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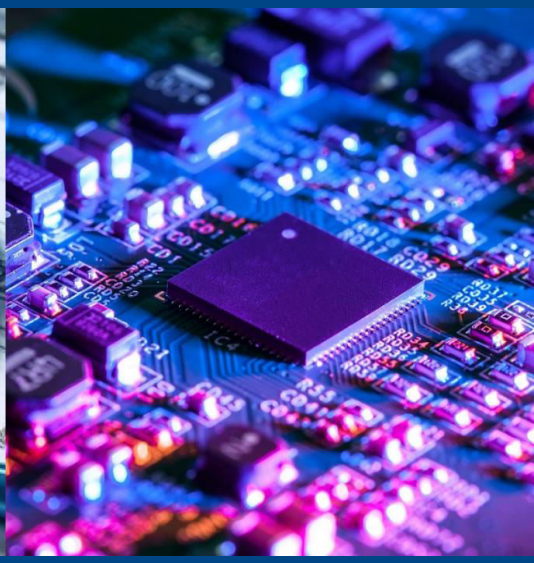

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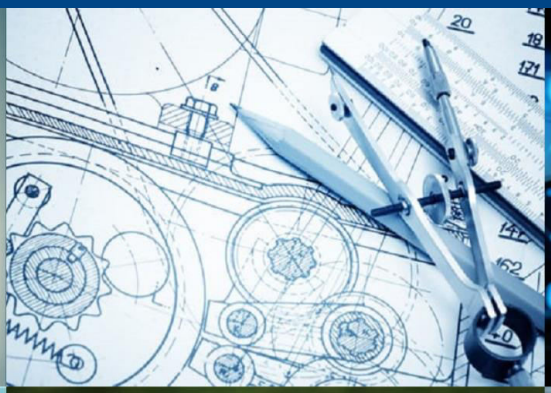

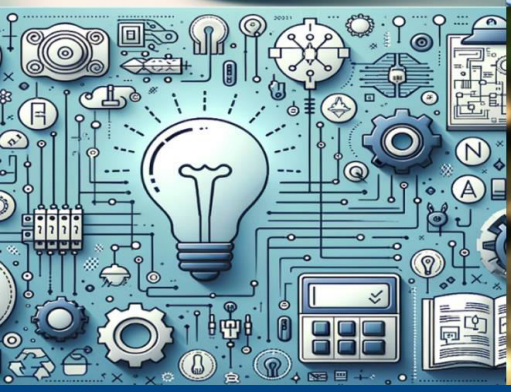

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Optimized MIMO Antenna for IoT Connectivity

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ABSTRACT: The rapid expansion of wireless communication and Internet of Things (IoT) applications necessitates high-performance, compact, and efficient antenna systems. This project focuses on the design and implementation of an IoT-enabled 2×2 MIMO (Multiple-Input Multiple-Output) microstrip patch antenna, optimized for enhanced signal transmission, high gain, and low interference. The proposed antenna is designed to operate in the required frequency band while maintaining an optimal Voltage Standing Wave Ratio (VSWR), S-parameters (S11, S12, S21), and isolation between elements to ensure superior performance. To validate the antenna's efficiency, simulations are conducted using HFSS or CST Studio, followed by real-time measurements using a Vector Network Analyzer (VNA) after fabrication. The integration of IoT capabilities ensures seamless connectivity, making the antenna suitable for various smart applications such as 5G, LoRa, Wi-Fi-based IoT networks, and industrial automation. The project aims to contribute to the development of reliable, high-gain, and scalable antennas that support next-generation communication technologies.

KEYWORDS: IoT, MIMO Antenna, Microstrip Patch Antenna, S-Parameters, Gain, VSWR, Wireless Communication, Vector Network Analyzer (VNA).

I. INTRODUCTION

MIMO (Multiple-Input-Multiple-Output) technology plays a vital role in modern wireless communication by offering improved spectral efficiency, better reliability, and faster data rates. This project presents the design and analysis of an optimized 2×2 MIMO microstrip patch antenna, specifically developed to support a wide range of IoT applications such as V2X communication, smart healthcare, and industrial automation. The antenna system operates efficiently in the 2.30 GHz to 2.50 GHz band, which is widely used for short-range, low-power wireless communication.

