DEVELOPMENT OF INVERTED "L"PATCH MIMOANTENNA FOR MULTIBAND WIRELESS APPLICATIONS

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ABSTRACT:

A slotted patch MIMO antenna with inset feeding was designed for optimal wireless performance, featuring compact dimensions of 70 x 60 x 1.6 mm³. Utilizing an FR-4 substrate with a permittivity (εr) of 4.4 and a low loss tangent of 0.02, the single-element antenna achieved an impressive frequency range from 3.2 GHz to 7 GHz resonating at 3.2GHz,5.04GHz,6.36GHz. The antenna innovation lies in the incorporation of a semicircular slot in the patch and the strategic use of the Defected Ground Structure (DGS) (+) technique to enhance bandwidth and gain. Simulations using High-Frequency Structure Stimulator (HFSS) software validated the design, serving as the foundation for a sophisticated two-element inset-fed slotted patch MIMO antenna. The proposed MIMO antenna exhibited exceptional diversity gain exceeding 9.9 dB, an envelope correlation coefficient consistently below 0.02, and favorable metrics including Channel Capacity Loss (CCL), Total Active Reflection Coefficient (TARC), and Mean Effective Gain (MEG). This innovative antenna design holds promise for optimizing MIMO system performance in diverse wireless communication applications.

KEYWORDS:

Defected Ground Structure(DGS), High-Frequency Structure Stimulator (HFSS),Channel capacity loss (CCL), Envelope correlation coefficient (ECC), Multiple-input-multiple-output (MIMO), Total active reflection coefficient (TARC).

INTRODUCTION:

In this article, a novel high-gain dual-band Microstrip Patch Antenna (MPA) is proposed. The antenna is designed to operate at multiple frequencies, catering to various wireless communication standards concurrentlyBuilt with two inverted L-shaped patches on an FR-4 substrate, it employs a Defected Ground Structure (DGS) to elevate its overall performance. The antenna consists of two inverted L-shaped patches positioned with a small gap "g" between them.

These design techniques are employed to achieve multi-band, leveraging the presence of two distinct current paths. This configuration ensures stable radiation characteristics across the entire operational frequency band.Inverted L patch MIMO antenna with improved performance across many frequency bands, utilizing creative slot design for multiband wireless applications. With its enhanced bandwidth, gain, and efficiency, this antenna meets the increasing need for adaptable wireless communication solutions. It ensures dependable and fast data transfer while integrating seamlessly into contemporary communication networks thanks to careful design and optimization. Because of its compatibility with WLAN, WiMAX, and other newer wireless standards, the slotted patch architecture makes it an adaptable option for a range of communication requirements. This introduction emphasizes how the antenna's reliable performance and flexibility to adapt to changing technological environments could revolutionize multiband wireless communication.

Researchers have developed numerous antennas for wireless applications. For instance,The multi-band microstrip patch antenna, spanning 1-6.5 GHz, features a copper patch on an FR4 epoxy substrate with a partial ground plane. Two strategically placed slits near the feed line enhance impedance matching and broaden bandwidth. However, a notable challenge lies in the need for adjustment of slit dimensions and positions to achieve desired impedance matching and bandwidth enhancement. Addressing this challenge involves conducting parametric studies and simulations to identify the optimal slit configuration [1].The limited bandwidth in a Microstrip patch antenna is a significant drawback. However, several established methods can enhance antenna bandwidth, such as increasing substrate thickness, utilizing low-dielectric substrates, and incorporating multiple resonators. It's important to note that antenna bandwidth and size are typically conflicting properties; improving one characteristic often results in the degradation of the other [2-3]. In wideband slotted microstrip patch antenna designed for Ku-band operation, featured a defective ground structure with circular patches. The defective ground incorporates circular patches to enable dual-frequency operation. The radiating element has two etched slots: one square and the other a circular ring[4].The incorporation of elliptical-shaped fractal geometry in the design of the microstrip patch antenna results in improved compactness, aiding its suitability for wireless applications. The incorporation of defected ground structures further facilitates a wide impedance bandwidth and increased gain. The antenna employs a compact microstrip feedline for efficient electromagnetic energy coupling to the radiator through a lumped port.

