Design of a Slotted Microstrip Patch antenna at Frequency 5.8 GHz for RFID Applications

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***Abstract*—The design and simulation of a circularly polarized microstrip patch antenna for RFID applications operating in the microwave frequency range that is 5.8 GHz using High-Frequency Structure Simulator. With the increasing demand for RFID technology in industries such as logistics, healthcare, and security, the need for efficient, compact, and cost-effective antennas has grown significantly.**

The proposed antenna is designed to operate in the microwave frequency range, ensuring high gain, wide bandwidth, and improved impedance matching for reliable RFID communication. Circular polarization is implemented to enhance signal stability and reduce polarization mismatches between the RFID reader and tag, improving overall system performance. The antenna is designed with Rogers (εr = 2.2) as the substrate material, chosen for its low dielectric constant and low loss tangent, which enhance antenna efficiency and performance.

Simulation in HFSS provide detailed insights into the antenna's return loss, axial ratio, gain, directivity, and radiation pattern, confirming its effectiveness for RFID applications. The final design aims to achieve a compact, lightweight, and high performance antenna suitable for real-world RFID implementations in the microwave frequency range.

Keywords—*Microstrip patch, RFID, High-Frequency Structure Simulator, Dielectric Constant.*

I. INTRODUCTION

In the modern era of wireless communication, the demand for efficient, compact, and high-performance antennas has significantly increased. Microstrip patch antennas have gained widespread popularity due to their low profile, lightweight structure, ease of fabrication, and suitability for high-frequency applications. Among various frequency bands, the 5.8 GHz band is commonly used for applications such as Wi-Fi, Wireless Sensor Networks, and dedicated short-range communication (DSRC) systems. This Paper focuses on designing a Slotted Microstrip Patch Antenna for operation at 5.8 GHz using ANSYS HFSS (High-Frequency Structure Simulator) software. The design process involves simulation and analysis without any fabrication or physical implementation. Radio Frequency Iidentification (RFID) technology has emerged as a crucial element in modern wireless communication systems. RFID systems facilitate automatic identification and tracking of objects, enhancing efficiency across various industries, including logistics, healthcare, transportation, and retail. The RFID system consists of three primary components: a reader, a tag, and an antenna. The design and performance of the antenna significantly influence the reliability and efficiency of RFID communication.

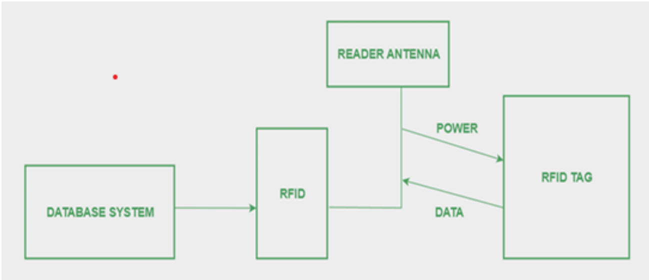

Fig 1 : Overview of RFID

Microstrip patch antennas are widely used in RFID applications due to their light weight, low profile, ease of fabrication, and cost-effectiveness. These antennas are commonly fabricated on dielectric substrates with a conductive patch on one side and a ground plane on the other. Their compact design makes them suitable for portable and embedded RFID systems. However, achieving optimal performance in terms of gain, bandwidth, impedance matching, and radiation efficiency requires careful design considerations, including substrate selection, patch dimensions, feeding techniques, and optimization strategies.

The design methodology adopted in this paper follows a systematic approach involving parametric modeling, simulation, and optimization. HFSS, an industry- leading electromagnetic simulation software, is used to analyze the antenna's performance characteristics, including return loss, VSWR (Voltage Standing Wave Ratio), gain, directivity, radiation pattern, and efficiency. The selection of substrate material plays a crucial role in determining the antenna's performance. For this design, a low-loss dielectric substrate such as FR4, Rogers RT/Duroid 5880, or Taconic is considered, ensuring minimal signal attenuation and improved radiation characteristics.

