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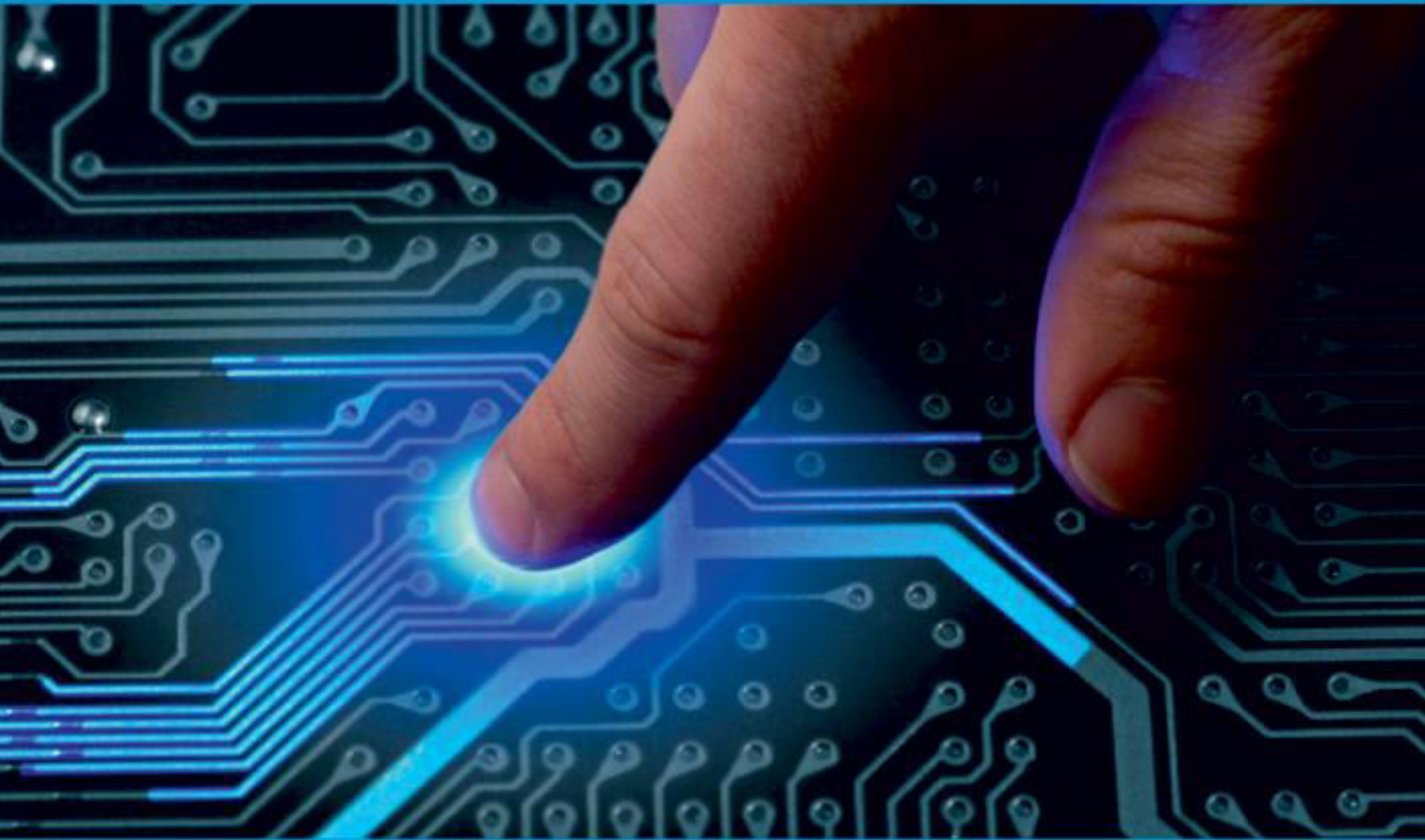

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Design of Microstrip Patch Antenna with Various Slots for Bandwidth Enhancement

