International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

4-Port MIMO Antenna Diversity Analysis for 5GApplications

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Submitted: 25/05/2023 **Revised**: 07/07/2023 **Accepted**: 23/07/2023

Abstract: In this research endeavor, we engage in the creation and computational modeling of a quad-port rectangular microstrip patch antenna. The antenna is strategically tailored to function within the 3.3 GHz frequency spectrum, aligning with its utilization in the context of 5G technology-oriented applications. MIMO channel with four spatial streams should be capable of four times the capacity of the SISO channel. IEEE 802.11n (WLAN) standard is designed to support MIMO configurations with as many as four spatial streams. At the highest data rate, bursts using a 64 QAM modulation scheme with a 5/6 channel code rate. To start, a single Dielectric Resonator Antenna (DRA) is intricately designed. The dielectric resonator takes on a square shape, with precise measurements of 19.868 mm in height and 15.482 mm in width. This antenna, engineered to operate with a frequency of 3.3 GHz, featuresan input impedance that closely resembles 50 Ω. The selection of FR4 (εr = 4.8) as the substrate material, along with a height (h) of 1.6 mm, contributes to this characteristic. The HFSS software is employed as the primary tool for initial simulation and for precisely determining the optimal positioning of the DRA, in alignment with diverse 5G applications. The analysis of the antenna's effectiveness encompasses metrics such as Gain, Reflection Coefficient, Voltage Standing Wave Ratio (VSWR), Impedance, and Antenna Bandwidth. Theconfiguration of the four-port microstrip antenna array was formulated utilizing an FR4 substrate, with its operational frequency centered at 3.3 GHz within the ISM band.

***Keywords**: Dielectric Resonator antenna, MIMO, ECC, MEG, Transmission Coefficient.*

1. Introduction

Modern wireless standards, such as IEEE 802.11n, 3GPP LTE, and mobile WiMAX systems,incorporate multiple-input, multiple-output (MIMO) antenna systems. This technique serves to enhance data throughput, particularly when faced with challenges like interference, multi-path effects, and fading. The rationale behind MIMO antenna systems lies in meeting the demand for heightened data rates across extended distances. By featuring multiple antennas at both the transmitting and receiving ends, MIMO systems facilitate improved data speeds, extended coverage, and heightened reliability, all without necessitating additional transmit power or bandwidth. These systems establish multiple autonomous communication paths, enabling the simultaneous transmission of multiple data streams [1].

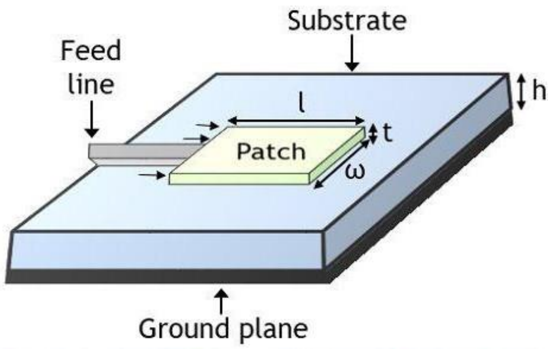

Fig.1: Configuration of the Rectangular Microstrip Patch Antenna

As seen in Figure 1, microstrip antennas are made of a thin (t) metallic strip (patch) that is kept above a ground plane and is positioned at a tiny wavelength (h). The microstrip patch is made to have a maximum pattern that is consistent with the patch (broadside radiator). By carefully selecting the mode (field configuration) of stimulation beneath the patch, this is achieved. Prudent mode selection can potentially result in end-fire radiation. The element's length L for a rectangular patch is typically $\lambda 0/3 < L < \lambda 0/2$. The strip (patch) and the plane of ground are separated by a dielectric material (called as the substrate), as shown in Figure [2]. This paper presents the simulation of a 4-port MIMO antenna operating within the 3.3 GHz frequency range. The feed mechanism employed for the antenna involves the coaxial inset technique, and the simulations were conducted

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utilizing HFSS software.

2. Creating A Dielectric Resonator Antenna (Dra) Design

The antenna array design commenced with a meticulous selection of an appropriate dielectric resonator. Initially, a solitary Dielectric Resonator Antenna (DRA) was formulated, characterized by its square dimensions of 19.868 mm in height and 15.482 mm in width. This particular antenna configuration was custom-tailored for optimal performance at a frequency of 3.3 GHz, while upholding a consistent input impedance of 50 Ω. The chosen substrate material was FR4 (εr = 4.8), with a height parameter (h) set at 1.6 mm. To precisely establish the placement of the DRA, an initial simulation was conducted using the HFSS software. Additionally, the design incorporated a coaxial line feed approach. Following the successful simulation, the transmission line was physically implemented on an FR4 board, which possessed a dielectric constant (εr) of 4.8 and stood at a height of 1.6 mm.

