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The Design of a Microstrip Patch Antenna with a Slotted Patch for Dual-Band Wireless Applications Operation Using CST Software

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ABSTRACT

Microstrip patch antennas(MPAs) are multifunctional in terms of their geometrical shapes and implementation. The proposed antenna consists of five rectangular slots, which are simulated by using CST programming. The lightweight structure and the suitability for integration with microwave integrated circuits are two more of their several advantages. Also, the simplicity of the structures makes this type of antennas appropriate for cost-effective manufacturing. And this is also one key characteristic why MSPs are used in wireless communication applications and it can give dual and circular polarization, dual-band frequency operation, and wide-band, feed line flexibility. Therefore, an optimized adjusting parameters and adding slot microstrip rectangular patch antenna introduced in this paper for wireless communication applications. The antenna was fabricated on h = 1.6 mm thick dielectric substrate with dielectric constant (ε_r = 4.3). The slots were holed on the top plane of the antenna substrate and fed through microstrip transmission line. The simulated results show that the slotted MPA resonates at 2.45 and 3.188 GHZ with a bandwidth of 0.67 GHz (27.34%) and 0.4 GHz (12.5%) within a reflection coefficient of -45.32and -46.11 dB respectively. The measured resonant frequencies are 2.40 and 3.05 GHz, showing good agreement with the simulated results. The simulated results also show antenna gains of 5.713 and 5.283 dBi, directivity of 6.17 and 5.46 dBi with Voltage standing wave ratio (VSWR) of 1.279 and 1.265 respectively.

Keywords: Dual-band, Microstrip patch antenna, Microstrip transmission line, Slot antenna.

1. INTRODUCTION

The rapid development of wireless communication technologies has increased the demand for compact, high-gain, and wide band microstrip antennas. Microstrip Patch Antennas (MPAs) are advantageous because they are lightweight, low cost, and easy to fabricate. However, conventional MPAs inherently suffer from narrow bandwidth and relatively low efficiency **(Balanis, 2016; Wong, 2002).** A small conducting strip is connected to the edge of the microstrip patch as shown in **Fig. 1 (Balanis, 2016)**. The microstrip feed line has a

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rectangular geometry, and its width is smaller than that of the patch. The radiating patch is typically fabricated from highly conductive materials such as gold or copper, and it may take various geometries such as rectangular, square, circular, elliptical, or triangular depending on the design requirements **(Balanis, 2016; Pozar, 2012).** The substrate used in microstrip antennas is a dielectric material that forms the backbone of the antenna structure. The radiating patch and feed line are commonly photo-etched on the dielectric surface. A thick substrate is desirable for improved radiation characteristics, while low dielectric constant substrates are preferred for better efficiency and reduced surface-wave losses. The ground plane, generally made of copper, suppresses back radiation and prevents degradation of antenna efficiency **(Balanis, 2016; Garg et al., 2001)**. Enhancing antenna performance - especially bandwidth - is therefore essential. Many well-established techniques exist to increase bandwidth, such as increasing substrate thickness, using low-permittivity materials, introducing slots in the patch, and applying different impedance-matching or feeding structures. Slotting the patch increases the effective current path, which improves bandwidth without significantly affecting antenna performance. This slotting technique is adopted in this work **(Garg et al., 2001; Wong, 2002; Abdelgwad, 2018).**

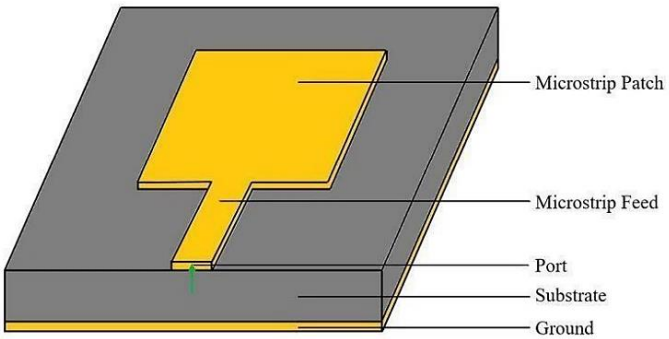


Figure 1. Basic structure of microstrip patch antenna **(Balanis, 2016)**

Numerous studies have been conducted on the microstrip patch antennas, such as the design of an antenna for an Internet of Things application with a small size and low consumption **(Anchidin et al., 2023)**. The researchers suggested designing a multi-frequency, compact antenna using hybrid technology to meet the needs of modern wireless communications **(Azeez et al., 2023).** The researchers proposed that the microstrip antenna resonates at two frequencies; 2.45 GHz and 5 GHz, where the ground section of the antenna was etched into L-shape but the antenna size was kept the same, suitable for Wi-Fi and IoT applications **(Şahin and Kaya, 2022)**. For 5G applications, researchers have proposed a millimeter wave microstrip patch antenna that has wide beamwidth and high radiation efficiency **(Kornprobst et al., 2017).** The researchers suggested developing a microstrip array antenna with a frequency of 5 GHz, which can be used for high-frequency applications due to its compact size and ease of fabrication **(Denceli et al., 2025)**. The study theoretically investigated how radiation efficiency and gain can be increased in the design of microstrip antennas using two methods: (1) by increasing the permittivity of the substrates and (2) by varying the geometric shape of the patch and compared the two. It also explained the effect of radiation efficiency on the bandwidth **(Nel et al., 2024).** The study showcased the use of multiple microstrip antennas, analyzed, and discussed the modern ways that work on improving and developing the antenna in terms of its performance and applications **(Hakeem et al., 2021).** Various microstrip antennas for 5G applications were designed and studied, and ways to increase gain and improve directivity for backhaul applications were

discussed **(Al-Gburi et al., 2022).** Microstrip antennas are applied as passive sensors for environmental, medical, and IoT applications, with studies focused on the various sensing mechanisms **(Islam et al., 2024)**. The researchers developed a Micro Strips Antenna, and they etched the portion of patch. Multiple beams for 5G applications were obtained with the help of these slots. Furthermore, the gain and matching were enhanced **(Nahas, 2025).** The researchers suggested a multi-layer antenna design. These layers have the effect of boosting gain and enhancing performance without adding to the size of the antenna. **(Öner, 2025).** The study discussed the materials used in the wearable antenna and the impact of different types of substrates and conductive material on gain, efficiency and flexibility **(Banale and Patil, 2025).** A microstrip antenna was designed and to reduce the testing steps and obtain the desired simulation, the hybrid algorithm of Taguchi and Quasi-Newton was used, while the size of the antenna was minimized. The design was successfully miniaturized, achieving a suitable performance for IoT applications **(Tiwari et al., 2025).** The researchers designed the antenna by introducing symmetrical rectangular slots inside the patch to generate multiple current paths, thereby generating multiple resonance frequencies that can be used for wireless communication applications and enhance the performance **(Hammas et al., 2020).** The researchers proposed and designed a microstrip patch antenna for C (4-8 GHz) and X (8-12 GHz) band applications with the inclusion of U-slot **(Gupta et al., 2013).** Further, the study proposed the use of circular microstrip patch antenna (MPA) for WLAN applications to decrease the size of the antenna while retaining its operation at 5.5 GHz frequency and enhance the matching **(Mukta et al., 2021).** While many slot-loaded microstrip patch antennas have been reported in literature, many of them have either complicated slot geometry or multilayer structure, or a narrowband impedance or dual-band performance. Besides, very few works have explored a simple 5-rectangular-slot configuration that can achieve dual-band operation with the single-layer structure and low manufacturing complexity. This work, hence, presents and experimentally verifies a miniaturized dual band microstrip patch antenna with an optimized five slot configuration. Based on simulated and experimental results, the proposed antenna has good impedance matching, acceptable gain and close agreement, and it can be used for dual-band (2.45 GHz, 3.188 GHz) operation, thus it is well suited for the practical wireless communication application. Microstrip patch antenna has received considerable research interest due to its small size, low cost of fabrication and its compatibility with modern wireless communication systems **(Lee and Tong, 2012).** A major drawback of these conventional patch antennas is their limited bandwidth and poor multiband performance. To overcome these constraints, the slot loading techniques have been used quite extensively to manipulate the surface current distribution of the radiating patch to improve the impedance matching and radiation characteristics **(Mushtaq et al., 2022)**. Controlled slot arrangements have also been made to produce multiband antenna operation. To achieve multiband characteristics **(Mohammed et al., 2024)** introduced a circular microstrip patch antenna with slit-shaped slots. Multiple resonant frequencies can be generated in the X-band and C-band without adding extra circuit components by changing the number and location of these slots. It was shown that the more the number of slots, the more the number of current paths that are effective, which can provide efficient multiband performance for wireless applications.

