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SUB-6 5G NETWORKS: DESIGN OF BUTTON MUSHROOM MIMO ANTENNA AND IT'S INVESTIGATION

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ABSTRACT

The unlicensed National Information Infrastructure radio band (n77, n78, and n46) is taken into consideration for this research work's "Multiple-input-multiple-output (MIMO)" antenna with dual band features. Gradually, the form design of simple single-patch MIMO antennas gives way to four-element MIMO antennas. Four microstrip antennas are integrated using button-like circular caps on the main patches. Reduced ground is also used in the construction of many band characteristics. Excellent isolation can be achieved by using Rectangular Metallic Strip (RMS). The suggested MIMO antenna has the advantage of covering two significant frequency bands. At 3.07 GHz and 6.31 GHz, the antenna system resonates with a total bandwidth of 2.43 GHz. The antenna design uses a FR4 substrate measuring 35 mm by 49 mm by 1.6 mm in thickness. For simulation purposes, Teflon and a specially made SMA connector with a perfect electrical conductor (PEC) are used to enhance impedance matching. An 8.2 mm feed line with an inset feed is also utilized. Research and investigation are conducted on radiation properties, including mean effective gain, envelope correction coefficient, reflection coefficient, and more. Both the reflection and isolation coefficients have values of less than -10 dB, with the former being less than -15 dB. It is a 16.30 dB increase overall. 5G applications will greatly benefit from having this smaller, four-element MIMO antenna.

Keywords: *MIMO, 5G, n77, n78, RMS.*

Introduction

The 5th generation (5G) communication system represents the latest breakthrough in wireless technology, characterized by its ability to deliver high-speed data transfer, ultra-low latency, and enhanced network efficiency. It is designed to support a wide range of applications, from mobile broadband to massive Internet of Things (IoT) and mission-critical communications. To achieve these ambitious goals, 5G networks extensively utilize advanced MIMO techniques, which form the backbone of their performance enhancements (1). Patch antennas are an excellent choice because to their compact design, low profile, and simplicity of integration with other circuit modules. The patch antenna is an intriguing choice for antennas, which are necessary for 5G systems (2). In 5G communication systems, Multi-Input Multi-Output (MIMO) technology is widely employed to advance the wireless channel's dependability, capability, and data transmission rate. Due to MIMO's innate capacity to make use of many antennas at the transmitter and receiver, wireless networks can take advantage of spatial diversity and multiplexing, which greatly improves performance. This capability is essential for meeting the growing demands of data-intensive applications and the expanding number of connected devices in 5G networks (3).Because closely placed antenna elements mutually couple, the MIMO technique—which is frequently employed in 5G systems to increase channel capacity and throughput—has performance

