Design and Analysis of Symmetrical Twin-Void Microstrip Patch Antenna for 2.4 GHz IoT Sensor Node and Smart Home Applications

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***Abstract*—This paper proposes a compact symmetrical twin-void microstrip patch antenna for 2.4 GHz IoT applications. The antenna is developed using CST Studio Suite with overall dimensions of 76 mm × 59 mm × 5 mm and a patch size of 37 mm × 25mm × 0.035 mm. Asymmetrical twin voids (9 mm × 0.74 mm, k = 5.62) are incorporated to modify surface current behavior and improve electromagnetic characteristics. The simulated results show good return loss, a stable directional radiation pattern, and a peak gain of about 6.88 dBi, making it suitable for compact, low-power wireless communication devices.**

***Index Terms*—Microstrip Patch Antenna, Asymmetrical Void, CST, Return Loss, Gain, Radiation Pattern, WLAN**

I. INTRODUCTION

With the development of wireless communication technologies, the need to design compact, efficient, and high-performance antenna systems is increasing. In today's communication scenario, antennas are playing a vital role in determining the overall efficiency of the system, especially in high frequency communication systems. Due to the increasing demand for compact wireless devices, microstrip antennas have gained significant importance because of their simple structure and ease of integration.

However, conventional designs suffer from limitations including narrow bandwidth and relatively low gain. These disadvantages restrict their direct application in high frequency communication systems. To overcome these disadvantages, various design modifications are proposed, such as slot loading, defected ground structure, and geometrical changes to the radiating patch.

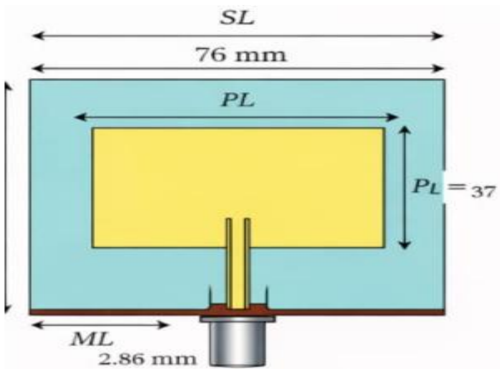
In the current work, the design and analysis of an asymmetrical twin -void microstrip patch antenna have been performed. The antenna design has been performed by using a simulation tool called CST studio suite. The antenna is designed with optimized geometrical dimensions of 25 mm x 37 mm. The antenna is designed with multiple voids in the structure of the microstrip patch antenna for improving the performance of the antenna. The microstrip line is used for feeding the antenna.

It can be anticipated that the new design will exhibit good radiation properties while maintaining the same structural simplicity and size. The performance analysis of the newly designed antenna includes the study of its radiation properties, antenna gain, and far-field radiation patterns. It is found that the inclusion of symmetrical slots in the design of the antenna has a significant influence on the electromagnetic behaviour of the antenna.

II. ANTENNA METHODOLOGY

The proposed antenna structure is based on a rectangular microstrip patch of dimensions 25 mm × 37 mm × 0.035 mm, integrated with asymmetrical voids to modify the surface current distribution and enhance radiation performance. The inner void has dimensions of 9 mm × 0.74 mm, which enhances bandwidth and overall antenna efficiency.

The antenna design is developed in a step-by-step manner to understand the effect of structural modifications on its performance. Initially, a simple rectangular microstrip patch antenna with a full ground plane is considered as the basic model. In the next stage, a rectangular slot is introduced into the patch to slightly alter the current distribution. Further, an additional rectangular cut is incorporated to form a modified patch structure, which helps in improving the antenna characteristics. Finally, the complete design is modeled and analyzed using CST Studio Suite to evaluate its performance.