In addition to conventional design techniques, the researchers proposed microstrip a patch antenna design that operates at dual frequencies, 2.4 GHz and 3.1 GHz, which can be used for WLAN and WiMAX applications. They used an algorithm inspired by the movement of bird and fish swarms to find the optimal antenna dimensions, saving time compared to trial

and error **(Behera et al., 2010)**. Furthermore, the researchers designed a Microstrip Patch Antenna that works at a frequency of 28 GHz, suitable for 5G applications, using machine learning instead of traditional simulations that take a lot of time. This allowed them to find the optimal dimensions and improve performance **(Rana et al., 2024).** Other investigations have focused on employing specialized slot geometries to achieve compact and multifunctional antenna designs. L-shaped and inverted L-shaped slot configurations have been reported to produce penta-band behavior by introducing multiple resonant paths within a single patch area **(Sakshi and Bharti, 2023).** Moreover, Rectangular Microstrip patch antenna using a metamaterial based Complementary Split Ring Resonator (CSRR) is designed for operating in dual band frequency range of 2.4–5.8 GHz **(Sarmah et al., 2015).** Additional research has explored the use of hexagonal spiral resonator-based tri-band patch antenna with an octagonal slot presented for Wi-Fi/WLAN applications. In order to get an additional resonant frequency while keeping the antenna small by adding resonant slots. Analytical studies have also confirmed that the location, size, and shape of the slot play an important role in determining bandwidth, reducing reflection coefficient, and improving impedance matching **(Rajalakshmi and Gunavathi, 2020).** The researchers designed a microstrip patch antenna with slots that achieved two resonance frequencies, 5.72 GHz and 10.28 GHz, while keeping the antenna compact and improving its performance, this antenna is used in microwave communication applications **(Das et al., 2013).** Previous studies indicate that one of the best and easiest ways to improve the performance of a microstrip patch antenna is the use of slots on the patch surface, as the location, shape, and size of these slots have greatly contributed to achieving multiple resonance frequencies, maintaining a small size, increasing the bandwidth, and reducing antenna losses, making it suitable for wireless and microwave applications.

3. PROCEDURE DESIGN

3.1 Design Methodology

The design methodology adopted in this work is illustrated as follows. First, a conventional rectangular microstrip patch antenna was designed using the standard design equations to resonate at 2.45 GHz. This initial design was simulated in CST Microwave Studio and used as the reference antenna. Subsequently, five rectangular slots were gradually introduced into the radiating patch. The slot positions and dimensions were optimized through a parametric study to generate a second resonant frequency while maintaining good impedance matching and stable radiation characteristics. Finally, the optimized antenna was fabricated and experimentally validated by comparing the measured and simulated results.

3.2 Design Equations of Microstrip Rectangular Patch Antenna

The effective dielectric constant (ε_{reff}) is the important parameter in designing microstrip patch antenna because the radiations travel through the air and then substrate to ground plane the air and substrate have a different dielectric value therefore the value of $\varepsilon_{reff}$is slightly less than substrate dielectric constant (ε_r) and can be calculated from Eq. (1) **(Garg et al., 2001):**

$$\varepsilon_{reff}=\frac{(\varepsilon_r+1)}{2}+\frac{(\varepsilon_r+1)}{2}\left[1+12\frac{\mathrm{h}}{w}\right]^{\frac{-1}{2}} \quad (1)$$

Where:
ε_{reff} : The effective dielectric constant of substrate
ε_r : The relative dielectric constant of the substrate
h: Substrate thickness
W: The width of the patch antenna
The extended length can be calculated from Eq. (2) **(Edwards, 2016)**:

$$\Delta L=0.142h\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (2)$$

Where:
ΔL: the extended length
The effective length can be calculated from Eq. (3) **(Balanis, 2016)**:

$$L_{eff}=\frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \quad (3)$$

Where:
L_{eff}: the effective length
C: the speed of light 3
f_o: the resonance frequency

The length of patch antenna can be calculated from Eq. (4) **(Balanis, 2016)**:

$$L=L_{eff}-2\Delta L \quad (4)$$

L: the length of the patch antenna
The width of patch antenna can be calculated from Eq. (5) **(Pozar, 2012)**:

$$w=\frac{c}{2f_o\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (5)$$

Where:
W: the width of patch antenna

The length and width of substrate plane equal to the length and width of ground plane respectively and can be calculated from Eqs. (6) and (7) **(Garg et al., 2001):**

$$L_g=2*L \quad (6)$$

$$W_g=2*W \quad (7)$$

Where:
L_g: the length of the ground plane (substrate)
W_g: the width of the ground plane (substrate)
The feed line width w_f can be calculated by Eq. (8) **(Gupta et al., 1996):**

$$W_f=\frac{7.48\times h}{e^{Z\frac{\sqrt{\varepsilon_r+1.41}}{87}}}-1.25\times h \quad (8)$$

Where Z is the characteristic impedance (50 Ω)

The dimensions of microstrip patch antenna that is shown in **Table 1**. Calculated by using design equations with resonance frequency f_o equal to 2.4 GHz, dielectric constant ε_r equal to 4.3, substrate thickness h equal to 1.6 mm and high of patch and ground plane h_t equal to 0.035 mm. The inset-feed dimensions (X_0 and Y_0) were determined through a CST Microwave Studio parametric optimization process. Different inset positions were investigated to obtain a 50-Ω input impedance and achieve the best impedance matching the operating frequencies. The final optimized inset dimensions were X0 = 2 mm and Y0 = 3 mm, as listed in **Table 1**. Although rectangular slots have been widely used in microstrip patch antennas to achieve multiband characteristics, the contribution of this work lies in the optimized five-rectangular-slot configuration. The proposed slot arrangement was carefully designed to modify the current surface distribution and excite two resonant modes while maintaining a compact antenna size. Compared with recently reported slotted patch antennas, the proposed design provides competitive bandwidth, impedance matching, and gain with a simple planar structure that is suitable for practical wireless communication applications.

Table 1. Dimensions of Microstrip patch antenna

Parameter	**Value (mm)**
W	37.02
L	28.4
L_g	38
W_g	46.6
W_f	2.88
Feed length L_F	7.5
X_0	2
Y_0	3

Fig. 2 presents the structural design of the microstrip patch antenna without incorporating any slots on the radiating patch. The antenna model was developed and simulated in CST Microwave Studio based on the standard design equations

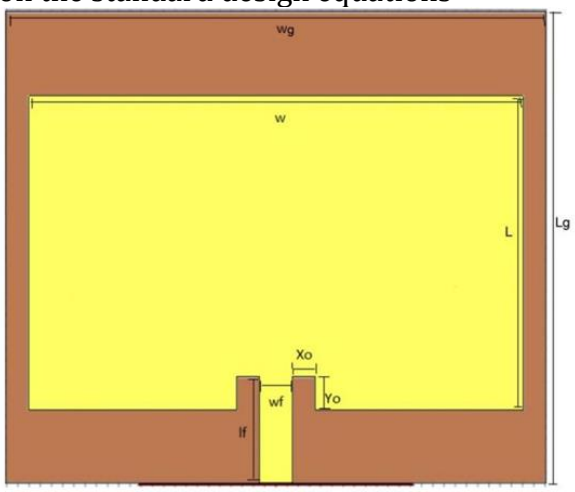


Figure 2. The designed microstrip patch antenna

The simulated response of the above antenna is presented in **Fig. 3**. This antenna operates on a single band of resonance frequency f_0=2.46 the reflection coefficient es is -16.077.