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problems. The key to reducing this problem is to use effective isolation strategies. The isolation for high-order MIMO applications in 5G mobile systems is greatly improved by a suggested hybrid decoupling technique that combines self-isolation and an orthogonal mode approach (4). Introduction of a novel 4-port MIMO microstrip patch antenna specifically engineered for 5G mid-band applications, addressing the stringent requirements for compactness, efficiency, and isolation in modern wireless networks. Their research underscores the significance of MIMO technology in achieving superior data rates and network reliability by optimizing antenna design for the specific characteristics of the 5G mid-band spectrum, which typically ranges from 3.5 GHz to 6 GHz (5). The trend towards smaller Radio Frequency (RF) systems has sparked growing interest in compact multi-antenna systems. However, shrinking antenna components have led to significant mutual coupling issues, distorting radiation properties. Researchers are actively exploring strategies to mitigate mutual coupling, aiming to enhance the compactness and performance of MIMO antenna systems (6, 7). These days, fourth-generation (4G) technology offers ample bandwidth and data rates, meeting the robust demands of the telecommunications industry. Its widespread accessibility supports high-speed internet, multimedia streaming, and reliable connectivity, fostering innovations in mobile applications and services worldwide. (8). Nevertheless, the amount of data traffic generated by the numerous social media apps, cloud services, IOTs, video streaming, and other such activities would exceed 4G infrastructure's capacity (9). Improvements in connections, latency, and energy consumption will further set future communications apart. Compared to 4G, 5G and the upcoming 6G technologies offer improved capabilities, thus these four qualities will be critical. Some of these characteristics include larger output, more frequency bands, wider bandwidth, lower latency, improved capabilities, wider connectivity, more robust linkage, and more data rates. For 5G mobile applications, the most often chosen solution is multiband multiple-input multiple-output, or MIMO, antennas.(10).The MIMO antenna system integrates slots on radiating and parasitic elements, along with a reduced ground plane, aiming to enhance performance metrics. The evaluation includes comprehensive analyses of return loss to ensure efficient impedance matching, radiation characteristics to optimize coverage patterns, and reduced mutual coupling to minimize interference between antennas. Additionally, mean effective gain measurements quantify the system's ability to transmit and receive signals effectively. Envelope correlation coefficients and channel capacity assessments further gauge the system's reliability and efficiency in diverse operational scenarios, contributing to advancements in MIMO antenna design and deployment strategies (11). The random phase excitations in MIMO antenna systems introduce challenges in maintaining optimal impedance matching and controlling mutual coupling. These fluctuations can lead to variations in the antenna's performance across different frequency bands and operational conditions. Effective design strategies, such as employing matching networks and isolation techniques, are crucial to mitigate these effects and ensure consistent antenna performance. (12). The total active reflection coefficient (TARC) computation provides a quantitative measure of the reflection characteristics in MIMO systems affected by random phase interactions. By calculating the square root of the total reflected power and dividing it by the total generated power, TARC assesses the efficiency of signal transmission and reception across multiple antenna elements. This metric is crucial for evaluating system performance, as high TARC values indicate significant signal loss due to reflections, highlighting the importance of minimizing impedance mismatches and optimizing antenna design. (13).The substrate integrated waveguide rectangular ring slot (SIW RRS) antenna design incorporates a low-profile structure with a broad bandwidth, leveraging the half-TE 110 cavity mode and TM patch mode for enhanced performance. By evaluating the bandwidth impacts of SIW cavities, the antenna achieves robust frequency coverage suitable for diverse communication applications. Its self-isolating nature facilitates the construction of an 8-element MIMO antenna system, effectively mitigating mutual coupling between elements. (14).the antenna, featuring a modest profile and constructed from four FR-4 substrate components, enhances its gain by employing a metasurface based on a superstrate design. This superstrate, positioned 15 mm below the antenna, effectively reduces coupling between the frequency selective surface (FSS) and antenna elements. By incorporating this innovative design approach, the antenna achieves improved performance in terms of gain and efficiency, making it well-suited for applications requiring enhanced signal strength and reduced interference in diverse operational environments.(15).For 5G wireless communications, a small, effective diamond-shaped MIMO antenna system is being developed. Elements are segregated, the envelope correlation coefficient is minimal, and the maximum diversity gain is 10 dB.(16).This innovative system not only meets the need for improved performance but also has impressive features including high efficiency, large bandwidth, and small size, making it a viable option for the changing millimeter-wave communication market. (17).The introduction of next-generation technologies like 5G has intensified the demand for high-speed, reliable, and pervasive wireless connectivity across various devices, notably smartphones. Addressing this need, a novel Dual-Polarized Wideband MIMO Antenna System has been developed specifically to operate within the N77 band, a critical frequency range for 5G networks. In order to meet the growing data requirements of contemporary applications like ultra-high definition video streaming and augmented reality, this antenna system is designed to maximize spectral efficiency and throughput.(18). The integration of electromagnetic metamaterial represents a groundbreaking approach to enhancing isolation in Two-Element MIMO Antennas. This novel technique leverages metamaterials' extraordinary properties, including negative permeability and permittivity, to manipulate electromagnetic waves effectively. By strategically placing metamaterial layers between antenna elements, the method disrupts and controls the propagation of electromagnetic fields, thereby reducing mutual coupling and improving isolation. (19).

Design Methodology

HFSS is a pivotal tool used for three-dimensional electromagnetic modeling and the design of MIMO (Multiple-Input Multiple-Output) antennas. This software is instrumental in achieving precise simulations that account for complex interactions in high-frequency environments, making it essential for the effective design and optimization of MIMO systems. Using HFSS, the design of a MIMO antenna begins with setting the fundamental parameters based on the application's requirements. The frequency range determines the size and type of antenna elements needed.

Single Antenna Design

In order to design this MIMO antenna, a single antenna with a 1.6 mm thick FR4 substrate is chosen. The obtained values are tuned to provide the intended outcomes. As illustrated in Figure 1, a single Microstrip patch antenna has an overall size of 26 × 26 mm2 and a radiating element of 18 x 16 mm2. Using materials such as Teflon and PEC, which have relative permittivity values of 2.1 and 1, respectively, the antenna is fed in this design using a 50 ohm SMA connector while maintaining an eye toward the realistic SMA connector. When utilizing simulation software instead of traditional wave port design, the results were excellent.