Simulation plays a vital role in the design process, enabling performance evaluation before physical fabrication. The HFSS software, based on the finite element method (FEM), provides an accurate solution to Maxwell's equations for the given antenna structure. The return loss (S11 parameter) is analyzed to ensure resonance at 5.8 GHz, ideally achieving values below -10 dB, indicating good impedance matching. Additionally, VSWR values close to 1, higher gain, and desirable radiation efficiency confirm the effectiveness of the design.

II. DESIGNING OF MICROSTRIP ANTENNA

Designing a microstrip patch antenna using ANSYS HFSS (High-Frequency Structure Simulator) involves the precise modelling, simulation, and optimization of antenna parameters to achieve efficient performance. HFSS, based on the Finite Element Method (FEM), is widely used for high-frequency electromagnetic analysis, making it an ideal tool for designing microstrip antennas used in applications like RFID, Wi-Fi, satellite communication, and 5G networks.

The design process in HFSS includes creating the antenna geometry, defining material properties, selecting the appropriate substrate and ground plane, and configuring the feeding mechanism (such as microstrip line or coaxial probe). The software enables the analysis of crucial performance metrics like S-parameters, return loss, impedance matching, gain, directivity, radiation patterns, and bandwidth.

By using adaptive meshing and parametric optimization, HFSS helps in fine-tuning the antenna's dimensions to meet the desired operating frequency and efficiency. The feeding mechanism is selected based on the antenna's application Coaxial probe feed. Adaptive meshing is applied to refine the geometry and enhance accuracy. A frequency sweep is set around 5.8 GHz to analyze the antenna's behavior over a range of frequencies. The convergence criteria are configured to ensure reliable simulation results. The feed position is carefully adjusted to achieve circular polarization, ensuring improved performance for wireless communication applications.

A. *Design process :*

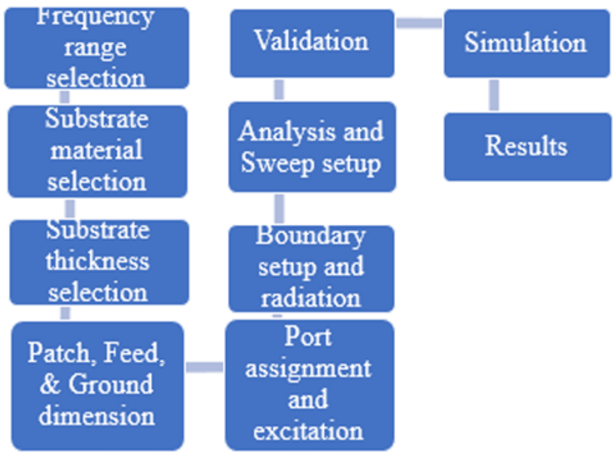

Fig 2 : Antenna design flow in HFSS

B. *Design Steps:*

The design process begins by opening ANSYS HFSS and creating a new project. The solution type is set to Driven Modal for full-wave electromagnetic analysis.

A Teflon substrate with a dielectric constant (εr) of 2.1 is defined. The substrate's dimensions are 64.1mm × 64.1mm, with a thickness of 2.6mm, ensuring proper support for the microstrip patch and ground plane.

Table 1: INITIAL ANTENNA DIMENSIONS

Antenna Constraints	**Value**
Substrate Material	Teflon
Resonant Frequency	5.8GHz
Dielectric Constant	2.1
Patch dimensions	PW =PL = 32.9mm
Ground plane dimensions	GL = GW = 64.1mm
Substrate dimensions	SL = SW = 64.1mm
Height	2.6mm

A rectangular patch is placed on the substrate, with a patch length and width of 32.9mm × 32.9mm, designed to operate at a resonant frequency of 5.8 GHz. The ground plane, identical in size to the substrate (64.1mm × 64.1mm), is positioned beneath the substrate to provide proper signal reflection.

