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COMPACT SELF-DIPLEXING MIMO ANTENNA WITH IMPROVED ISOLATION CHARACTERISTICS

Mr. N. Bujji babu[1],K. Karthik[2], L. Sai[3], K. Sridhar[4],K. Kumar Raju[5]

Department of Electronics and Communication Engineering,

Andhra Loyola Institute of Engineering and Technology, Vijayawada, Andhra Pradesh, India[1-5]

Abstract*:* The design and analysis of a small multiple-input multiple-output (MIMO) antenna for wireless and Internet of Things applications operating in the 2.4 GHz to 2.7 GHz frequency range are presented in this research.The suggested antenna is created using a straightforward planar construction and examined utilizing several electromagnetic simulation tools, in contrast to traditional designs that depend on substrate integrated waveguide (SIW) structures and CST-based calculations Within the designated ISM band, the antenna is intended to provide dual-port operation with enhanced isolation and effective radiation characteristics. The design guarantees lower mutual coupling between antenna parts without requiring intricate decoupling structures by utilizing suitable slotting and efficient feed procedures. Throughout the operational frequency range, the suggested setup provides appropriate gain, steady radiation patterns, and good impedance matching. To verify the antenna behavior, performance metrics such S-parameters, return loss, isolation, and radiation characteristics are examined.The findings show that the antenna provides dependable performance appropriate for short-range wireless communication systems, such as Bluetooth, Wi-Fi, and Internet of Things devices.

Keywords: Compact Antenna , Self-Diplexing Antenna , MIMO Antenna , High Isolation , IoT Connectivity , Dual-Band Antenna, Microstrip Patch Antenna , Defected Ground Structure (DGS) , Mutual Coupling Reduction , HFSS Simulation ,Wireless Communication , Return Loss (S11) , Envelope Correlation Coefficient (ECC) , Gain Enhancement , 2.4 GHz / 5 GHz Bands.

I. INTRODUCTION

Theneed for high data rates, dependable connectivity ,and effective spectrum utilisation has grown dramatically due to the quick development of wireless communication technology.Compactandhigh-performanceantennasthatcansupportseveralfrequency bands in a constrained space are necessary for modern applications like 4G, 5G, and Internet of Things (IoT) systems. Antenna design is now a crucial component of contemporary communication systems as a result. Multiple communication protocols could not be supported by conventional antennas because they were primarily intended for single-band operation. Multi-band antennas were created to get around this restriction. Nevertheless, these systems frequently depended on extra parts like filters and diplexers, which raised the communication system's total size, cost, and complexity.Self-diplexing antenna technology has become a viable answer to these problems. Self-diplexingantennasdonotrequireexternaldiplexersbecausetheycanoperateindifferent frequency bands with asinglestructure.This makes thesystem more compact, efficient, and less complicated, which makes it ideal for contemporary wireless gadgets.

Antenna design and analysis are now more precise and effective thanks to the development of electromagnetic simulation technologies. ANSYS HFSS, which offers accurate assessment of important characteristics like return loss, bandwidth, gain, and isolation prior to fabrication, is used in this work to design and analyse the suggested compact self-diplexing MIMO antenna. In order to be appropriate for contemporary wireless communication applications, the suggested antenna seeks to accomplish dual-band operation with enhanced isolation and small dimensions. For next-generation communication systems, the combination of self-diplexing with MIMO techniques provides an effective and workable solution.

B. Objectives of the Work

The main objective of the proposed system is to design and simulate a compact self-diplexing MIMO antenna with improved isolation using HFSS.

The specific objectives include:

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- To design a dual-band self-diplexing antenna for IoT applications
- To achieve high isolation between MIMO antenna elements
- To reduce mutual coupling effects
- To ensure good performance parameters such as:
- Low return loss (S11 < -10 dB)
- High isolation (S21 < -15 dB or better)
- Acceptable gain and radiation efficiency
- To develop a compact and low-cost antenna structure
- To simulate and analyze the antenna using HFSS

Additionally, the system aims to support modern IoT communication requirements by providing a scalable and efficient antenna solution suitable for wireless devices.