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ABSTRACT: In the realm of wireless communication systems, the demand for compact, efficient, and high-performance antennas continues to grow. Microstrip patch antennas have emerged as a popular choice due to their low profile, lightweight design, and compatibility with integrated circuit technology. This paper investigates the design and optimization of microstrip patch antennas with various slot configurations to enhance bandwidth performance in wireless communication systems. Results demonstrate that strategically designed slots can effectively broaden the antenna's bandwidth while maintaining desirable radiation properties, offering promising solutions for next-generation wireless communication applications. Additionally, a novel antenna design is proposed and simulated, showing improved performance in Quarter wave feed by using two slots of distance of 32mm, particularly in the 2.4 GHz frequency band. With a return loss of −28 dB and a bandwidth of 0.161 GHz.

KEYWORDS: Wireless Sensor Networks, Microstrip Patch Antenna, Return Loss, Bandwidth

I. INTRODUCTION

Within the domain of wireless communication systems, there is an increasing need for antennas that are compact, efficient, and deliver high performance. Microstrip patch antennas have emerged as a popular choice due to their low profile, lightweight design, and compatibility with integrated circuit technology. This paper presents a comprehensive investigation into the design and analysis of microstrip patch antennas with various slot configurations aimed at enhancing bandwidth. By strategically incorporating slots into the patch structure, we aim to overcome the limitations of conventional microstrip antennas and achieve significant improvements in bandwidth while maintaining desirable radiation characteristics.. This paper explores the design and optimization of microstrip patch antennas with the incorporation of various slot configurations to enhance bandwidth performance. Microstrip patch antennas are widely utilized in modern wireless communication systems due to their compact form factor and compatibility with integrated circuit technology. However, achieving sufficient bandwidth remains a critical challenge for these antennas. Simulation studies using advanced electromagnetic modeling techniques are conducted to analyze the effects of slot dimensions and placements on antenna performance metrics such as return loss, gain, VSWR, etc. Experimental validation of the proposed designs is performed to confirm the simulation results. The antenna was designed and simulated. From the obtained results, it ensured a high level of performance and can be used in any applications specific to the 2.4 GHz frequency band. We find an optimal structure of the microstrip patch antenna with a return loss of −28 dB and a bandwidth of 0.161 GHz in Quarter wave feed by using two slots of Distance of 32mm. After analyzing the designed novel antenna, we concluded that the proposed antenna can increase the performance level of wireless communications. Some of the applications are Continuously striving for performance improvement through iterative design iterations, feedback from real-world deployments, and incorporation of latest advancements in antenna theory, modeling, and simulation techniques.

II. LITERATURE SURVEY

In 2023, Amit A Deshmukh and Venkata A P Chavali analyzed variation of square microstrip antenna loaded with u-slot and pair of rectangular slots for circular polarized response which clearly explains variations of U-slot and pair of rectangular slots (E-shape) cut rectangular and square microstrip antenna are reported for the circularly polarized response. This provides a detailed review-based study to explain the functioning of the resonant slot-cut circular polarized microstrip antenna in terms of the resonant modes present.

The paper titled application of PSO and Curve Fitting for the Optimization of Compact L-shaped Open Ended Slot loaded Rectangular patch antenna by Ramesh Kumar Verma in 2023 demonstrates an application of PSO (particle swarm optimization) for bandwidth optimization of L-shaped open ended slot antenna. An L-shaped open ended slot antenna design (non-optimized) has been optimized by

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MATLAB-based PSO for bandwidth enhancement at frequency 2.50 GHz. Various parameters of L-shaped open ended slot antenna have been changed one by one at a time for generating the data for bandwidth and resonant frequency.