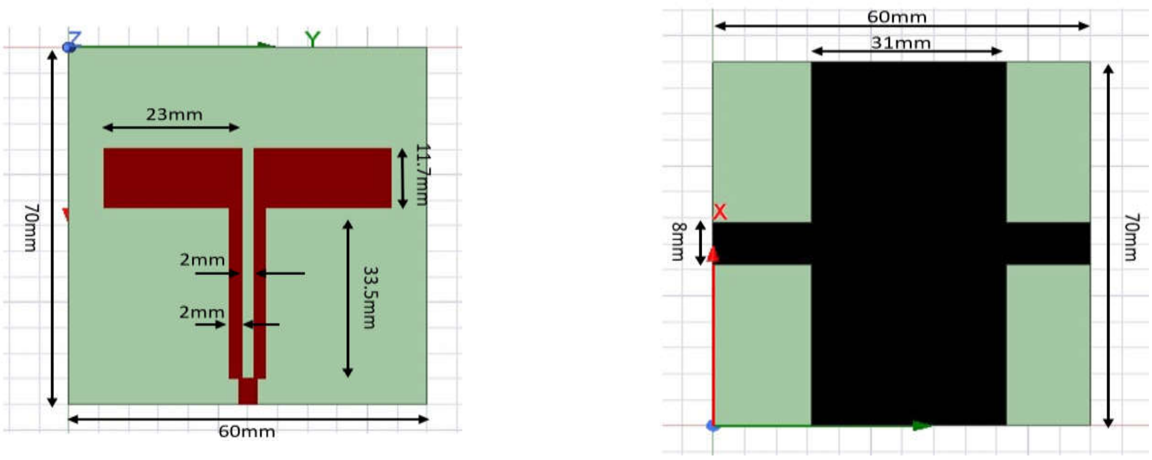
MIMO antennas revolutionize data transmission by employing multiple antennas for simultaneous sending and receiving. This innovative approach enhances data rates and signal quality, particularly in challenging environments with weak signals or interference. MIMO is integral to modern telecommunication standards, prevalent in Wi-Fi networks, 4G LTE, 5G technology, and power-line communication. Distinguished from SISO (Single Input, Single Output) antennas, which have one transmitter and receiver, MIMO exploits space diversity to capitalize on diverse radio paths in terrestrial environments. To optimize MIMO technology, antennas with minimal mutual coupling and limited space are crucial, as clustering antennas in a confined area can lead to severe mutual coupling and reduced diversity performance. Various strategies have been developed to mitigate these challenges. Utilizing different antennas for transmission and reception, multi-input multi-output (MIMO) antennas enhance data transmission performance and channel capacity without compromising additional energy and bandwidth. Addressing issues like multiple fading, where signals mix destructively at the receiver due to varying amplitudes and phases, MIMO antenna systems not only improve antenna performance but also mitigate challenges such as reduced mutual coupling and correlation between antenna elements.

The advancements and improvements in Inverted L patch patch MIMO antennas are examined in this paper, with a focus on their applicability in wireless applications. Various techniques have been developed to improve the isolation between individual components in MIMO antennas.Good isolation between the two antennas would be achieved by placing the antennas in such a way that they have sufficient space between them [7]. The enhancement of isolation can be achieved by modifying the ground plane, [8]. This modification may involve incorporating slits [9,10].

The proposed antenna exhibits multiband characteristics, resonating at 3.2 GHz, 5.04 GHz, and 6.36 GHz frequency bands, with corresponding impedance bandwidths of 269 MHz, 955MHz, and 448 MHz with peak gain of 2.36dB

SINGLE ANTENNA ELEMENT DESIGN:

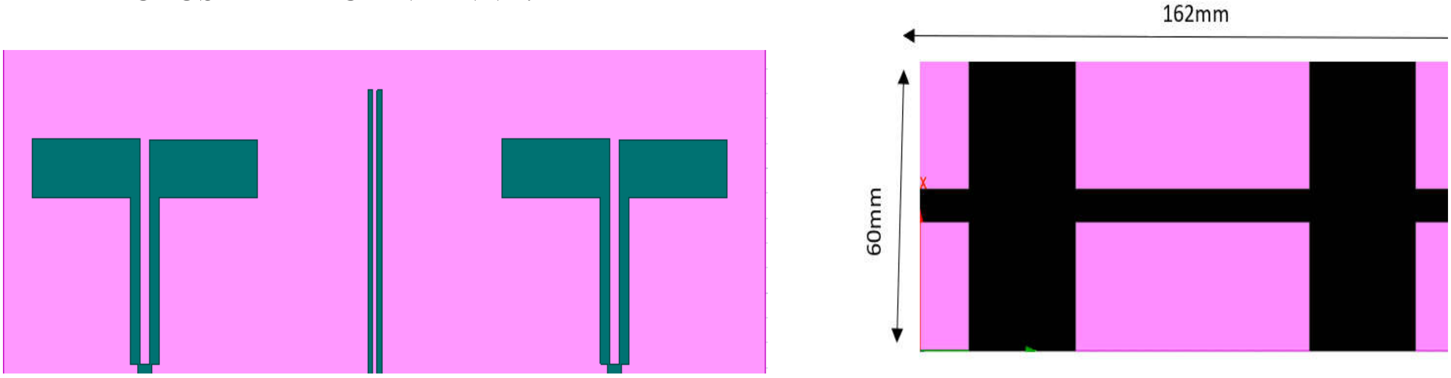
The schematic representation of the dual-band microstrip patch antennas is depicted in Fig. 1, featuring dimensions of 70×60 mm² and utilizing FR-4 material with a relative permittivity (ϵr) of 4.3 and a tanδ of 0.025 as the substrate, with a thickness of 1.6 mm. The antenna design process begins by establishing fixed parameters, with transmission line parameters determined using equations detailed in [11]. Figures 1(a) and 1(b) illustrate the schematic top and bottom views of the proposed antenna, respectively. This design incorporates a two inverted L patch, coupled with the Defected Ground Structure (DGS) technique, showcasing a sophisticated approach to enhancing both bandwidth and gain.



(a) (b)

Fig .1 Schematic view of the proposed antenna. (a) Top-view. (b) Bottom-view

PROPOSED MIMO ANTENNA:



(a) **(b)**

Fig .2 proposed MIMO antenna a) Top view b) Bottom view

The development process from a single-element antenna to a MIMO (Multiple-Input Multiple-Output) configuration with coupling involves careful consideration of dimensions, substrate properties, and innovative features such as the Inverted L patch and Defected Ground Structure (DGS) technique. Initially ,Inverted L patch antenna with inset feeding is designed for its compact size (70 x 60x 1.6 mm^3) and broad frequency range (3.1 GHz to 6.7GHz), utilizing an FR-4 substrate with a relative permittivity (εr) of 4.4 and a low loss tangent of 0.02. Transitioning to a MIMO configuration requires accommodating multiple elements and ensuring effective coupling between them, leveraging the foundation laid by the single-element antenna's design.

Throughout the iterative refinement and testing stages, adjustments to element placement, coupling mechanisms, and substrate properties are made to achieve optimal MIMO performance. The resulting MIMO antenna configuration represents a sophisticated solution for enhancing wireless communication performance in diverse applications. With exceptional diversity gain (exceeding 9.9 dB), low correlation coefficients (consistently below 0.02), and favorable metrics such as Channel Capacity Loss (CCL), Total Active Reflection Coefficient (TARC), and Mean Effective Gain (MEG), it holds the promise of optimizing MIMO system performance across various wireless communication scenarios.

Parameters	Wm	Lm
Values	60	162

ANTENNA STAGES	Operation Bandwidth (GHz)	Bandwidth (in MHz)	Peak Gain(dB)
STAGE 1	3.31 – 3.57 4.83-6.23	0.260 900	1.98dB
STAGE 2	3.287 – 3.556 4.851– 5.806 6.200-6.648	0.269 0.955 448	2.36dB

RESULTS:

The development of a slotted patch MIMO antenna with inset feeding signifies a significant leap in wireless communication technology. Validation through simulations using High-Frequency Structure Stimulator (HFSS) software provides a robust foundation for the design, enabling the creation of a sophisticated two-element inset-fed slotted patch MIMO antenna. This proposed MIMO antenna demonstrates outstanding performance metrics, including diversity gain exceeding 9.9 dB, an envelope correlation coefficient consistently below 0.02, and favorable indicators like Channel Capacity Loss (CCL), Total Active Reflection Coefficient (TARC), and Mean Effective Gain (MEG). With its groundbreaking design and promising results, this innovative antenna holds immense potential for optimizing MIMO system performance across various wireless communication applications, ushering in a new era of efficiency and reliability in wireless networking.