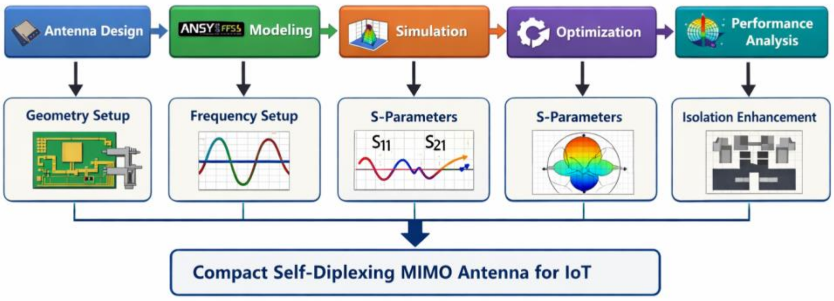

Fig.1: Implementation Flow

C.Background of Self-Diplexing MIMO Antennas

With the rapid growth of Internet of Things (IoT) devices, there is an increasing demand for compact, efficient, and multi-band antenna systems. IoT devices often operate in multiple frequency bands such as 2.4 GHz and 5 GHz, requiring reliable communication while maintaining small size and low power consumption.Traditional antenna systems use external diplexers to separate frequency bands, which increases system complexity, cost, and size. Additionally, when multiple antennas are placed close together in MIMO systems, mutual coupling becomes a major issue, degrading performance and reducing isolation between antenna elements.

Recent advancements in antenna design have introduced self-diplexing antennas, which inherently operate at multiple frequency bands without requiring external circuits. Combined with MIMO technology, these antennas can significantly improve data rates and communication reliability. However, challenges such as achieving high isolation, compact design, and efficient radiation performance still remain.

D. Self-Diplexing MIMO Antenna Concept

The proposed system is a compact self-diplexing MIMO antenna designed to operate at multiple frequency bands for IoT applications.

In this system:

Two antenna elements are designed to resonate at different frequency bands (e.g., 2.4 GHz and 5 GHz) , Each antenna port operates independently, eliminating the need for an external diplexer. The antenna structure is optimized to reduce mutual coupling and improve isolation . The design is implemented and simulated using ANSYS HFSS, where electromagnetic parameters such as return loss, isolation, gain, and radiation patterns are analyzed.

E. Motivation of the Work Most conventional multi-band antenna systems rely on external components like diplexers and filters, which increase hardware complexity and cost. Moreover, closely spaced antennas in MIMO systems often

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suffer from high mutual coupling, leading to poor isolation and reduced system efficiency.Existing designs may also lack compactness, making them unsuitable for modern IoT devices where space is limited. Additionally, achieving high performance across multiple frequency bands while maintaining a simple structure remains a challenging task.

II. LITERATURE SURVEY

Recent research has focused on improving wireless communication systems by developing compact, efficient, and multi-band antenna designs suitable for modern IoT applications. With the rapid growth of connected devices, there is a strong demand for antennas that support high data rates, reliable connectivity, and reduced system complexity. Many antenna systems have been developed to achieve multi-band operation, enhance signal quality, and improve overall communication performance using advanced design techniques and simulation tools.

Researchers have explored various approaches such as microstrip antenna design, MIMO technology, and self-diplexing techniques to address challenges like limited bandwidth, mutual coupling, and large antenna size. These systems aim to improve isolation between antenna elements, reduce interference, and enable efficient spectrum utilization. The integration of advanced electromagnetic simulation tools like ANSYS HFSS has further enhanced the design and optimization process. This section reviews existing approaches related to traditional antenna systems, compact antenna designs, MIMO antenna configurations, and self-diplexing techniques. It also highlights the limitations of current methods and emphasizes the need for a compact, high-isolation MIMO antenna solution for IoT connectivity.