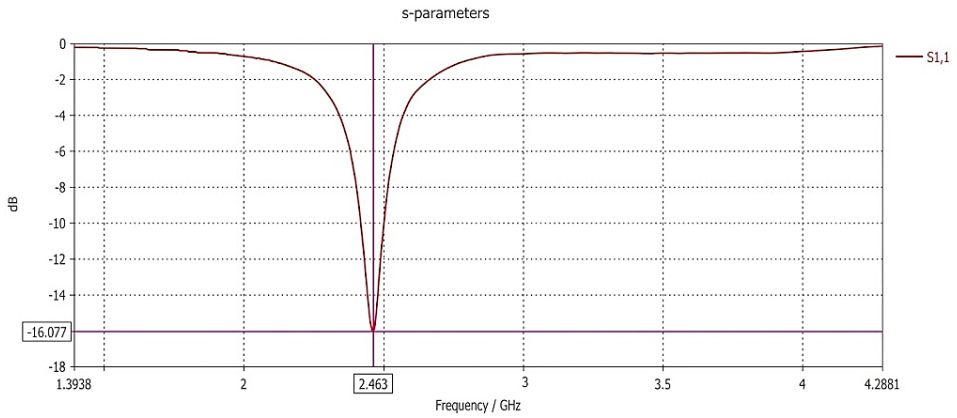


Figure 3. The simulated response of Microstrip patch antenna.

To achieve dual-band operation, five rectangular slots were introduced into the radiating patch and optimized using CST Microwave Studio. The number, positions, and dimensions of the slots were selected through parametric optimization to generate the second resonant frequency while maintaining good impedance matching and stable radiation characteristics. The slots were placed in regions of high surface current density to effectively modify the current path and excite the additional resonant mode. The longer slots primarily increase the effective current path for the lower resonant frequency, whereas the shorter slots provide fine tuning of the upper resonant frequency and improve impedance matching. The optimized slot dimensions are listed in **Table 2.**

Table 2. Showing the optimized dimensions of rectangular slots

Parameters	**Dimension (mm)**
Width of slots	1
Length of slot1, sl1	8
Length of slot2, sl2	8
Length of slot3, sl3	4
Length of slot4, sl4	4
Length of slot5, sl5	1

The geometrical configuration of the proposed antenna is illustrated in **Fig. 4.** The equivalent circuit of the rectangular slotted antenna is designed to achieve dual-band performance and a low reflection coefficient.

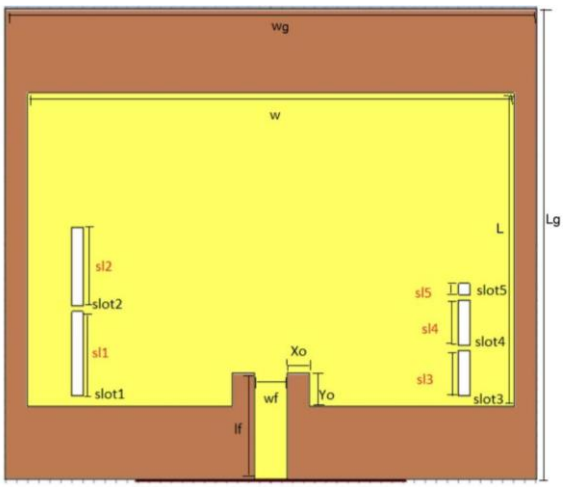


Figure 4. Microstrip patch antenna with rectangular slots at patch

4. SIMULATION RESULT

The design presented in this paper was simulated using the CST software. This antenna was fabricated by rectangular slots on the FR4 substrate with a height of 1.6 mm and a dielectric constant of 4.3. The dielectric loss quantifies the inherent indulgence of electromagnetic energy, which can be denoted by loss angle δ. The overall antenna size, including transmission line, was 46.6 mm × 38 mm. The results of the simulation, related to the reflection coefficient and gain, are shown in **Figs. 5 and 6**, respectively. Directivity and VSWR are shown in **Figs. 7 and 8** respectively, related to the dual-band characteristics. The first band frequency was 2.45 GHz, the bandwidth was 0.67 GHz (27.34%), the reflection coefficient was -45.32, the gain was 5.713 dBi and the directivity 6.17 dBi, the total and radiation efficiencies were −0.4095 dB (91%) and −0.457 dB (90%), respectively. As the difference between the two efficiency values was 0.0475, the loss of impedance mismatch was low. The VSWR is 1.27,98 indicating excellent impedance matching and efficient power transfer .The second band frequency was 3.188 GHz, the bandwidth was 0.4 GHz (12.5%), the reflection coefficient was -46.11, the gain was 5.283 dBi and the directivity of 5.46 dBi, the total and radiation efficiencies were −0.177 dB (96%) and −0.176 dB (96.03%), respectively. The two efficiency values are nearly identical, indicating negligible. The VSWR is 1.265, indicating excellent impedance matching and efficient power transfer.

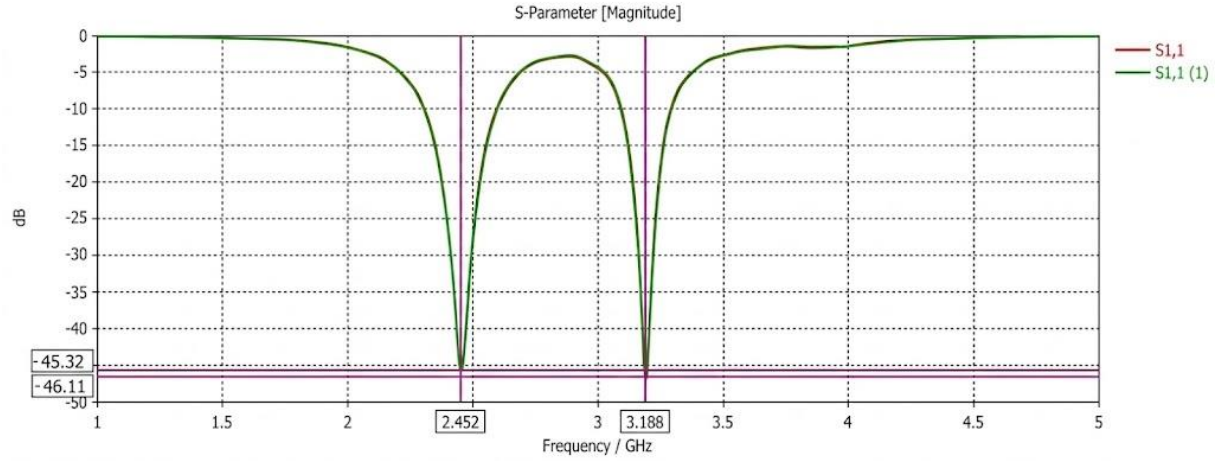
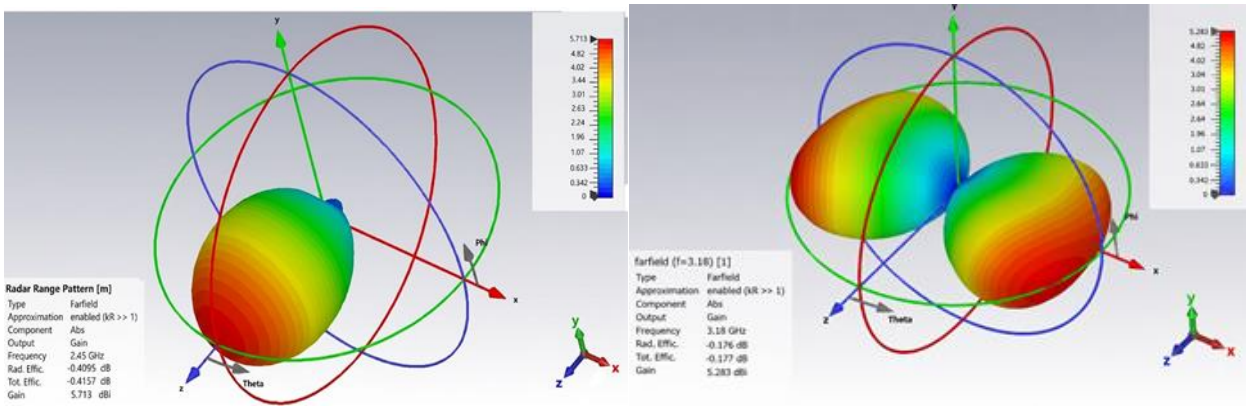
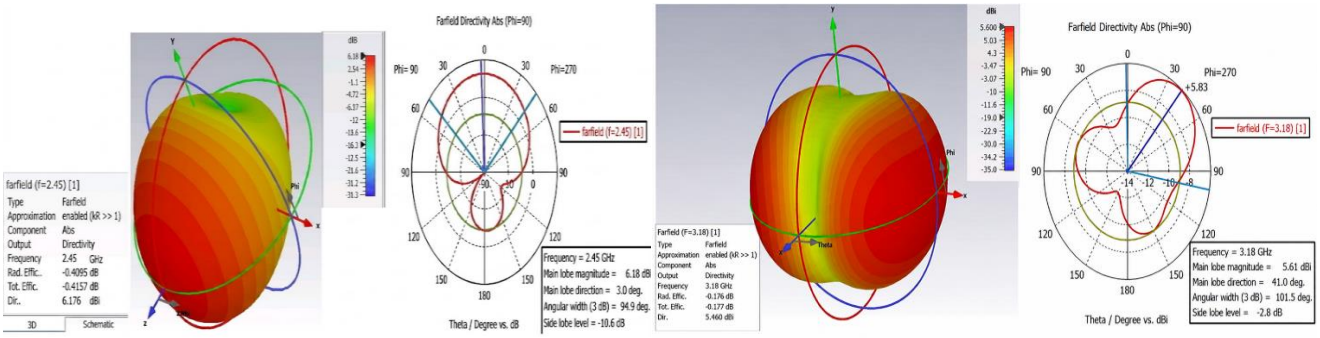


Figure 5. The simulated reflection coefficient of Microstrip patch antenna with rectangular slots.