Microstrip antennas are commonly known as patch antennas. Microstrip dipoles are appealing due to their inherent characteristics of possessing ample bandwidth and efficient space utilization, rendering them favorable for deployment in arrays. Both linear and circular polarizations can be attained using individual microstrip elements or arrays thereof. Utilizing microstrip arrays, equipped with single or multiple feeds, offers the potential to enable scanning functionalities and enhance directivity [3].

The rectangular patch is by far the most widely used configuration. It is very easy to analyze using both the transmission-line and cavity models, which are most accurate for thin substrates.The dimensions of slots are as shown in Table 1.

Table 1: Dimension of antenna

Sr. No.	Side Name	Dimension in mm
01	a	15.482
02	b	19.868
03	c	11.482
04	d	5
05	e	5
06	f	20
07	g	3
08	h	4.15
09	i	3

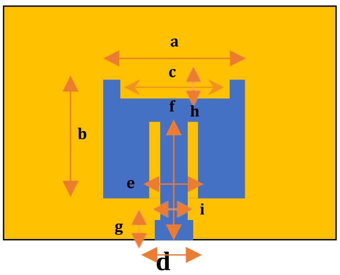


Fig 3: Geometry of single port antenna

3. Related Work

In order to quantify various antenna parameters necessary for multipath propagation in 5G MIMO systems, In their work, Pravin Latane and Paresh Jain [4] delve into modern technologies that center around the creation and assessment of MIMO antenna arrays tailored for 5G applications. Subsequently, they outline a methodology for conducting diversity analysis through the utilization of the S-parameters technique, aimed at uncovering correlation. The study also delves into correlation and polarization aspects, alongside presenting various performance metrics for antennas, expressed in terms of Mean Efficient Gain (MEG). Additionally, the investigation takes into account the Front to Back Ratio (FBR) bandwidth for instances of unidirectional patterns.

In the study by Nosherwan Shoaib and colleagues [5], they introduced a 16-port MIMO antenna with an H-shaped configuration, functioning at a frequency of 25.2 GHz. The antenna boasts a percentage bandwidth of 15.6% and achieves a gain surpassing 7.2 dB. This design incorporates Rogers RT-5880 substrate material and leverages CST simulation software, catering to the requirements of compact 5G devices. Circularly polarized MIMO dielectric resonator antennas with an electromagnetic band-gap structure etched onto the ground plane are employed by Hsiang Nerng Chen and collaborators [6]. These antennas operate within a frequency range spanning from 3.3 to 3.8 GHz, and their diversity analysis substantiates bandwidths of 18.5%. Evaluation for 5G wireless applications is carried out within an anechoic chamber. Botao Feng and colleagues [7] employ dual-layer U-shaped electric dipoles characterized by bandwidths extending to 22.6% and gains reaching

6.9 dBi. These dipoles are employed at operational frequencies of 3.5 GHz and 4.9 GHz for 5G microcell applications. The antenna patch, fashioned from a 0.3 mm thick copper material, is designed using HFSS software and features a loss tangent of 0 along with a dielectric constant of 1. In their work, Yasin Kabiri and colleagues [8] have implemented a 4-port MIMO antenna with an operational frequency of 2.11 GHz and a bandwidth spanning 100 MHz. The fabrication of this massive MIMO antenna involves the utilization of FR4 substrate material.

In the work conducted by M. Waqas et al. [9], a compact 4x4 arrangement of Massive Multiple Input Multiple Output (mMIMO) antennas was devised, designed to cater to forthcoming 39 GHz millimeter-wave (mm-Wave) communication demands within the ambit of 5th Generation (5G) networks. This configuration encompasses a bandwidth spanning approximately 1.43 GHz. The attained peak gain within the designated frequency band reaches

6.38 dB. Additionally, the study delves into the outcomes pertaining to the Envelope Correlation Coefficient (ECC), Diversity Gain (DG), and the Mean Effective Gain (MEG). In the study by J. Zhou and M. Yang [10], a novel six-port antenna is developed utilizing a shared U-shaped patch design, aiming to explore both frequency and radiation pattern diversity. The research investigates the antenna's characteristics in detail. Experimental findings reveal that frequency diversity is evident, particularly when exciting ports 1, 3, 4, and 6 individually. This operational configuration enables the six-port antenna to function within the 4.73-5.02 GHz range, achieving a peak gain of 5.38 dBi. Moreover, the antenna demonstrates varied radiation patterns, showcasing a commendable total efficiency of up to 84.8%. Importantly, the port isolation within the two designated bandwidths surpasses 21.7 dB and 18.5 dB, underscoring the antenna's suitability for potential 5G applications. Muhannad Y. Muhsin and co-authors