*A.Traditional Antenna System*s

Traditional wireless communication systems commonly use single-band antennas or multi-band antennas combined with external components such as diplexers and filters. These systems are widely used in communication devices but have several limitations.The use of external diplexers increases the overall size, cost, and complexity of the system. Additionally, when multiple antennas are used in close proximity, mutual coupling becomes a major issue, leading to reduced efficiency and poor isolation.These conventional designs are not suitable for modern IoT devices, which require compact size, low power consumption, and multi-band operation.

B.Microstrip and Compact Antenna Designs

With the advancement of wireless technologies, microstrip patch antennas have become popular due to their:

- Low profile
- Lightweight structure
- Ease of fabrication

Researchers have developed compact antenna designs using techniques such as:

- Slotting methods
- Meandered structures
- Fractal geometries

These approaches help in reducing antenna size and achieving multi-band characteristics. However, compact designs often suffer from reduced gain and narrow bandwidth, which affects overall performance.

C. MIMO Antenna Systems

MIMO (Multiple Input Multiple Output) antenna systems are widely used to improve:

- Data rate
- Channel capacity
- Signal reliability

In MIMO systems, multiple antennas are placed close to each other, which introduces mutual coupling to:

- Poor isolation

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- Increased signal interference
- Reduced system efficiency
- Various techniques have been proposed to reduce coupling, such as:
- Parasitic elements
- Neutralization lines
- Spatial diversity

Despite these improvements, achieving high isolation in a compact structure remains a major challenge.

D.Limitations of Existing Systems

Despite significant advancements, existing antenna systems still face several limitations:

- Traditional antennas require external diplexers, increasing complexity
- Compact antennas often suffer from low gain and limited bandwidth
- MIMO systems experience high mutual coupling
- Self-diplexing antennas may have poor isolation if not properly designed

These challenges highlight the need for a compact, high-performance self-diplexing MIMO antenna that can:

- Operate efficiently at multiple frequency bands
- Provide high isolation between elements
- Reduce system complexity
- Meet the requirements of modern IoT applications

III. METHODOLOGY

The proposed system presents a compact self-diplexing Multiple Input Multiple Output (MIMO) antenna designed to operate within the 2.4–2.7 GHz Industrial, Scientific, and Medical (ISM) band for modern wireless communication applications such as IoT, WLAN, and Bluetooth. The antenna adopts a microstrip patch configuration consisting of radiating elements printed on a dielectric substrate with a ground plane on the opposite side, ensuring a low-profile and easily manufacturable planar structure. The design integrates two antenna elements on a single substrate to enable MIMO operation, thereby improving data throughput, signal reliability, and overall system performance in multipath environments.

A key feature of the proposed system is its self-diplexing capability, which allows the antenna to operate at multiple frequency bands without the need for external diplexers or filtering components. This is achieved through careful structural modifications in the radiating patch that control current distribution and enable frequency-selective behavior within a single compact geometry. As a result, the system significantly reduces hardware complexity, cost, and physical size while maintaining efficient dual-band performance.

To address the challenge of mutual coupling between closely spaced antenna elements, the proposed design incorporates isolation enhancement techniques such as slot-based modifications, optimized element orientation, and ground plane adjustments. These techniques effectively suppress unwanted electromagnetic interactions and improve isolation between antenna ports without introducing complex decoupling structures. The antenna is further designed to achieve good impedance matching, low signal correlation, stable radiation patterns, and adequate gain across the operating frequency range.

Overall, the proposed system offers a compact, cost-effective, and high-performance antenna solution suitable for integration into wireless sensor networks, IoT devices, and portable communication systems. Its simple structure, efficient dual-band operation, and enhanced isolation characteristics make it a reliable candidate for next-generation wireless communication applications.

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IV. PROPOSED SYSTEM

The proposed system is a compact self-diplexing MIMO antenna designed and simulated using ANSYS HFSS. The antenna is developed to support multi-band operation for IoT applications while maintaining high isolation between antenna elements.

Unlike conventional antenna systems that require external diplexers and complex circuitry, this design integrates self-diplexing capability within the antenna structure itself. The system uses advanced electromagnetic design techniques to achieve efficient radiation, reduced mutual coupling, and improved overall performance. The main objective is to provide a compact, cost-effective, and high-performance antenna solution suitable for modern wireless communication systems and IoT devices.