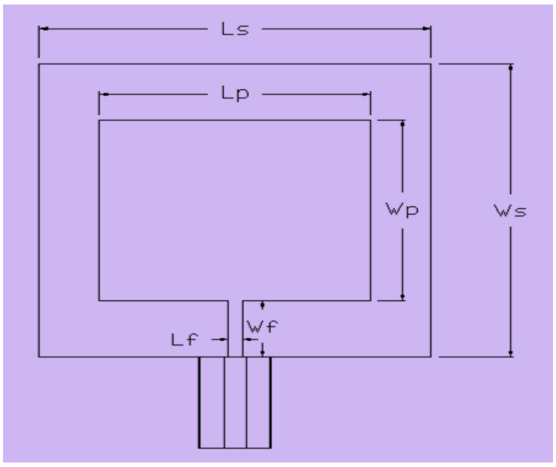


Figure 1: Geometrical representation of single antenna (Antenna 1)

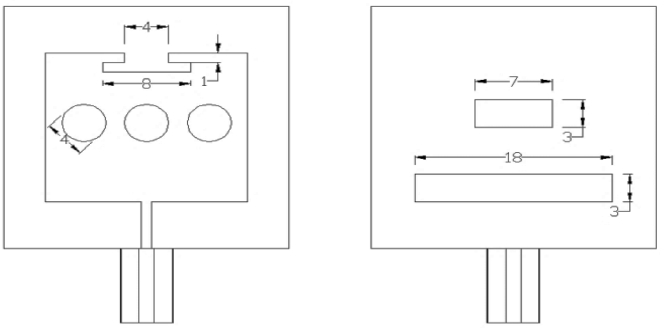
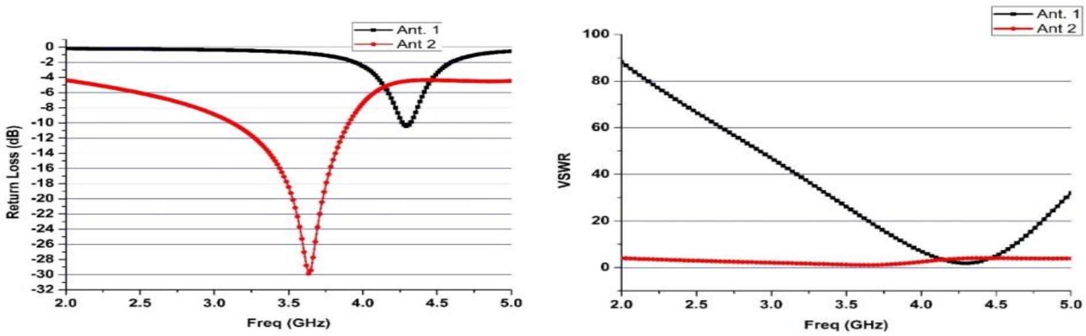


Figure 2: Modified design of single antenna (Antenna2)

The return loss of this design, when simulated with HFSS, is -10.41 dB at 4.29 GHz with a VSWR of 1.86. Circular and rectangular slots on the radiating element have been used to incorporate additional alterations to this design. Figure 2 illustrates how this design incorporates deficient ground by means of slots in the ground.



(A) (B)

Figure 3: (A) Return loss and (B) VSWR of Antenna 1 and 2

This design has resonated at 3.63 GHz with bandwidth of 760 MHz, return loss of -29.86 dB and VSWR 1.06. Implementation of rectangular and circular slots, operating frequency is changed from 4.29 GHz to 3.6 GHz. Return loss and VSWR are compared and shown in fig.3.