III. Proposed Algorithm

CST Studio Suite antenna design covers a wide range of industries. Public broadcasting (TV/Radio), military, aerospace, and nautical industries have been using antennas for decades. More recently, we have seen the emergence of antennas in devices in our homes and handheld, smart devices. Oftentimes these devices contain several different antennas for communications at different frequencies. The most obvious example is a smartphone. In a smartphone, antennas are required for the 4 or 5G mobile network for the standard talk and internet connectivity. We have a Bluetooth antenna for accessories such as a speaker or headphones. There is a Wi-Fi antenna, for internet connectivity at home or in the office and an NFC antenna that allows us to pay with a tap of our phone.

IV. Design and Simulation on Position and Number of Slots

This chapter deals with enhancing the performance of microstrip patch antennas through strategic slot configurations. As the demand for compact, efficient antennas grows in wireless communication systems, microstrip patch antennas stand out for their low profile and compatibility with integrated circuits. However, achieving sufficient bandwidth remains a challenge. This study focuses on systematically analyzing the impact of slot positions and quantities on antenna performance metrics such as return loss, VSWR, and bandwidth.

V. Design Procedure

The frequency utilized is 2.4 GHz, with FR4 serving as the substrate material. The substrate has a height of 1.6mm and a dielectric constant of 4.4.

(i) The width of the patch is given by

$$w = \frac{C}{2fr}\sqrt{\frac{2}{\varepsilon r+1}}$$

(ii) Actual length of the patch is determined as

$$L = \frac{c}{2f_r\sqrt{eeff}} - 2(\nabla l)\frac{c}{2f_r\sqrt{eeff}}$$

(iii)The extension length Dl is usually deducted from the calculated length L of the rectangular microstrip patch antenna (RMPA) in order to retain the actual length of the patch constant.

$$\nabla L = 0.412\ \frac{(eeff + 0.3)\ \frac{W}{(h+0.264)h}}{(eeff-0.258)\ \frac{W}{h+0.8}}$$

Here, ϵeff is the effective dielectric constant and is calculated using the formula,

$$\varepsilon_{eff} = \varepsilon_{r+}\frac{1}{2}{}_{+}\varepsilon_{r-2}\frac{1}{\sqrt{1+12\frac{h}{w}}}$$

(iv)Design of elemental length (L) :

Once the extension length and effective dielectric constant are determined using above equations, then elemental length of RMPA is found by using equation

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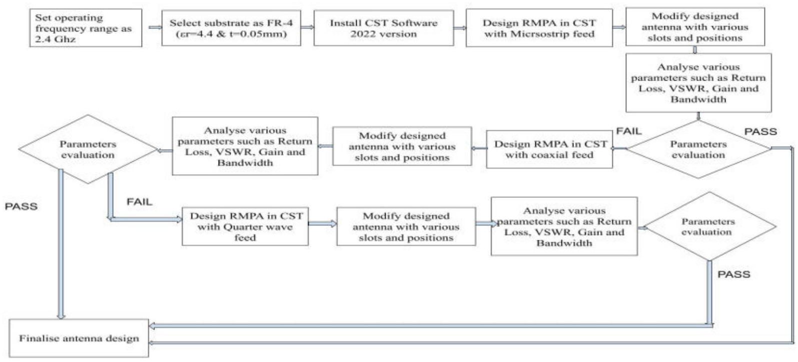
$$L = \frac{c}{2f_r\sqrt{\epsilon_{eff}}} - 2(Dl)$$

$$L_f = \frac{\lambda_g}{4}$$

Using the above formulas, the calculated values of width and length of rectangular microstrip patch for FR4 substrate of dielectric constant 4.4 modeled and optimized in CST software.

VI. DESIGN METHODOLOGY

This paper outlines the significance of designing steps in optimizing microstrip patch antennas through strategic slot configurations. This study focuses on elucidating the critical steps involved in the design process, depicted in a flowchart format, aimed at enhancing antenna performance metrics such as return loss, VSWR, and bandwidth.



VII. CST SPECIFICATIONS

Subsequently, we conducted a thorough analysis of various parameters using CST Studio, a sophisticated electromagnetic simulation software. Through this approach, we aimed to optimize antenna performance and investigate the effects of different design configurations on key metrics. This comprehensive analysis facilitated a deeper understanding of the antenna's behavior and performance characteristics, enabling us to refine and enhance its overall efficiency and effectiveness in wireless communication systems.