A.System Architecture

The system architecture is designed as a structured antenna design and simulation framework consisting of the following components:

• Antenna Design Layer

Design of dual-port MIMO antenna elements

Each element operates at different frequency bands (e.g., 2.4 GHz & 5 GHz)

• Substrate Layer

Material selection (e.g., FR4)

Defines dielectric properties and thickness

• Feeding Mechanism Layer

Microstrip line or CPW feeding technique

Separate ports for each antenna element

• Isolation Enhancement Layer

Techniques such as:

Defected Ground Structure (DGS)

Parasitic elements

Slot structures

• Simulation Layer

Electromagnetic simulation using HFSS

Analysis of S-parameters, gain, and radiation pattern

• Performance Evaluation Layer

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Evaluation of antenna parameters:

Return Loss (S11)

Isolation (S21)

Gain

Efficiency

B. Software Components

The proposed system uses the following tools and technologies:

- **ANSYS HFSS**

Used for antenna design, modeling, and simulation

- **MATLAB**

Used for post-processing and performance analysis

- **Electromagnetic Theory**

Used for antenna calculations and optimization

C. Working Principle

The system operates based on electromagnetic resonance and multi-band antenna design principles:

1. Antenna geometry is designed in HFSS
2. Substrate and material properties are defined
3. Two antenna elements are created for different frequencies
4. Feeding ports are assigned to each element
5. Simulation is performed over desired frequency range
6. Antenna resonates at multiple frequency bands
7. Isolation techniques reduce mutual coupling
8. Performance parameters are analyzed (S11, S21, Gain)
9. This process ensures efficient dual-band operation and high isolation for MIMO communication.

D. Advantages of Proposed System

- Compact size (no external diplexer required)
- Cost-effective design
- Multi-band operation (self-diplexing)
- High isolation between antenna elements
- Improved data transmission using MIMO
- Easy integration into IoT devices

E.Applications

- IoT devices and smart sensors
- Wireless communication systems
- Smart home networks
- Industrial IoT
- Wearable and portable devices

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V. SYSTEM IMPLEMENTATION

The implementation of the proposed system is carried out using electromagnetic simulation and antenna design techniques. The system integrates antenna geometry design, material configuration, feeding mechanisms, and simulation analysis to achieve efficient multi-band operation and high isolation. The design and implementation are performed using ANSYS HFSS, which enables accurate modeling and performance evaluation of the antenna. The system is divided into several functional modules, including antenna design, simulation setup, isolation enhancement, performance analysis, and result optimization.

A.Antenna Design Module

This module is responsible for creating the physical structure of the antenna.

- Geometry Design
- A compact dual-element MIMO antenna is designed
- Each element is structured to operate at different frequencies (e.g., 2.4 GHz and 5 GHz)
- Substrate Selection
- Material such as FR4 is used
- Parameters like dielectric constant and thickness are defined
- Patch Structure
- Microstrip patch or slot-based structures are designed
- Dimensions are optimized for desired resonant frequencies

B.Simulation and Analysis Module

This is the core module where antenna performance is analyzed.

Model Setup

Antenna geometry is modeled in HFSS

Boundary conditions and excitation ports are assigned

Frequency Setup

Simulation is performed over a wide frequency range (e.g., 1–6 GHz)

Parameter Analysis

Key parameters evaluated include:

- Return Loss (S11)
- Isolation (S21)
- VSWR
- Radiation pattern

C. Isolation Enhancement Module

This module focuses on improving isolation between antenna elements.
Techniques Used
Defected Ground Structure (DGS)
Slot implementation in ground plane
Parasitic elements placement
Isolation Logic

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Reduces electromagnetic coupling between antenna ports
Ensures independent operation of each antenna element

D. Overall Working Flow

- Antenna structure is designed in HFSS
- Substrate and material properties are defined
- Dual antenna elements are created
- Feeding ports are assigned
- Simulation is executed over desired frequency range
- Antenna resonates at multiple frequencies
- Isolation techniques reduce mutual coupling
- Performance parameters are analyzed and optimized

VI. RESULTS AND DISCUSSION

The proposed compact self-diplexing MIMO antenna was designed and simulated using ANSYS HFSS to evaluate its performance for IoT communication. The antenna was analyzed based on key performance parameters such as return loss, isolation, gain, and radiation characteristics.The simulation results demonstrate that the proposed antenna successfully achieves dual-band operation and provides improved isolation between antenna elements, making it suitable for modern wireless applications.