[11] introduce compact, low-profile Multi-Input Multi-Output (MIMO) antenna arrays comprising four and eight elements. These innovative antenna systems are tailored for integration into 5G smartphone devices. The proposed arrays exhibit dual-band operation, encompassing triple resonance frequencies that encompass the extended Personal Communication Purposes (PCS) n25 band, the mobile China's band, and LTE Band-46, thereby addressing a range of related applications. The assessment of these antenna systems encompasses an array of performance metrics, including scattering parameters, antenna efficiencies, gains, radiation characteristics, envelope correlation coefficients (ECCs), and mean effective gains (MEGs), all evaluated in the context of 5G mobile terminals. Four-port MIMO antennas with self-decoupling mechanisms are discussed by Achari P. Abhilash et al.

[12] for frequency ranges pivoting on 2.47 GHz and 5.25 GHz, with impedance bandwidths of 23.7% and 42.4%, respectively, and minimum isolations of 34 dB and 26 dB.

a. Design Of 4 Port Microstrip Antenna Array

Modern wireless standards, such as IEEE 802.11n, 3GPP LTE, and mobile WiMAX systems, incorporate multiple-input, multiple-output (MIMO) antenna systems. This approach enhances data throughput, even when faced with challenges like interference, signal fading, and multipath effects.

The configuration of a 4-port microstrip antenna array has been devised utilizing an FR4 board, specifically tailored for operation within the 3.3 GHz ISM band. The choice of a microstrip array antenna for this endeavour is rooted in its capability to address challenges arising from surface waves and mutual coupling effects between the array's elements. Illustrated in Figure 4 is the 4-port microstrip antenna array. The primary objectives encompass the mitigation of surface waves, thereby alleviating mutual coupling effects among radiating patches along the H-plane. Additionally, the endeavour aims to suppress side and back lobes of the antenna. To this end, a concerted effort has been made to enhance the antenna's performance through the incorporation of the aforementioned techniques, as detailed in the depicted configuration showcased in Figure 4.