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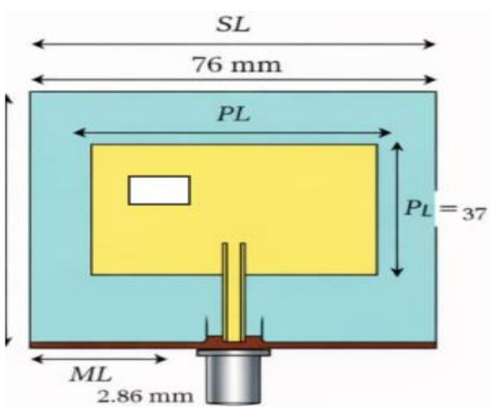

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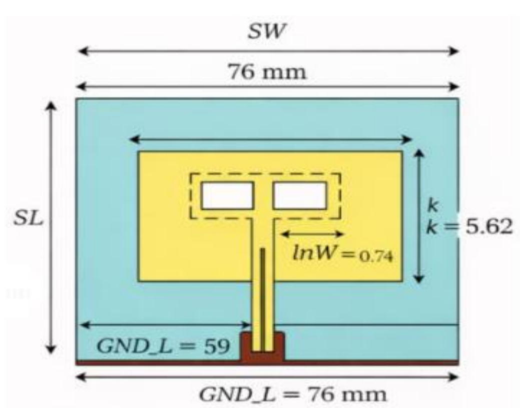

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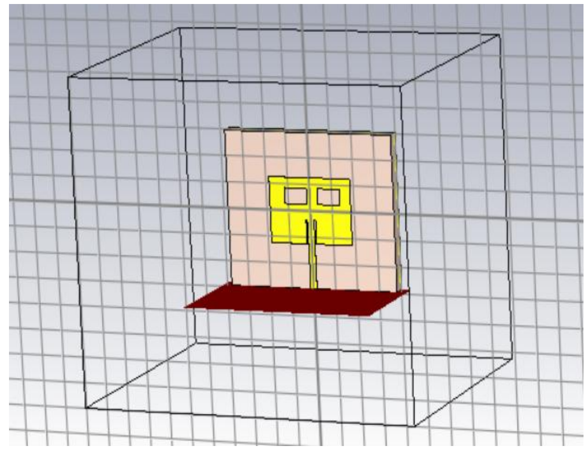


(d)

Fig 1. (a), (b), (c), (d): Symmetrical twin-void microstrip patch antenna and its evolution

A. Antenna Geometry Configuration

The geometry of the proposed antenna is carefully designed using a rectangular radiating patch embedded with symmetrical voids to alter current flow and enhance radiation efficiency. These voids are not placed uniformly, which helps in changing the path of current flow across the surface. Because of this, the antenna is able to radiate more effectively. The overall structure is designed carefully so that it supports stable operation and gives the required performance at the intended frequency.

B. Substrate Material Selection

An FR4 epoxy substrate (εr ≈ 4.4) is used in the proposed antenna design due to its low cost and suitable dielectric properties. It helps maintain a compact structure while ensuring stable performance at the operating frequency. The substrate thickness is carefully chosen to balance antenna performance and mechanical strength.

C. Feeding Technique Design

To supply energy to the antenna, a microstrip line feed is used. This method is simple and easy to implement, especially when compared to other feeding techniques. The dimensions of the feed line are adjusted carefully so that the signal is transferred efficiently from the source to the patch. Proper positioning of the feed ensures that reflections are minimized and most of the input power is radiated.

D. Patch Shape Optimization
Instead of using a plain rectangular patch, this design includes small voids within the patch. These voids help in controlling how the current spreads across the surface. As a result, the antenna shows improved radiation characteristics. The presence of these cuts also helps in reducing sudden changes in impedance, which leads to better matching and stable performance.

E. Ground Plane Configuration
The ground plane is placed below the substrate and acts as a reference layer for the antenna. In this design, the size of the ground plane is chosen carefully so that it supports proper radiation. A partial ground structure is used, which helps in improving the overall performance, especially in terms of impedance matching. It also reduces unwanted radiation in the backward direction.

F. Thickness and Conductive Material Considerations
. The conducting parts of the antenna, such as the patch and feed line, are made using copper. Copper is selected because it allows current to flow easily with very little loss. The thickness of the metal layer is kept small, but sufficient enough to maintain good conductivity. The combination of substrate thickness and metal layer plays an important role in deciding how efficiently the antenna works.