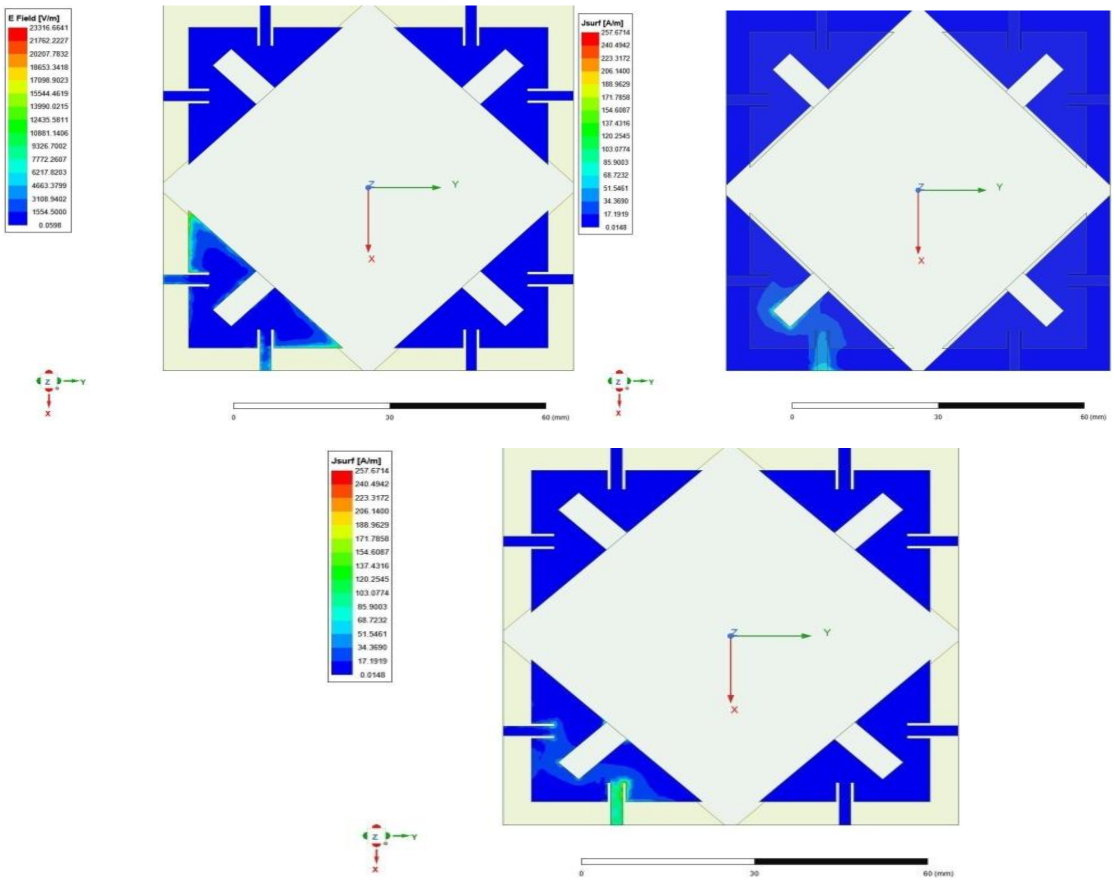

Fig2:Electrified Views

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A. Return Loss (S11) Analysis

The return loss (S11) of the antenna was evaluated to determine its impedance matching performance.