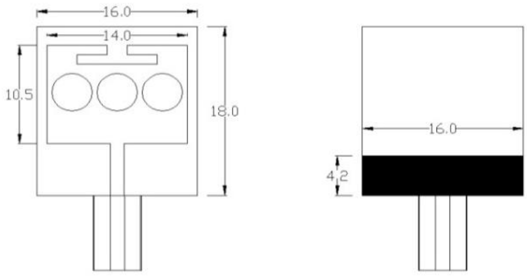


Figure 4: Antenna 3 with Reduced Ground

As shown in Figure 4, which has a resonance frequency of 3.67 GHz and a significant increase in bandwidth from 760 MHz to 3.320 GHz, this design has been further refined to achieve size reductions of up to 50% with partial ground. The radiating element loses its rectangular shape and becomes triangular. On the margins of the radiating element shown in Figure 5, punch holes are also added. Thus, the antenna's radiating area is decreased. This aids in extending the antenna's usable bandwidth. Plot figure 6 illustrates this. However, there is evidence that it modifies the antenna's emission. Plots are shown in Figure 6 to illustrate the return loss of -15.24 dB at 3.65 GHz with an improved bandwidth of 3.10 GHz.

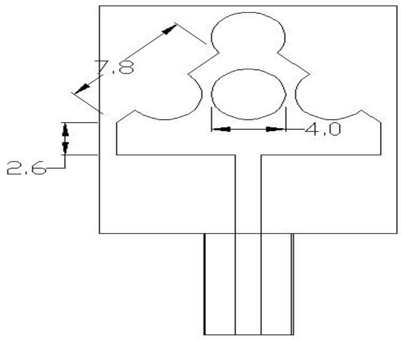
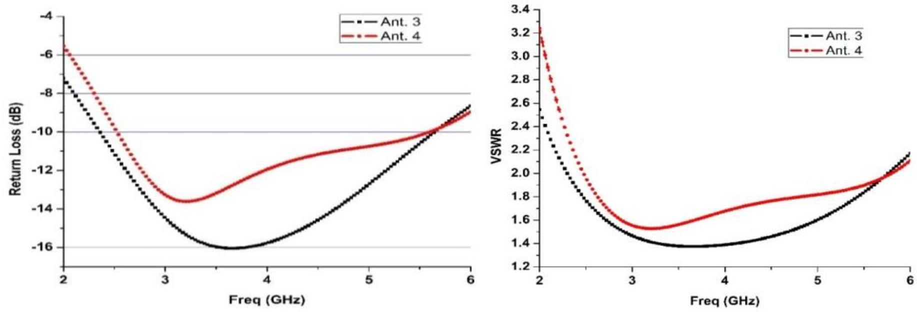


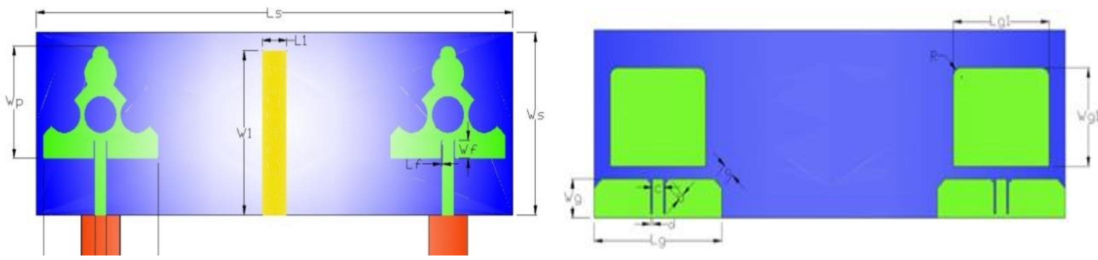
Figure 5: Antenna 4 with Triangular Antenna with Punch Holes

The basic mode, or first configuration, of the advised MIMO antenna is revealed in fig. 7. This clearly demonstrates that the MIMO antenna has two individual terminals. Microstrip feed lines and radiators in the shape of triangle having punch holes with reduced ground plane at the end of feed line and square shape with removed corners and slots below the radiator. Centrally placed Rectangular Strip Material (RSM) of dimensions 18 mm x 3.00 improved the isolation between elements. The critical separation between the radiating elements is achieved by positioning each antenna 43.00 mm center to center distance. This construction uses a FR4 substrate that is 1.6 mm.



(A) (B)

Figure 6: Simulation results of (A) Return Loss (B) VSWR of Antenna3 and 4



(A) (B)

Figure 7: 2 x 1 MIMO antenna configuration (A) front, (B) back profile

The depicted antenna system features a dual-antenna configuration aimed at improving MIMO performance for high-order 5G applications. The design incorporates two distinct antenna elements, each positioned symmetrically about a central axis, and these parameters are shown in fig.7. Key geometric parameters include:

- Ls (Length of Substrate): The total length of the substrate housing both antenna elements.
- Lp (Length of Patch): The length of each antenna patch element.
- Ws (Width of Substrate): The width of the substrate.
- Wp (Width of Patch): The width of each antenna patch element.
- L1 (Length of Isolation Structure): The length of the central isolation structure.