The feeding mechanism is selected based on the antenna's application Coaxial probe feed. The feed position is carefully adjusted to achieve circular polarization, ensuring improved performance for wireless communication applications. A radiation boundary is defined at a distance of λ/4 or λ/2 from the antenna to simulate free-space radiation accurately. The appropriate port type (Wave Port or Lumped Port) is assigned to excite the antenna for analysis. Adaptive meshing is applied to refine the geometry and enhance accuracy. A frequency sweep is set around 5.8 GHz to analyze the antenna's behavior over a range of frequencies. The convergence criteria are configured to ensure reliable simulation results.

C. *Design 1*

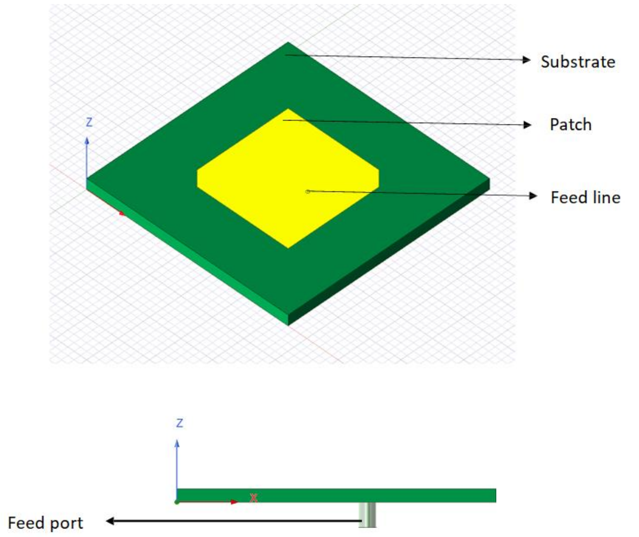

Fig 3 : Microstrip Patch Antenna Design 1

The above microstrip patch antenna is the initially designed structure followed by finding the theoretical calculations and verified it and later simulated the design in HFSS software.

D. *Simulation Result of Design 1*

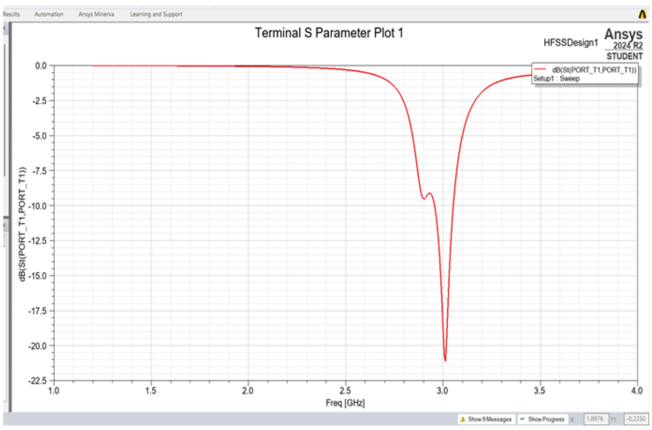

Fig 4 : S-Parameter Plot of Design 1

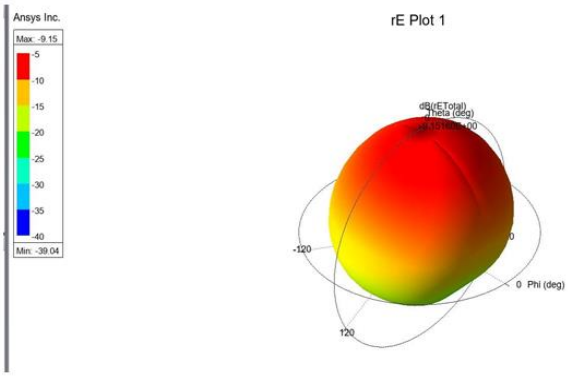

Fig 5 : 3D Polar plot of Design 1

The S-parameter shows the response at 3.0 Ghz, Since this microstrip patch antenna design didn't meet the expected output and further need to change the dimensions and feeding techniques and may lead to change the thickness also. The patch dimensions, feed position, and substrate properties are fine-tuned to ensure the antenna meets the desired performance criteria. Adjustments are made to enhance bandwidth and improve impedance matching.

III. PROPOSED MICROSTRIP ANTENNA

The microstrip patch antenna is redesigned using a Rogers 5880 substrate (εr = 2.2) with updated dimensions to achieve an operating frequency of 5.8 GHz. A slot is introduced in the patch to improve antenna performance.

