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Design, Simulation and Fabrication of a Slot Loaded 2.45 GHz Microstrip Patch Antenna for ISM Band Wireless Applications

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Abstract
*Due to an exponential increase in wireless devices in recent time, there is demand for development of low cost, low profile, less weight, highly reliable antennas which is backbone of any effective wireless devices. This paper presents the design, simulation, fabrication, and experimental validation of a slot loaded 2.45GHz microstrip patch antenna intended for Industrial, Scientific, and Medical (ISM) band applications. A new compact edge slot antenna was designed using conventional transmission line theory and implemented on an FR-4 substrate of relative permittivity of 4.4 and thickness of 1.6mm. Computer Simulation Technology (CST) was employed to model and optimize the antenna for enhancement of the antenna. The proposed antenna was fabricated by chemical etching method using $FeCl_3$ as the etchant. The fabricated prototype was tested using a Vector Network Analyzer (*miniVNA tiny 1 - 3GHz*) to validate simulated results. The simulation results obtained were; resonant frequency is 2.45GHz with a return loss is –37.506 dB, bandwidth is 106.67MHz, VSWR is 1.03, gain is 5.04dB and radiation efficiency of 52.7 %. While the measured results of the fabricated antenna were; resonant frequency is 2.5GHz with a return loss of –27.21dB, bandwidth of 80.75MHz, and VSWR is 1.09, these results are good enough for the proposed antenna to be suitable for ISM band wireless applications such as Wi-Fi, Bluetooth, and IoT devices.*

Keywords: *Microstrip patch antenna (MPA), 2.45 GHz, ISM band, CST simulation, Internet of Things (IoT).*

1.0 Introduction

The rapid expansion of wireless communication systems has significantly increased the demand for compact, low-cost, and efficient antennas operating within the Industrial, Scientific, and Medical (ISM) band [1]. The popular 2.45 GHz frequency (ISM band) has become most widely utilized band due to its global allocation for unlicensed use and compatibility for short-range, high-data-rate communication [2]. This band supports a wide variety of applications, such as Wireless Local Area Networks (WLAN) and WiMAX, Bluetooth, ZigBee, and all Internet of Things (IoT) devices, which rely on stable and energy efficient wireless links [2, 3, 4].

Among the critical components of any wireless system, the antenna stands out as a fundamental and indispensable element, as it facilitates the quality of transmission and reception of electromagnetic signals [5]. However, the integration of antennas into multifunctional devices poses several design and performance challenges. Primarily, the physical dimensions of the antenna often impose substantial constraints of the size and the performance efficiency on the overall design of the device [6]. Therefore, antenna designs must balance the performance with practical constraints such as size, cost, and ease of integration [6].

A wide variety of antenna types that are designed for embedded wireless applications includes; microstrip patch antennas, wire antennas, aperture antennas, metasurface reflectors [2, 7, 8, 9]. Among these microwave antennas, microstrip patch antennas edge out others because of their inherent advantages such as; compact size, planar profile, low manufacturing cost, low power consumption and ease of integration with microwave circuits [1, 2, 3, 5]. Despite these compelling benefits, the conventional microstrip patch antenna is plagued by critical performance trade-offs. Its most significant drawback is a notoriously narrow impedance bandwidth, typically only a few percent of the center frequency, which limits its operational flexibility [6]. Furthermore, achieving high gain, radiation efficiency and sensitivity to substrate parameters especially in miniaturized designs within a compact footprint remains a persistent challenge. These limitations impede the rates of development of next-generation IoT devices that required higher data rates matching within the system [2, 3].

The fundamental structure of a typical single rectangular MPA is illustrated in Figure 1, the standard structure consists of ground at the bottom, a metallic patch at the top, and a dielectric substrate sandwich in between. The radiator is generally made of conducting material such as copper the most popular or any other conducting materials, and it can take any possible shape. Dielectric constant of the substrate (ϵ_r) is typically in the range 2.2<

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ϵr <12. For good antenna performance, a low dielectric constant with thick dielectric substrate is desirable, as it provides better radiation, better efficiency and larger bandwidth [3].

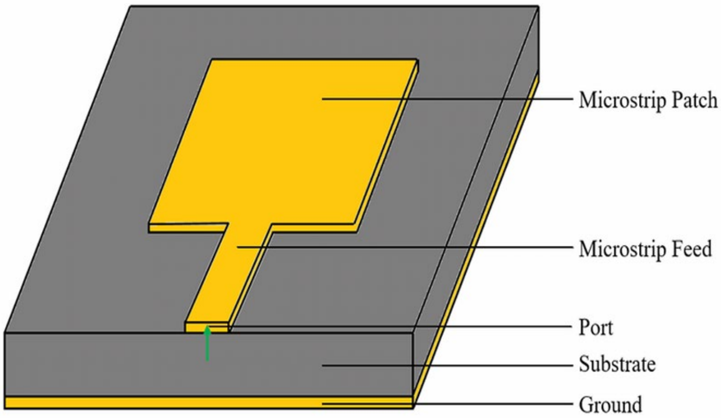

Figure 1: Constructional view of Microstrip Antenna and feed line [10]

Attempt to overcome the stated challenges associated with MPA has motivated an extensive research into innovative design in antenna industries and applications. Various types of geometry and patch-shaping modification techniques have been extensively investigated in the literature, these include using of slots, fractal geometries, defected ground structures (DGS), metamaterial-inspired elements, and irregular or special shaped patches [10, 11]. Such approaches are known to improve antenna performance by altering the surface current distribution, effectively increasing the electrical length of the radiator without expanding the patch footprint, enhancing impedance matching, enabling size reduction and bandwidth enhancement. But techniques such as slots, slits, meanders and fractal contours remain the dominant strategies to compress physical dimensions while tuning the resonant mode to desire frequency [12]. Thus, the development of highly effective microstrip patch antennas for 2.45GHz ISM band remains a critical area of study, for enabling the continued growth of wireless technologies and supporting the increasing demand for reliable, high-performance communication devices in modern applications. Also, size reduction, bandwidth increment and overall efficiency have emerged as key design considerations for the majority of commercial MSA applications [6].