The green sections represent the antenna patches, while the yellow section indicates an isolation structure aimed at reducing mutual coupling, thereby improving isolation and enhancing overall performance.

Table 1: Parameter Values of the Projected Two Elements MIMO antenna

Parameter	Value (mm)	Parameter	Value (mm)
Ls	59.00	Ws	20.00
Lp	14.20	Wp	12.30
L1	3.00	W1	18.00
Lg	16.00	Wg	4.20
Lg1	12.00	Wg1	10.50

The design is carefully crafted to balance the need for compactness and high performance. As per the table 1the substrate dimensions (Ls and Ws) provide a foundation for the antenna elements and isolation structures. The patch dimensions (Lp and Wp) are optimized for resonant frequency and bandwidth requirements, while the isolation structure dimensions (L1 and W1) are crucial for minimizing mutual coupling. The ground plane dimensions (Lg, Wg, Lg1, and Wg1) help stabilize the antenna's performance, ensuring good impedance matching and radiation efficiency.

Antenna Geometry

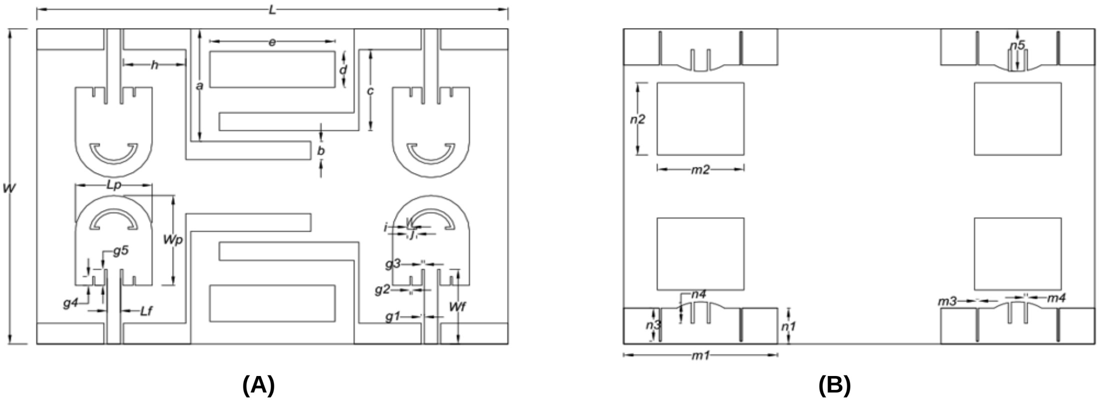


Figure 8: 4 x 1 MIMO antenna configuration (A) front, (B) back profile.

The Microstrip patch antenna consists of a rectangular form with a circular button mushroom structure on top, including small slits at the bottom. It is also equipped with a Microstrip feed line that has a thickness of 1mm. A C-shaped slot is incorporated on the radiating element to reduce surface current. The FR4 substrate is utilised with a thickness of 1.6 millimetres. The dimensions of the 4-element MIMO antenna are 49 mm by 35 mm. The ground is modified with slits of 16 mm X 4 mm within the element, along with an arc-like shape. These modifications are designed to enhance the resonance of the antenna at the required frequency and minimise mutual coupling. A supplementary ground measuring 9mm x 8mm is employed on the rear side of the radiating element to enhance the radiation properties of the antenna system. Each radiating element is accompanied with an inverted L-shaped bracket, which serves to enhance isolation and MIMO performance. The depicted antenna system features a dual-antenna configuration aimed at improving MIMO performance for high-order 5G applications. The design incorporates four distinct antenna elements, each positioned symmetrically about a central axis, and these parameters are shown in fig.8.

