IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Gain And Bandwidth Enhancement Of Hybrid Shaped Microstrip Patch Antenna Using High Frequency Structure Simulator

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ABSTRACT

This paper presents the design and simulation of a hybrid-shaped microstrip patch antenna (MPA) that combines the benefits of U-shaped cutouts and a hexagonal shape to achieve enhanced gain and bandwidth at 2.45 GHz. The antenna is designed by incorporating U-shaped cutouts within a hexagonal structure to improve its performance compared to conventional U-shaped and hexagonal antennas.

The antenna was designed and simulated on an FR4 substrate with a dielectric constant of 4.4 and a thickness of 1.6 mm. The design and simulations were carried out using High-Frequency Structure Simulator (HFSS). The simulation results indicate that the hybrid-shaped antenna achieved a gain of 5.4 dB and a bandwidth of 1.96 GHz, which are improved values relative to the individual designs. These enhanced characteristics make the antenna well-suited for wireless communication applications such as Wi-Fi, Bluetooth, and Zigbee. The combination of higher gain and wider bandwidth highlights the potential of the proposed antenna for integration into modern wireless systems.

Keywords: Analysis System High-frequency structure simulator (ANSYS HFSS), Hybrid-shape antenna, U-cut, hexagon patch, FR4 board, 2.45 GHz, HFSS, signal gain, frequency range, wireless use, Wi-Fi, Bluetooth, Zigbee.

1.0 INTRODUCTION

Microstrip patch antennas (MPAs) play a crucial role in present-day wireless technologies because of their compact design, minimal weight, ease of construction, and cost-effectiveness. These characteristics make them suitable for a wide range of applications such as wireless communication networks, asset tracking, mobile devices, and positioning systems. This work presents a uniquely structured patch antenna that blends a hexagonal geometry with U-shaped cuts to improve its performance. FR4 epoxy is used as the substrate material, featuring a dielectric constant of 4.4 and a thickness of 1.6 mm. The design was validated through simulations carried out in ANSYS HFSS at 2.45 GHz. Results show that the antenna offers enhanced gain and broader bandwidth. A 50-ohm feed line is employed to maintain impedance matching, making the design suitable for technologies like Wi-Fi, Bluetooth and Zigbee.

1.1 OBJECTIVES

The key objectives of this study are listed below:

- To design a hybrid-shaped microstrip patch antenna by combining U-shaped cutouts with a hexagonal patch to operate at 2.45 GHz.
- To simulate the antenna using HFSS and evaluate its performance in terms of gain, bandwidth, return loss, and VSWR.
- To compare the results of the hybrid design with conventional U-shaped and hexagonal antennas and show improvements in bandwidth and gain.

1.2 NECESSITY OF THE DESIGN

With the increasing demand for compact and high-performance antennas in modern wireless communication systems such as Wi-Fi, Bluetooth, and Zigbee. There is a growing need for antennas that can provide higher gain and broader bandwidth while maintaining a compact structure. Traditional microstrip patch antennas, including U-shaped and hexagonal geometries, often suffer from limited bandwidth and moderate gain, making them less effective in high-data-rate or short-range communication environments.

To address the limitations of conventional patch antennas, this work introduces a novel hybrid structure that integrates U-shaped slots into a hexagonal patch layout. This modified geometry is intended to enhance the antenna's performance. This unique structure helps:

- Increase the operational bandwidth to cover more communication channels.
- Improve gain, allowing stronger signal transmission and reception.

The antenna operates at 2.45 GHz (ISM band) and is implemented using a low-cost FR4 epoxy substrate (εr = 4.4, thickness = 1.6 mm), making the design suitable for mass production and integration in portable wireless devices.

Thus, this design is necessary to meet the performance demands of modern communication systems by offering a compact, cost-effective, and efficient antenna solution.

Software Requirements

The antenna design and simulation are performed using ANSYS High Frequency Structure Simulator (HFSS), a widely used three-dimensional electromagnetic simulation tool. HFSS is particularly effective for analyzing high-frequency components such as microstrip antennas and antenna arrays. It is commonly applied in fields like wireless communications, Internet of Things (IoT), radar systems, and satellite communication. The software offers reliable and precise solutions to complex 3D electromagnetic problems. It allows for the visualization and evaluation of antenna characteristics through both 2D and 3D models, facilitating accurate analysis of parameters such as gain, bandwidth, and return loss.