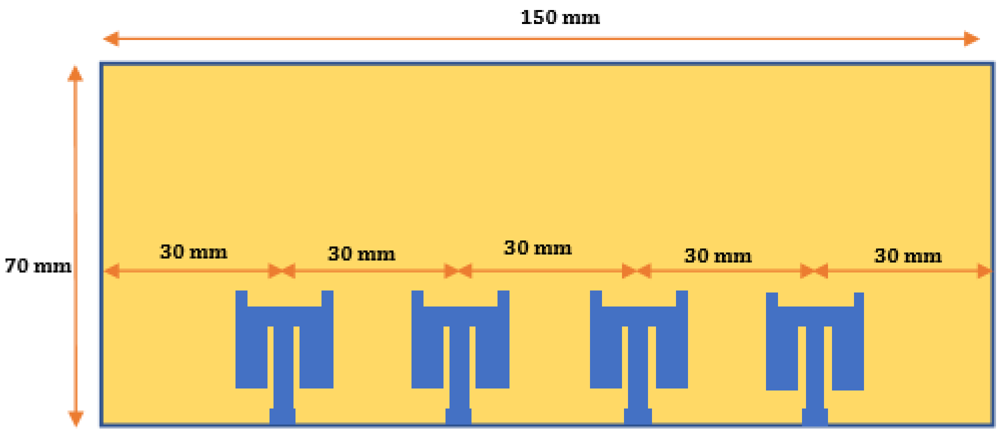


Fig 4: Placement of 4 Port MIMO Microstrip Antenna Array

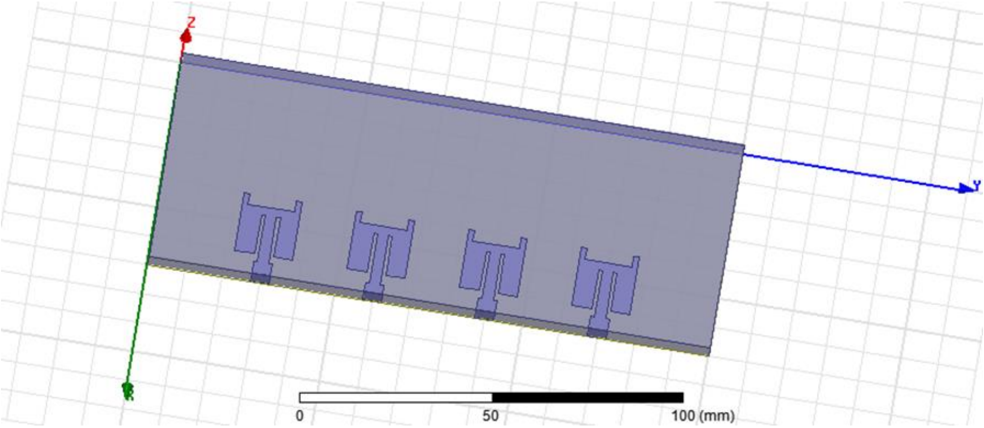


Fig.5 Structural Configuration of 4-Port MIMO Antenna

The microstrip patch antenna's configuration is depicted in Figure 5. The substrate's measurements are 150 mm x 70 mm, with a substrate thickness of 1.6 mm. The substrate material chosen is FR4, characterized by a dielectric constant of 4.4 and a loss tangent of 0.02.

The patch is rectangular shape with slots. The quarter wavelength matching and coaxial inset feed are used as the feeder for each patch to obtain the maximum matching impedance and provides good antenna. The position of feed point is on YZ plain of substrate.

i. Outcome Of Simulations

The HFSS software is employed for simulating the aforementioned design. The substrate utilized is FR4, characterized by a dielectric constant of 4.4, and the dimensions provided are applied for the simulation. The design functions at an operational frequency of 3.3 GHz, yielding a return loss of -18.04 dB and a gain of 21.32 dB. Figure 3 illustrates a graphical representation of the reflection coefficients (S11, S22, S33, S44) relative to frequency, demonstrating a bandwidth of 100 MHz.

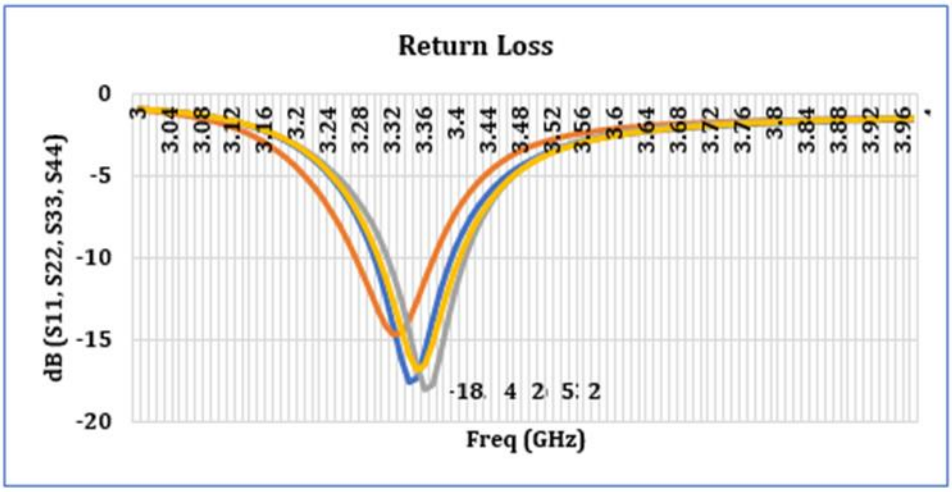


Fig.3. Return Loss Measurements (S11, S22, S33, S44) for 4-Port MIMO Antenna on FR4 Figure 4 showcases the three-dimensional radiation pattern of the antenna, providing insightinto the antenna's total gain as well. As illustrated in the accompanying diagram, the antenna's total achieved gain while utilizing FR4 as the substrate material is recorded at 21.32 dB.

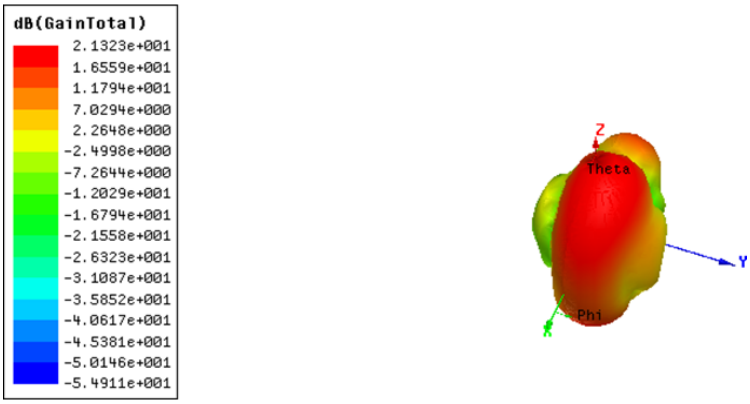


Fig.4. Total Gain of 4 port MIMO antenna using FR4 material

The antenna's gain experiences an increment as one moves away from its vicinity. Fig.5 portrays a two-dimensional radiation pattern of the antenna, highlighting a radiation pattern characterized by unidirectional emission, featuring both a prominent main lobe and a back lobe. The highest gain value of 21.32 dB is attained at an angle (θ) of 0 degrees, discernible throughthe presence of marker m1.