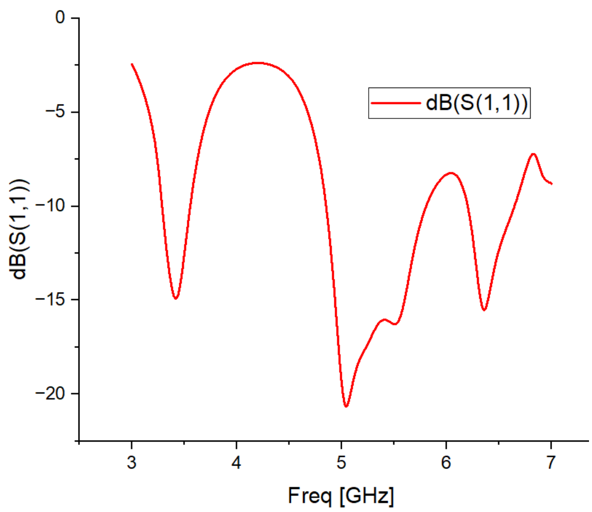


Figure 3 – Reflection Co-efficient(S11) graph

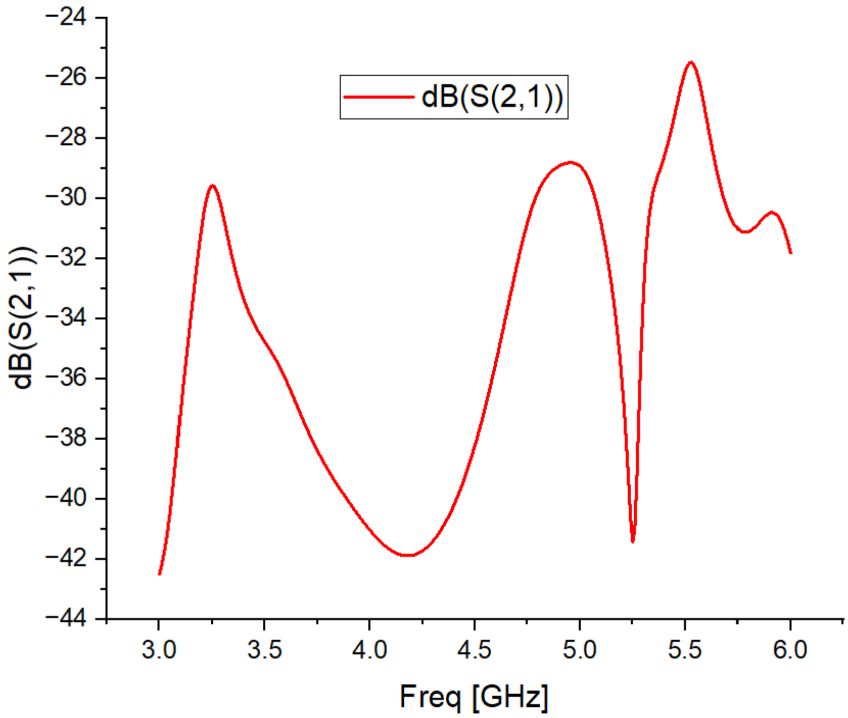


Figure4– Reflection Co-efficient(S21) graph

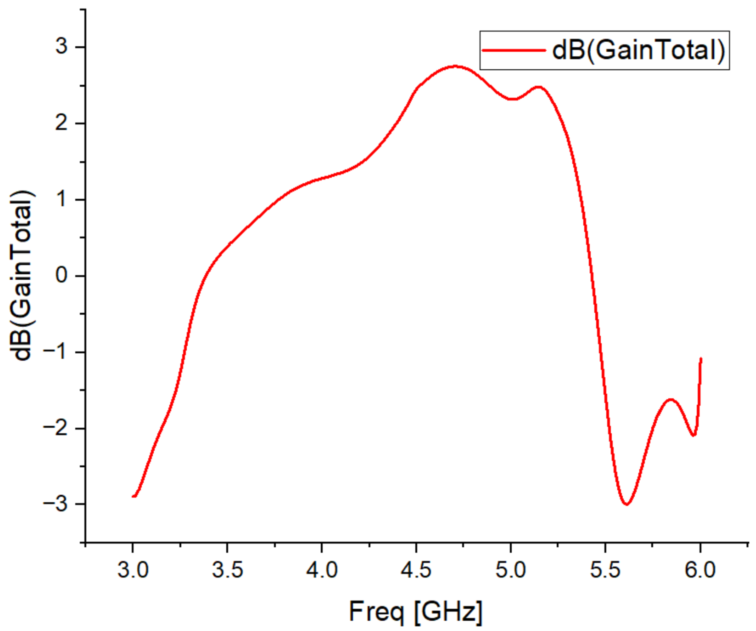


Fig .5Gain plot

MIMO ANTENNA EVALUATION PARAMETERS:

This section looks into the MIMO antenna parameters, including the envelope correlation coefficient, diversity gain, and total active reflection coefficient (TARC).

Envelope Correlation Coefficient (ECC):

The envelope correlation coefficient (ECC) stands as a pivotal metric in assessing the synergy between neighboring MIMO antenna elements, crucial for optimizing wireless diversity. Traditionally derived from either radiation patterns or S-parameters, the preference leans towards utilizing far-field radiation patterns for ECC evaluation in MIMO systems. This preference