G. Simulation and Parameter Optimization
Different values for dimensions such as patch length, width, and void size are tested one by one. By observing the results, the parameters are adjusted until the desired performance is achieved. This step-by-step process helps in improving the antenna characteristics like gain and return loss.

H. Design Objectives and Performance Targets
The main aim of this design is to develop an antenna that performs well while keeping the size small. The antenna should be able to radiate efficiently with minimum loss. It is also expected to maintain stable performance with acceptable gain and proper impedance matching. These targets guide the selection of dimensions.
The structure consists of three layers: a ground plane at the bottom, a dielectric substrate in the middle, and a copper patch with a feed line on top. Each part of the antenna is designed carefully to ensure proper operation.
These voids modify the surface current distribution and help in reducing impedance mismatches across the patch. As a result, the antenna is able to achieve better radiation characteristics compared to a standard rectangular design. A partial ground plane is used to support stable radiation and enhance impedance matching. Important dimensions such as patch length (25 mm) and width (37 mm) are carefully adjusted. The final design shows proper resonance with return loss below −10 dB and delivers consistent performance suitable for high-frequency communication systems.
In this design, the inclusion of non-uniform voids within the patch helps in controlling the flow of current more effectively, which directly improves the radiation behaviour of the antenna. The structure, along with a partial ground plane, ensures better impedance characteristics and stable operation. By fine-tuning the geometric parameters through simulation in CST Studio Suite, the antenna is made to resonate at the desired frequency. The optimized dimensions enable the antenna to maintain acceptable return loss values and provide a steady radiation pattern with moderate gain.

Name	Expression	Description
PL	25	Patch Length
PW	37	Patch Width
SL	59	Substrate Length
SW	76	Substrate Width
SH	5	Substrate Height
Mt	0.035	Metal Thickness (Patch & Ground)
ML	17	Feed Line Length
MW	2.86	Feed Line Width
lnL	9	Inner Void Length
lnW	0.74	Inner Void Width
k	5.62	Shape Factor (Void Geometry Control)
GND_L	59	Ground Length
GND_W	76	Ground Width

Table 1: Antenna parameters

III. RESULT AND DISCUSSION

Design and analysis of the proposed symmetric dual void microstrip patch antenna were conducted by means of CST Studio Suite in order to assess its performance at the desired frequency band, which is 2.4 GHz. Characteristics of the antenna were assessed through essential parameters like return loss (S11), VSWR, Surface Current Distribution, and Radiation Patterns.

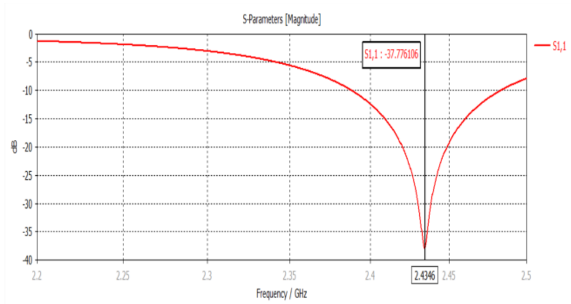


Fig 2: Simulated return loss (S11) of the twin void antenna

According to the simulated S11 (return loss) values, the frequency at which the antenna operates is 2.4346 GHz. The frequency falls within the 2.4 GHz ISM band. The antenna has a minimum return loss of −37.77 dB at this resonant frequency. This value is way below the acceptable limit of −10 dB. This implies effective impedance matching between the feed line and the radiating patch.

The improved impedance matching is mainly due to the introduction of asymmetrical voids in the patch structure. These voids modify the surface current path and reduce impedance discontinuities, resulting in enhanced electromagnetic performance compared to a conventional rectangular microstrip patch antenna.

