

Design of a Compact Two Element MIMO Antenna System with Improved Isolation frequency using Ansys HFSS

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Abstract- This project focuses on the optimal design and performance analysis of a 2×2 MIMO (Multiple Input Multiple Output) antenna system for wireless communication applications. The goal is to enhance signal quality, increase data rates, and improve spectral efficiency by addressing key design factors such as element spacing, orientation diversity, and radiation patterns. The project involves simulation and practical implementation to evaluate how MIMO antennas perform in real-world scenarios. Simulation tools are used to analyze antenna behavior, with emphasis on reducing multipath fading and boosting overall signal reliability. The optimized design ensures better channel capacity and stable communication in varying environments. Results show that the MIMO antenna system significantly enhances wireless performance, making it suitable for advanced technologies like 5G and IoT. This project contributes valuable insights toward the development of efficient and reliable MIMO antenna systems for next-generation wireless networks, highlighting their importance in meeting the demands of modern communication systems.

Key Words: MIMO Antenna, Wireless Communication, 2×2 Antenna Array, Spectral Efficiency, Multipath Fading, Channel Capacity, Antenna Optimization.

I. INTRODUCTION

Multiple-Input Multiple-Output (MIMO) antenna technology has become a key enabler in modern wireless communication systems, offering improved data rates, spectral efficiency, and reliability. Unlike traditional systems with single antenna paths, MIMO uses multiple transmitting and receiving antennas to utilize spatial diversity and minimize signal fading, significantly enhancing communication performance.

It plays a central role in advanced technologies like 5G, LTE, and Wi-Fi, supporting high-speed data transmission and robust connectivity in dense environments.

This project focuses on the design and simulation of a 2×2 MIMO microstrip patch antenna with fractal geometry operating across S, C, X, and Ku bands. Microstrip antennas are widely used due to their low profile, ease of fabrication, and compatibility with modern circuits. Despite limitations like low efficiency and narrow bandwidth, design enhancements such as fractal geometries and metamaterial concepts are adopted to achieve multiband operation and improved radiation properties.

The study involves analyzing antenna performance parameters like radiation patterns, directivity, and efficiency using simulation tools. These parameters are critical in determining antenna behavior in real-world applications. MIMO systems, with innovations in antenna design, continue to shape the future of high-performance wireless communication, making them essential in IoT, 5G, and satellite communication systems.

1.1 LITERATURE SURVEY

1. Chiu et al. (2015) proposed a compact MIMO antenna design using Defected Ground Structures (DGS) to suppress surface waves and minimize mutual coupling. The approach achieved over 20 dB isolation between antenna elements without increasing system size.

2. Ghosh et al. (2018) demonstrated the use of Electromagnetic Bandgap (EBG) structures and parasitic elements in a two-element MIMO antenna. Their simulation and measurement results showed improved isolation (above 18 dB) and low envelope correlation coefficient (ECC), proving effectiveness for 2.4 GHz applications.
3. Rani et al. (2020) introduced a T-shaped stub and neutralization line between elements to reduce mutual coupling. The design achieved isolation greater than 22 dB with compact size and enhanced S11, S21 parameters, suitable for Wi-Fi and LTE bands.
4. Ali et al. (2019) presented a fractal-based MIMO antenna system designed using HFSS. The structure achieved multiband operation and high isolation (>25 dB) by optimizing the element placement and geometry using simulation tools.