1.3 DESIGN METHODOLOGY

1.3.1 Feeding Technique

Feeding is the essential method used to link transmitting and receiving antennas, enabling the transfer of information between them. Since antennas operate at radio frequencies, the feed mechanism works within the same frequency range. These radio frequency signals serve as the medium for communication.

1.3.2 Microstrip Line Feed Technique

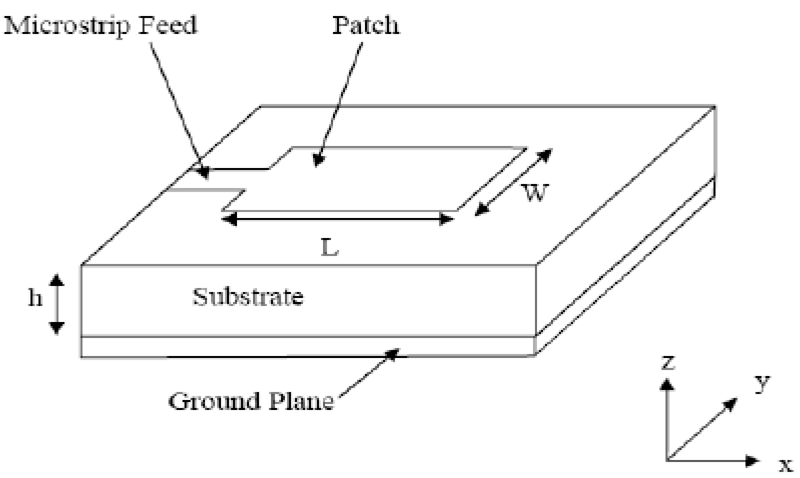

Fig. 1. Microstrip patch antenna using microstrip line feed technique. [1]

The microstrip line feed technique is a commonly used method for supplying power to microstrip patch antennas due to its simplicity and ease of integration. In this approach, a narrow conductive strip is printed on the same layer as the patch and substrate, directly connecting to the radiating element. This technique supports a low-profile design and is compatible with standard printed circuit board (PCB) fabrication processes, making it suitable for compact and cost-effective antenna systems. In this project, the microstrip line feed method was selected to excite the hybrid-shaped antenna combining U-shaped cut-outs and a hexagonal patch. The feed was carefully designed and positioned to ensure efficient signal transmission and good impedance matching. This helped achieve the desired performance improvements in terms of gain and bandwidth, specifically at the 2.45 GHz frequency used in wireless applications such as Wi-Fi, Bluetooth, and Zigbee.

1.3.3 Design Equations of Patch Antenna

The designed microstrip patch antenna operates at a resonant frequency of 2.45 GHz, using FR4 epoxy as the substrate, which has a dielectric constant (ε_r) of 4.4 and a thickness of 1.6 mm.

The width of the rectangular MSA is given by:

$$W = \frac{C}{2f_r \frac{\sqrt{(\varepsilon_r+1)}}{2}}$$

where, C is the speed of light, is the resonant frequency, and $\boldsymbol{\varepsilon_r}$ is the Relative dielectric constant of the substrate. The value of c =$3 \times 10^8 m/s$, f =2.45GHz and $\boldsymbol{\varepsilon_r}$=4.4

The effective dielectric constant is given by:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + \frac{12h}{w}]^{-0.5}$$

Here, h is the height of the substrate i.e. FR-4 Epoxy material, ε_r is the dielectric constant of the substrate.

The effective length is calculated by:

$$L_{eff} = \frac{C}{2f_{r\sqrt{\varepsilon_{eff}}}}$$

The difference in length, which is a function of the effective dielectric constant and ratio of width to height is given as:

$$\Delta L = 0.412h \frac{(\varepsilon_{eff} + 0.3)(\frac{w}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{w}{h} + 0.8)}$$

Finally, the actual length of the patch which is given as:

$$L = L_{eff} - 2\Delta L$$

The Length of the substrate or Length of the ground is given as:

$$L_G = 6h + L$$

The Width of the substrate or Width of the ground is given as:

$$W_G = 6h + W$$

TABLE 1: DIMENSIONS OF SIMULATED ANTENNA

Name of the parameters	Length (mm)
Length of Substrate	40mm
Width of Substrate	50mm
Width of Left Vertical Rectangle	1mm
Length of Left Vertical Rectangle	10mm
Width of Right Vertical Rectangle	1mm
Length of Right Vertical Rectangle	10mm
Width of Horizontal Rectangle	10mm
Length of Horizontal Rectangle	1mm
Height of Substrate	1.6mm
Length of Feedline	2mm
Width of Feedline	0.5mm
Width of Ground	50mm
Length of Ground	40mm