Recent work on patch antenna improvement techniques; majorly selected from the use of slot technique to improve the antenna parameters which is pertinent to this work are reviewed. In [1], a new low-cost compact antenna for the 2.45 and 5.8 GHZ ISM bands was presented, the proposed prototype consists of a low-cost patch antenna, 40 mm × 24 mm in size, the final structure consists of slots in the central ring and a ground plane with a crenellated shape at the top, with a relatively wideband operational bands of 140 MHz at 2.45 GHz, S_{11} of −13.82 dB, gains of 2.41 dBi and a radiation efficiency of over 90% were the results obtained. Authors in [13], presents an Automated antenna design and optimization frame work using multi-objective genetic algorithms (MOGAs). A normal insert feed rectangular patch was slotted on the ground plane with concentric o ring shape, they were able to achieved return loss values of −21.56dB, VSWR of 1.2, with maximum gain of 1.96dBi, at 2.4GHz and 16.29% antenna reduction. In [14], A 2-bit reconfigurable microstrip antenna capable of selectively switching its operating frequency and polarization is presented. The design features a novel dual-embedded, crossed-slot topology where slots created both on the top patch and the ground plane are controlled independently by two p-i-n diodes. At 2.45GHz, S11 is -32.1dB, maximum gain of 2.7dBi with 1% bandwidth improvement. For the researchers in [15], a compact dual-band antenna with paired L-shape slots for on/off body wireless communication was presented; the proposed antenna resonates in ISM band at two different frequencies, at 2.45 GHz and 5.8 GHz. The radiator was loaded with pairs of L shape slot facing each other, the pairs was duplicated one on upper side and the other on the lower side. At 2.45 GHz, the results obtained for s_{11} is -35dB, the gain is greater than 3 dBi total radiation efficiency is more than 80% and specific absorption rate (SAR) values are low, with 0.19 W/kg. Authors in [16] work on slot-loaded microstrip patch sensor antenna for high-sensitivity permittivity characterization, a high-sensitivity microstrip patch sensor antenna operating at 2.5 GHz was proposed, incorporating a thin rectangular slot along the upper radiating edge of the patch for permittivity measurement. The measured sensitivity of the proposed design is approximately 3.54–4.53 times higher than that of a conventional patch antenna. Additionally, the antenna exhibits an improved return loss (S_{11}) of −30 dB. However, the VSWR fractional bandwidth is reduced to 0.28% compared to 0.8% for the patch without the slot. Furthermore, the quality factor of the resonant frequency increases significantly to 357, indicating enhanced selectivity relative to the conventional design. The effect of the slot makes the difference on the results

A 2.45 GHz microstrip patch antenna design, simulation, and analysis for wireless applications was presented by Authors in [17], an insert slot on the top patch and rectangular slot on the ground plane was loaded on the

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patch. The design was carried out on two different substrates. Simulations with FR-4 material showed that the return loss was -20.405 dB, the gain was 2.592 dB, the directivity was 7.47 dBi, the voltage standing wave ratio (VSWR) was 1.221, the bandwidth (BW) was 0.0746 GHz, and the efficiency was 34.69%. Also, Rogers RT/duroid material gives results of a return loss of -12.542 dB, a bandwidth (BW) of 0.0349 GHz, a gain of 8.092 dB, a directivity of 8.587 dBi, and an efficiency of 94.24%. In [18], A microstrip rectangular patch antenna with inset fed and defected ground structure operating at 2.458 GHz frequency was presented. The ground was loaded with slots to make it defected from normal complete ground. The presented antenna return loss is −32.65 dB with bandwidth for S_{11} less than −10dB is 2.475 to 2.494 GHz, which covers IEEE 802.11 g/n OFDM 20MHz channel bandwidth. The antenna has directional far field pattern at boresight direction of 0°, it achieved good directive gain of 6.76 dBi and VSWR of 0.47 at a frequency of resonance, Authors in [19] designed a cross-slot patch antenna for 2.45 GHz ISM band (medical hyperthermia use) with optimized feed placement. The innovative cross-slot structure combined with trimmed patch corners produces a compact antenna with dimensions of $50 \times 50 \times 1.6\ mm^3$, significantly reducing size while maintaining robust frequency performance, they were able to achieved –20.08 dB return loss at the target frequency. While [20], present development of 2,4GHz Microstrip Patch Antenna for WLAN, 4G and 5G Network using HFSS. The antenna size is 60 mm x 60 mm x 1.6 mm. The simulation results obtained are as follows: 2.4011 GHz resonant frequency and reflection coefficient S_{11} is -31.766 dB, 67 MHz bandwidth, 3.13 dB gain, 6.29 dBi directivity, and 20.91 dB electric field radiation (rE).

Overall, all these reviewed works demonstrate a significant progress in the use of slot for miniaturization, bandwidth enhancement, gain and efficiency improvement of microstrip patch antennas. These advancements directly support the growing demand for efficient, low-cost antennas in IoT and wireless communication systems, while ongoing research continues to balance trade-offs between size, and gain or efficiency.

Therefore, the aim of this present study is to use unconventional rectangular slots in an innovated position on the patch to improve the performance of the normal rectangular microstrip patch antenna parameters operating at 2.45 GHz. With the objectives of complete lifecycle development from theoretical design, simulation and geometry modification to fabrication and experimental testing. Emphasis is placed on achieving optimal impedance matching, enhanced bandwidth, and stable radiation characteristics through design optimization and slot loading with respect to state-of-the-art designs found in the literature. The key novelty of this work lies in the systematic integration of rectangular slot on the patch radiator in a strategic position for enhancement of antenna parameters.

2.0 Materials and Method

The major materials used to carry out this works were; Substrate material (FR-4), thermo transfer paper, oil paint, SMA Connectors, miniVNA Tiny Vector Network Analyzer (1 - 3GHz). etchings chemicals ($FeCl_3$) and Tina, Antenna modeling software (CST Studio Suite 2021), vnaj 3.4.6 software and Personal Computer (PC).