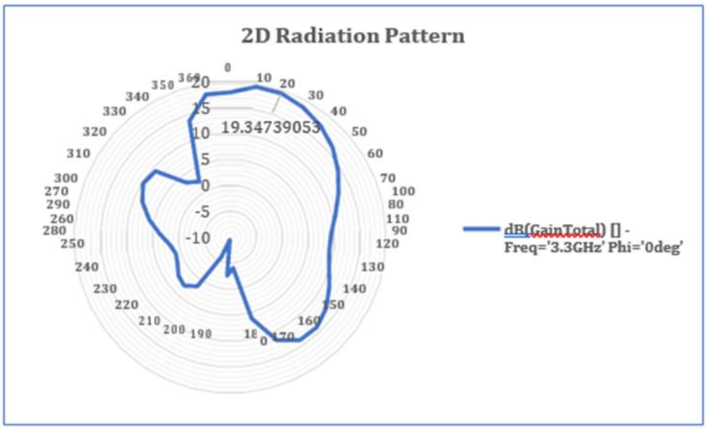


Fig.5. Two-dimensional Radiation Pattern of 4-Port MIMO AntennaThe graph of VSWR vs frequency is as shown in fig.6

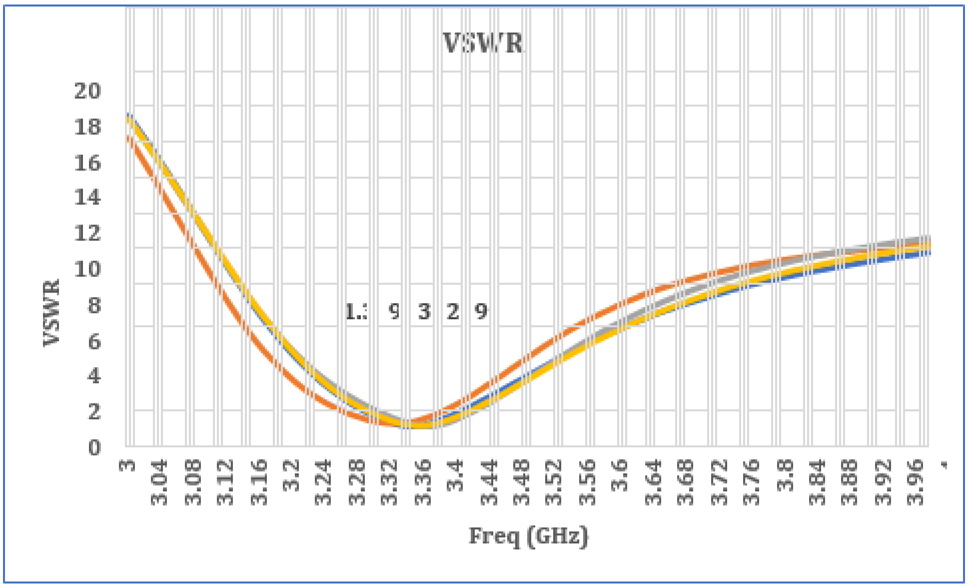


Fig.6. Graph of VSWR vs Frequency

The impedance plotted against frequency is depicted in Figure 7, revealing that at the frequency of 3.3 GHz, the antenna's impedance measures 40.69Ω. This characteristic facilitates seamless connection between the antenna and a 50Ω transmission line.