1.4 RESULTS AND DISCUSSION

1.4.1 Antenna Simulation

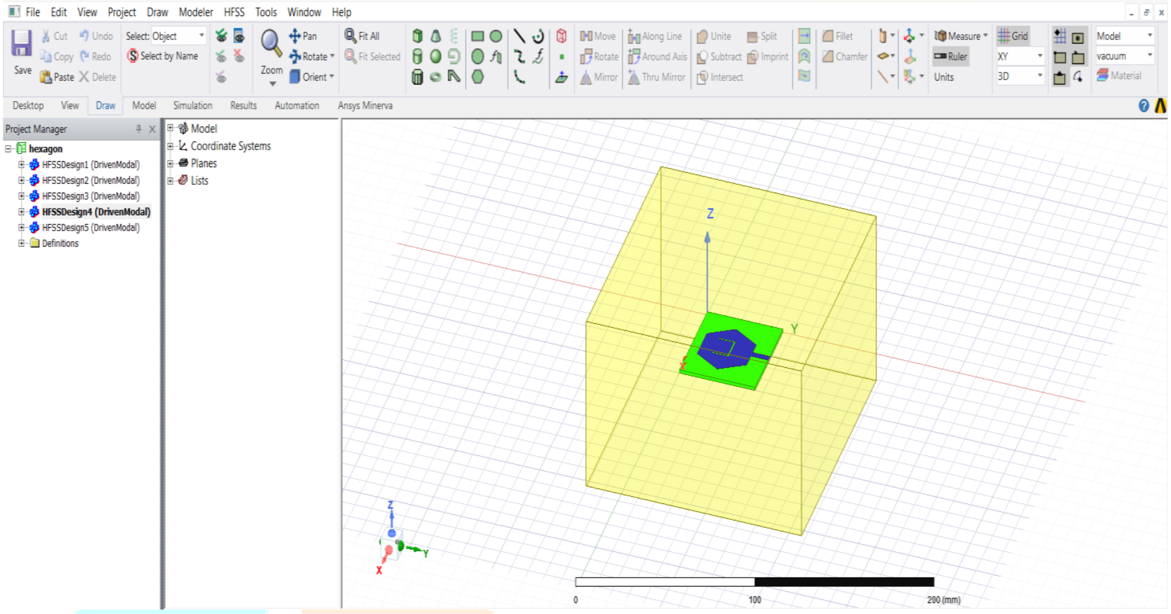

Fig.2 Design of the Antenna

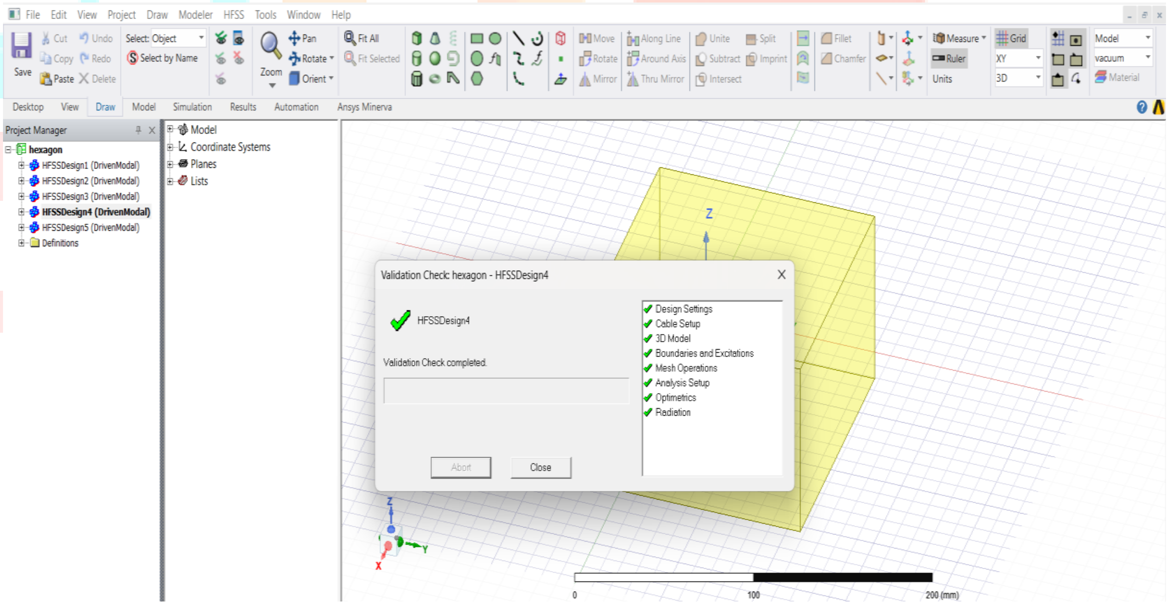

Fig. 3 Validation Check of the Antenna

1.5 SIMULATION RESULTS

1.5.1 Scattering Parameters

S-parameters, or scattering parameters, are commonly used to analyze how an electrical system such as an antenna or a component network responds across a range of frequencies. Among these, parameters like S11, S12, S21, and S22 help describe how signals are transmitted and reflected within the system. Specifically, the S11 parameter is essential for evaluating antenna performance, as it indicates the proportion of the input