- The antenna shows resonances at 2.4 GHz and 5 GHz bands
- S11 values are observed to be less than -10 dB, indicating good matching
- This confirms efficient transmission and minimal signal reflection

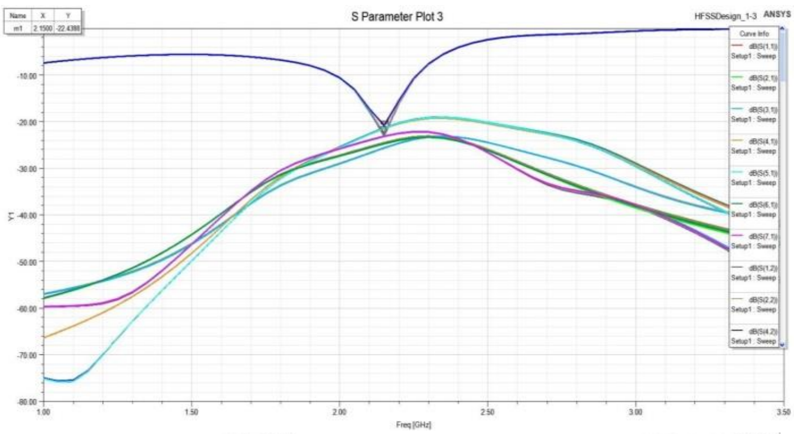
B. Isolation (S21) Performance

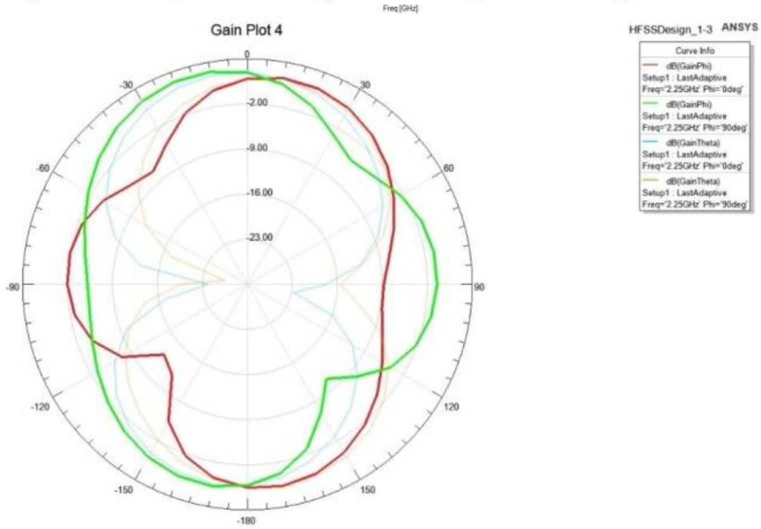
Isolation between the two antenna elements is a critical parameter in MIMO systems.

- The proposed design achieves isolation greater than 15–20 dB
- Mutual coupling between antenna elements is significantly reduced
- Isolation improvement techniques (DGS, slots) proved effective

The radiation characteristics of the antenna were analyzed to evaluate signal coverage.

- The antenna provides a gain of approximately 2–5 dBi
- Radiation patterns are stable and nearly omnidirectional
- Suitable for IoT applications requiring uniform signal distribution