II. METHODOLOGY

i. EXISTING METHADODOLOGY

The existing methodologies for designing MIMO antenna systems primarily rely on conventional microstrip patch antennas or monopole structures fabricated on common substrates such as FR-4. These designs often utilize simple configurations with linear or orthogonal placements to achieve diversity, while mutual coupling is generally reduced by maintaining sufficient spacing between antenna elements. Isolation improvement techniques like defected ground structures (DGS) or stubs are sometimes employed, but not consistently optimized. Simulation tools such as CST or basic EM simulators are commonly used, focusing mainly on key parameters like S11 (return loss) and impedance bandwidth. However, parameters critical to MIMO systems, such as isolation (S21), envelope correlation coefficient (ECC), and diversity gain, are often underexplored or insufficiently optimized. The optimization process is largely manual and lacks iterative tuning of antenna geometry, substrate properties, and feed configuration. Furthermore, most designs do not consider scalability or compactness as a major factor, resulting in larger form factors that may not be suitable for modern compact wireless devices.

ii. PROPOSED METHADODOLOGY

The proposed methodology presents a novel approach to designing a compact two-element MIMO antenna

system using suspended microstrip patch technology, optimized and simulated with Ansys HFSS. The design process begins with the careful selection of the substrate material, with options like Rogers RT/Duroid being considered due to their low-loss and high-permittivity properties, which enhance both bandwidth and radiation performance. The unit antenna is carefully modeled by adjusting key parameters such as patch size, feed type, and substrate height to optimize return loss, gain, and efficiency. The initial design is then simulated to check fundamental parameters, including S11 (return loss), impedance bandwidth, and radiation pattern, ensuring that the antenna meets the performance criteria for the desired frequency bands. The design also prioritizes low mutual coupling and high isolation between antenna elements, which is a critical consideration for MIMO systems.

..... (1)

To mitigate the effects of mutual coupling, advanced isolation techniques such as defected ground structures (DGS), suspended microstrip structures to reduce surface wave propagation, and the potential use of electromagnetic bandgap (EBG) materials are incorporated. These techniques help confine the electromagnetic fields and minimize interference between antenna elements. Unlike traditional designs that rely on fixed parameters, this methodology employs an iterative optimization process where the feed position, substrate thickness, and patch geometry are systematically adjusted for better performance. The two-element MIMO configuration is evaluated through critical performance metrics, including S11, S21 (with the goal of achieving $S21 < -20$ dB), Envelope Correlation Coefficient ($ECC < 0.3$), and diversity gain. This ensures a balanced radiation pattern, good isolation, and low correlation between the antenna elements. By focusing on these key metrics, this design achieves enhanced isolation in a compact form factor, offering significant improvements over traditional methods. Furthermore, this methodology sets the groundwork for future fabrication and real-world deployment of high-performance MIMO antenna systems.

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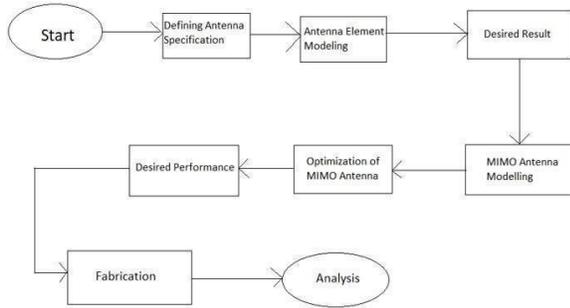


Fig1. Block diagram for the Two Element MIMO Antenna System.

ANTENNA DESIGN AND MODELING FOR MIMO SYSTEMS

The design of antennas for MIMO (Multiple Input Multiple Output) systems plays a crucial role in ensuring the optimal performance of wireless communication networks. This process involves multiple phases, each focused on enhancing specific antenna characteristics and system parameters to meet the demands of modern communication systems.

Antenna Specifications are the first step in the design process. These include determining the frequency range that aligns with the operating bands for the targeted data rates, radiation patterns (e.g., omnidirectional or sectorized), gain settings, and polarization type. The polarization could be linear (horizontal or vertical) or circular, depending on the propagation environment. The antenna impedance must also be matched to prevent signal loss and reflections, ensuring the integrity of the transmission. Size and form factor are critical for real-world deployment, as the antenna must fit within the physical constraints of the infrastructure. Additionally, for MIMO systems, the number of antenna elements must be defined to enhance multiplexing and diversity, improving throughput and system reliability.