signal that is reflected back due to impedance mismatch. A well-designed antenna will have a significantly negative S11 value, indicating minimal reflection and better impedance matching. Although achieving an infinitely negative S11 is theoretically ideal, it is not possible in practical implementations. Therefore, designs aim for an S11 value that is as low (negative) as feasible.

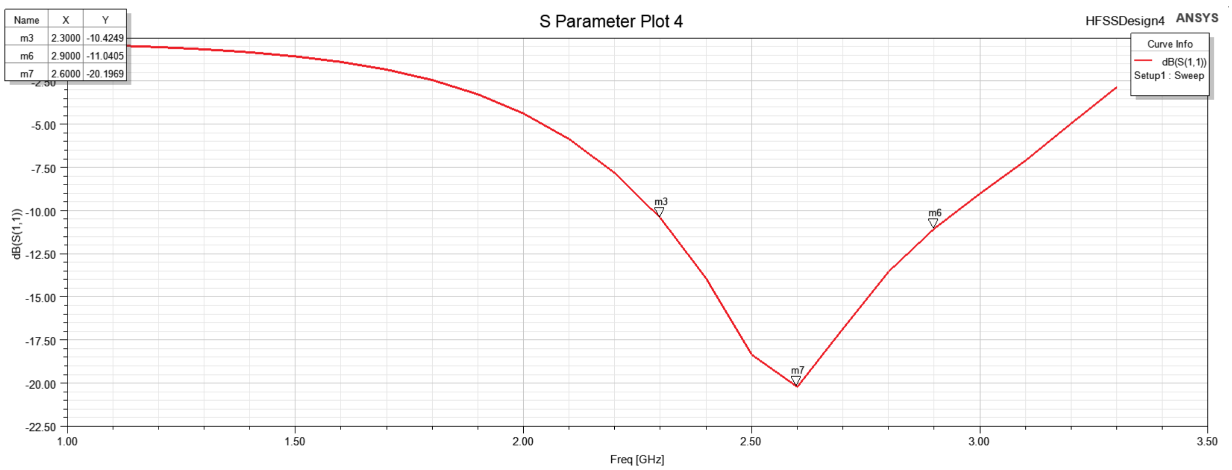

Fig.4 Output of the Antenna S Parameter

1.5.2. Bandwidth

Bandwidth refers to the range of frequencies over which the antenna operates effectively with minimal reflection. It is typically measured between the points where the return loss (S11) falls below –10 dB.