A new project is created in ANSYS HFSS, selecting the Driven Modal solution type for full-wave electromagnetic analysis.

A. *Improved Antenna Dimesions*

Table 2: IMPROVED DESIGN DIMENSIONS

Antenna Constraints	**Value**
Substrate Material	Rogers RT/Duroid 5880™
Resonant Frequency	5.8GHz
Dielectric Constant	2.2
Patch dimensions	PW =PL = 28mm
Ground plane dimensions	GL = GW = 70mm
Substrate dimensions	SL = SW = 70mm
Height	1.53mm

The substrate material is defined as Rogers 5880 with a dielectric constant (εr = 2.2).The ground plane and substrate dimensions are set to 70mm × 70mm, with a thickness of 1.53mm.A square patch of 28mm × 28mm is placed on the top surface of the substrate. A slot is introduced in the patch, designed to enhance antenna performance, such as impedance matching and bandwidth improvement. The ground plane, identical to the substrate dimensions (70mm × 70mm), is positioned below the substrate. A suitable feeding mechanism (such as Microstrip Line Feed or Coaxial Probe Feed) is incorporated.

The feed position is adjusted for optimal impedance matching and excitation. A radiation boundary is set up to simulate free-space conditions. The excitation port (Wave Port or Lumped Port) is assigned to feed the antenna appropriately. Adaptive meshing is enabled for accurate simulation in critical areas. A frequency sweep is performed around 5.8 GHz to analyze antenna performance across a range of frequencies.

The S-parameters (S11) are analyzed to ensure effective return loss. VSWR is observed to confirm proper impedance matching (target: VSWR < 2).The radiation pattern, gain, and directivity are evaluated. The effect of the slot on antenna performance is analyzed. Further modifications to slot dimensions, feed position, and patch size are made if necessary to achieve resonance at 5.8 GHz. Additional optimizations focus on improving bandwidth and radiation efficiency.

B. *Design 2*

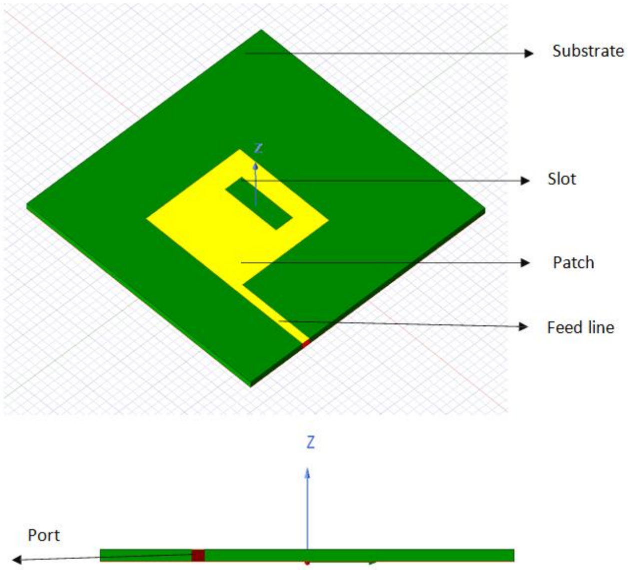

Fig 4 : Microstrip patch antenna design 2

IV. SIMULATION RESULTS

This HFSS-based design process ensures that the microstrip patch antenna with a slot, using Rogers 5880 substrate, meets the required 5.8 GHz operating frequency with enhanced performance characteristics