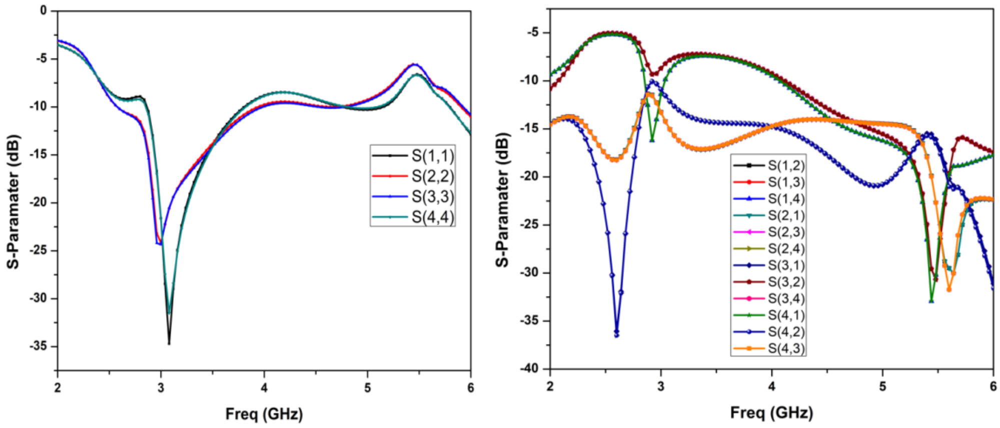
Table 2: Parameter values of the projected four elements MIMO antenna.

Parameter	Value (mm)	Parameter	Value (mm)
Ls	49.00	Ws	35.00
Lp	08.00	Wp	10.00
Lf	1.00	Wf	08.00
g1	0.300	g2	0.200
g3	0.300	g4	1.00
a	13.00	b	2.00
c	9.00	d	4.00
g5	1.00	e	13.00

The design is carefully crafted to balance the need for compactness and high performance. As per the table 1the substrate dimensions (Ls and Ws) provide a foundation for the antenna elements and isolation structures. The patch dimensions (Lp and Wp) are optimized for resonant frequency and bandwidth requirements, The additional geometrical parameters (a, b, c, d, and e) fine-tune the antenna's electromagnetic characteristics, potentially affecting factors like return loss, bandwidth, and radiation pattern.

Results and Discussion

The two frequencies in which the designed MIMO antenna resonantly operates are 3.28 and 5.4 GHz. Moreover, at working frequencies of 3.28 and 5.4 GHz, respectively, the antenna's maximum reflection coefficient is −15.33 dB and – 29.11 dB, and its isolation is −30.53 dB and −42.59 dB. Figure 8 illustrates these charts. With a dual band nature, this 2-element MIMO antenna operates between 2.75 GHz and 4.64 GHz and 5.24 GHz and 5.53 GHz. This encompasses the frequency bands n77, n78 (C-Band), and n46 (unlicensed National Information Infrastructure radio band). 2.18 GHz of total bandwidth is obtained with this arrangement.



(A) **(B)**

Figure 9: Reflection Coefficients (A) S11, S22, S33, S44(B) S12 and others

HFSS software is used to plot the simulated radiation pattern for the E and H planes, or far-field radiation properties. Plots of the radiation patterns for all ports are shown. This plotis demonstrated in fig. 10