$$\text{Bandwidth} = 2.900\ \text{GHz} - 2.300\ \text{GHz} = 600\ \text{MHz}$$

1.5.3. Gain Plot

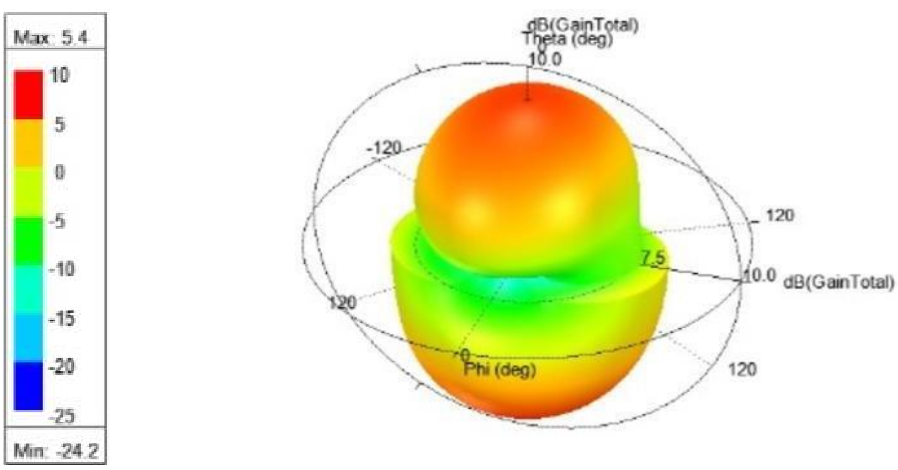

Fig.5 Output of the Antenna Gain plot

A gain plot represents how effectively an antenna transmits or receives signals across various frequencies. It illustrates the variation in signal strength, indicating amplification or reduction at specific frequency points.

1.6 CONCLUSION

This study introduced a hybrid-shaped microstrip patch antenna that combines U-shaped slots within a hexagonal patch to enhance its electromagnetic performance. The antenna was developed on an FR4 substrate featuring a relative permittivity of 4.4 and a thickness of 1.6 mm, and the design was evaluated through simulations using ANSYS HFSS. The results demonstrate that the proposed structure achieves a peak gain of 5.4 dB and supports a wide operational bandwidth of 1.96 GHz. The return loss plot indicates strong impedance matching at multiple resonant frequencies, specifically around 2.4 GHz, 3.5 GHz, and 5.8 GHz, aligning with widely used communication bands such as Wi-Fi, WiMAX, and ISM. The gain pattern further confirms that the antenna delivers directional radiation with minimal energy loss in undesired directions, making it ideal for applications that demand focused signal propagation.

The combination of improved gain, extended bandwidth, and multi-frequency operation confirms the effectiveness of the proposed hybrid configuration for use in contemporary wireless communication systems including Wi-Fi, Bluetooth, Zigbee, and IoT networks.

ACKNOWLEDGEMENT

The authors would like to sincerely thank **Sk. Khaja Mohiddin** for his valuable contributions, consistent support, and active involvement throughout the course of this project. His dedication and teamwork greatly enhanced the quality and outcome of this work.

REFERENCES

[1] Balanis, C. A. (1997). *Antenna theory: Analysis and design* (2nd ed.). Wiley.

[2] Pathak, S., & Singh, S. K. (2021). Comparative study of microstrip patch antenna with different shapes and its applications. *International Research Journal of Engineering and Technology (IRJET)*, 8(6), 3028–3032.

[3] Rashmitha, R., & Reddy, P. (2020). Microstrip patch antenna design for fixed mobile and satellite 5G communications. *Procedia Computer Science*, 171, 2073–2079.

[4] Bathula, L. N., & Bhavanam, S. N. (2015). Design and simulation of triple frequency triangular patch antenna using HFSS 14.0. *International Journal of Applied Engineering Research*, 10(20), 18585–18588.

[5] Prakasam, V., & Reddy, N. (2021). Hexagonal shaped micro-strip patch antenna design for 2.45 GHz WLAN system. In *Proceedings of the 2021 6th International Conference on Inventive Computation Technologies (ICICT)* (pp. 13–18). IEEE.

[6] Niharika, M. S. A., & Sreenivasulu, G. (2020). A novel hexagonal microstrip antenna for UWB applications. *International Journal of Engineering Research & Technology (IJERT)*, 8(12), 394–399.

[7] Ovsenik, L., Turán, J., Urbanský, J., & Wachta, H. (2019). Comparison of microstrip patch antennas operated on 2.45 GHz. *Acta Electrotechnica et Informatica*, 19(4).

[8] Verma, S. S., Kumar, A., & Agrawal, N. (2023). Design and performance analysis of a rectangular microstrip patch antenna for wireless communication at 2.4 GHz. *International Journal on Recent and Innovation Trends in Computing and Communication*, 11(7s).

[9] Singh, V. K., & Ali, Z. (2010). Dual band U-shaped microstrip antenna for wireless communication. *International Journal of Engineering Science and Technology*, 2(6), 1370–1373.