2.1 Theoretical Design of the Antenna

The antenna was designed based on standard transmission line theory; this theory provides a well-established framework for determining the appropriate dimensions of the antenna sizes, transmission lines and ensuring proper impedance matching for effective signal propagation and minimal return loss. These transmission line equations as listed in [21] were used to theoretically determine the dimensions of the antenna operating at 2.45GHz frequency on the FR4 substrate of a relative permittivity (ε_r) of 4.3, loss tangent (tan δ) = 0.002, and thickness (h) of 1.6mm. The numerical dimensions of the normal RMPA antenna obtained with the equations were summarized in Table 1. The proposed antenna geometry is depicted in Figure 2.

Table1: Calculated values used in designing the proposed antenna

Description	Symbol	Value (mm)
Length of Patch	L_p	29.3
Width of Patch	W_p	37.61
Length of Substrate	L_s	37.8
Width of Substrate	W_s	47.21
Width of Feedline	W_f	2.00
Lenght of Feedline	L_f	4.80
Insert Length	F_i	3.65
Insert Gap	G_p	1.80
Width of Slot	w_x	1.00
Lenght of Slot	L_y	20.00

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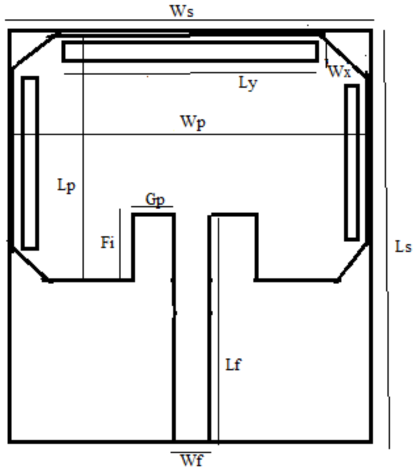

Figure 2: Proposed antenna geometry

2.2 Modeling the Proposed Antenna in CST Studio

The antenna was simulated using CST Microwave Studio with the dimensions value derived above. Key priority during simulation included; achieving resonance at 2.45 GHz, minimizing return loss (S_{11}), optimizing bandwidth, improving gain and radiation characteristic.

A convectional rectangular MPA was initially modeled; after which optimization was performed to enhance its performance. The optimization procedures involve maximizing some parameters and minimize some others to achieve the resonance at the target frequency. The normal rectangular patch was then modified with slots to get the proposed patch, modification that was carried out includes; creating an insert slot was introduced along the feed line, afterward three symmetrical rectangular-shaped slots of length and width 20mm by 1mm respectively was created along the edges of the radiating part of the antenna (one horizontal slot at the top and two vertical slots at the sides), the slots were created one after the other and the effect were monitor progressively. These slots increase the overall electrical length of the surface current, resulting in a frequency shift from the higher band to the lower band, and it induce adequate capacitances to the input impedance for a proper impedance matching. The last step involves chamfering an isosceles triangle section measuring 10 × 10 x10 mm from the patch's edges as a way of tailoring the current path at the edge, and that the original dimension of the patch gets reduced which resulted in resonating frequency been shifted towards target frequency. Modelling of normal patch and proposed patch modification in CST environment are showed in Figure 3 and 4 respectively.

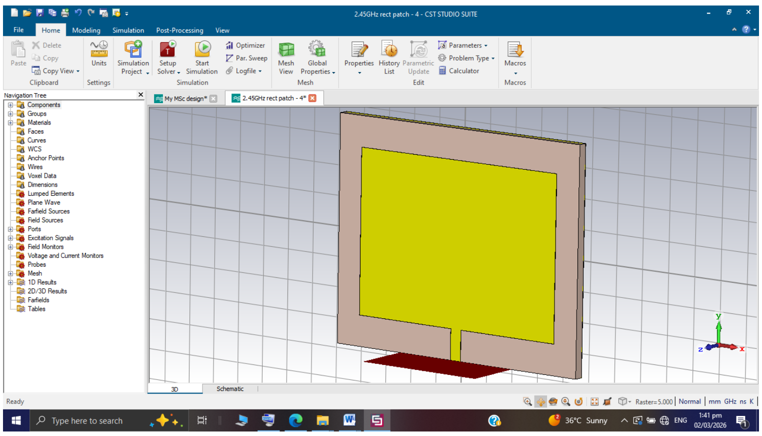

Figure 3: Normal RMPA in CST environment

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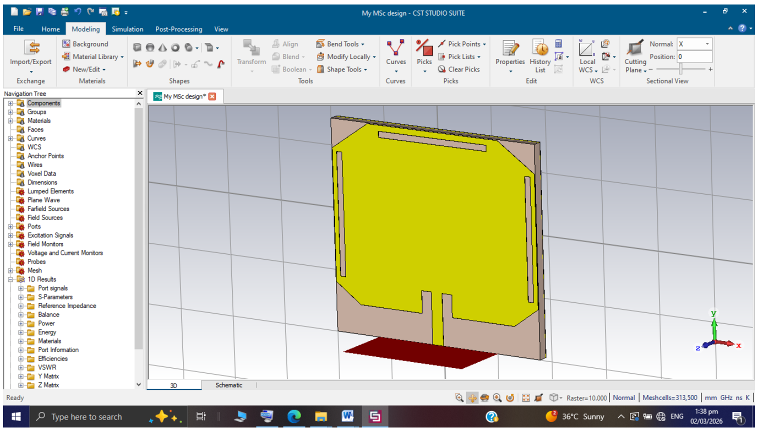

Figure 4: Proposed Antenna in CST environment

2.3 Fabrication Procedures of Proposed Patch Antenna

Antenna fabrication Procedure dictates that; dimensional tolerances are critical. Hence, considerable care is required in the fabrication process. Fabrication of the proposed antenna was done with the method of chemical etching, the first step is exporting the design from CST environment and print the mirror image of the antenna geometry in a thermo transfer paper; then transfer the antenna pattern to one side of the double sided FR4 substrate with hot pressing iron, the substrate was soaked in water and gently remove the paper with finger without destroying the transferred ink as shown in Figure 5. The unwanted areas from the geometry pattern were etched out by normal etching process with Ferric Chloride (FeCl3) solution as shown in Figure 6a. Finally, the ink on a printed design and the oil paint at the back was removed by immersed in a Tina chemical and scrub the ink and paint with finger for easy remove as shown in Figure 6b. The substrate was left with the actual design of the patch.

