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Design and Fabrication of 2.5 GHz Antenna for Wireless Routers

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ABSTRACT: The rapid growth of wireless communication systems has increased the demand for efficient and compact antenna designs capable of operating in the Industrial, Scientific, and Medical (ISM) frequency bands. Antennas play a crucial role in ensuring reliable data transmission in wireless routers and communication devices. This research work focuses on the design and simulation of a 2.5 GHz circular microstrip patch antenna for wireless router applications. The proposed antenna is designed using an FR-4 substrate with a dielectric constant of 4.4 and a thickness of 1.6 mm. The antenna structure is modelled and analysed using ANSYS HFSS (High Frequency Structure Simulator) to evaluate important parameters such as return loss (S_{11}), Voltage Standing Wave Ratio (VSWR), and radiation characteristics. The results obtained from the simulation demonstrate good impedance matching and stable performance at the target frequency band. The proposed antenna design provides a low-cost, compact, and efficient solution suitable for wireless communication systems, particularly for wireless routers operating around the 2.5 GHz frequency band. The proposed design also ensures improved signal propagation and stable radiation performance for reliable wireless connectivity. Furthermore, the antenna structure can be easily fabricated and integrated into modern wireless communication devices.

KEYWORDS: Microstrip Patch Antenna, 2.5 GHz Antenna, Wireless Routers, HFSS Simulation, FR-4 Substrate, Wireless Communication.

I. INTRODUCTION

Wireless communication has become an essential part of modern technology, enabling seamless connectivity between devices such as smartphones, laptops, wireless routers, and Internet of Things (IoT) systems. Antennas play a crucial role in wireless communication as they are responsible for transmitting and receiving electromagnetic signals. Among different antenna types, microstrip patch antennas are widely used due to their compact size, low weight, low fabrication integration electronic circuits. With the rapid growth of wireless communication technologies, there is an increasing demand for efficient antennas that can operate effectively in specific frequency bands such as the 2.4–2.5 GHz Industrial, Scientific, and Medical (ISM) band, which is commonly used for wireless routers to the communication devices. In recent years, several antenna designs have been proposed to improve antenna performance for wireless communication applications. Circular microstrip patch antennas are particularly attractive due to their symmetrical radiation pattern and simple design structure. In this work, a 2.5 GHz circular microstrip patch antenna is designed and simulated using HFSS software with an FR-4 substrate. The proposed design focuses on achieving good impedance matching s, making the antenna suitable for a wireless router communication systems operating around network to the 2.5 GHz frequency band.

II. RELATED WORK

Microstrip patch antennas have gained significant attention in recent years due to their compact structure, low cost, and ease of fabrication. Researchers have focused on improving antenna performance parameters such as gain, bandwidth, return loss, and radiation efficiency for wireless communication applications. Earlier antenna designs were often limited by narrow bandwidth and poor impedance matching, which affected the overall performance of wireless communication systems. With the advancement of electromagnetic simulation tools such as ANSYS HFSS, CST, and FEKO, antenna design and optimization have become more efficient and accurate.

A. Microstrip Patch Antennas for Wireless Communication

Various antenna structures such as rectangular, circular, and slotted microstrip patch antennas have been proposed for wireless communication systems. Circular patch antennas are widely used because they provide symmetrical radiation patterns and stable performance. However, achieving good impedance matching and maintaining compact antenna size while operating at the desired frequency still remains a challenge.

B. Antenna Design Optimization Techniques

To improve antenna performance, researchers have introduced several optimization techniques such as slotting methods, stacked patch structures, and feed optimization techniques. These techniques help in improving bandwidth, gain, and return

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loss characteristics of the antenna. Simulation tools like HFSS allow designers to analyze antenna parameters such as S11 (return loss), VSWR, radiation pattern, and gain before fabrication. In this work, a 2.5 GHz circular microstrip patch antenna is designed and simulated using HFSS software with an FR-4 substrate, aiming to achieve good impedance matching and stable radiation characteristics suitable for wireless router applications.