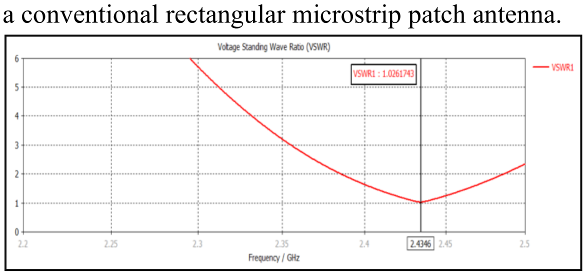


Fig 3: VSWR of the twin void antenna

Moreover, the VSWR behavior also supports the performance of the antenna. It is observed that the simulated VSWR value at the resonance point is 1.026, which is nearly equal to one. It signifies that power can be effectively transferred from the feed line to the antenna. Also, the increasing trend of VSWR with distance from the resonance point shows that the antenna is correctly adjusted for operating frequencies.

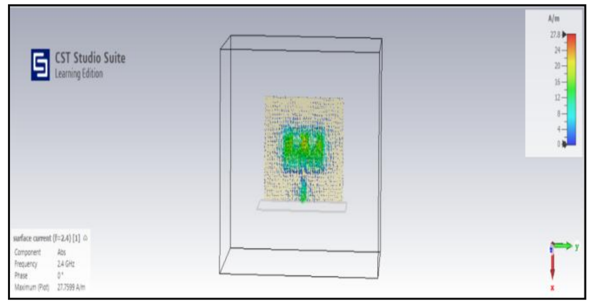
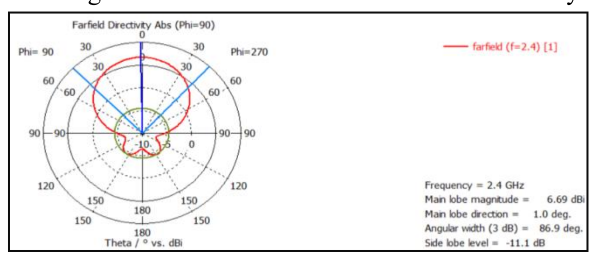
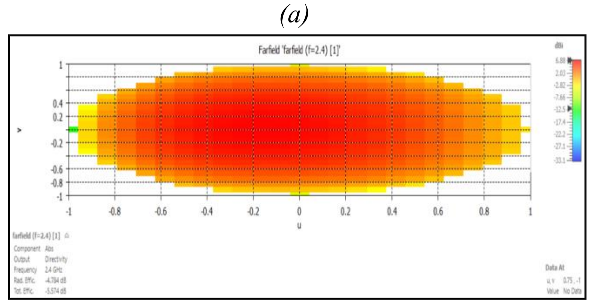


Fig 4: Surface Current Distribution of the twin void antenna

The current distribution on the surface helps in understanding the antenna's radiating characteristics. From the simulation output, it can be seen that the current is mainly distributed at the patch edges and the areas with voids, with the peak value being about 27.8 A/m. The inclusion of voids leads to an optimal distribution of current, resulting in improved radiating efficiency.



(a)



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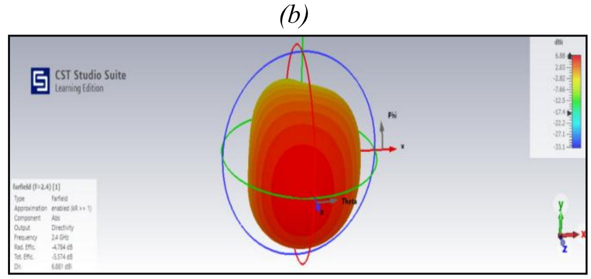

(c)

Fig 5: (a) 1D plot (b) 2D plot (c) 3D plot

Radiation patterns in one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) planes are employed to study the radiation properties of the far-field region. It can be seen that the radiation of the antenna is highly directional, and the peak value of the main lobe is about 6.69 dBi at a broadside angle position. In addition, the beamwidth 3 dB corresponds to 86.9°, and the side lobe level is about -11.1 dB.

In 2D radiation analysis, it can be seen that the radiation efficiency and overall efficiency of the antenna are −4.784 dB and −5.574 dB, respectively. This means that there is some loss due to dielectrics and conductors but there is no loss regarding stability in radiation. In the 3D radiation analysis, it is seen that the gain is about 6.88 dBi.