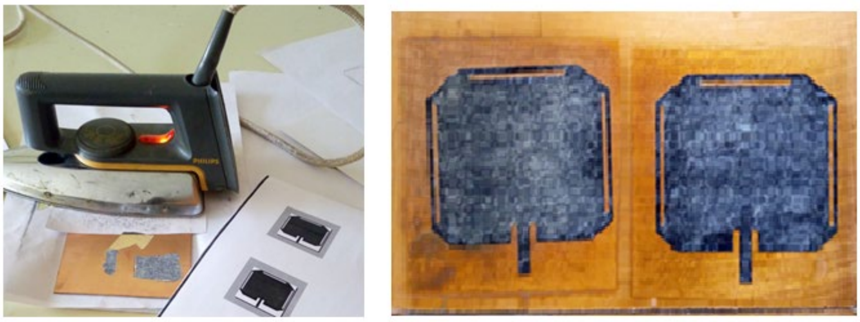

Figure 5: Transferring to the PCB by heat method

Figure 6: (a) Chemical etching (b) Removing of etchant resistance

SMA (subminiature version A) connector with a characteristic matching impedance of 50Ω was carefully connected to the antenna, the inner conductor of the SMA port is soldered to the patch feed line while the outer conductor of the SMA is soldered to the ground plane as shown in Figure 7.

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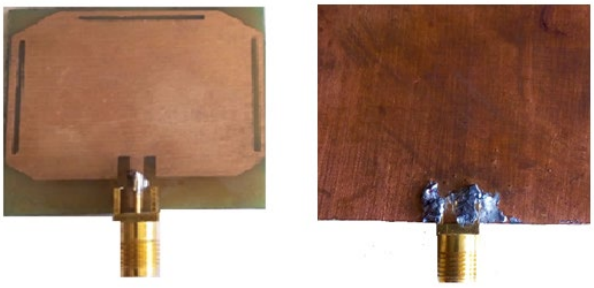

Figure 7: Proposed Antennas (front and back views)

2.4 Performance Measurement of the Fabricated Antenna

Performance testing of the antenna is done using a Two-port miniVNA Tiny Vector Network Analyzer (1 - 3GHz). This VNA provides simple and complete vector network measurements in a compact, fully integrated RF network with built-in RF source, it offers good data handling, higher accuracy and faster sweeps speed in addition.

The antenna was connected to the VNA through a 50Ω coaxial cable connected to the SMA soldered to microstrip feeding line; the VNA is connected to the Personal Computer (PC) through USB cable which doubles as an interface connector and powered cable for VNA. The measurement setup was placed on a laboratory work table and all electromagnetic emitting devices were removed far from the setup area to avoid the near-field interactions. The measurement setup is shown in Figure 8.

Figure 8: Antenna performance measurement setup

3.0 Results and Discussion

3.1 Simulation Results

The performance results of the proposed rectangular microstrip patch antenna obtained from simulation shows strong agreement with the design objectives for ISM-band operation. The antenna achieves a return loss of −37.50 dB at the 2.45 GHz resonant frequency as shown in Figure 9, indicating an exceptionally good impedance match between the patch and the 50 Ω feed networks. At this level of return loss, the reflected power is negligible, meaning that almost all the input energy is delivered to the antenna for radiation. This is further supported by the extracted input impedance of 49.03 Ω shown in Figure 11, which lies very close to the ideal 50 Ω reference value and confirms that the chosen inset-feed configuration has produced an optimal match without the need for additional matching circuitry. Correspondingly, the VSWR value of 1.027 in Figure 10 reflects a nearly ideal standing-wave ratio, reinforcing the effectiveness of the feed design.

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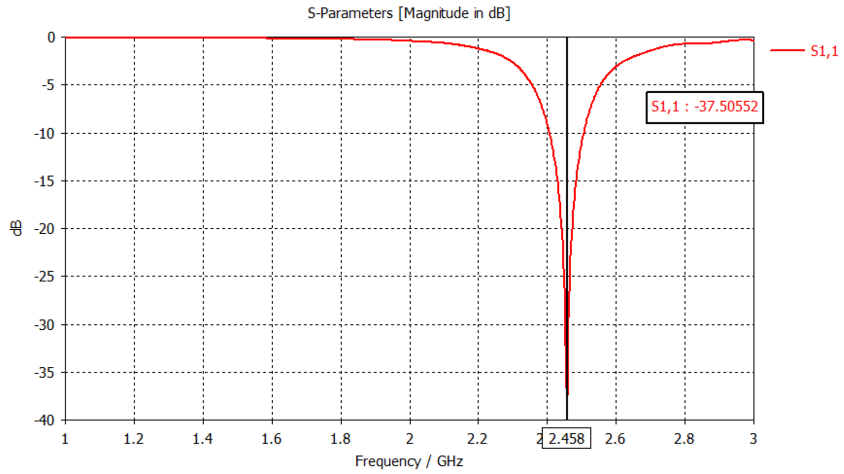


Figure 9: Return Loss of proposed patch antennas.