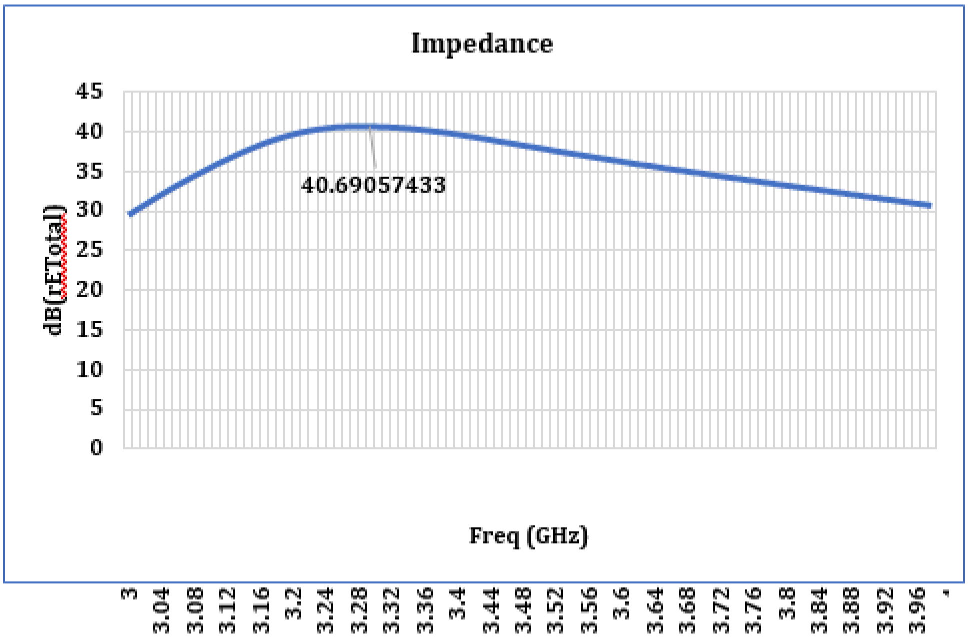


Fig.7. Graph of Impedance Vs frequency

The incident power for 4 port MIMO is 1W each, the radiation efficiency of antenna is 72.04%. The achieved performance in terms of the port isolations and cross-polarization radiations is very good. On the other hand, the FBRs under each port excitation are over 11.66dB within the frequency band of interest, showing low backward radiations. Front-to-Back Ratio (FBR) is determined by the difference in gain, expressed in dB, between the points φ= 0deg, θ= 0deg (represented by marker m1), and φ= 0deg, θ= 180deg (indicated by marker m2).

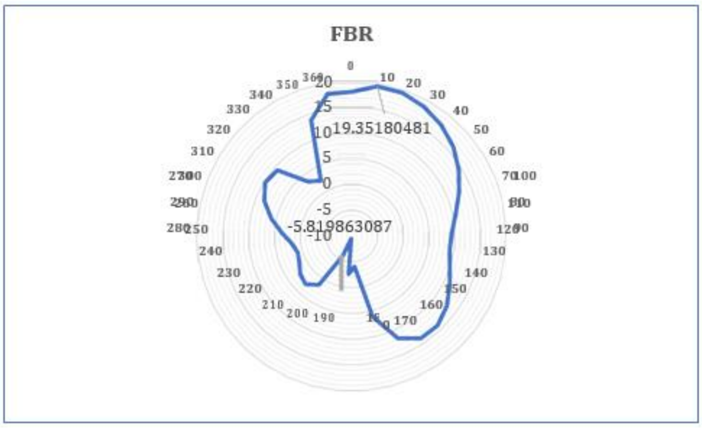


Fig.8. FBR calculation using 2D radiation pattern

The analysis of diversity performance for the proposed MIMO antenna entails an examination utilizing Mean Effective Gain (MEG), correlation coefficient, and diversity gain. Mean Effective Gain is calculated by comparing the average power received at the antenna to the combined average power of vertically and horizontally polarized waves, as received by an isotropic antenna [13]. The calculation of MEG for each port is facilitated through theutilization of S-parameters and can be determined using equation 3.

$$MEG_i = 0.5\eta_{i,\,rad} = 0.5\left[1 - \sum_{j=1}^{M} |S_{ij}|\right] \quad (3)$$

MIMO antenna system determines the Mean effective gain (MEG) values are given in Table1.

Table 1: Mean effective gain (MEG) determined by MIMO antenna

Mean effective gain	Value	Centre Frequency
MEG1	-2.56dB	3.3 GHz
MEG2	-2.08dB	3.3 GHz
MEG3	-2.06dB	3.3 GHz
MEG4	-2.71dB	3.3 GHz

The values for MEG are less than 3 dB which satisfies the equality criterion for the fourantennas. Figure 9 shows the computed MEG for all Antenna. The MEG curves are almost the same that signifies the independent and identical polarization diversity. These good performances are attributed to the symmetrical conformal design.