stems from its ability to elucidate the independence of radiating units, crucial for accurate assessment. However, caution is warranted when applying S-parameters for ECC determination, particularly with planar antennas susceptible to loss. To streamline ECC calculations, a derived formula based on MIMO radiation pattern parameters offers a concise and effective approach, enhancing precision in evaluating antenna interaction and system performance.

$$ECC = \frac{|s_{11}^{*}s_{12}+s_{21}^{*}s_{22}|^{2}}{(1-|s_{11}|^{2}-|s_{21}|^{2})(1-|s_{22}|^{2}-|s_{12}|^{2}}$$

S_{11} is the reflection coefficient of Antenna 1.

S_{12} and S_{21} are the mutual coupling of the MIMO Antenna.

S_{22} is the reflection coefficient of Antenna 2.

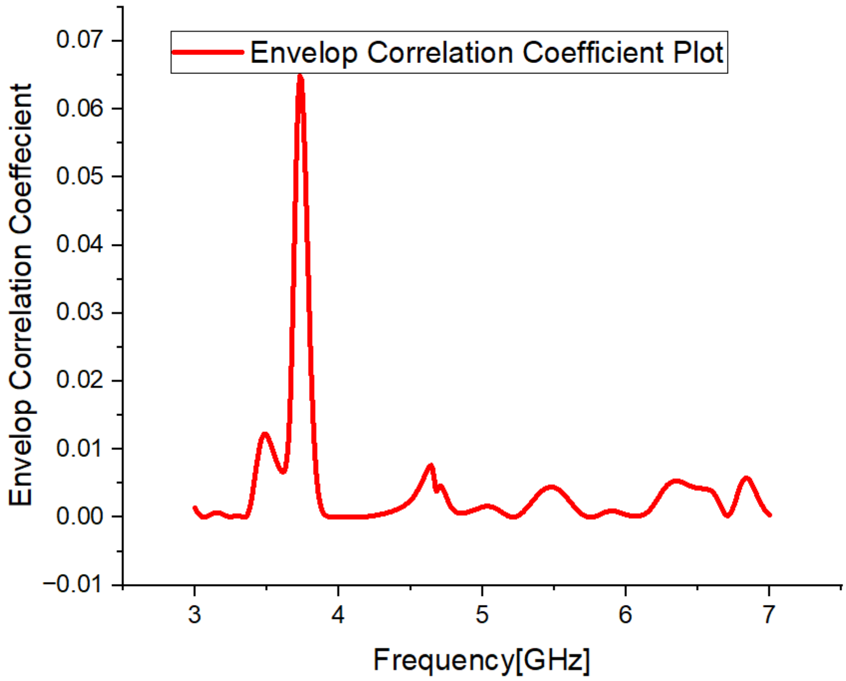


Fig6: Envelope Correlation Co-efficient

Channel Capacity Loss(CCL):