(a) **(b)**

Figure 6. The simulated gain of Microstrip patch antenna with rectangular slots at (a) 2.45 GHz (b) 3.188GHz



(a) **(b)**

Figure 7. The simulated Directivity of Microstrip patch antenna with rectangular slots at (a) 2.45 GHz (b) 3.188GHz

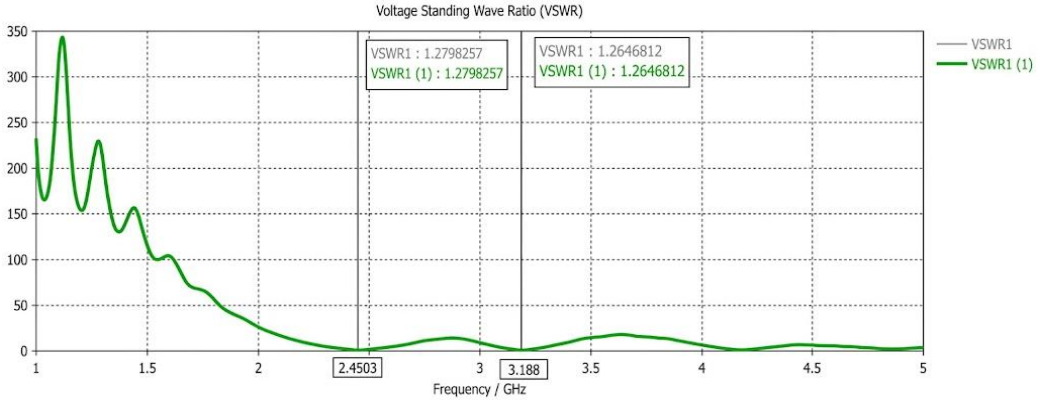


Figure 8. Microstrip patch antenna with rectangular slots has simulated VSWR as shown in the figure. The simulated gain and directivity of the proposed antenna are shown in

Fig. 9 which is done with the CST Microwave Studio software. The simulated directivity is at the maximum of 6.176 dBi at 2.45 GHz and 5.46 dBi at 3.188 GHz, and the simulated gain is at the maximum of 5.713 dBi at 2.45 GHz and 5.283 dBi at 3.188 GHz. Directivity is the ability of the antenna to focus radiated power in a direction with respect to an isotropic radiator, neglecting losses. Gain on the other hand is a measure of the efficiency of the antenna, so it includes the effect of dielectric, conductor, and mismatch losses. From the radiation pattern, it can be noticed that the antenna has a stable main lobe with a concentrated effective power in the desired direction.

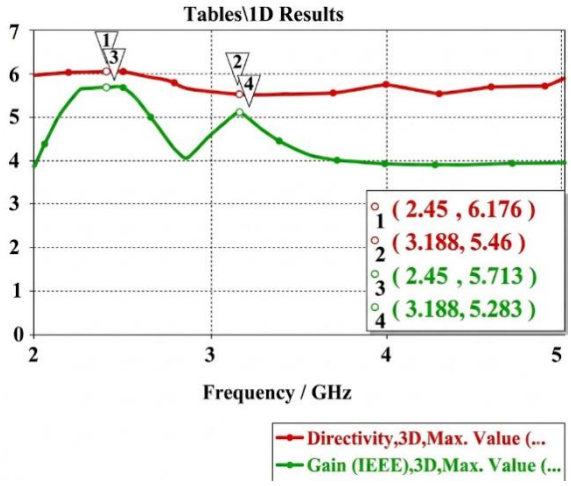


Figure 9. Simulated Gain and directivity graph of proposed antenna

The gain is well below the directivity value which means that the radiation efficiency is high and losses in the antenna structure are low. This validates that the proposed antenna offers a well-balanced performance in terms of directional radiation, efficiency, etc.
The overall radiation patterns show that the antenna is suitable for wireless communication applications for the operating frequencies with adequate gain and well controlled directivity. The E-field and H-field radiation patterns in **Figs. 10 and 11** respectively give an insight into the antenna's radiation pattern in various directions. The E-field pattern indicates where the electric field is distributed, and the H-field pattern indicates the distribution of the magnetic field around the antenna. The polar plots at 2.45 GHz and 3.188 GHz will provide insight into the radiation characteristics of the antenna at both resonant frequencies. These plots enable the directivity, antenna coverage and performance to be judged in the frequency bands in which the antenna is to be used. The radiation patterns are seen to have similar shapes in the E-plane and H-plane at the two frequencies of operation. This is primarily because of the almost symmetrical geometry of the proposed antenna and the dominant radiation mode. But the two patterns are for two field types (electric and magnetic fields) and have different physical quantities and units (V/m and A/m, respectively).

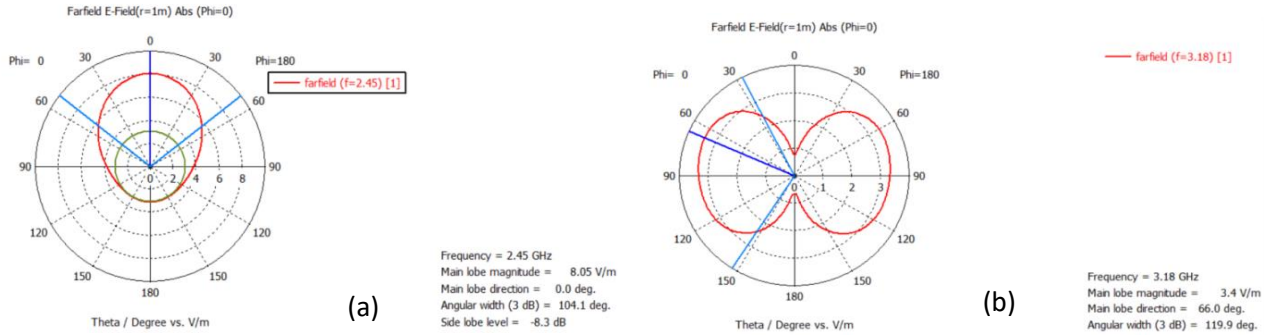


Figure 10. Simulated far-field E-field magnitude at ϕ=0◦ for (a) 2.45GHz and (b) 3.18GHz