The focus of this project is to achieve a compact, cost-effective antenna solution with moderate gain (~5.71 dB), improved impedance matching (S11 ~ -20 dB), and high isolation between ports. These factors are crucial for ensuring stable MIMO performance in dense environments. The design addresses challenges in achieving low envelope correlation and strong diversity performance within limited device form factors, making it ideal for deployment in portable and embedded IoT devices.

Key MIMO performance metrics, such as channel capacity and spatial diversity, are considered to validate the effectiveness of the antenna. The isolation between antenna elements, represented through S12 and related S-parameters, is optimized to minimize mutual coupling and enhance data throughput.

As the IoT ecosystem expands, seamless and efficient connectivity becomes essential. This proposed antenna is optimized for real-time data transfer, low latency, and energy efficiency, making it well-suited for the next generation of smart devices and wireless sensor networks.

II. ANTENNA DESIGN

The structure and dimensions of the proposed antenna array are shown in Figure 1. As observed, the antenna system consists of a 2×2 MIMO microstrip patch configuration designed to operate efficiently within the frequency range of 2.30–2.50 GHz. Each patch element measures 29.4 mm × 38 mm, with edges smoothly cut using a 2.3 mm radius to

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improve radiation performance and impedance matching. All four antenna elements follow the same structural design to ensure uniform performance across the array.

The entire antenna structure is fabricated on an FR4 substrate with a thickness of 1.8 mm, having a relative permittivity of 4.4 and a loss tangent of 0.02. The overall size of the MIMO antenna is 120 mm × 120 mm, making it a compact and cost-effective solution suitable for wireless applications, especially in IoT-based systems requiring reliable and space-efficient antenna integration.

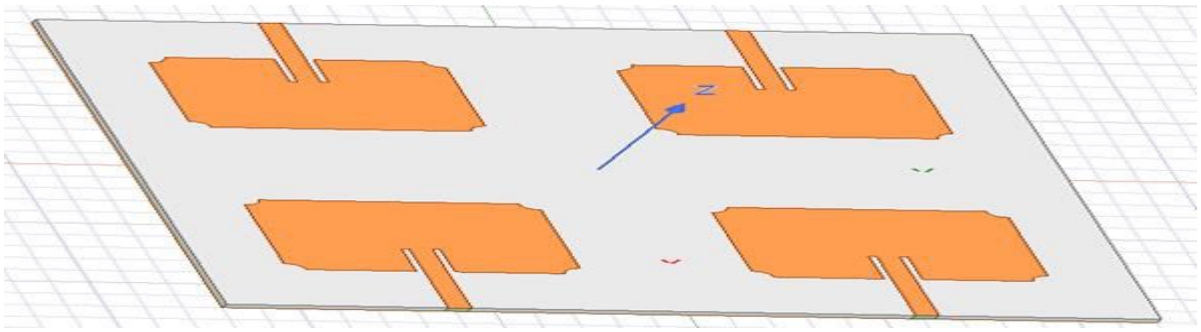

Figure 1: Proposed 2x2 MIMO Antenna

III. RESULTS AND DISCUSSION

The simulated results were obtained using ANSYS HFSS. Figure 2 illustrates the simulated S-parameters of the proposed 2×2 MIMO microstrip patch antenna. As shown, the reflection coefficients (S11, S22, S33, S44) are all below –17 dB throughout the operational frequency range of 2.30–2.50 GHz, indicating effective impedance matching for each antenna element. Figure 3 presents the transmission coefficients (S12, S13, S14, etc.), which are observed to be less than –25 dB, signifying low mutual coupling and good isolation between elements—crucial for MIMO performance and reduced interference.

Figure 4 displays the Voltage Standing Wave Ratio (VSWR) for each port, and all values remain below 2 within the target frequency band, confirming optimal power transfer and minimized reflection. Figure 5 shows the total radiation efficiency of each antenna element, which is measured to be nearly 60% across the operating band. This demonstrates effective radiation with minimal loss, suitable for wireless IoT communication. Due to the symmetric layout of the antenna elements on the 120 mm × 120 mm FR4 substrate (with a thickness of 1.8 mm), similar performance is observed between diagonally placed patches. This layout ensures balanced response, enhanced spatial diversity, and reduced envelope correlation coefficient (ECC), making it ideal for IoT applications requiring compact, efficient, and reliable MIMO antennas.