Reference	Gain (dBi)	S11(dB)	VSWR	Patch Type
[4]	5.8	-28.5	1.08	Rectangular
[5]	5.2	-22.3	1.16	Slot-loaded
[8]	6.2	-30.1	1.05	High-gain patch
[12]	5.5	-26.7	1.10	Multiband patch
Proposed Work	6.88	-37.77	1.026	Symmetrical Multi-void

Table 2: Comparison of the twin void Antenna with Reference Designs

From the above table, it can be clearly seen that the suggested antenna provides superior performance for all critical parameters like S11, VSWR, and gain compared to existing antennas. From the comparison table, it can be seen that the suggested antenna offers an extremely low S11 value. The VSWR value is very close to unity, which confirms efficient power transmission between the feed and the radiating structure. In addition, the proposed design exhibits higher gain compared to most of the referenced antennas, resulting in improved radiation efficiency and signal strength. These enhancements are mainly due to the introduction of symmetrical multi-void structures, which effectively modify the surface current distribution and optimize the overall antenna performance.

On the whole, the suggested antenna offers an optimal compromise among compactness, simplicity, and electromagnetic functionality. Therefore, this antenna can be used in real wireless communication systems like WLAN, Bluetooth, and IoT at the 2.4 GHz frequency band.

IV. CONCLUSION

The symmetrical twin-void microstrip patch antenna design has been accomplished effectively for the application in the 2.4 GHz Industrial, Scientific and Medical (ISM) band. This antenna demonstrates good impedance matching with its S11 parameter value of −37.77 dB at a frequency of 2.4346 GHz with a VSWR ratio near unity. Moreover, it possesses a stable directional radiation pattern with a maximum gain of 6.88 dBi.

The incorporation of asymmetrical voids improves surface current distribution and enhances overall antenna performance. The compact design and reliable characteristics make the antenna suitable for WLAN, Bluetooth, and IoT applications. Future work can focus on fabrication and further performance optimization.

REFERENCE

[1] P. Laxman et al., “Design of microstrip patch antenna for 5G applications,” J. Electron. Autom. Eng., vol. 4, no. 2, pp. xx–xx, Jun. 2025.
[2] S. I. Farghaly et al., “High-performance microstrip patch antenna with MIMO configuration for 5G and IoT applications,” EURASIP J. Wireless Commun. Netw., 2025.
[3] M. K. ElAbbasi, “Optimizing microstrip patch antenna performance using computational techniques,” Results in Engineering, 2025.
[4] M. Karahan, “Wideband and high-efficiency 2.4 GHz microstrip patch antenna for wireless communication,” Recent Adv. Electr. Electron. Eng., 2026.
[5] J. J. Tiang et al., “Novel microstrip patch antenna design for mmWave communication systems,” Frontiers in Materials, vol. 11, 2024.
[6] A. Ait Lahcen et al., “Enhanced wideband circularly polarized microstrip antenna design,” ITM Web Conf., 2024.
[7] M. Asfar Saeed et al., “Rectangular microstrip patch antenna array for 5G communication,” in Proc. IEEE Int. Conf. Commun., 2024.
[8] N. M. Sayem et al., “Development of high-gain microstrip patch antennas for 6G applications,” Prog. Electromagn. Res. C, vol. 137, 2023.
[9] M. Karahan et al., “Microstrip patch antenna design for X-band applications,” 2023.

[10] B. A. Nel et al., "Radiation efficiency and gain analysis of microstrip patch antennas," 2024.
[11] L. Chang and H. Liu, "Low-profile dual-band microstrip antenna for 5G mobile terminals," IEEE Trans. Antennas Propag., vol. 70, no. 3, 2022.
[12] S. P. Lavadiya et al., "Multiband microstrip patch antenna for wireless communication systems," Int. J. Commun. Syst., vol. 35, no. 9, 2022.
[13] A. Bekasiewicz and S. Koziel, "Efficient design optimization of antenna structures," Eng. Optim., vol. 50, no. 2, 2023.
[14] Y. Elias et al., "Gain optimization of low-profile antennas for wireless systems," IEEE Access, vol. 9, 2023.
[15] C. A. Balanis, Antenna Theory: Analysis and Design, 4th ed. Hoboken, NJ, USA: Wiley, 2023.