Table 1: Quarter wave geometry

Parameter	Value(mm)
Length of the patch	28.37
Width of the patch	38.03
Height	1.6
Thickness	0.05
Feed width	3.058
Quarter wave width	0.534
Feed length	8.562

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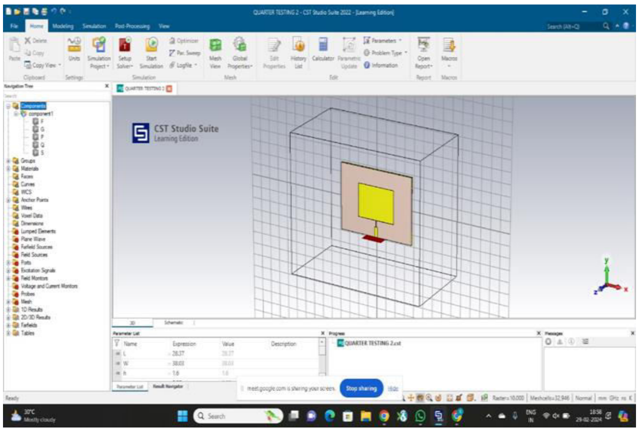

Figure 1: Quarter wave RMPA (Conventional)

The dimensions of the microstrip patch antenna were calculated through the design process. A conventional antenna with a 1.6 mm thick FR-4 substrate, an operating frequency of 2.4 GHz, a minimum gain of 3 dB, a minimum return loss of -28 dB, and a 50Ω feed line.

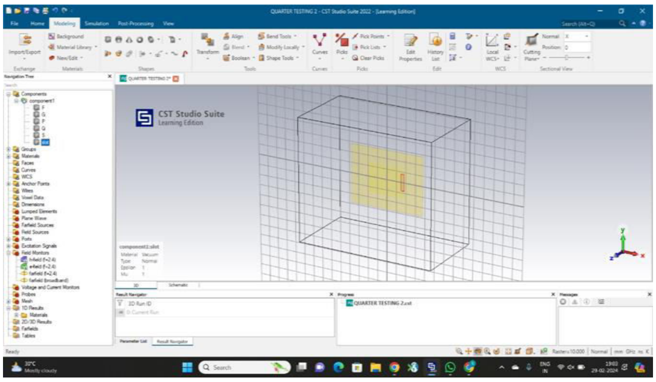

Figure 2: Quarter wave RMPA with single slot in right corner

In the microstrip antenna we are adding a single slot in the right corner with a 1.6 mm thick FR-4 substrate, an operating frequency of 2.4 GHz, a minimum gain of 3 dB, a minimum return loss of -28 dB, and a 50Ω feed line.

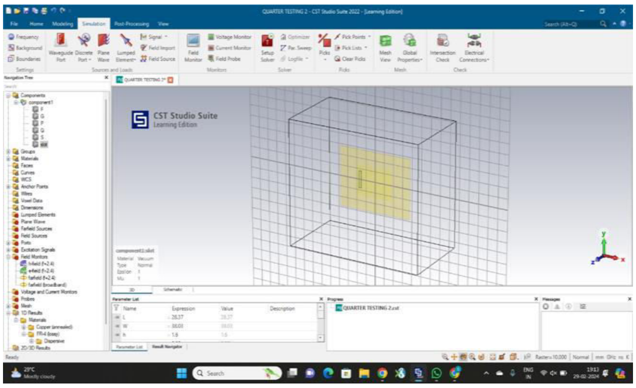

Figure 3: Quarter wave RMPA with single slot in left corner

In the microstrip antenna we are adding a single slot in the left corner with a 1.6 mm thick FR-4 substrate, an operating frequency of 2.4 GHz, a minimum gain of 3 dB, a minimum return loss of -28 dB, and a 50Ω feed line.