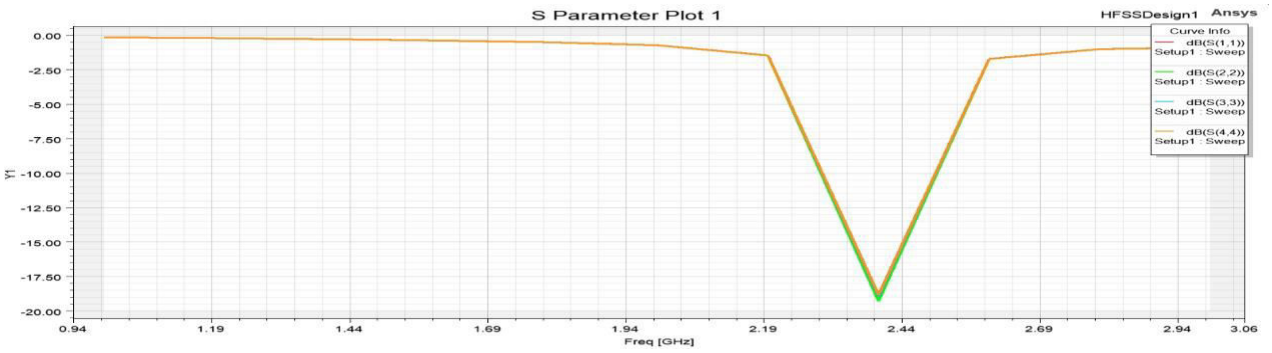

Figure 2: Reflection coefficient 2x2 MIMO antenna

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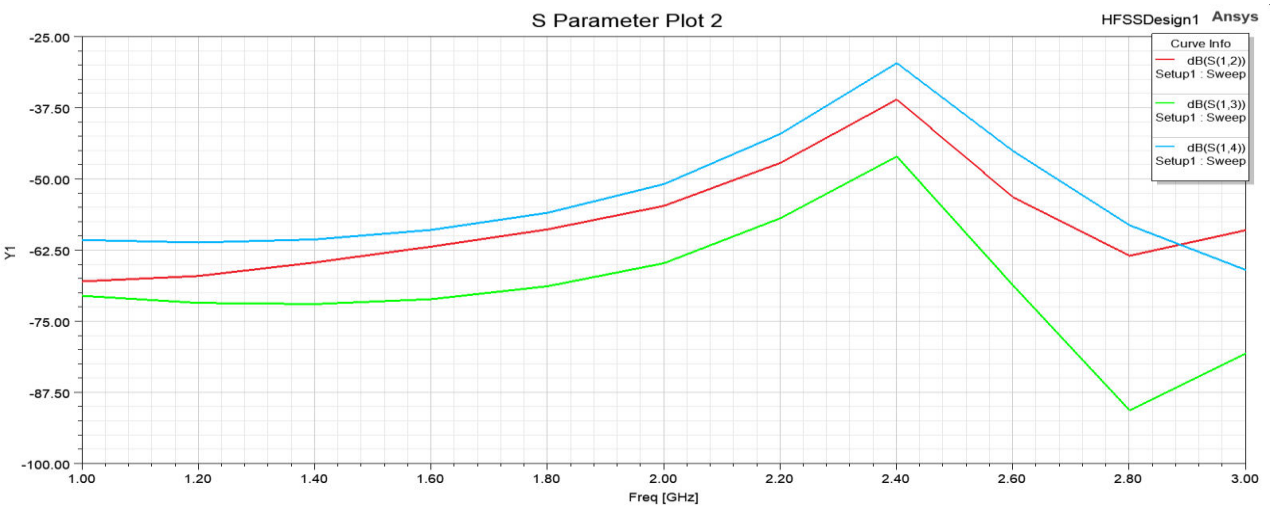