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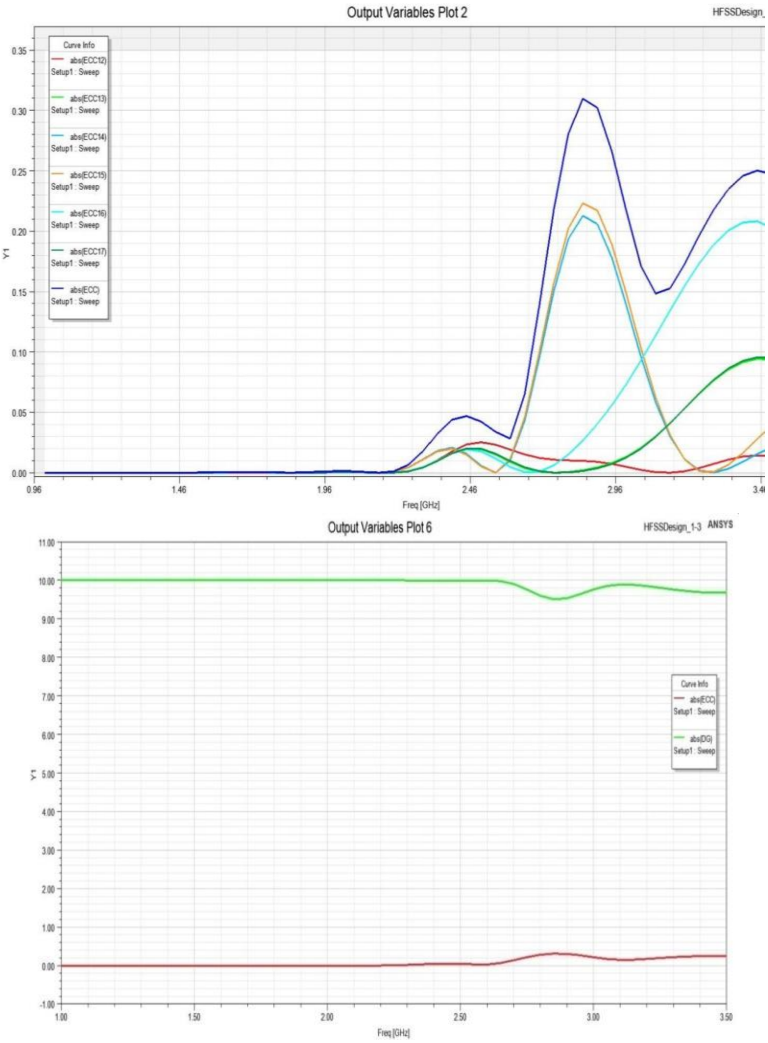

Fig 3: Parameter Plots

C. Envelope Correlation Coefficient (ECC)

ECC is used to evaluate diversity performance in MIMO systems.

- The ECC value is observed to be less than 0.02
- Indicates excellent diversity performance
- Confirms minimal interference between antenna elements

D. Overall Performance Evaluation

The simulation results confirm that:

- The antenna achieves self-diplexing operation without external circuits
- High isolation ensures efficient MIMO performance
- Compact structure makes it suitable for IoT devices
- All key parameters meet the required design standards

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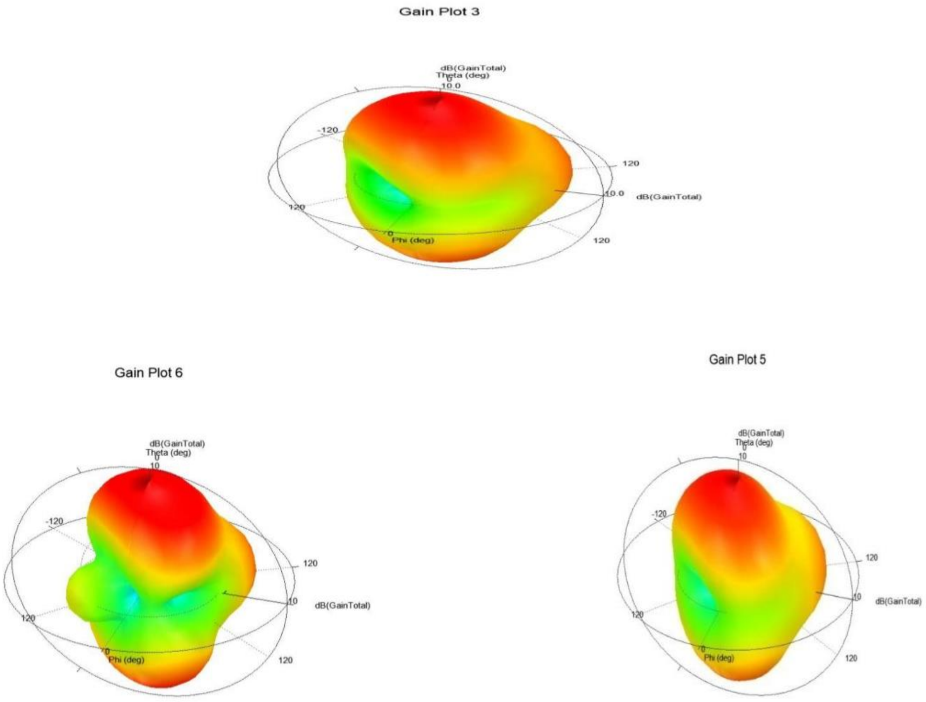