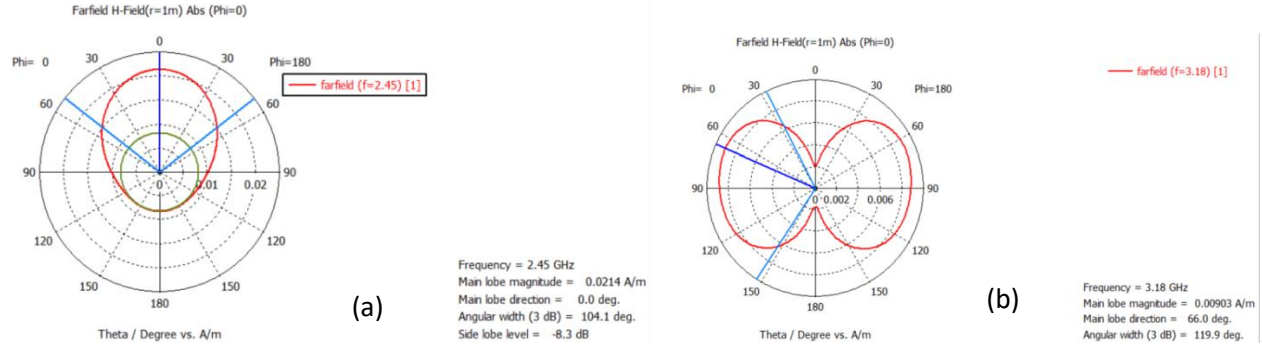
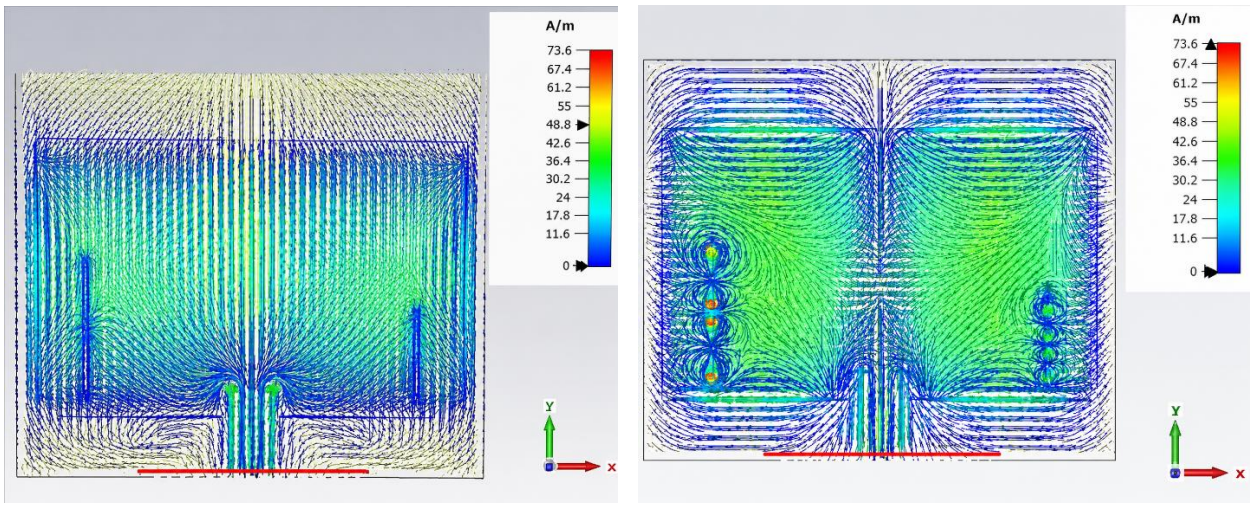


Figure 11. Simulated far-field H-field magnitude at ϕ=0◦ for (a) 2.45GHz and (b) 3.18 GHz

The simulated surface current distributions of the proposed antenna at two operating frequencies 2.45 GHz and 3.188 GHz are shown in **Fig. 12**. For the 2.45 GHz band, the electrical surface current is predominantly distributed around the inset-feed region and the two longer rectangular slots on both sides of the radiating patch. These slots enhance the current path and thus the lower resonant mode is exciting. On the other hand, the present distribution, at 3.188 GHz, is concentrated along the periphery of the patch and the smaller rectangular slots, which shows that the latter are useful for fine tuning of the higher resonant mode and improve the impedance matching. The various currents of the two operating frequencies also show that the optimized five-slot configuration alters the surface current

flow to obtain the desired dual-band response without changing the radiation characteristics.



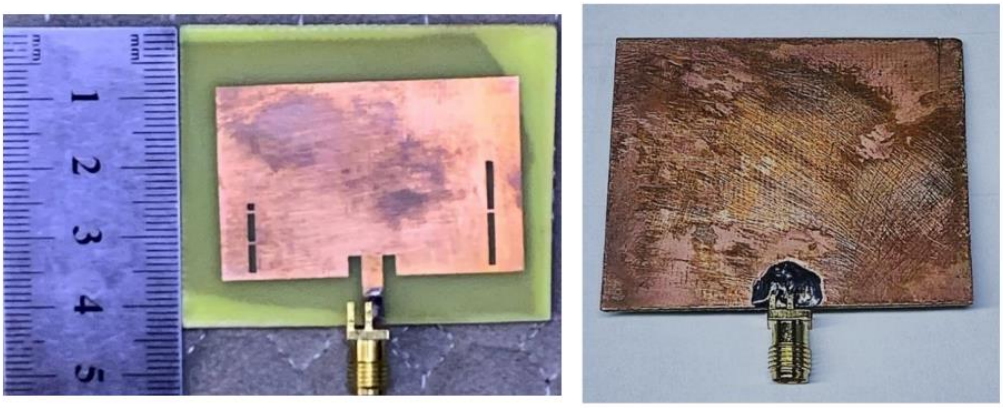
(a) (b)

Figure 12. Surface current distributions of proposed antenna at (a) 2.45 GHz and (b) 3.188 GHz using simulation.

5. ANTENNA IMPLEMENTATION AND COMPARISON BETWEEN THE MEASUREMENT AND SIMULATION RESULT

The five-slot structure can be seen as an effective change of the radiating patch surface current paths and thus results in two resonant modes at 2.45 GHz and 3.188 GHz. Optimization on slot location to enhance the impedance match was performed without adversely affecting the radiation characteristics and the geometry of the antenna. Moreover, the results of the simulation and measurement are in close agreement, which verifies the validity of the proposed design and confirms its feasibility.

A rectangular slotted antenna was experimentally implemented, based on the numerical analysis and simulation results obtained in this paper. Then, the prototype of the proposed design was fabricated and tested to ensure that the simulated performance was verified as shown on **Fig. 13**.



(a) (b)

Figure 13. Photograph the fabricated prototype of rectangular slots microstrip patch antennas: (a) front view, (b) back view.

The fabricated antenna was experimentally characterized using an Anritsu MS462A Vector Network Analyzer (VNA). Prior to the measurements, the VNA was calibrated over the operating frequency range to minimize systematic measurement errors. The fabricated antenna was connected through an SMA connector, and the reflection coefficient (S11) was measured. The antenna gain was measured in an anechoic chamber using a standard gain horn as the reference antenna and the measured results were compared with the simulated CST results to validate the proposed antenna performance. The fabricated antenna was connected to the Anritsu MS462A Vector Network Analyzer (VNA) through an SMA connector to experimentally measure the reflection coefficient (S11). The VNA measurement setup and the measured S11 response of the fabricated antenna are shown in **Fig. 14.**

The measured and simulated S parameters are shown on **Fig. 15**. There is a good correlation between the two sets of results and hence the validity of the design is confirmed. The fabricated antenna exhibits the dual-band characteristics. The frequency of the first resonance is 2.4GHz and the bandwidth is 0.53GHz (22.08%) and the reflection coefficient is −40 dB. The second resonance is located at the frequency of 3.05 GHz with a bandwidth of 0.35 GHz (11.4%) and a reflection coefficient of −39.5 dB.

The percentage deviation of the resonant frequency obtained from the simulation and the experiment is determined by the following equation:

$$\text{Percentage Deviation (\%)} = \frac{|f_{sim} - f_{mea}|}{f_{sim}} \times 100 \quad (9)$$

Where:

f_{sim}: Simulated resonant frequency

f_{mea}: Measured resonant frequency

There are small differences between the measured and simulated resonant frequencies. The first resonant frequency was found to change from 2.45 GHz (simulated) to 2.40 GHz (measured), with a percentage difference of about 2.04%. In a similar way, the second resonant frequency also deviated from 3.188 GHz to 3.05 GHz with a deviation of about 4.33%. These deviations are in the acceptable range for FR4 based Microstrip Antennas. The frequency shifts observed may be due to the fabrication tolerances, the actual dielectric constant and loss tangent of the FR4 substrate, the effect of the SMA connector and soldering process, and calibration uncertainties of the measurement. A small bit more deviation can be noticed at the 2nd operating band. This discrepancy is primarily due to the fact that the upper resonant frequency is more sensitive to fabrication tolerances, variance of FR-4 dielectric properties and slot dimensions. However, the second obtained bandwidth is still in good agreement with the simulated results, showing dual-band operation of the proposed antenna.

The gain results from the simulation and measurement are shown in **Fig. 16**. It is seen that there is good agreement between the simulated and experimental results, thus verifying the reliability of the proposed antenna design. The fabricated antenna is dual-band with the first resonance at 2.4 GHz and the second at 3.05 GHz. The realized gain is 4.82 dBi and 4.46 dBi at the two resonance frequencies, respectively. These results are compared with the measured VSWR in **Fig. 17** and the agreement is good at both the bands. The first resonance is at 2.4 GHz with a VSWR value of 1.033, second resonance is at 3.05 GHz with a VSWR value of 1.235. In both, the measured VSWR curve shows the same general form as the simulated, and the resonant frequencies occur very close to the same points on the curve.