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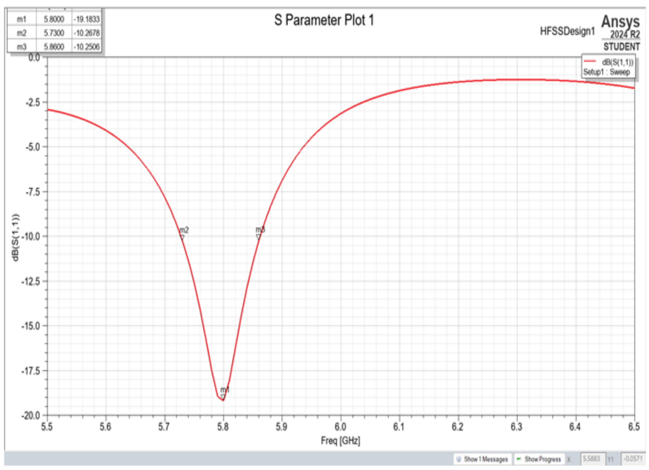

Fig 5 : S-Parameter Plot of Design 2

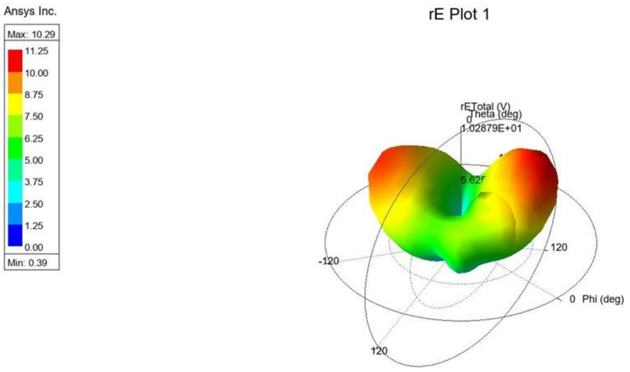

Fig 6 : 3D polar plot of design 2

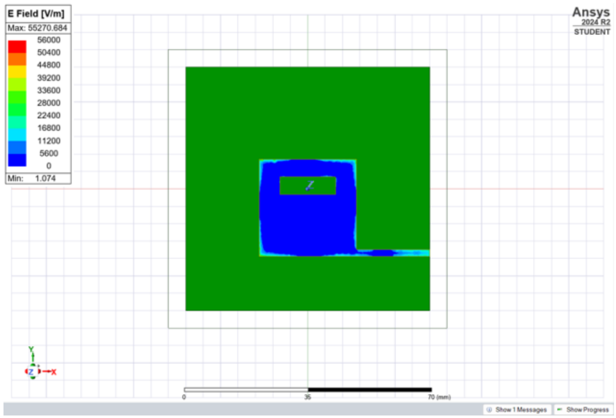

Fig 7 : Magnetic E-Field of design 2

The microstrip patch (MPA) final design provides a gain around 6 dB, and a return loss (S11) of -21.06 dB at 3GHz while the microstrip patch slot antenna (MPA) design 2 have achieved a total antenna gain of 6.04 dB and a return loss (S11) of -19.18 dB at 5.8 GHz for a patch length of 28mm and width of 28mm. The most important parameter for an antenna used for RFID applications is that it must have relatively good gain as higher is the gain, higher will be the directivity. Thus, it is clear that though the results produced by the antenna in design 1 are good, introducing one slot technique as seen in design 2 has further improved the antenna gain.

V. CONCLUSION

This paper centering on the design of a microstrip patch antenna for RFID applications, offered a valuable exploration into the practicalities of wireless communication. It fostered a deeper understanding of RFID technology, encompassing its operating frequencies and diverse applications, from logistical tracking to secure access systems. By meticulously adjusting antenna parameters like patch dimensions and substrate materials, the project illuminated the direct correlation between these design choices and performance metrics such as resonant frequency return loss, and gain, reinforcing the foundational principles of electromagnetic wave propagation and antenna theory.

The insights gained into impedance matching and radiation patterns are crucial for future endeavors in wireless systems. Observed the impact of design decisions on these characteristics is essential for achieving efficient signal transmission and reception. The project underscored the importance of optimizing these aspects to ensure effective communication within an RFID system.

Looking forward, this paper has established a solid foundation for exploring the evolution of RFID and wireless communication. This includes the development of antennas tailored for the expanding IoT sector, where compact and efficient designs are paramount. There is also the potential to investigate higher frequency bands to accommodate the increasing demand for data throughput, as well as the integration of advanced materials and fabrication techniques to enhance antenna performance.

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