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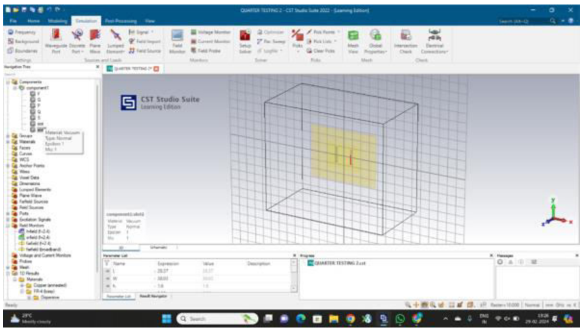

Figure 4: Quarter wave RMPA with two slots of distance=16mm

The above diagram depicts two slots with a distance of 16 mm and following the dimensions of 1.6 mm thick FR-4 substrate, an operating frequency of 2.4 GHz, a minimum gain of 3 dB, a minimum return loss of -28 dB, and a 50Ω feed line.

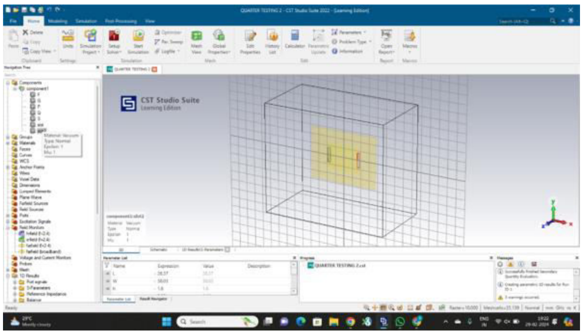

Figure 5: Quarter wave RMPA with two slots of distance=32mm

The above diagram depicts two slots with a distance of 32 mm and following the dimensions of 1.6 mm thick FR-4 substrate, an operating frequency of 2.4 GHz, a minimum gain of 3 dB, a minimum return loss of -28 dB, and a 50Ω feed line.