MIMO Antenna Modeling involves the simulation of the entire antenna array, considering the interaction between all antenna elements. This step ensures that the MIMO array maximizes its diversity gain, minimizes mutual coupling, and optimizes the system's performance by providing insights into the collective behavior of the array.

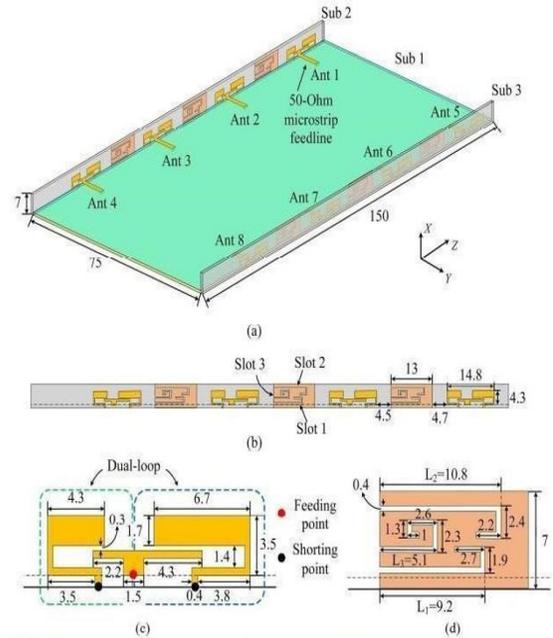


Fig 2. Configuration of Eight Element array

III.PROJECT DESIGN AND ARCHITECTURE

The design and implementation of the MIMO antenna system involve a comprehensive process that addresses critical performance parameters such as gain, polarization, radiation patterns, frequency range, bandwidth, and impedance matching. These factors are tailored to meet the objectives of the intended wireless communication system. Using advanced simulation tools like Ansys HFSS, each antenna element in the MIMO array is meticulously modeled and analyzed to understand its radiation behavior, mutual coupling, and diversity gain. Optimization plays a crucial role in fine-tuning the antenna layout, spacing, and orientation to maximize performance and minimize interference. These prototypes undergo rigorous testing in controlled environments to validate key metrics such as return loss (S_{11}), isolation (S_{21}), gain, radiation patterns, and impedance matching. The success of the project relies on a multidisciplinary team with expertise in antenna design, signal processing, and electromagnetic theory, working in a structured, iterative manner. Ultimately, the goal is to seamlessly integrate the validated antenna system into a larger wireless communication framework, ensuring reliable and efficient real-world operation.

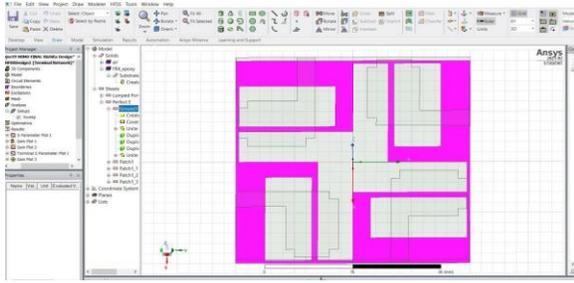


Fig 3 Ground Design of MIMO Antenna

IV SOFTWARE REQUIREMENTS AND HARDWARE COMPONENT

5.1 Software Requirements

Ansys HFSS (High-Frequency Structure Simulator) is a leading electromagnetic simulation tool used for designing high-frequency components like antennas, waveguides, and RF circuits. It uses the Finite Element Method (FEM) for accurate 3D analysis of electromagnetic fields. HFSS is ideal for MIMO antenna design, offering insights into parameters such as gain, impedance matching, and mutual coupling. Key features include adaptive meshing, S-parameter analysis, and support for circuit and thermal co-simulation. Widely used in 5G, IoT, radar, and satellite applications, it also supports phased array design and high-performance computing for efficient simulations.