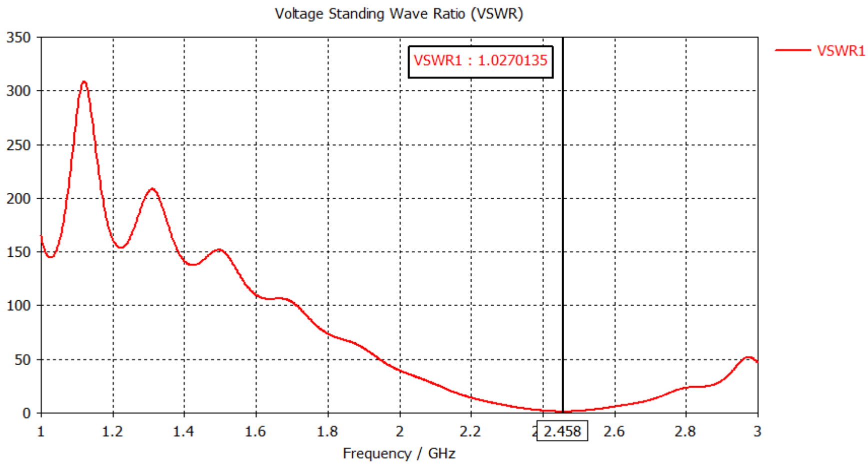


Figure10: VSWR at resonant frequency of 2.45GHz

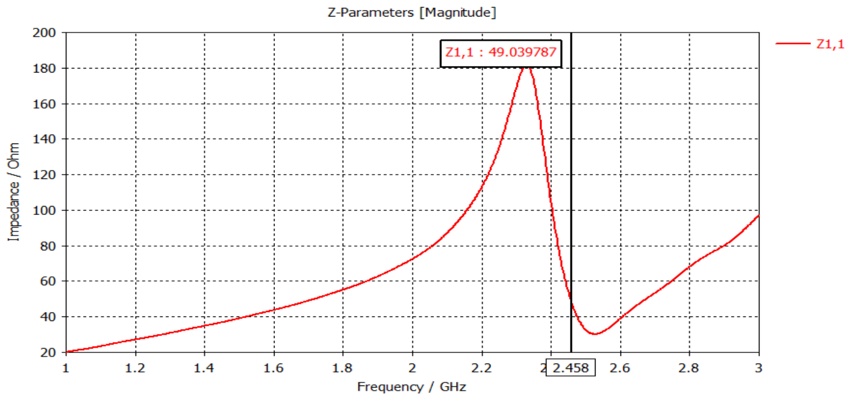


Figure 11: Z-parameter at resonant frequency of 2.45GHz

The value of f_1 and f_2 are taken at -10dB in Figure 12 which gives 2.4041GHz and 2.5107GHz respectively, the difference of these values gives 106.67 MHz, representing a fractional bandwidth of approximately 4.35%. For a conventional single-layer rectangular MPA, which is typically narrowband in nature, this bandwidth is considered robust and ensures stable operation across the entire ISM range.

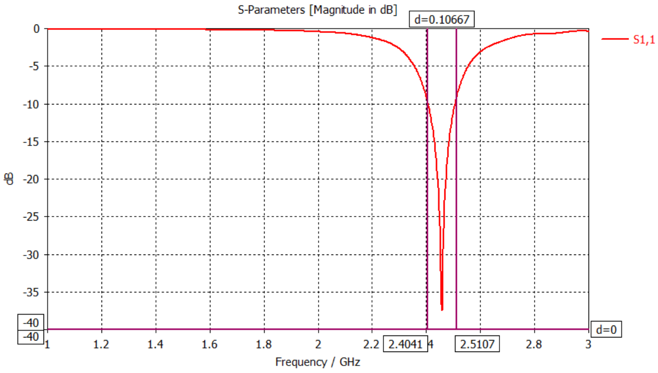
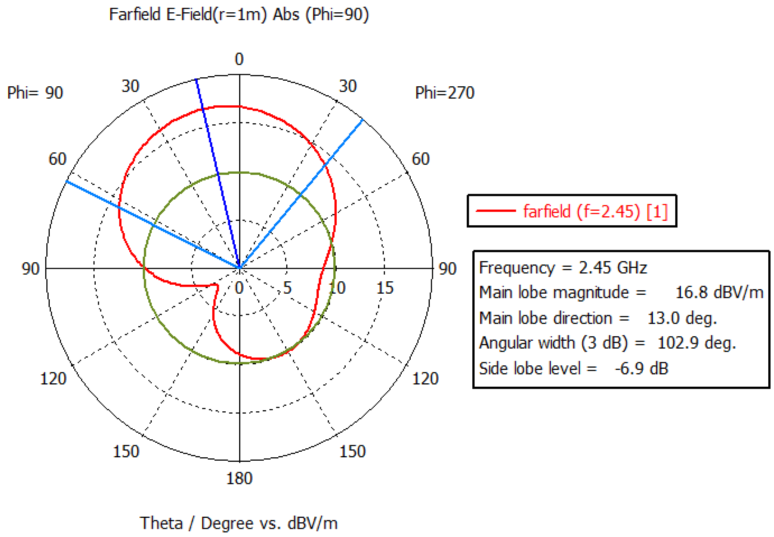


Figure 12: Bandwidth of proposed antenna

A radiation pattern describes how the energy is radiated out into space by the antenna or how it is received. It is represented by the far-field radiation properties of the antenna as a function of the spatial coordinates specified by the elevation angle Theta and the azimuth angle Phi. The 2D far-field radiation patterns of the proposed rectangular microstrip patch antenna are shown in Figure 13 a and b. Figure 13a demonstrates the polar plot of the E-field pattern of the proposed rectangular microstrip patch antenna. It is seen that at the target frequency of 2.45 GHz, the main lobe magnitude is 16.8 dBV/m, the main lobe direction is 13.0 degrees, the angular width is 102.9 degrees, and the sidelobe level is –6.9 dB.



Figures 13a: Far-field E-field pattern of the proposed antenna

While Figure 13b demonstrates the polar plot of the H-field pattern of the proposed rectangular microstrip patch antenna. At the frequency of operation 2.45 GHz, the main lobe magnitude is –34.7 dBA/m, main lobe direction is 13.0 degrees, the angular width is 102.9 degrees, and the sidelobe level is –6.9 dB.