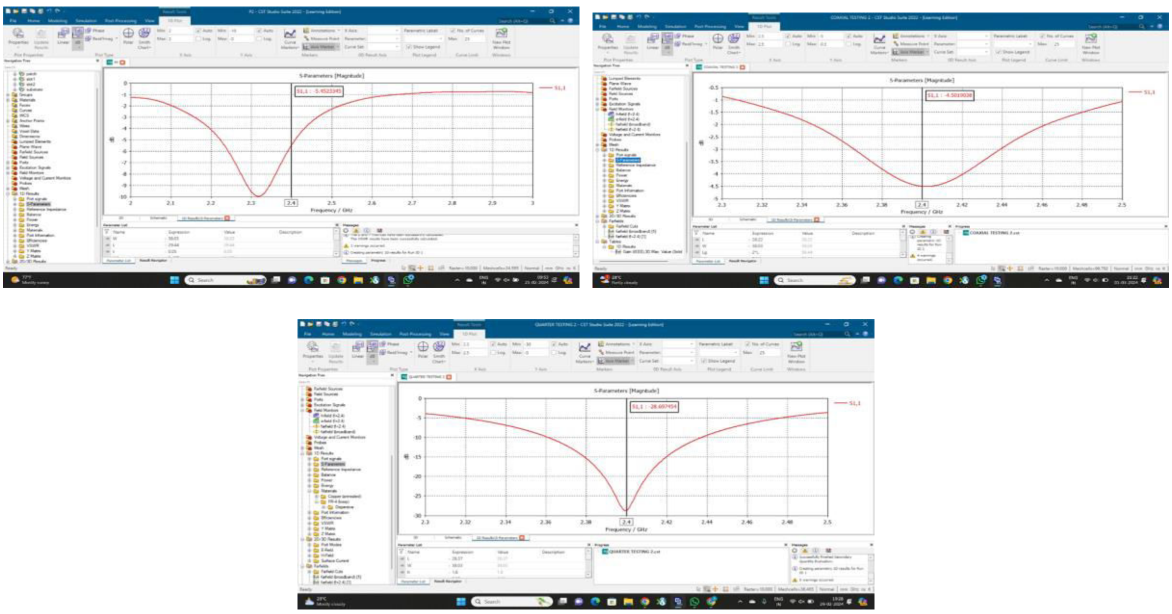

Figure 6 Return loss for Three Types of Feeds in Two slots of Distance 32 mm

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The simulated S parameter values for the three feed types microstrip, coaxial, and quarter wave are displayed above. The quarter-wave feed has a dB value of -28.69, the coaxial feed has a dB value of -4.501, and the microstrip feed has a dB value of -5.452. We have among these the best return-loss value in the quarter-wave feed.

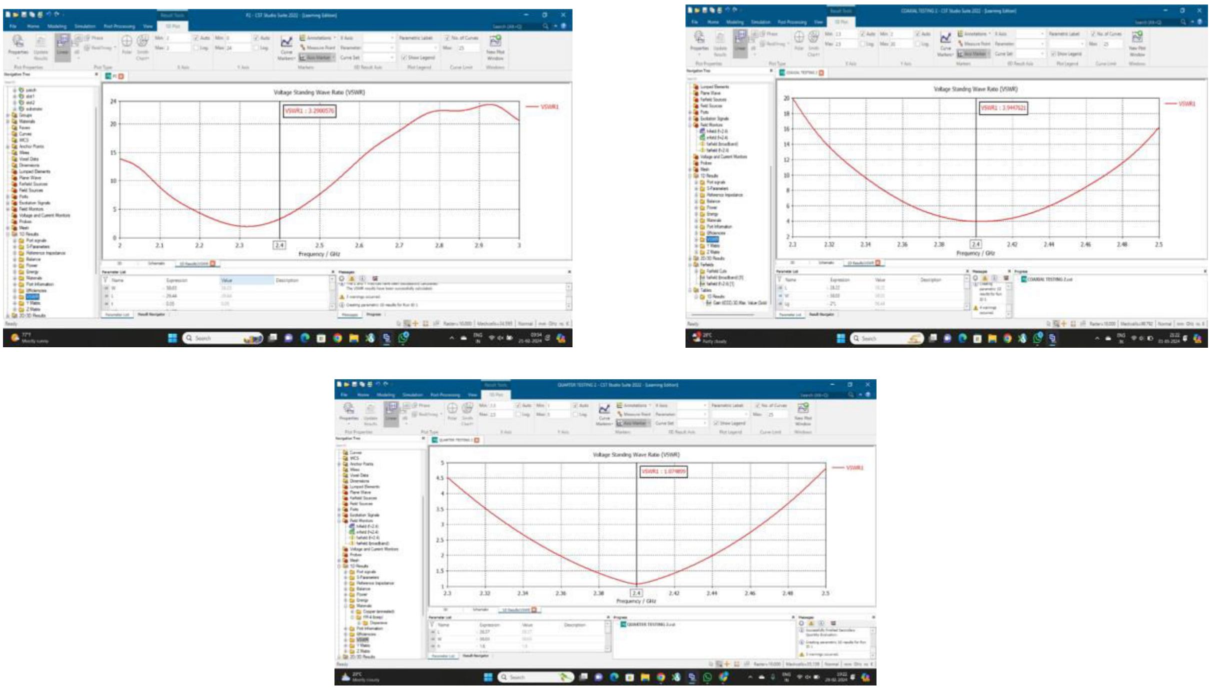

Figure 7 VSWR for Three Types of Feeds in Two slots of Distance 32 mm

The VSWR values for the three feed types microstrip, coaxial, and quarter wave are displayed above. The quarter-wave feed has a dB value of 1.074, the coaxial feed has a dB value of 3.944, and the microstrip feed has a dB value of 3.290 db. We have among these the best VSWR value in the quarter-wave feed.