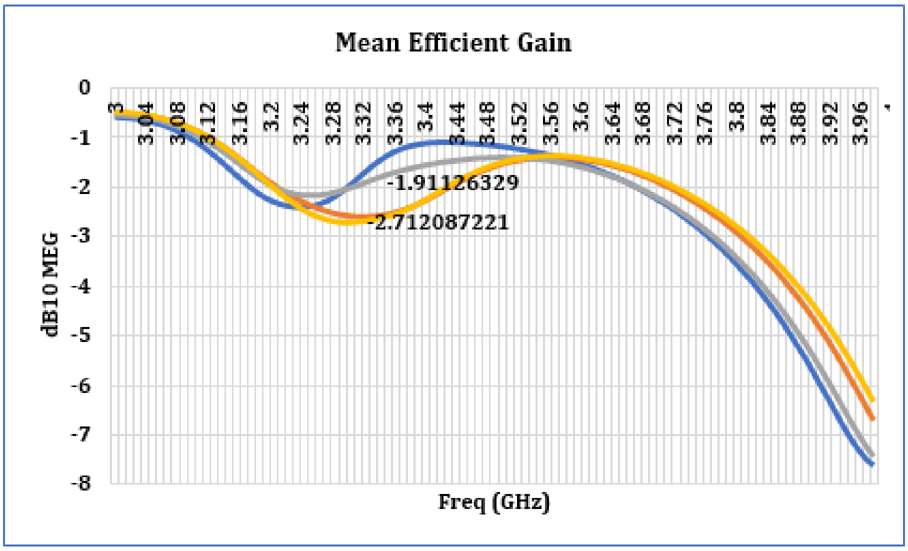


Fig 9: Recorded MEG values of 4 port Antenna.

Figure 10 shows that, all the Envelope Correlation Coefficient (ECC) parameters (ρ_e) remain below 0.02, indicating minimal coupling energy between adjacent antenna elements. Furthermore, the graph underscores the significance of Diversity Gain (DG) as a pivotalparameter that guarantees robust diversity and MIMO functionality.

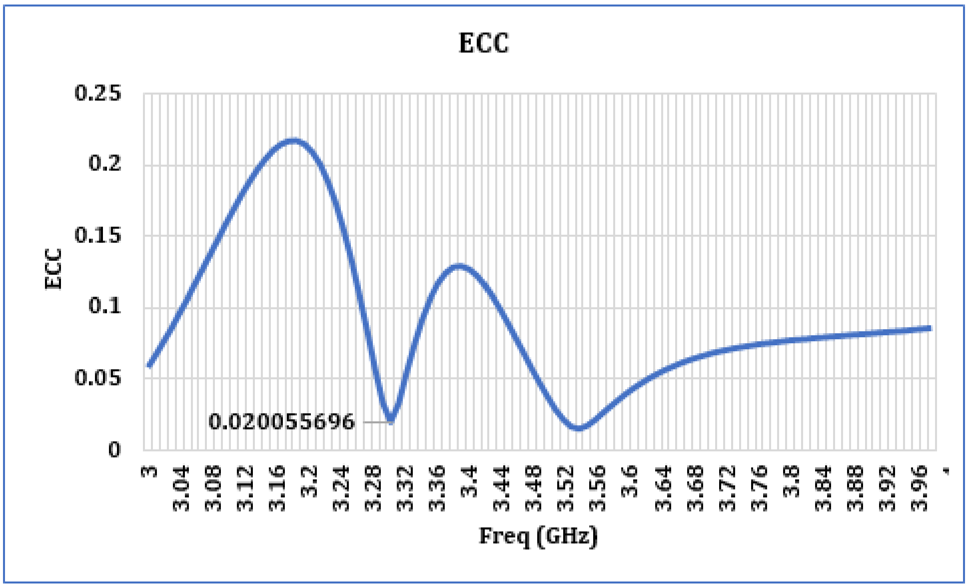


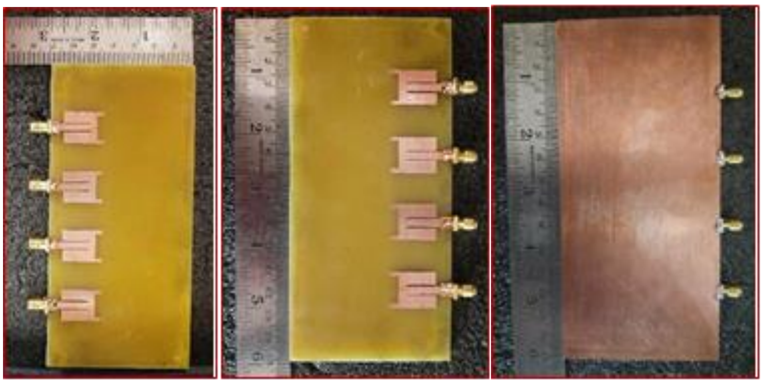
Fig.10. Graph of ECC Vs frequency

In the scope of this study, the calculation of DG is executed through the utilization of Equation(1).

DG = 10eρ (1)

Where $e\rho = \sqrt{(|1 - |0.99\rho_e|^2)}$ (2)

For measurement purposes, we have fabricated antenna prototype as shown below:



Front View Back View

Fig 11. Fabricated Antenna Module

The performance of 4 port MIMO patch antennas is measured using Anritsu Dual Port Combinational Analyzer MS2037C (VNA Master+Spectrum Analyzer) (5 kHz -15 GHz) in ananechoic Chamber. The compact 4 port MIMO patch antenna fabricated on FR4 is measured using Anritsu Dual Port Combinational Analyzer MS2037C (VNA Master+Spectrum Analyzer) (5 kHz -15 GHz) in an Anechoic Chamber as shown in Fig 12. The proposed antenna offers measured -18.04 dB return loss bandwidths of 0.210 GHz at 3.3 GHz.