III. PROPOSED METHODOLOGY

The proposed methodology focuses on the design and simulation of a 2.5 GHz circular microstrip patch antenna for wireless router applications. The design process involves several stages including antenna modeling, parameter optimization, and performance analysis using electromagnetic simulation tools. The antenna structure is developed using ANSYS HFSS (High Frequency Structure Simulator) to analyze important performance parameters such as return loss (S_{11}), Voltage Standing Wave Ratio (VSWR), and radiation characteristics. The workflow of the proposed system mainly consists of three stages: antenna design, simulation and optimization, and performance evaluation.

1) 3.1 Antenna Design Parameters

The antenna is designed as a circular microstrip patch antenna operating at a frequency of 2.5 GHz. The antenna consists of a circular patch mounted on an FR-4 dielectric substrate with a ground plane on the opposite side. The FR-4 material is selected because of its low cost, good mechanical strength, and suitable dielectric properties for microwave applications.

The important parameters considered in the antenna design include the dielectric constant of the substrate, substrate thickness, patch radius, and ground plane dimensions. These parameters are carefully calculated and optimized to achieve resonance at the desired frequency.

a) 3.1.1 Circular Microstrip Patch Antenna Design

A circular microstrip patch antenna is chosen due to its compact structure and symmetrical radiation pattern, which makes it suitable for wireless communication systems. The antenna is designed using standard antenna design equations to determine the patch radius required for operation at 2.5 GHz.

The antenna structure consists of three main layers:

• Radiating circular patch
• FR-4 dielectric substrate
• Ground plane

Antenna Design Equation

Patch Radius Formula

The radius of the circular microstrip patch antenna is calculated using the standard microstrip antenna design equation:

$$a = \frac{F}{\sqrt{1 + \frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]}}$$

Where:

- **a** = radius of circular patch
- **h** = substrate thickness
- **εr** = dielectric constant of substrate
- **F** = Intermediate radius value

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}}$$

- **fr** = resonant frequency (2.5 GHz)

Antenna Dimension Table

Antenna Design Parameters

Parameter	Description	Value
fr	Resonant Frequency	2.5 GHz
εr	Dielectric Constant	4.4
h	Substrate Thickness	1.6 mm
a	Patch Radius	18.2 mm (approx)
Lg	Ground Length	70 mm
Wg	Ground Width	70 mm
Substrate	Material	FR-4

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The patch is excited using a coaxial feed or port feed, which provides proper impedance matching between the antenna and transmission line. By adjusting the patch dimensions and feed position, the antenna can achieve good return loss and stable radiation characteristics at the target frequency band.

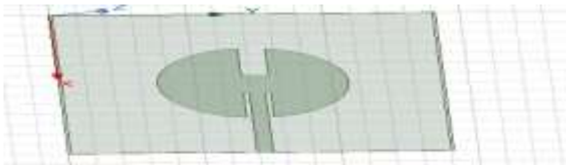

Fig 1 circular patch antenna

b) 3.1.2 HFSS Simulation and Optimization

High Frequency Structure Simulator (HFSS) is an advanced electromagnetic simulation tool widely used for the design and analysis of microwave components such as antennas, waveguides, and RF circuits. In this work, ANSYS HFSS software is used to model and simulate the proposed 2.5 GHz circular microstrip patch antenna. HFSS uses the Finite Element Method (FEM) to solve Maxwell's equations and accurately analyze the electromagnetic behavior of the antenna structure. The antenna model is created by defining the circular patch, FR-4 substrate, and ground plane, along with the feed port used to excite the antenna. Important antenna parameters such as return loss (S_{11}), Voltage Standing Wave Ratio (VSWR), gain, and radiation pattern are analyzed through simulation. By adjusting the patch radius, substrate thickness, and feed position, the antenna design can be optimized to achieve resonance at the desired 2.5 GHz frequency band.