The Channel Capacity Loss (CCL) encapsulates the optimal information transmission potential across a communication medium with minimal loss, a critical consideration in MIMO systems. With a predefined threshold set at less than 0.4 bits/s/Hz, MIMO systems aim to maximize efficiency while minimizing loss. Leveraging S-parameters, an equation is derived to quantify CCL, providing a concise means to assess and optimize information transmission capabilities. This unique approach offers a clear insight into system performance, facilitating the fine-tuning of MIMO configurations for enhanced efficiency and reliability in wireless communication.

$CCL = - \log_2 \det(\beta^R)$

$\beta^R = \begin{bmatrix} \beta 11 & \beta 12 \\ \beta 21 & \beta 22 \end{bmatrix}$

$\beta_{11} = (1 - (|S_{11}|^2 + |S_{12}|^2))$

$\beta_{22} = (1 - (|S_{21}|^2 + |S_{22}|^2))$

$\beta_{12} = -(s^*_{11}\, s_{12} + s^*_{21}\, s_{22})$

$\beta_{21} = -(s^{*}_{22}\, s_{21} + s^{*}_{12}\, s_{11})$

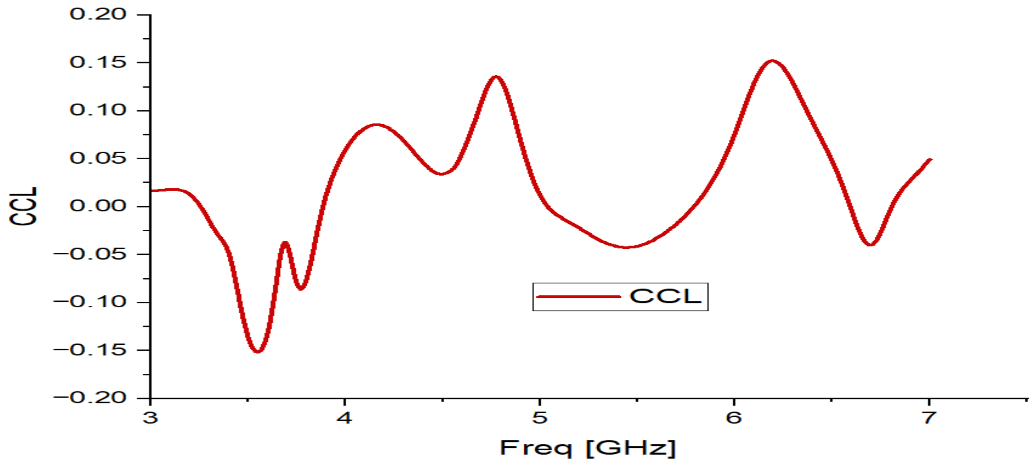


Fig 7: Channel Capacity Loss

Total Active Reflection Co-efficient (TARC):

The Total Active Reflection Coefficient (TARC) plays a critical role in MIMO systems by indicating the equilibrium between the power reflected by radiating elements and the power incident on the patch, thereby influencing overall system performance.It epitomizes the antenna's ability to harness all incoming power efficiently, with an ideal scenario aiming for a TARC value of zero. As the design unfolds, optimizing antenna diversity parameters within specified thresholds becomes imperative, ensuring seamless integration of MIMO capabilities while maximizing transmission efficacy. Anchored by the equation for calculating the generalized TARC for an N-port MIMO antenna, this approach offers a unique avenue for fine-tuning system performance, underlining the quest for unparalleled efficiency and reliability in wireless communication.

$$\text{TARC} = \frac{\sqrt{\left(\left|S11+S12\, e^{j\theta}\right|^{2}\right)+\left(\left|S21+S22\, e^{j\theta}\right|^{2}\right)}}{\sqrt{2}}$$