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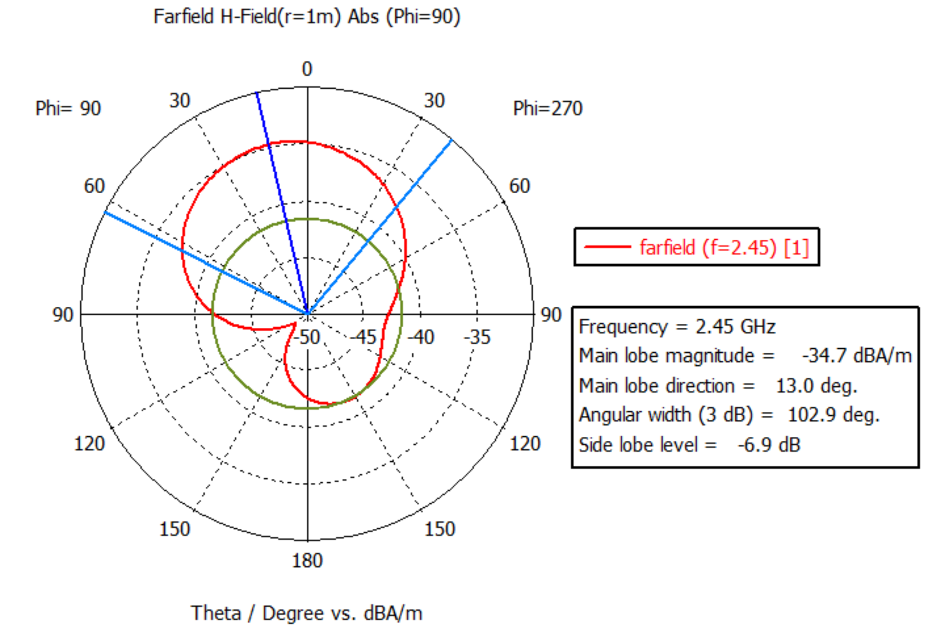
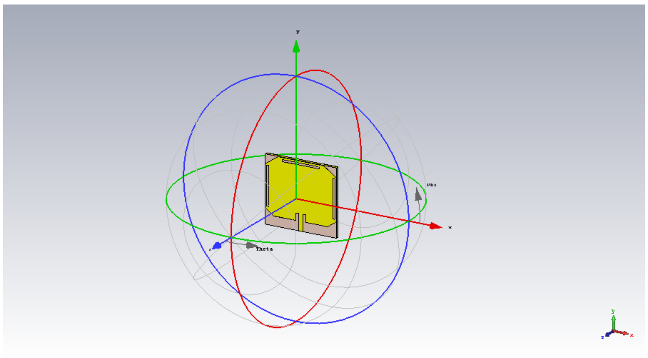


Figures 13b: Far-field H-field pattern of the proposed antenna

The results demonstrate a broadside radiation characteristic, which is typical of microstrip patch antennas, with the main lobe directed normal to the patch surface. The E-plane pattern exhibits a nearly stable and symmetric shape, indicating uniform current distribution along the effective radiating edges, while the H-plane shows an omnidirectional or quasi-omnidirectional profile, which is desirable requirement for many wireless communication applications such as WLAN and IoT devices. Additionally, the absence of significant back radiation suggests that the ground plane effectively suppresses unwanted radiation, thereby improving antenna directivity. The combination of high radiation efficiency and stable radiation pattern confirms that the proposed antenna is well-suited for 2.45 GHz ISM band applications, offering a good balance between compactness, efficiency, and radiation characteristics.

Figure 14 (a & b) shows the 3D pattern of radiation characteristics, the simulated structure exhibits a directivity of 6.005 dBi. The directional radiation pattern supports effective signal propagation in wireless communication scenarios, particularly for indoor environments. Such directivity is suitable for applications where a stable, moderately focused radiation pattern is desired, such as wireless sensor networks, short-range communication systems, and point-to-point links within the ISM band.



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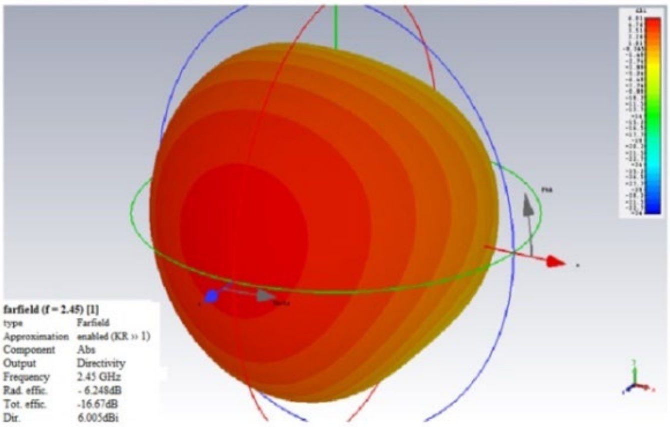

b

Figure 14: 3D plot of far field directivity of the proposed antenna at 2.45 GHz

From Figure 15 the simulated gain of the designed antenna is approximately 5.04 dB in the complete frequency band of interest, suggesting a good radiation capability which is required to impinge the wave into the object under test.

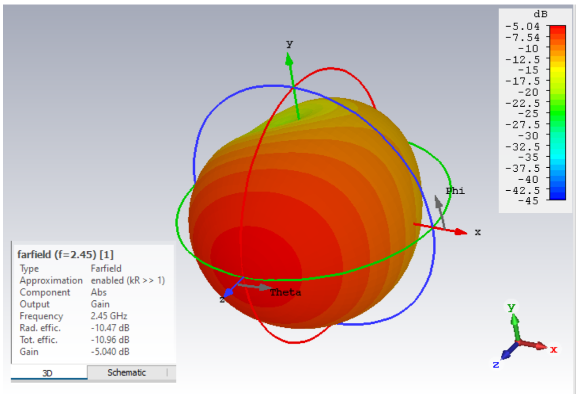

Figure 15: 3D plot of fair field gain of the proposed antenna at 2.45 GHz

Figures 16 shows the simulated surface current distribution on the patch wings of the antenna at resonant frequency of 2.45 GHz with phase angles of 22.5 and the maximum current flow of 68.95A/m. The slots introduced on the radiating edges suppress unwanted surface currents that would otherwise flow vertically toward the end-fire direction, thereby preserving the antenna's directive radiation characteristics. Also, the slot perturbs the conventional current flow, Lengthening signal paths to increase the effective electrical length, thereby enabling miniaturized operation and improved radiation performance.