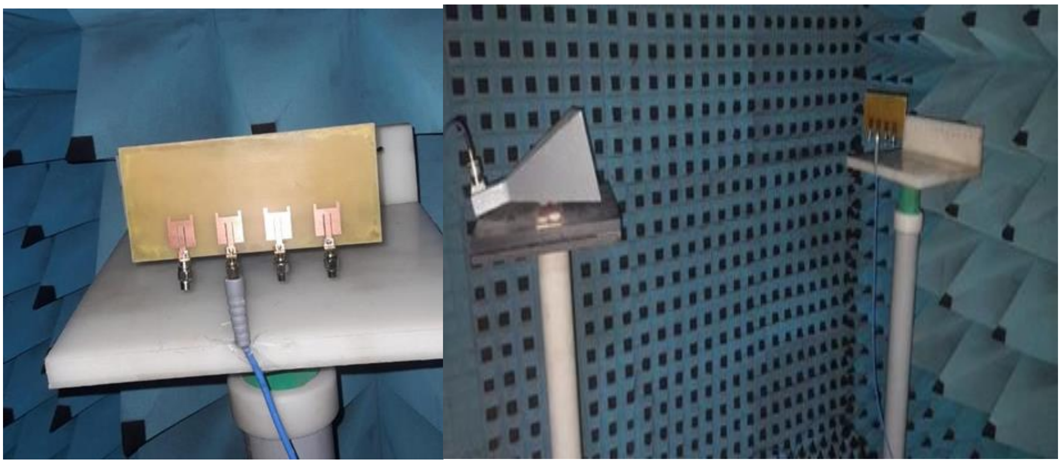


Fig 12. Testing in Anechoic Chamber

Table 2 presents a comparative analysis of the research variables pertaining to the state-of-the-art 4-port MIMO antenna investigations.

Table 2: Comparison of Research Variable

Research Variable survey for MIMO Antenna Array for 5G Application									
Reference No	Frequency (GHz)	Gain (dBi)	Bandwidth (%)	Isolation (dB)	Radiation Efficiency	Front to Back Ratio (FBR) (dB)	Diversity Analysis		
							Mean Efficient gain (MEG)	Envelope Correlation Coefficient (ECC)	Diversity Gain (EDG) (dB)
[5]	3.45 GHz	4.83 dBi	18.70%	> 26 dB	-	-	-	< 0.03	9.80 dB
[6]	3.5 GHz	7.2 dBi	22.60%	30.84 dB	varies from 81% to 93%,	varies from 24 dB to 9 dB	Identical to all 6 Port	< 2x10^-4	-
[7]	2.11 GHz		20%	24 dB	55%	-	-	0.008	9.9 dB
[8]	25.2 GHz	8.732 dB	15.60%	15 dB	78.30%	-	4.07 Identical to all 8 Port)	0.03	15.8 dB
[9]	37 GHz	5.1 dBi	1.43GHz	23 dB	88%	-	3.01dB same for all 16 port	0.014	9.99 dB
[10]	4.73-5.02 GHz	5.38dBi	14.60%	21.7 dB	84.80%	-	Same for all 6 port	< 0.25	9.9 dB
[11]	4.8-5 GHz	5.3 dbi	4.8-5 GHz	17 dB	82%	-	Same for all 4 port	0.005	
This Work	**3.3 GHz**	**21.3dB**	**210 MHz**	**19 dB**	**72.04 %**	**13.54 dB**	**Same for all 4 port**	**0.02**	**9.99dB**

4. Conclusion

This paper introduces and devises a 4-port MIMO antenna through the utilization of arectangular microstrip patch design, realized using the HFSS software. The antenna design exhibits a considerable bandwidth of 210 MHz, coupled with a radiation efficiency of 72.04%. At the operational frequency, the antenna yields an impressive total gain of 21.32 dB. Additionally, the VSWR stands at 1.3, while the antenna maintains an impedance of 40.69Ω. This impedance characteristic enables seamless connection of a 50Ω transmission line to the antenna, thus mitigating the occurrence of impedance mismatch losses. The ECC values significantly remain below 0.5 within the designated frequency bands, thereby establishing favorable diversity performance. Notably, diversity gain within these frequency bands reachesan approximate enhancement of 10dB. The uniformity observed in the MEG curves indicates the presence of independent and congruent polarization diversity. These observations collectively bolster the proposition that the designed antenna holds substantial potential for integration into contemporary 5G wireless communication systems.

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