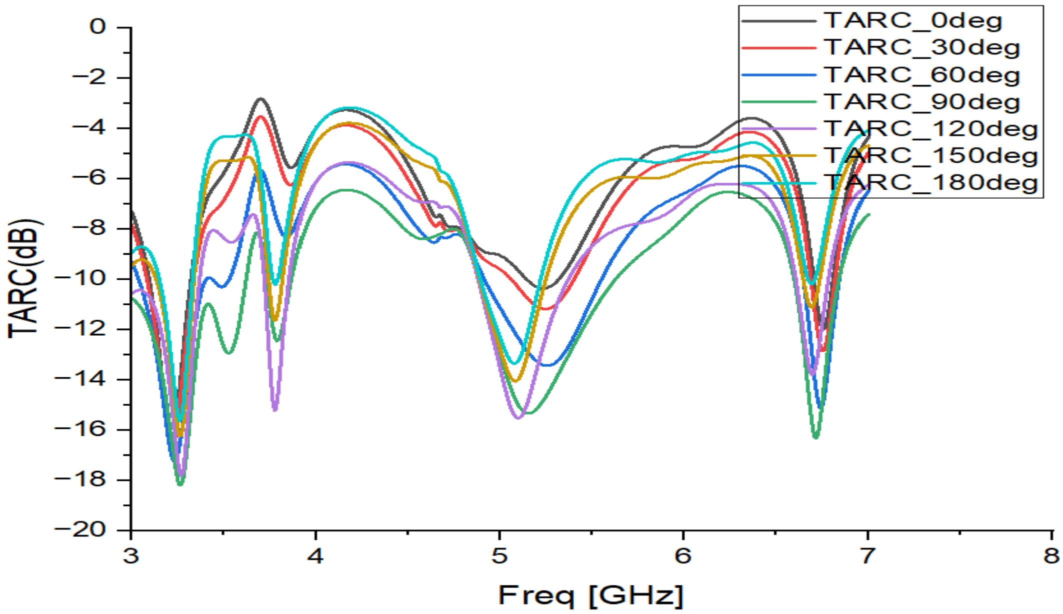


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Fig 8: Total Active Reflection Co-efficient

Mean Effective Gain:

The Mean Effective Gain (MEG) functions as a critical conductor, intricately assessing the efficacy of Multiple-Input Multiple-Output (MIMO) antenna setups through comprehensive analysis of all potential transmit and receive antenna configurations.It delves into the spatial intricacies of the wireless channel, accounting for factors like spatial correlations among antennas and their environmental placement. Acting as a guiding force, MEG navigates through the complexities of signal reception and interference mitigation, ultimately optimizing link quality. Its insights aid in the design and optimization of MIMO configurations, unlocking higher data rates, reliability, and spectrum efficiency, thus solidifying its role as a vital metric in wireless communication systems.