5.2 Hardware Components

MIMO antenna systems rely on key hardware components for optimal performance. A metallic ground plane (usually copper or aluminum) provides a return path for RF currents and reduces interference. Substrate materials like FR-4 or Duroid 5880 influence signal behavior through properties such as dielectric constant and loss tangent. Coaxial connectors (SMA, BNC, N-Type) ensure low-loss signal transmission between components.

For processing, systems use CPUs, MCUs, DSPs, or ASICs, depending on the application. RAM (e.g., DRAM, DDR) offers fast temporary data storage, while ROM (EEPROM, Flash) stores permanent firmware and bootloaders. These components together support reliable MIMO system operation and testing.

Results

6.1 Return Loss (S₁₁) and Reflection Coefficient (Γ)

Return Loss (S₁₁) indicates the amount of power reflected from the antenna due to impedance

mismatch. Lower values (more negative) signify better performance.

Reflection Coefficient (Γ) is the ratio of reflected power to incident power, calculated using:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$S_{11}(\text{dB}) = 20 \log_{10} |\Gamma| \quad S_{11}(\text{dB}) = 20 \log_{10} |\Gamma|$$

An antenna is considered well-matched when S₁₁ is below -10 dB. Values near -20 dB or lower indicate excellent matching with minimal power loss.

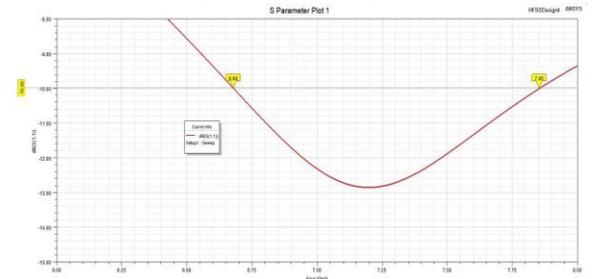


Fig4.Return loss of unit element and MIMO

6.2 Impedance Bandwidth

The bandwidth is the range of frequencies over which the antenna maintains S₁₁ below -10 dB.

It is expressed as a percentage of the center frequency:

$$\text{Bandwidth (\%)} = \frac{f_{\text{max}} - f_{\text{min}}}{f_{\text{center}}} \times 100$$

A wider bandwidth means the antenna can operate over a larger range of frequencies, which is desirable for modern wideband or multi-band systems.

6.3 Gain (dBi)

Gain measures how effectively the antenna radiates energy in a particular direction compared to an ideal isotropic source.

It is influenced by the antenna's efficiency and directivity:

$$G = \eta D \quad G = \eta D$$

Higher gain (>6 dBi) is beneficial for directional and long-range communication. Lower gain (around 2 dBi) is suitable for omnidirectional applications like IoT and mobile devices.

6.4 Radiation Pattern

A radiation pattern visually shows how the antenna radiates energy in space.

It is usually represented in polar plots for the E-plane and H-plane.

Common types include:

Omnidirectional: Uniform radiation in all directions (e.g., dipoles).

Directional: Focused energy beam in one direction (e.g., Yagi antennas).

Bi-directional: Radiation in two opposite directions (e.g., dipole figure-8).

Key features include the main lobe (strongest direction), side lobes (undesired), and back lobe (opposite radiation, usually undesirable).

6.5 Efficiency

Efficiency is the percentage of input power that is radiated by the antenna:

$$\eta = \frac{P_{\text{radiated}}}{P_{\text{input}}} \times 100$$

High-performance antennas have efficiencies above 80%. Efficiencies below 50% indicate substantial power loss due to resistive losses, poor matching, or dielectric absorption.

6.6 Isolation (S₂₁) in MIMO Antennas

Isolation (S₂₁) represents the level of power leakage from one antenna element to another in a MIMO system.

Lower S₂₁ values (e.g., < -20 dB) indicate minimal coupling and better performance.

High coupling (e.g., > -10 dB) can cause interference and degrade MIMO effectiveness.