Figure 3: Transmission Coefficient of 2x2 MIMO antenna

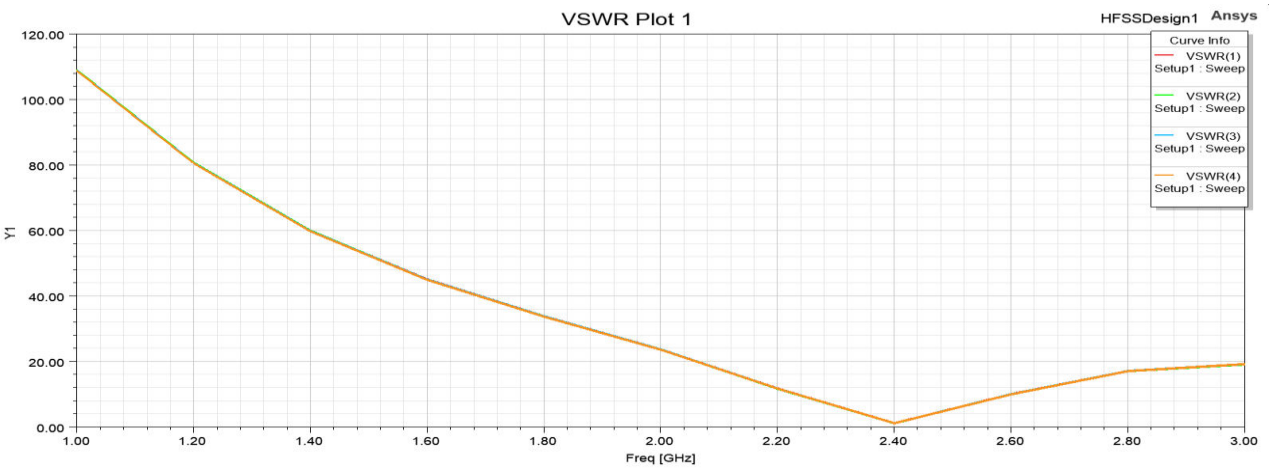

Figure 4: VSWR of 2x2 MIMO antenna

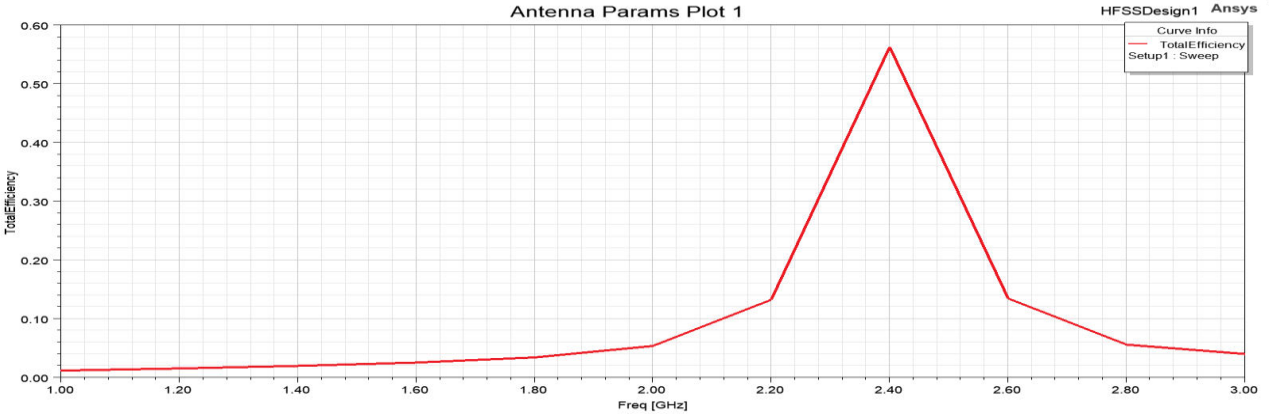

Figure 5: Efficiency of 2x2 MIMO antenna

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IV. MIMO ANTENNA PARAMETERS

Evaluation of MIMO antenna performance involves assessing various parameters such as ECC (Envelope Correlation Coefficient), DG (Diversity Gain). A lower correlation coefficient indicates better support for higher data rates. For practical purposes, an acceptable ECC value is typically less than 0.1. The ECC of the proposed antenna is calculated using the equation below as referenced in [6].

$$ECC_{(i,j,\ldots,N)} = \frac{\left|\sum_{n=1}^{N} S_{i,n}^{*} S_{n,j}\right|^{2}}{\prod_{k=i,j}\left[1-\sum_{n=1}^{N} S_{k,n}^{*} S_{n,k}\right]}$$

where i and j are antennas 1 and 2, and N is the number of antennas. Figure 6 displays the ECC graph for the proposed MIMO antenna, indicating ECC values below 0.1 across all operating frequencies. The formula for calculating directivity gain (DG) using ECC is represented below. Figure 7 illustrates the diversity gain of the proposed MIMO antenna for operating frequencies, exhibiting a favourable value of around 10 dB.