$MEG1 = 0.5(1-(|S_{11}|^2 + |S_{12}|^{2)})$

$MEG2 = 0.5(1-(|S_{12}|^2 + |S_{22}|^2)$

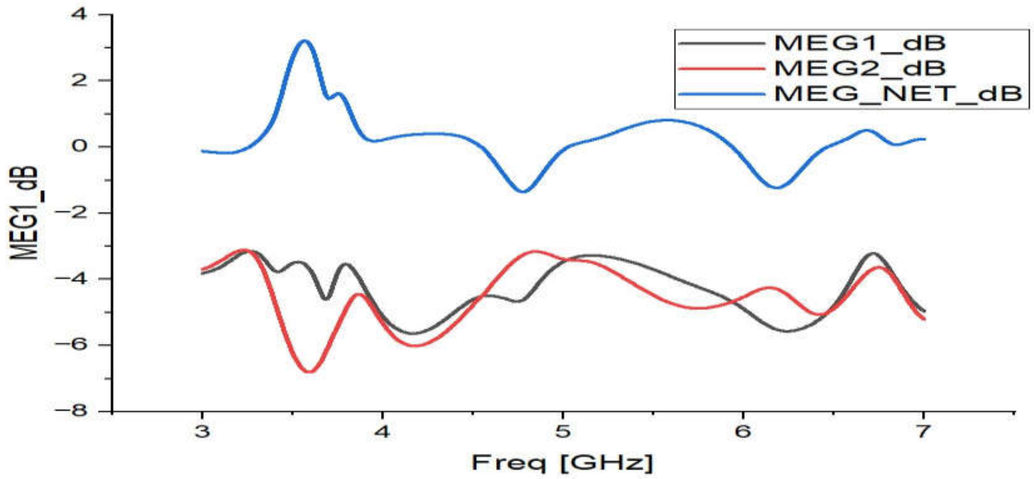

Fig 9: Mean Effective Gain

Diversity Gain(DG):

Diversity gain epitomizes the resilience of wireless communication systems, harnessing the power of multiple antennas to bolster reliability amidst the capriciousness of the wireless medium. Like a symphony of voices blending in harmony, it amplifies signal quality through the amalgamation of diverse signal versions, each sculpted uniquely by the vagaries of fading. This fusion serves as a shield against the erosive forces of fading, fortifying signal robustness, extending coverage, and augmenting capacity, especially in challenging environments. Rooted in the assumption of uncorrelated diversity antennas and independent fading channels, diversity gain stands as a mathematical testament to the art of leveraging multiplicity to triumph over uncertainty in the wireless realm.

$DG = 10 \cdot \log 10(N)$

Where:

DG is the diversity gain in decibels (dB)

N is the number of independent diversity branches or antennas.

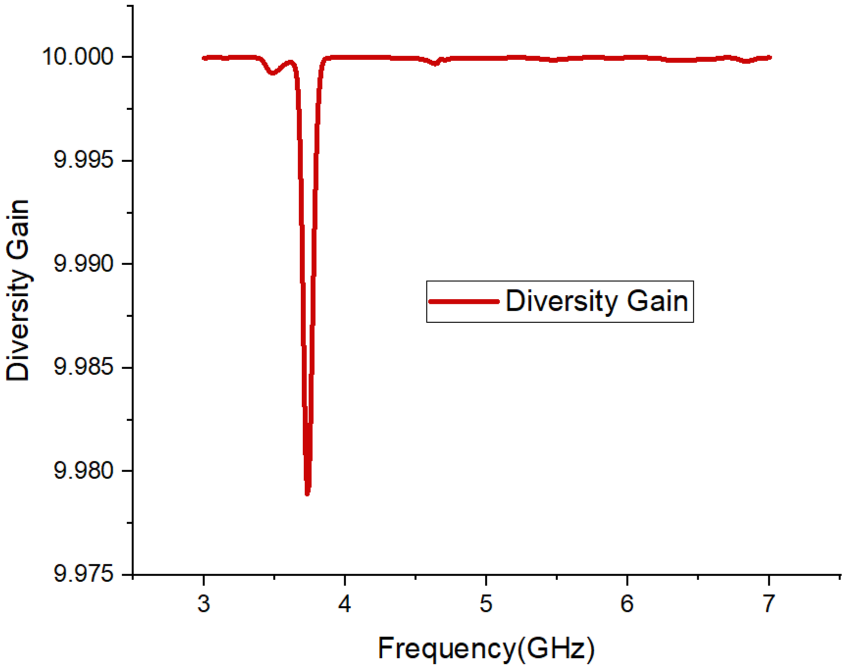

Fig 10: Diversity Gain

Conclusion:

In conclusion, the development of a slotted patch MIMO antenna with inset feeding showcases a significant advancement in wireless communication technology. Through meticulous design and utilization of innovative techniques such as incorporating a semicircular slot in the patch and employing the Defected Ground Structure (DGS), the antenna achieves impressive bandwidth and gain enhancements.The proposed MIMO antenna exhibited an impedance bandwidth spanning from 3.287 GHz to 3.556 GHz , 4.851 GHz to 5.806 GHz and 6. 2GHz to 6.648 GHz coupled with low mutual coupling across the frequency range.The proposed MIMO antenna design demonstrated exceptional diversity performance, characterized by an Envelope Correlation Coefficient (ECC) of less than 0.1, Diversity Gain (DG) exceeding 9.9, and mutual coupling below -10 dB.

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