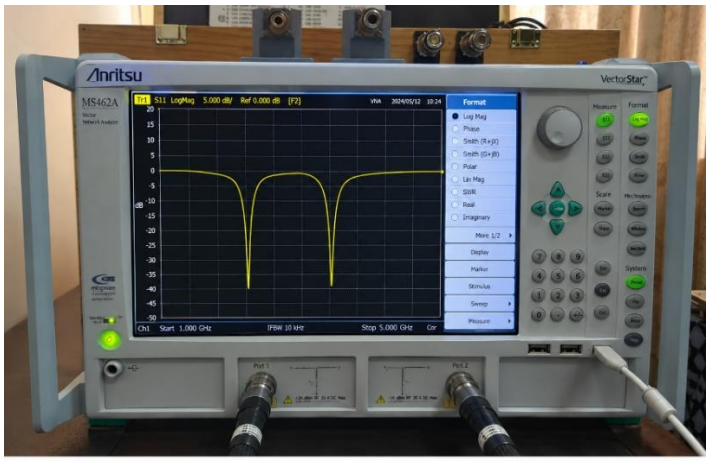


Figure 14. Experimental setup for measurement of reflection coefficient (S11) of fabricated antenna by using Anritsu MS462A Vector Network Analyzer (VNA).

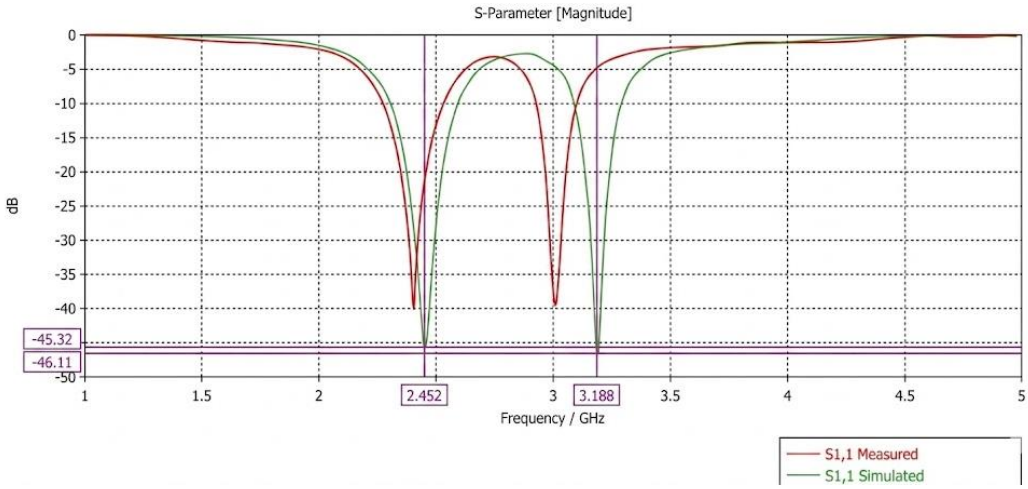


Figure 15. Comparing the simulated and measured s11 parameter of prototype of rectangular slots microstrip patch antenna.

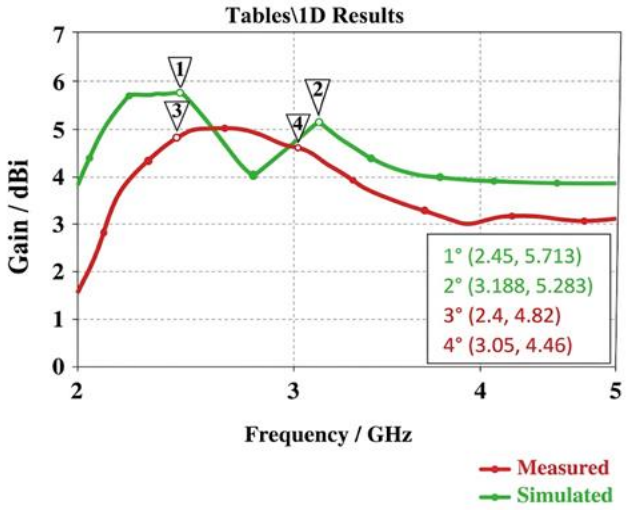


Figure 16. Gain comparison of the simulated and measured result of prototype of rectangular slots microstrip patch antenna.

There are small differences between the simulated and measured results, which are primarily due to fabrication tolerances, connector/cable losses, and measurement uncertainties. However, the VSWR values are still far less than acceptable, and impedance matching is good. The close correlation between the simulated and experimental results validates the antenna design and shows the effectiveness of the proposed antenna structure. This agreement shows that the antenna works well under practical operating conditions, proving it to be suitable for real world wireless applications.

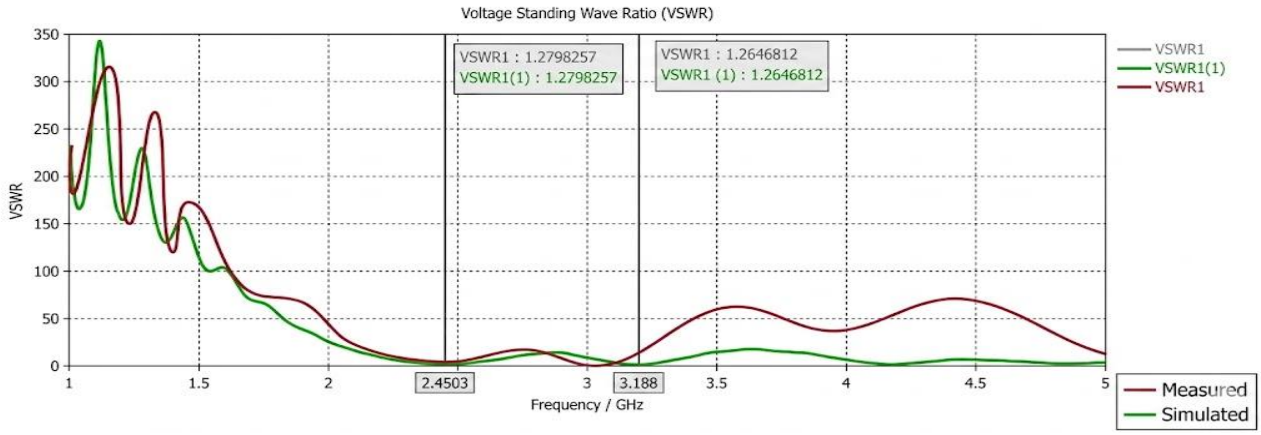


Figure 17. The comparison of the simulated and measured VSWR of prototype of rectangular slots microstrip patch antenna.

Table 3 provides the simulated and measured results of the proposed slotted antenna. The simulated resonant frequencies are 2.45 GHz and 3.188 GHz while the measured resonant frequencies are 2.40 GHz and 3.05 GHz, respectively. The results show that there is a good agreement between the simulated and measured results. The measured gains of 4.82 dBi and 4.46 dBi are obtained at the measured resonant frequencies of 2.40 and 3.05 GHz, respectively, while the simulated ones are 5.713 and 5.283 dBi at 2.45 and 3.188 GHz, respectively. The simulated bandwidths are 27.34% and 12.5% while the measured ones are 22.08% and 11.4% respectively. The measured and simulated S11 values are −40 and −45.32 dB respectively, while for the second case, these values are −39.5 and −46.11 dB respectively. The discrepancies between the simulated and measured results are small, and can be attributed to manufacturing tolerances, actual Dielectric properties of FR-4 substrate, and losses in SMA connector which are not taken into account in the simulation. Based on the overall measured results and practical implementation of the proposed antenna, it can be concluded that the measured results agree well with the simulated results confirming the dual-band operation of the proposed antenna.

Table 3. Briefly summarizes the comparison of the proposed design of slotted antenna based on simulated and measured results.

Parameters	**f_o (GHz)**	**BW (%)**	**S11 (dB)**	**Gain (dBi)**	**VSWR**
Simulation results	2.45/3.188	27.34/12.5	-45.32/-46.11	5.713/5.283	1.2798/1.264
Measured results	2.4/3.05	22.08/11.4	-40/-39.5	4.82/4.46	1.0332/1.235

A comparison of the proposed antenna with other microstrip patch designs in the band of wireless communication application is shown in **Table 4.** The proposed model shows better performances in terms of the gain and reflection coefficient in comparison with the antennas reported in the following table. It also has a higher fractional impedance bandwidth than the

referenced designs. The overall conclusion indicates that the proposed antenna has a simple and compact structure, with low fabrication complexity and that its dual band performance is verified experimentally with respect to previous studies.

