65	$0.69 \times 0.69$	640 (2.16–2.80 GHz)	230
[8]	3.57	$0.57 \times 0.57$	100 (2.4-2.5 GHz)	100
[9]	2.95	$0.28 \times 0.28$	400 (2.2-2.6 GHz)	250
Prop.	6.55	$0.21 \times 0.21$	230 (2.37-2.60 GHz)	100

## CHAPTER 6 - CONCLUSION

this paper presents a novel design for a circularly polarized (CP) cross-dipole antenna. The antenna achieves a remarkably compact size, measuring only  $0.213\lambda_0 \times 0.213\lambda_0 \times 0.013\lambda_0$  ( $\lambda_0$  being the wavelength at the center frequency). This compactness is achieved through the use of a unique dipole structure comprised of half arrow-shaped elements with perpendicular stubs.

Circular polarization is ingeniously realized by implementing two key features:

1. Phase-shifted dipole elements: These elements likely have a slight structural difference that introduces a specific phase shift between the currents they carry. This phase difference is crucial for generating the characteristic electric field rotation required for circular polarization.
2. Delay line between perpendicular elements: This delay line introduces a controlled time difference between the arrival of the signals from the two perpendicular dipoles. When combined with the phase shift from the elements themselves, this time delay creates the necessary conditions for circular polarization.

The antenna operates within the UHF band (Ultra High Frequency) and exhibits impressive performance characteristics. It boasts a wide impedance bandwidth of 230 MHz (ranging from 2.37 GHz to 2.60 GHz), indicating its ability to function effectively across a significant range of frequencies. Furthermore, it achieves a notable axial ratio bandwidth of 100 MHz (from 2.37 GHz to 2.47 GHz). Axial ratio is a key parameter for CP antennas, and a lower value signifies a more purely circular polarization.

Most importantly, the antenna delivers a peak gain of 6.55 dB centered at 2.45 GHz. This gain indicates the antenna's efficiency in radiating electromagnetic waves in its preferred direction. The combination of compact size, wide bandwidths, and good gain makes this antenna a highly promising candidate for various wireless communication systems where space constraints are a concern but high performance is still desired.

In conclusion, this paper has introduced a circularly polarized cross dipole antenna having compact size of  $0.213\lambda_0 \times 0.213\lambda_0 \times 0.013\lambda_0$ . The dipole structure consists of half arrow shaped element with a perpendicular stub. By implementing phase-shifted dipole elements and employing a delay line between perpendicularly positioned elements, the antenna achieves circular polarization. Operating within the UHF band, it demonstrates an impedance bandwidth of 230 MHz (2.37 - 2.60 GHz), an axial ratio bandwidth of 100 MHz (2.37 - 2.47 GHz) with a notable peak gain of 6.55 dB centered at 2.45 GHz. The design is remarkably compact. This innovative design holds promise for applications demanding compact yet high-performing antennas, particularly in the realm of wireless communication systems.

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