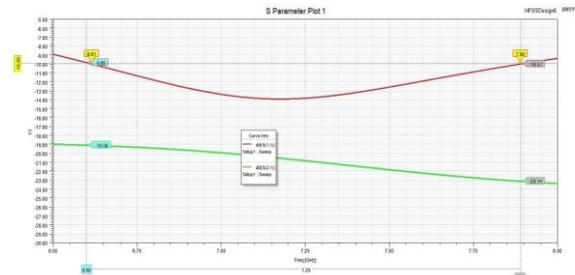


Fig 6.2 Return loss and isolation of MIMO

6.7 Voltage Standing Wave Ratio (VSWR)

VSWR indicates how well the antenna is impedance-matched to the transmission line:

$$VSWR = 1 + \frac{|\Gamma|}{1 - |\Gamma|}$$

A VSWR less than 2 is generally acceptable, with a value of 1 representing a perfect match and no reflected power.

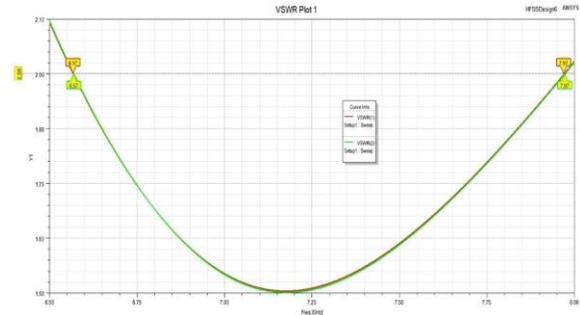


Fig 6.3 VSWR of MIMO

6.8 Directivity

Directivity measures how focused the antenna's radiation is compared to an isotropic source:

$$D = \frac{U_{\text{max}}}{U_{\text{avg}}}$$

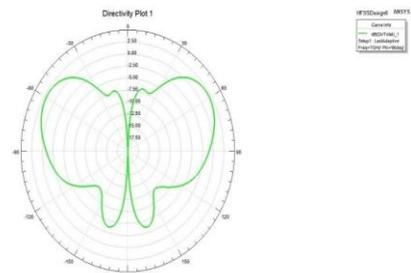


Fig 6.5 DIRECTIVITY OF MIMO

IV CONCLUSION

The Two-Element MIMO (2×2 MIMO) antenna system remains a cornerstone of modern wireless communication, offering a practical balance between performance, cost, and energy efficiency. Its ability to mitigate multipath fading, enhance signal quality, and increase spectral efficiency makes it a vital component across a wide range of applications—from smartphones and IoT devices to automotive networks and satellite systems. As wireless communication continues to evolve with the advent of 5G and the future rollout of 6G, 2×2 MIMO systems will play an increasingly significant role in maintaining robust and high-speed connectivity in both low-power and high-demand environments.

Despite the growing interest in higher-order MIMO configurations such as 4×4, 8×8, and massive MIMO, 2×2 MIMO maintains a strong foothold due to its minimal hardware complexity and suitability for compact devices. Its integration into technologies such as Wi-Fi 6/7, vehicular communication networks

(V2X), and low Earth orbit (LEO) satellite systems underlines its versatility. Furthermore, the adaptability of 2×2 MIMO to future technologies including terahertz (THz) communication, AI-driven optimizations, and quantum computing demonstrates its lasting relevance.

Ongoing research continues to push the boundaries of what 2×2 MIMO can achieve. Innovations such as AI-enhanced beamforming, machine learning-based channel estimation, and quantum-safe security protocols are poised to elevate the performance and security of MIMO systems. Additionally, the development of energy-efficient MIMO designs supports the global shift toward sustainable, green communication infrastructures.

In conclusion, 2×2 MIMO is not only a mature and widely deployed technology but also a scalable and forward-compatible solution. Its continued evolution will be instrumental in shaping the next generation of wireless networks, ensuring that communication systems remain fast, secure, energy-efficient, and universally accessible.

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