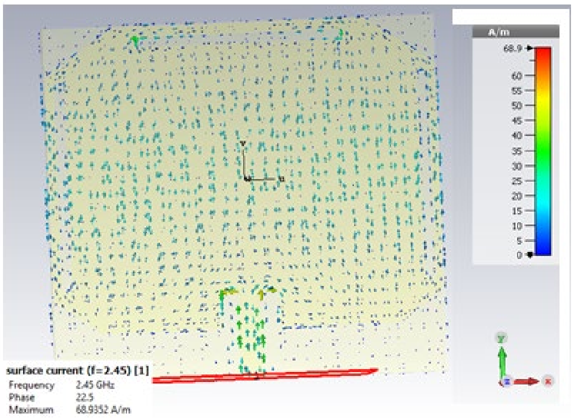

Figure 16: Surface current distributions

Antenna efficiency measures how much energy radiates in the air in all directions. It is determined by the ratio of the radiated power to the incident power at the antenna. For high-performance antennas, antenna efficiency needs to be high. Figure 17 shows the radiation efficiency of the proposed antenna. It is seen that the radiation efficiency is 52.7 % at the resonant frequency of 2.45 GHz.

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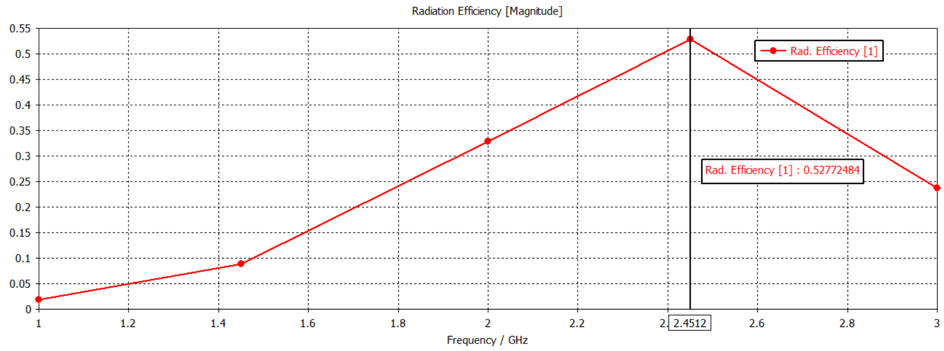
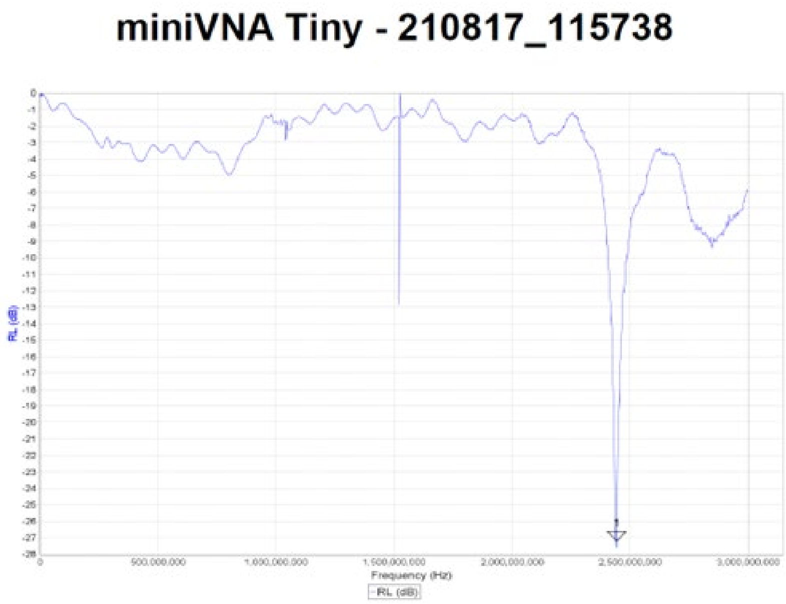


Figure 17: Radiation efficiency of the proposed antenna

3.2 Measured results

The fabricated antenna exhibited strong performance at the measured resonant frequency of 2.46 GHz, which is very close to the intended 2.45 GHz ISM band target, indicating good fabrication accuracy. The measured return loss of –27.21 dB demonstrates excellent impedance matching, as values below –10 dB are generally considered acceptable for efficient operation. The antenna achieved a bandwidth of 80.75 MHz, which is sufficiently wide for most ISM-band wireless applications, ensuring stable performance even in the presence of manufacturing tolerances or environmental variations. Additionally, the measured VSWR of 1.09 indicates minimal reflection and highly efficient power transfer between the feed line and the antenna. Figure 18 shows the print out of the measured s_{11} from the computer.



Marker	Freq. (Hz)	RL (dB)	RP (°)	|Z| ()	Rs ()	Xs ()	Theta	SWR
1	2,442,492,704	-27.21	19.71	54.3	54.3	1.6	1.7	1.09:1

Figure 18: Measured S11

3.3 S_{11} and VSWR Parameters of Simulation versus the Measured

A comparison between the simulated and measured S_{11} and VSWR parameters provides insight into the accuracy of the antenna design and fabrication process. A good agreement between the simulation result and measured values of S_{11} and VSWR was achieved as it can be seen in export plot of Figures 19 and 20. The slight frequency shift is attributed to common factors such as fabrication tolerances, substrate inhomogeneity, soldering effects, or environmental influences such as reflections and absorption from nearby objects or metallic supports. Measurement error like Inaccurate Open-Short-Load-Thru (OSLT) calibration or drift in reference standards of VNA can lead to small discrepancies in measured S-parameters. Also, the presence of coaxial cables and SMA connectors introduces additional insertion loss that is not present in simulation, these losses slightly reduce the measured signal reaching the antenna, which can result in higher S_{11} values or apparent degradation in measured return loss. More so, the connector interface can introduce small parasitic inductance or capacitance, subtly shifting the resonant frequency.