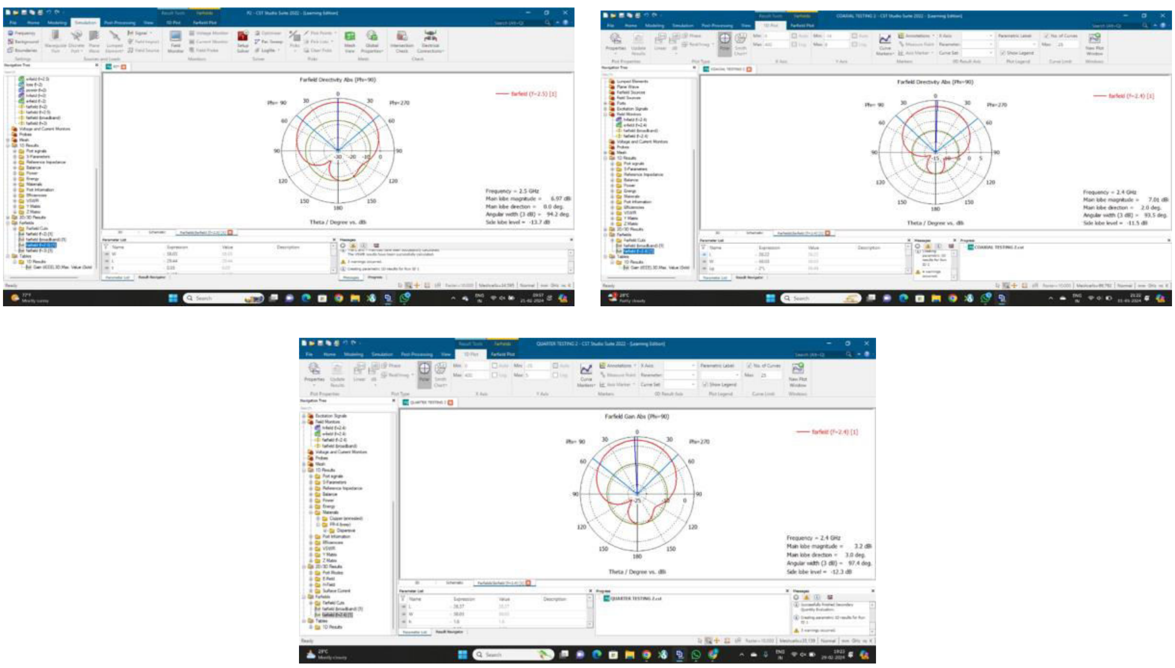

Figure 8 Radiation Pattern for Three Types of Feeds in Two slots of Distance 32 mm

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The far-field radiation pattern analysis reveals distinct outcomes for two slots spaced 32 mm apart. Using a Microstrip feed, the mainlobe magnitude reaches 6.97 dB, accompanied by a side lobe level of -13.7 dB and HPBW of 94.2 degrees. With a coaxial feed, the mainlobe magnitude slightly increases to 7.01 dB, with a side lobe level of -11.5 dB and an HPBW of 93.5 degrees. Remarkably, the quarter-wave feed yields the most favorable results, boasting a mainlobe magnitude of 3.2 dB, a side lobe level of -12.3 dB, and an HPBW of 97.4 degrees.

VIII. RESULTS AND DISCUSSION

This paper involved a comprehensive design, simulation, and analysis process, where various slot configurations were strategically placed on different sides of the microstrip patch antennas. Through thorough examination, we evaluated crucial parameters such as return loss, VSWR, and bandwidth. The results were meticulously tabulated and presented alongside essential graphs to illustrate the effectiveness of each slot configuration in enhancing antenna performance. This rigorous investigation aimed to overcome the bandwidth limitations of conventional microstrip antennas. Our findings provide valuable insights into optimizing antenna designs for next-generation wireless communication systems, promising improved performance and versatility across diverse applications.