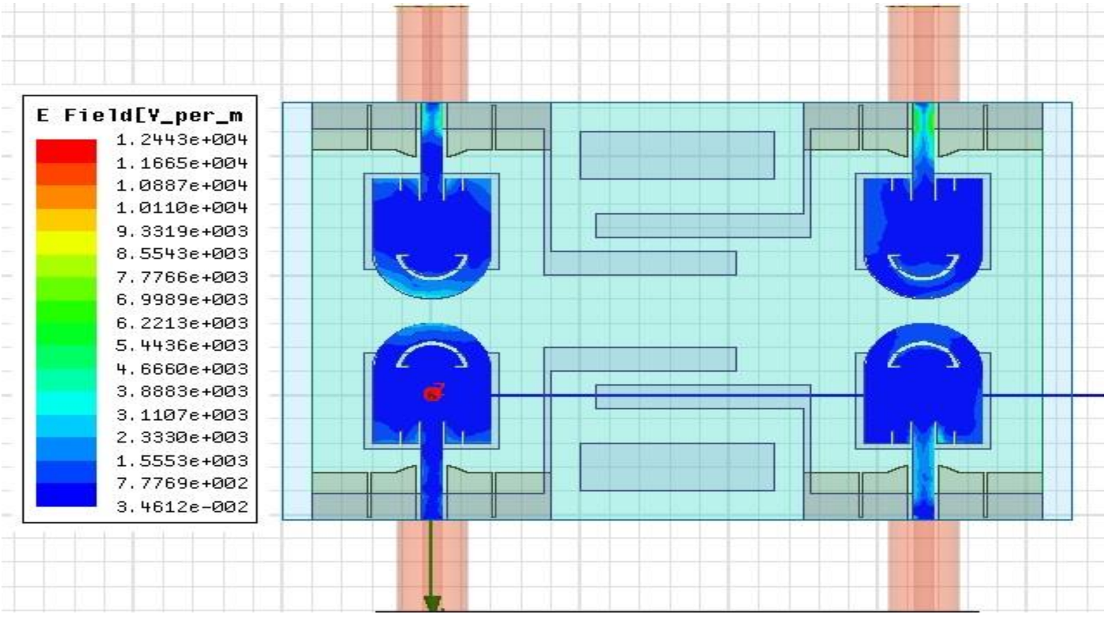


Figure 10: Surface Current Distribution for Four Element MIMO

The gain, measured in decibels (dB), shows distinct patterns for each angle, with the black line representing the gain at Φ=0° and the red line representing the gain at Φ=90°.At Φ=0°, the antenna exhibits a more uniform gain pattern with peaks reaching maximum up to 16.30dB. This indicates strong and consistent signal strength in this orientation. In contrast, at Φ=90°, the gain pattern is more varied, with several lobes and nulls, reaching a maximum gain of around 12 dB. This suggests that the antenna has directional properties, providing different levels of gain depending on the orientation.

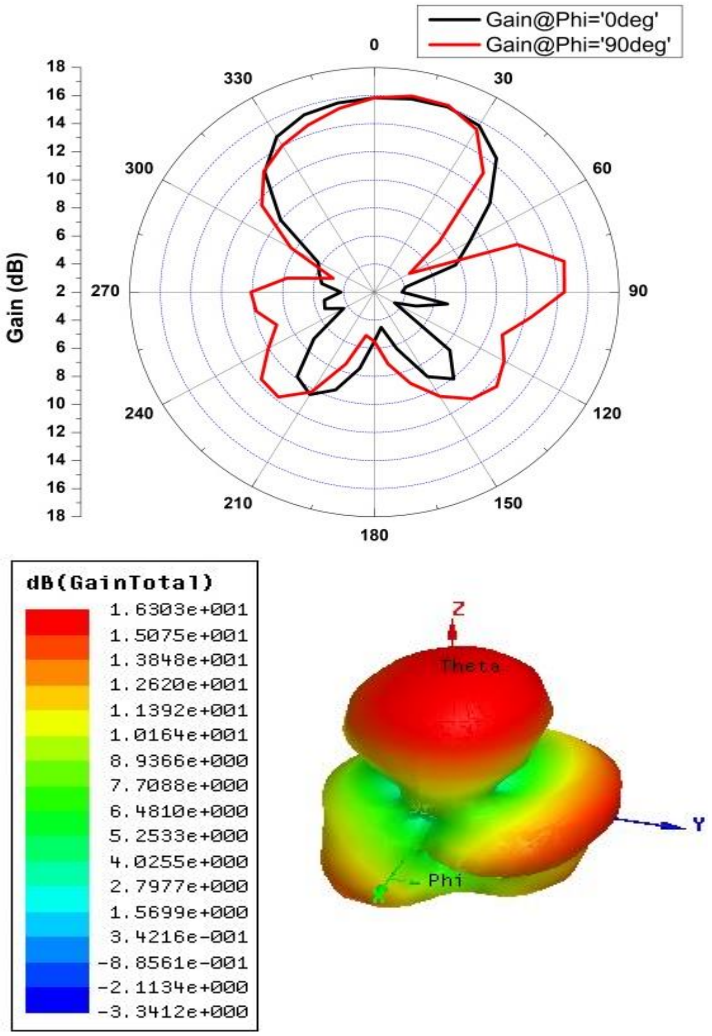


Figure 11: Gain of the Proposed Antenna

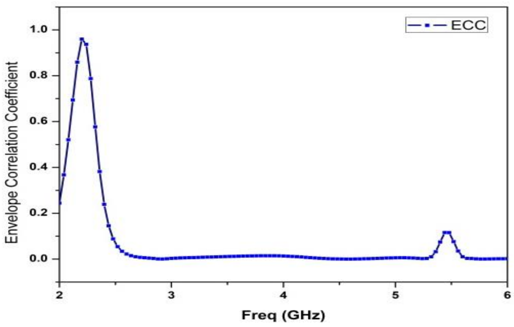
Diversity Performances

When assessing a MIMO antenna's performance, diversity performance indicators are among the most crucial things to take into account. In order to assess the effectiveness of MIMO antennas, it is imperative that the DG and ECC properties be carried out as precisely as possible. ECC values can be determined by using S-parameters and 3-D radiations. Important MIMO antenna parameters include "CCL, MEG, TARC, DG, and ECC." (20) are studied and presented here