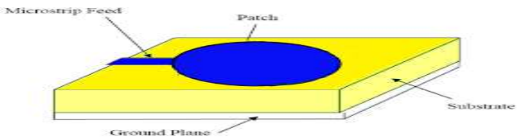

Fig 2 Antenna Architecture

1) 3.2 Antenna Design Architecture

The proposed antenna design focuses on the development of a 2.5 GHz circular microstrip patch antenna for wireless router communication systems. The antenna structure consists of three main components: the circular radiating patch, dielectric substrate, and ground plane. These components work together to transmit and receive electromagnetic signals effectively. The antenna is designed using an FR-4 substrate with a dielectric constant of 4.4 and a thickness of 1.6 mm. This substrate is commonly used because of its low cost and suitable dielectric properties for microwave applications. The complete antenna model is created and analyzed using ANSYS HFSS simulation software. The simulation helps in evaluating important antenna parameters such as return loss (S11), VSWR, gain, and radiation pattern. These parameters determine the efficiency and performance of the antenna. By adjusting the antenna dimensions and feed configuration, the design is optimized for the desired frequency. The optimized antenna achieves stable performance at the 2.5 GHz frequency band, making it suitable for wireless router applications.

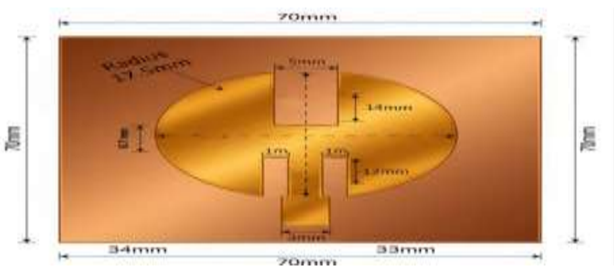

Fig 4 Antenna Design

a) 3.2.2 Antenna Simulation Using HFSS

ANSYS HFSS is a powerful electromagnetic simulation software used for designing and analyzing antennas and RF components. It uses the Finite Element Method (FEM) to accurately solve Maxwell's equations and predict antenna behavior. In this work, HFSS is used to model the 2.5 GHz circular microstrip patch antenna and analyze its performance. The software helps evaluate important parameters such as return loss (S11), Voltage Standing Wave Ratio (VSWR), gain, and radiation pattern. This simulation process helps optimize the antenna design before fabrication, ensuring better performance for wireless router communication systems

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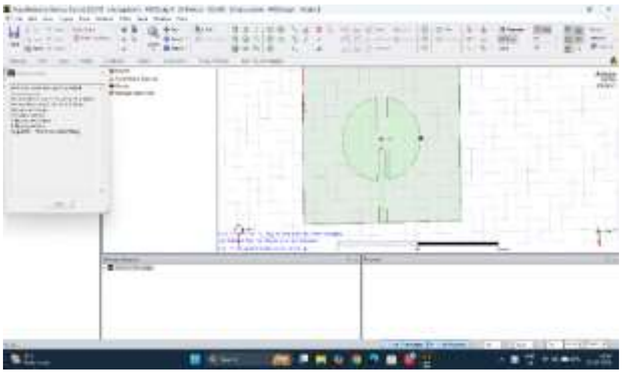

Fig 5 HFSS Software

3.2.3 Antenna Fabrication

The antenna fabrication process focuses on constructing the designed 2.5 GHz circular microstrip patch antenna using suitable substrate and conductive materials. The fabrication involves creating the circular patch, substrate layer, and ground plane according to the calculated design parameters. Commonly used substrate materials such as FR-4 are selected due to their low cost, good dielectric properties, and ease of availability. During the fabrication process, the circular patch is etched or printed on the top surface of the substrate using copper material, while the ground plane is placed on the opposite side. The dimensions of the patch, substrate thickness, and feed mechanism are carefully maintained to achieve the required resonant frequency of 2.5 GHz. A coaxial probe or microstrip line feed can be used to excite the antenna After fabrication, the antenna is connected to the communication system to transmit and receive electromagnetic signals. Proper fabrication ensures good impedance matching and radiation characteristics, which directly affect the antenna performance. The fabricated antenna can then be tested and compared with the simulated results obtained from ANSYS HFSS, analyzing parameters such as return loss (S11), VSWR, gain, and radiation pattern to verify its efficiency in wireless communication applications.