Fig4: Frequency of Gains

VII. ADVANTAGES OF THE PROPOSED SYSTEM

The proposed compact self-diplexing MIMO antenna offers several advantages over conventional antenna systems used in wireless communication. One of the major advantages is self-diplexing capability, where the antenna operates at multiple frequency bands (e.g., 2.4 GHz and 5 GHz) without requiring external diplexers. This significantly reduces system complexity, size, and cost.

Another key advantage is high isolation between antenna elements. By incorporating techniques such as Defected Ground Structure (DGS) and optimized antenna placement, the system minimizes mutual coupling, ensuring efficient MIMO performance and reduced signal interference. The antenna also provides compact size and low-profile design, making it highly suitable for integration into IoT devices where space is limited. Additionally, the use of ANSYS HFSS enables precise design and optimization, improving overall performance.

The system ensures good radiation characteristics, including acceptable gain and stable radiation patterns, which are essential for reliable wireless communication. Furthermore, the antenna supports enhanced data transmission rates due to the implementation of MIMO technology. Another important advantage is cost-effectiveness and ease of implementation, as the design eliminates the need for additional external components and can be fabricated using standard materials like FR4. Overall, the proposed system provides an efficient, compact, and high-performance antenna solution for modern IoT communication systems.

VIII. LIMITATIONS

One limitation is the narrow bandwidth typically associated with microstrip antennas. This may restrict operation to specific frequency bands unless further optimization is applied. Another limitation is the dependence on precise design parameters. Small variations in dimensions, substrate properties, or fabrication tolerances can affect antenna performance, including resonant frequency and impedance matching.

The system also faces challenges related to mutual coupling in compact MIMO configurations. Although isolation techniques are used, achieving extremely high isolation in a very small form factor remains difficult. Additionally, simulation results obtained using ANSYS HFSS may slightly differ from real-world measurements due to fabrication

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imperfections and environmental conditions. Finally, the antenna performance may vary under practical deployment conditions, such as nearby objects, device casing, or human body effects in wearable applications.

VIII. CONCLUSION

This study presented the design and simulation of a compact self-diplexing MIMO antenna with improved isolation for IoT connectivity. The proposed antenna integrates dual-band operation, MIMO technology, and self-diplexing functionality into a single compact structure. By eliminating the need for external diplexers, the system reduces complexity while maintaining efficient performance. The antenna was designed and analyzed using ANSYS HFSS, and key performance parameters such as return loss, isolation, gain, and radiation pattern were evaluated.

The results demonstrate that the antenna achieves:

- Good impedance matching
- High isolation between ports
- Stable radiation characteristics
- Efficient multi-band operation

Overall, the proposed system provides a scalable, cost-effective, and high-performance solution for modern wireless communication and IoT applications. It highlights the importance of advanced antenna design techniques in meeting the growing demands of compact and efficient communication systems.

IX. FUTURE WORK

One major enhancement is the design of wideband or multiband antennas to support additional communication standards beyond 2.4 GHz and 5 GHz. The system can be further improved by implementing advanced isolation techniques, such as metamaterials or electromagnetic bandgap (EBG) structures, to achieve even higher isolation. Future work may include fabrication and practical testing of the antenna to validate simulation results and analyze real-world performance.

Integration with 5G and advanced IoT technologies can also be explored to support next-generation communication systems. Additionally, optimization using machine learning techniques can be applied to automatically improve antenna design parameters. The antenna can also be adapted for wearable and flexible electronics, expanding its application in healthcare and smart devices.

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