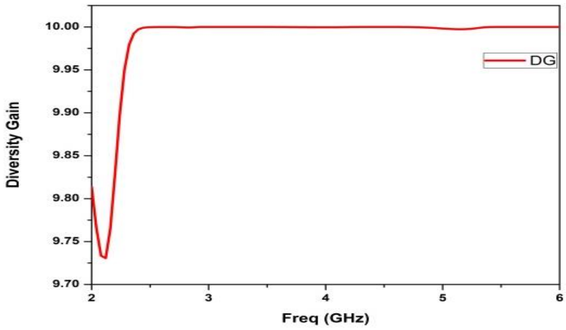
$$ECC = \frac{|S_{ii}*S_{ij}+S_{ji}*S_{jj}|^2}{(1-|S_{ii}|^2-|S_{ji}|^2)\left(1-|S_{jj}|^2-|S_{ij}|^2\right)} \quad ....(1)$$

The coefficients of reflection in this equation are Sii and Sjj, while the coefficients of transmission are represented by Sij and Sjj. The greatest value that may be used for a MIMO antenna is much higher than the ECC, which was found to be approximately 0.01. Plot of the ECC is displayed in fig. 10(a). In fig. 10(b), the plot of diversity gain is displayed. Diversity Gain is connected to ECC, which is greater than 9.99 dB.

$$DG = 10\sqrt{1-ECC^2} \quad .... (2)$$



(A)



(B)

Figure 12: (A) Plot for ECC and (B) DG

It is anticipated that a TARC value of less than 0 dB will be present in order for a MIMO to function appropriately

$$TARC = \sqrt{\frac{(S_{11}+S_{12})^2+(S_{22}+S_{21})^2}{2}} \quad .... (3)$$

CCL is a measurement that determines whether or not the information or signal can be transmitted across the channel path without becoming disrupted in any way. Consequently, it is a very helpful aspect to test the quality of a MIMO antenna and the components that are associated with it. It is possible to compute CCL by utilizing the equation (4 - 6) (20).

$$CCL = -log_2\, det(a) \quad .... (4)$$

where a is matrix of correlation.

$$a^R = \begin{pmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{pmatrix} \quad .... (5)$$

$$\rho_{ii} = 1 - \left(|S_{ii}|^2 + |S_{ij}|^2\right), and ..$$

$$\rho_{ij} = -\left(s_{ii} * s_{ij} + s_{ij} * s_{jj}\right),$$

$$for\ \ i\ and\ j = \ 1\ and\ 2 \quad .... (6)$$

It can be seen to determine that the CCL is lower than the practical specified limit of 0.6 bits/sec/Hz, and that the lowest possible amount of CCL is accomplished within the operational bands of the projected MIMO antenna. The design of a small, dual-band planar MIMO antenna with a FR-4 substrate is presented in this study. The suggested antenna reduces surface waves and enhances inter-element isolation by using a 1 × 2 array with a Resonant Slot Mode (RSM). With a low profile and compact dimensions, the antenna is ideal for 5G n78/79 channel applications. S-parameters, VSWR, DG, TARC, ECC, and CCL are some of the metrics used to evaluate its performance. Interestingly, at 0.0002, the ECC value is remarkably low.

Conclusion

Reducing the size of the original design was an attempt to improve the performance of a MIMO antenna and reach the target frequency. The objective was to design a small, dual-band planar MIMO antenna for C-Band frequencies utilizing a FR-4 substrate. To improve isolation and stop surface waves, this design uses four elements with an additional resonant structure mechanism (RSM) at the middle. The final antenna has a low profile and is suitable for 5G n78/79 channels. An exceptionally low ECC value of 0.01 and a high gain of up to 16.30 dB indicate excellent isolation. MIMO antennas play a crucial role in 5G since they boost data throughput and dependability. A greater gain can be achieved by further optimizing methods such as substrate integrated waveguides, artificial magnetic conductors, or cavities between the patch and ground.

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