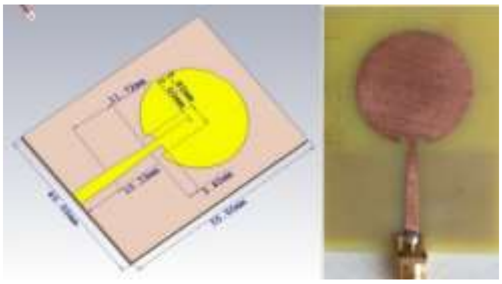

Fig 6 Antenna communication Framework

IV. RESULTS AND DISCUSSION

The proposed 2.5 GHz circular microstrip patch antenna was designed and simulated using ANSYS HFSS software to evaluate its performance parameters. The simulation results show that the antenna achieves good impedance matching at the target frequency band. Important parameters such as return loss (S11), Voltage Standing Wave Ratio (VSWR), gain, and radiation pattern were analyzed to determine the antenna performance. The return loss graph indicates that the antenna resonates near 2.5 GHz, with S11 values below –10 dB, which confirms efficient signal transmission.

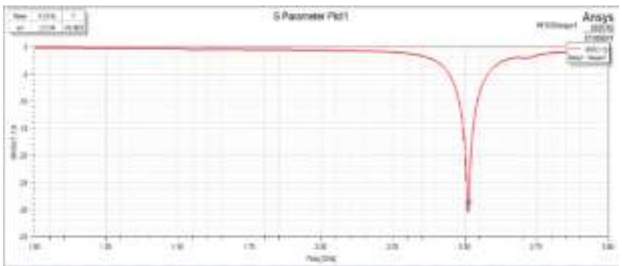

Fig 7 S11(return loss)

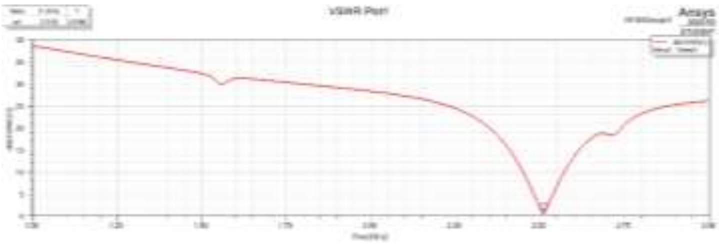

Fig 8 VSWR

The VSWR values obtained from the simulation are close to 1, indicating proper impedance matching between the antenna and transmission line. The radiation pattern analysis shows stable signal propagation and good radiation characteristics suitable for wireless communication applications. The gain results also indicate that the antenna can effectively support wireless signal transmission for router communication systems. Overall, the simulation results confirm that the proposed antenna design provides reliable performance within the 2.5 GHz wireless communication band.

V. CONCLUSION

This study presented the design and simulation of a 2.5 GHz circular microstrip patch antenna intended for wireless router communication systems. The antenna was designed using an FR-4 substrate with a dielectric constant of 4.4 and thickness of 1.6 mm, and the structure was modeled and analyzed using ANSYS HFSS simulation software. Important antenna parameters such as return loss, VSWR, gain, and radiation pattern were evaluated to verify the antenna performance. The simulation results demonstrate that the proposed antenna design achieves good impedance matching and stable radiation characteristics at the desired 2.5 GHz frequency band. The antenna structure provides a compact, low-cost, and efficient solution for wireless communication applications, particularly for wireless routers and short-range communication systems. The design also shows potential for integration into modern wireless devices.

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VI. FUTURE WORK

The proposed antenna was successfully fabricated and experimentally validated using a Vector Network Analyzer (VNA). The measured results were compared with the simulated outcomes to assess key performance parameters such as return loss, bandwidth, gain, and radiation efficiency. A close agreement between simulation and measurement was observed, with minor discrepancies attributed to fabrication tolerances and material losses. Further work may involve the application of advanced optimization techniques, precise fabrication methods, and the use of improved substrate materials to enhance overall antenna performance for 2.5 GHz wireless communication applications.

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