$$DG = 10 \times \sqrt{1 - |ECC|}$$

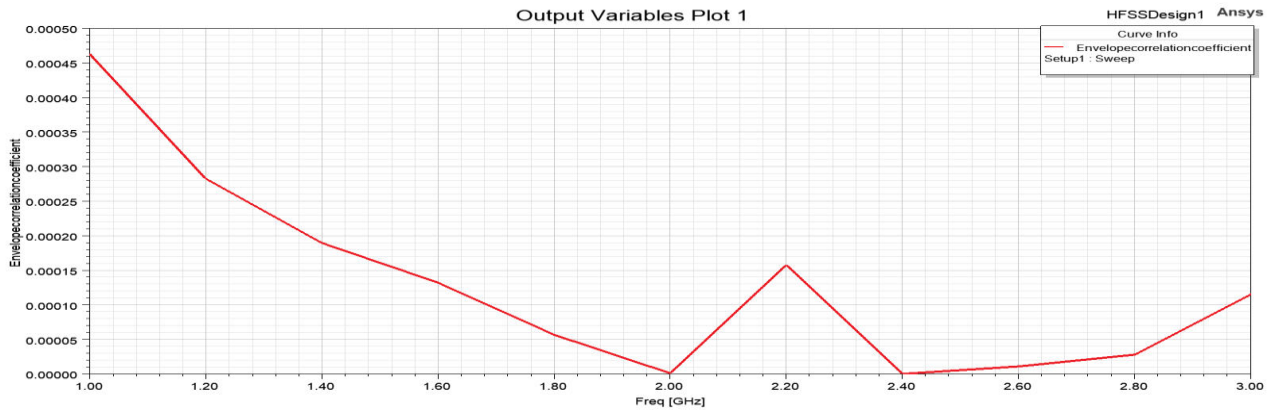

Figure 6: Envelope correlation coefficient of 2x2 MIMO antenna

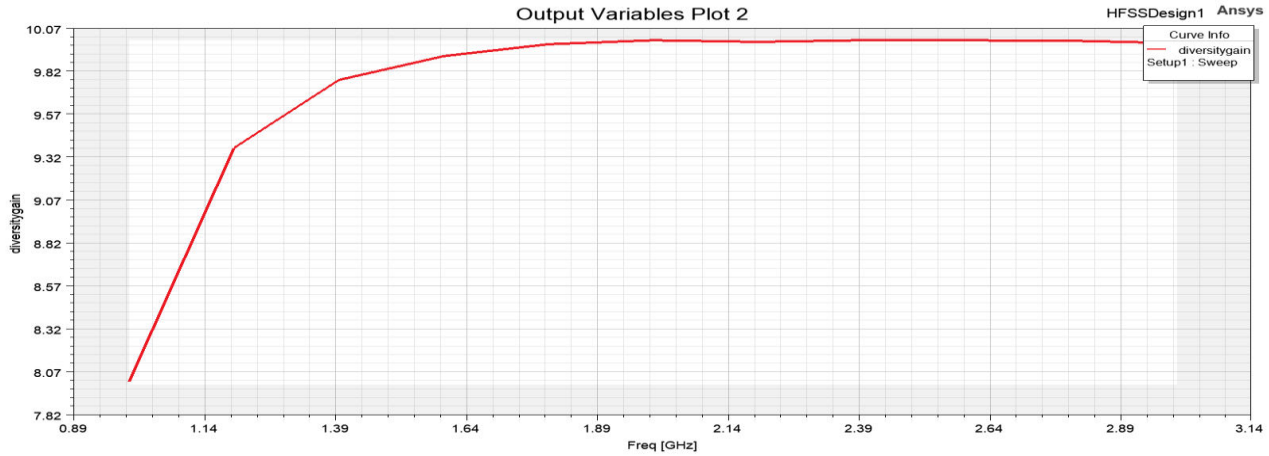

Figure 7: Diversity Gain of 2x2 MIMO antenna

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V. CONCLUSION

This paper presents a compact 2×2 MIMO microstrip patch antenna designed for IoT connectivity, operating in the 2.30–2.50 GHz frequency range. The antenna demonstrates a return loss (S11) of less than –17 dB and maintains an isolation better than 25 dB between elements, ensuring minimal mutual coupling. The performance analysis includes key diversity parameters, with Envelope Correlation Coefficient (ECC) values below 0.1 and a Diversity Gain (DG) close to 10 dB, indicating excellent MIMO capabilities. Due to its compact size, moderate gain of 5.71 dB, and reliable impedance characteristics, the proposed antenna serves as an efficient and cost-effective solution for IoT, V2X, and other wireless communication applications.

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