Table 2 Results and graph table of Quarter wave RMPA

Type	Return Loss	Gain	VSWR	BANDWIDTH
Conventional	-28.357	3.213	1.079	0.160
One Slot (Right)	-28.848	3.202	1.074	0.156
One Slot (Centre)	-28.872	3.202	1.074	0.158
One slot (Left)	-28.872	3.200	1.074	0.158
Two Slot (Corner)	-28.697	3.196	1.074	0.161
Two Slot (Centre)	-28.697	3.192	1.076	0.159

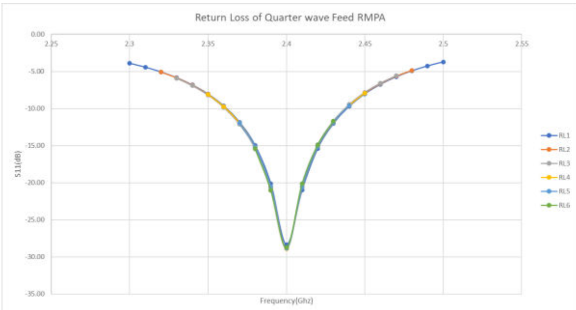

Figure 9 Return Loss of Quarter Wave Feed for all slot configuration

The graph above illustrates the return loss values for the quarter-wave feed antenna with different slot configurations, including the conventional slot, one slot at various positions, and two slots with varying distances.

In conclusion, our study has successfully demonstrated the effectiveness of utilizing a Quarter wave feed configuration with two slots positioned optimally to achieve maximum bandwidth in the microstrip patch antenna design. Through comprehensive analysis and simulation, we have shown that this particular configuration yields superior performance in terms of bandwidth expansion. The resultant graphs clearly illustrate the significant enhancement in bandwidth achieved, indicating the practical feasibility and potential applicability of this antenna design in real-world wireless communication systems.

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IX. CONCLUSION AND FUTURE SCOPE

In conclusion, the investigation into microstrip patch antennas with various slot configurations for bandwidth enhancement has yielded promising results. Through simulation studies and experimental validation, it has been demonstrated that strategically designed slots can effectively broaden the antenna's bandwidth while preserving desirable radiation characteristics. This antenna is designed to operate at 2.4 GHz. For this frequency, antennas have large sizes, i.e, L = 28.37 mm and W = 38.03 mm with the aim to increase the electrical length of the patch. The antenna was manufactured on an FR-4 substrate with electrical permittivity, εr = 4.4 and loss tangent, tanσ = 0.02. The antenna was placed on the upper side of the configuration, and the ground plane on the bottom side of the configuration. The final antenna had a rectangular form with a thickness of 0.05 mm and a substrate high of 1.6 mm. After the antenna was designed and simulated, it was physically produced and tested in a real time operating condition. This paper thus proposes a new antenna design that is able to increase the performance level of applications by means of an original design. The antenna was tested in a real operating environment and its performance was compared with two reference antennas: one omnidirectional and one microstrip antenna, both designed for the 2.4 GHz frequency band. The antenna was designed, simulated, tested and evaluated and from the obtained results, it ensures a high level of performance that can be used in various applications specific to the 2.4 GHz frequency band regardless of the wireless communication protocol used. A new antenna design has been suggested and simulated, demonstrating enhanced performance with a Quarter wave feed configuration. This improvement is achieved by incorporating two slots positioned 32mm apart, specifically optimized for the 2.4 GHz frequency band. The proposed antenna exhibits a return loss of −28 dB and a bandwidth of 0.161 GHz, effectively enhancing wireless communication capabilities.

The future scope of this paper is vast and holds immense potential for further advancements in wireless communication antenna technology. Here are several avenues for future exploration and development:

1. Explore integration possibilities with emerging technologies such as 5G, IoT, and AI to enhance antenna performance and compatibility with next-generation wireless communication systems.
2. Further optimize antenna designs to cater to specific application requirements, such as medical implants, automotive communication systems, and aerospace applications.

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