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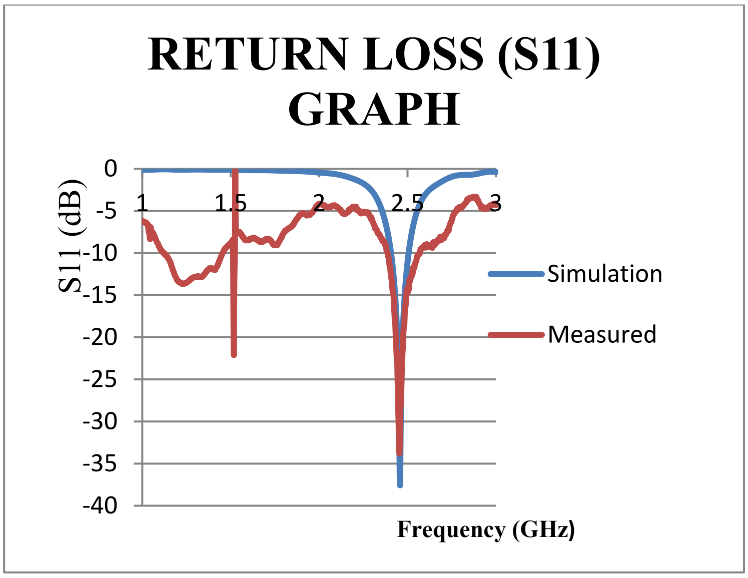

Figure 19: S_{11} graph of simulation and measured

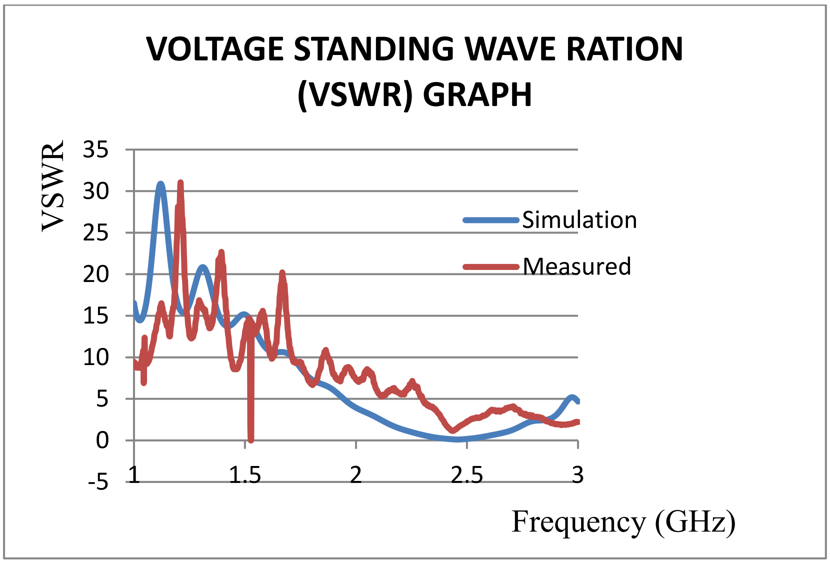

Figure 20: VSWR graph of simulation and measured

Table 2 shows the numerical results of the proposed antenna performance in terms of S11, VSWR, and Bandwidth.

Table 2: Simulated vs Measured Performance

	f_r (GHz)	S_{11} (dB)	BW (MHz)	VSWR
Simulation	2.45	-37.50	106.67	1.03
Measured	2.46	-27.21	80.75	1.09

Simulated and measured results exhibit close alignment as shown by the numerical comparison table, this confirmed the reliability of the proposed antenna. Although minor shifts in frequency and bandwidth occurred, these differences fall within acceptable fabrication and measurement tolerances. Overall, the numerical results verify that the antenna maintains the expected operational characteristics in both simulated and practical conditions.

3.4 Previous Works Versus Present Work Results

The proposed antenna's simulated performance was evaluated against state-of-the-art designs with other antennas reported in the literature in terms of dimension, center frequency, S11, VSWR, gain, directivity and

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efficiency. The comparison is summarized in Table 3. Our proposed antennas exhibit better comparable results with others which make it suitable for ISM band applications.

Table 3: Comparison of present and past results

Research work	Year	Antenna dimension (mm)	Substrate dimension (mm)	Working frequency (GHz)	Return loss (dB)	VSWR	Gain (dB)	Directivity (dBi)	Efficiency (%)
[13]	2026	22.8x18.5	41.6x37.9	2.4	−21.56	<1.5	1.96	N/A	N/A
[1]	2025	40 × 24		2.45& 5.8	N/A	N/A	2.41&5.22	N/A	>90
[19]	2025	40 × 40	50 × 50	2.45	–20.08	N/A	5.1	N/A	0.03
[20]	2024	37.6x29.1	49.2x 8.2	2.45	-27	1.1	2.28	5.99	N/A
[22]	2023	40 x 28.4	100x100	2.45	-20.4	1.2	2.59	7.47	34.69
[6]	2021	37.6x29.1	47.2x38.7	2.45	-47.20	1.009	3.18	5.18	61.57
This work		37.6x29.3	47.2x37.8	2.45	–37.50	1.03	5.04	6.005	52.7

4.0 Conclusion and Recommendations

Design, simulation and fabrication of a slotted loaded 2.45 GHz microstrip patch antenna for ISM band wireless applications was successfully carried out. The simulation results demonstrate good consistency with measured data, validating the theoretical model's ability to predict real-world performance and it confirm that the patch antenna is practically useful for ISM-band wireless applications. The fabricated prototype demonstrated a resonant frequency of 2.46 GHz, closely matching the simulated target, with a strong measured return loss of –27.21 dB and an excellent VSWR of 1.09. These values indicate efficient impedance matching, low reflection, and reliable operational performance. Although slight deviations in frequency and bandwidth were observed, they fall within normal fabrication and environmental tolerances. Overall, the strong agreement between simulated and measured results validates the design methodology, confirming that the antenna is well-suited for practical ISM-band communication systems. The key novelty of this work lies in the systematic integration of a novel slot on the patch, while this work contributes to knowledge the template for optimized slots loaded MPA.

While this present work provides solutions to some certain problems associated with patch antenna design, future work may focus on bandwidth enhancement using complex slotting techniques, array configurations, or incorporation of metamaterials to further improve all the performances.

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