Table 4. Comparisons of the proposed antenna with other Microstrip patch antenna designs are shown.

Parameter	Overall antenna dimensions(mm^2)	Substrate	Resonant Frequency (GHz)	BW (MHz)	S11 (dB)	Gain (dBi)	Directivity (dBi)	Fabrication Complexity	Slot configuration	Difference from proposed work
(Deepa et al., 2023)	40 × 30	FR-4, εr = 4.4, h = 1.6 mm	2.29 / 3.34	N/A	−14.24 / −12.01	1.058 / 7.01	N/A	Moderate – single-layer slotted microstrip patch antenna with inset/coaxial feeding	Slots introduced in the radiating patch for dual-band operation.	Different slot geometry and resonant frequencies; lower S11 performance.
(Kaplan and Gocen, 2022)	40 × 50	FR-4, εr = 4.3, h = 0.8 mm	2.4/5	600 /1250	-31.17 - 42.05	6.2/5.8	N/A	Simple single-layer microstrip patch antenna with a microstrip feed line.	Dual-rectangular slots	Two slot configuration
(Abdel Halim, 2023)	50 × 50	FR-4, εr = 4.4, h = 1.6 mm	3.22	110	-28	5.9	6.1	Moderate – Single-layer CPW-fed microstrip patch antenna with crossed slots and a semicircular ground plane.	Coplanar slot	Different slot geometry
(Chakraborty et al., 2013)	40 × 50	FR-4, εr = 4.4, h = 1.6 mm	2.4/3.188	90/100	-22/-24	5.7/5.5	6.2/6	Moderate – Single-layer microstrip patch antenna with multiple rectangular slots and a defected ground structure (DGS).	T-shaped DGS	Ground-plane modification
Our proposed antenna (Simulation results)	46.6 × 38	FR-4, εr = 4.3, h = 1.6mm	2.45/3.188	670/400	-45.32 /-46.11	5.713/ 5.283	6.176/ 5.46	Single-layer PCB with five rectangular slots	Five asymmetrically distributed rectangular slots (two on the left side and three on the right side of the radiating patch)	Optimized five-slot arrangement for dual-band operation

6. CONCLUSIONS

A dual band micro strip patch antenna has been designed and fabricated with single layer FR-4 substrate, which can be incorporated with various electronic systems easily. The antenna is designed for wireless applications, e.g., wireless communication application. The unique feature of this design is its simplicity because the slots to increase the electrical path length can be etched in the top layer of the antenna. With this modification, the antenna can

be used at low frequencies and has a low reflection coefficient. The resonant frequencies for the simulated and measured frequencies were 2.45 and 3.188 GHz, and 2.40 and 3.05 GHz, respectively. The measured results of S11 were also good in terms of the matching with simulation results with small frequency shifts at the resonant frequencies. The deviation is primarily due to the uncertainties in the true value of the dielectric constant (εr) and very slight variations in manufacture. Also, there is a small difference in the reflection coefficient that is probably due to losses incurred through the SMA connector. The simulated results showed satisfactory dual-band performance at 2.45 and 3.188 GHz, while the measured resonances were at 2.40 and 3.05 GHz respectively. Measured results were compared with the simulated results and the results showed good agreement proving the validity of the proposed design. The advantage of the proposed antenna is that it is compact in size, very simple in single-layer FR-4 construction and has a low fabrication cost, which is suitable for practical dual-band wireless communication applications in the 2.4 GHz ISM band and lower S-band. The dual-band slot-loaded microstrip patch antennas have been widely reported in the literature, but the novelty of this work is not the idea of slot loading per se. Instead, it is the particular slot configuration used in a small, simple single-layer FR-4 structure to achieve the desired dual-band functionality with no extra layers or elaborate feeding structures. However, some of the previously reported dual band slotted microstrip antennas are able to provide better performance parameters. Thus, it is not claimed that the proposed antenna outperforms all existing designs, but it is simple and practical design with low fabrication complexity and provides the desired dual band operation and experimentally verified performance.

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Credit Authorship Contribution Statement:

Hafsa Amer Jassim: Writing – original draft, Methodology, Software, Validation, Investigation and Data curation. Manar Naji Ghayyib: Writing –review & editing and verification of the mathematical equations.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Abdel Halim, A.S., Mostafa, A.M. and Hamdy, O., 2023. Design and implementation of 3.2-GHz co-planar miniaturized antenna for s-band communication and wireless applications. *Wireless Personal Communications*, 132(3), pp. 1887–1897. https://doi.org/10.1007/s11277-023-10686-9.

Abdelgwad, A.H., 2018. Microstrip patch antenna enhancement techniques. *International Journal of Electronics and Communication Engineering*, 12(10), pp. 703–708. https://doi.org/10.5281/zenodo.1474773.

Al-Gburi, A.J.A., Zakaria, Z., Ibrahim, I.M. and Halim, E.B.A., 2022. Microstrip patch antenna arrays design for 5G wireless backhaul application. *Lecture Notes in Electrical Engineering*, 865, pp. 77–88. https://doi.org/10.1007/978-981-16-9781-4_9.

Anchidin, L., Lavric, A., Mutescu, P.M., Petrariu, A. and Popa, V., 2023. The design and development of a microstrip antenna for internet of things applications. *Sensors*, 23(3), Article 1062. https://doi.org/10.3390/s23031062.

Azeez, Y., Abboud, M. and Qasim, S., 2023. Design of miniaturized multi-band hybrid-mode microstrip patch antenna for wireless communication. *Indonesian Journal of Electrical Engineering and Computer Science*, 31(2), pp. 794–801. https://doi.org/10.11591/ijeecs.v31.i2.pp794-801.

Balanis, C.A., 2016. *Antenna Theory: Analysis and Design*. 4th ed. Hoboken, NJ: Wiley.

Banale, A.K. and Patil, S., 2025. Designs and materials of flexible wearable microstrip patch antennas: A systematic review. *Discover Applied Sciences*, 7(1), pp. 1–25. https://doi.org/10.1007/s42452-025-06933-2.

Behera, S.K., Choukiker, Y., Mishra, D. and Mishra, R.K., 2010. Design and optimization of dual-band microstrip antenna with resonant frequencies at 2.4 GHz and 3.1 GHz. *Journal of Infrared, Millimeter, and Terahertz Waves*, 31(12), pp. 1346–1354. https://doi.org/10.1007/s10762-010-9722-0.

Chakraborty, U., Bandyopadhyay, S.K. and Bhattacharjee, A.K., 2013. Frequency tuning and miniaturization of square microstrip antenna embedded with T-shaped defected ground structure. *Microwave and Optical Technology Letters*, 55(4), pp. 869–872. https://doi.org/10.1002/mop.27417.

Das, A., Datta, B., Chatterjee, S. and Mukherjee, M., 2013. Dual-band slotted microstrip patch antenna design for application in microwave communication. *In: Proceedings of the 2013 International Conference on Information Communication and Embedded Systems (ICICES),* Chennai, India, 21–22 February 2013. IEEE. https://doi.org/10.1109/ICICES.2013.6508247.

Deepa, M., Reba, P., Shanmuha Priya, S., Annalakshmi, H., Mohammed Riyaz, A., and Suthindhira, S., 2023. Design and fabrication of dual band slotted microstrip patch antenna – 3.5 GHz and 2.4 GHz, *2023 International Conference on Intelligent Systems for Communication, IoT and Security (ICISCoIS)*, pp. 208-211. https://doi.org/10.1109/ICISCoIS56541.2023.10100371.

Denceli, O., Bhuvanesh, N.S. and Abishek, M., 2025. Simulation and performance analysis of a 5 Ghz microstrip patch antenna. *In: Proceedings of the 2025 5th International Conference on Intelligent Technologies (CONIT)*, Hubballi, India, 20–22 June 2025. IEEE. https://doi.org/10.1109/CONIT65521.2025.11167611.

Edwards, T.C., 2016. *Foundations for Microstrip Circuit Design*. *New York: John Wiley & Sons*. https://doi.org/10.1002/9781118936160.

Islam, Z.U., Wang, J., Zhang, X. and Li, Y., 2024. A review of microstrip patch antenna-based passive sensors. *Sensors*, 24(19), Article 6355. https://doi.org/10.3390/s24196355.

Garg, R., Bhartia, P., Bahl, I. and Ittipiboon, A., 2001. *Microstrip Antenna Design Handbook*. Boston, MA: Artech House.

Gupta, K.C., Garg, R., Bahl, I. and Bhartia, P., 1996. *Microstrip Lines and Slotlines*. Norwood, MA*: Artech House.*

Gupta, S., Dhillon, S.S., Khera, P. and Marwaha, A., 2013. Dual band U-slotted microstrip patch antenna for C band and X band radar applications. In: *Proceedings of the 2013 5th International Conference on*

Computational Intelligence and Communication Networks (CICN), Mathura, India, 27–29 September 2013. IEEE, pp. 41–44. https://doi.org/10.1109/CICN.2013.18.

Hakeem, M.J., Salman, L.M. and Ismael, M.M., 2021. Improving the performance of a microstrip antenna by adding a slot into different patch designs. *Engineering, Technology & Applied Science Research*, 11(5), pp. 7647–7652. https://doi.org/10.48084/etasr.4280.

Hammas, H.A., Hasan, M.F. and Jalal, A.S.A., 2020. Compact Multiband Microstrip Printed Slot Antenna Design for Wireless Communication Applications. *Advanced Electromagnetics*, 9(2), pp. 52–59. https://doi.org/10.7716/aem.v9i2.1393.

Kaplan, Y. and Gocen, C., 2022. A dual-band antenna design for 2.4 and 5 GHz Wi-Fi applications. *European Journal of Science and Technology*, Special Issue 34, pp. 685–688. https://doi.org/10.31590/ejosat.1084161.

Kornprobst, J., Wang, K., Hamberger, G. and Eibert, T.F., 2017. A mm-wave patch antenna with broad bandwidth and a wide angular range. *IEEE Transactions on Antennas and Propagation*, 65(8), pp. 4293–4298. https://doi.org/10.1109/TAP.2017.2710261.

Lee, K.F. and Tong, K.F., 2012. Microstrip patch antennas—Basic characteristics and some recent advances. *Proceedings of the IEEE,* 100(7), pp. 2169–2180. https://doi.org/10.1109/JPROC.2012.2183829.

Mohammed, A.J., Zoory, M.J. and Mohamad, H.J., 2024. Design of a simulated tri-bandwidth circular patch with slot for X and C bands applications. *Al-Muthanna Journal of Pure Science (MJPS)*, 11(1), pp. 29–41. https://doi.org/10.52113/2/11.01.2024/29-41.

Mukta, C., Rahman, M. and Islam, A.Z.M.T., 2021. Design of a compact circular microstrip patch antenna for WLAN applications. *International Journal on AdHoc Networking Systems (IJANS)*, 11(3), pp. 1–11. https://doi.org/10.5121/ijans.2021.11301.

Mushtaq, M.T., Shah, S.M.A., Munir, S., Hussain, M., Iqbal, J. and Khan, U.H., 2022. Dual band microstrip semicircular slot patch antenna for WLAN and WIMAX applications. *Radioengineering,* 31(3), pp. 406–412. https://doi.org/10.13164/re.2022.0406.

Nahas, M., 2025. A multi-slotted multi-band microstrip patch antenna design for 5G communication devices. *Engineering, Technology & Applied Science Research*, 15(4), pp. 24605–24610. https://doi.org/10.48084/etasr.11441.

Öner, G.G.B., Başbuğ, S. and Altuncu, Y., 2025. Design of a compact multilayer high-gain microstrip patch antenna for IoT applications. *Journal of Electromagnetic Engineering and Science*, 25(6), pp. 570–583. https://doi.org/10.26866/jees.2025.6.r.323.

Pozar, D.M., 2012. *Microwave Engineering*. 4th ed. Hoboken, NJ: Wiley.

Rajalakshmi, P. and Gunavathi, N., 2020. Compact modified hexagonal spiral resonator based tri-band patch antenna with octagonal slot for Wi-Fi/WLAN applications. *Progress in Electromagnetics Research C*, 106, pp. 77–87. https://doi.org/10.2528/PIERC20081803.

Rana, M.S., Islam, S.M.R. and Sarker, S., 2024. Machine learning based on patch antenna design and optimization for 5G applications at 28 GHz. *Results in Engineering*, 24, Article 103366. https://doi.org/10.1016/j.rineng.2024.103366.

Şahin, D.A. and Kaya, A., 2022. 2.4 GHz and 5 GHz dual band Wi-Fi antenna design for IoT based smart media application. *European Journal of Science and Technology*, (39), pp. 17–20. https://doi.org/10.31590/ejosat.1144355.

Sakshi and Bharti, M., 2023. Penta-band planar monopole circular antenna design using inverted L-shaped slot for UWB application. *Journal of Electronic Materials*, 52, pp. 8281–8292. https://doi.org/10.1007/s11664-023-10744-9.

Sarmah, K., Sarma, A., Sarma, K.K. and Baruah, S., 2015. Dual-band microstrip patch antenna loaded with complementary split ring resonator for WLAN applications. In: Mandal, J.K., Satapathy, S.C. and Sanyal, M.K. (eds.), *Information Systems Design and Intelligent Applications: Proceedings of the Second International Conference INDIA* 2015, Kalyani, India, 8–9 January 2015. *Advances in Intelligent Systems and Computing*, 339. Cham: Springer, pp. 573–580. https://doi.org/10.1007/978-81-322-2250-7_57.

Tiwari, A., Sharma, R. and Kumar, P., 2025. Compact wearable microstrip antenna design using hybrid textile substrate. *Scientific Reports,* 15, Article 83864. https://doi.org/10.1038/s41598-024-83864-9.

Wong, K.L., 2002. *Compact and Broadband Microstrip Antennas*. New York: Wiley.

تصميم هوائي رقعة مايكروسترب ذو رقعة مشقوقة لتطبيقات الاتصالات اللاسلكية ثنائية النطاق باستخدام برنامج CST

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الخلاصة

تُعد هوائيات الرقعة الميكروسترب (Microstrip Patch Antennas – MPAs) متعددة الاستخدامات من حيث الأشكال الهندسية وإمكانية التطبيق. يتكون الهوائي المقترح من خمسة شقوق مستطيلة(Rectangular Slots) ، وقد تمت محاكاته باستخدام برنامج **CST**. ومن أهم مزايا هذا النوع من الهوائيات خفة الوزن وإمكانية دمجه مع الدوائر المتكاملة للمايكروويف (MICs)، بالإضافة إلى بساطة التركيب التي تجعل عملية التصنيع منخفضة الكلفة. كما تتميز هوائيات الميكروسترب بقدرتها على توفير استقطاب خطي أو دائري، والعمل عند نطاقين ترددين أو أكثر، وتحقيق عرض حزمة واسع، فضلاً عن مرونة تصميم خط التغذية. لذلك تم في هذا البحث تقديم هوائي رقعة ميكروسترب مستطيل مزود بشقوق مع تحسين أبعاده التصميمية ليعمل في تطبيقات الاتصالات اللاسلكية. تم تصنيع الهوائي على ركيزة عازلة بسماكة 1.6 ملم وثابت عزل كهربائي (εr = **4.3**) وقد تم حفر الشقوق على السطح العلوي للركيزة، بينما تمت تغذية الهوائي بواسطة خط نقل ميكروسترب. أظهرت النتائج أن الهوائي يعمل عند ترددين رنينيين هما 2.45 GHz و 3.188 GHz مع عرض جزمة مقداره(27.34%) 0.67 GHz و (12.5%) 0.4 GHz على التوالي. كما حقق الهوائي قيمة فقدان عودة (reflection coefficient) بلغت 45.32– dB و 46.11 dB–عند الترددين المذكورين. كذلك بينت النتائج تحسناً في الكسب (Gain) ليصل إلى 5.713 dBi و 5.283 dBi وفي التوجيهية (Directivity) لتبلغ 6.17 dBi و 5.46 dBi، مع نسبة موجة وقوف جهد VSWR تساوي 1.279 و 1.265على التوالي.

الكلمات المفتاحية: خط نقل الميكروسترب، هوائي الرقعة الميكروسترب، ثنائي الحزمة(Dual–Band) ، هوائي الشقوق (Slot Antenna)