# Design of MIMO for a single monopole antenna for N78 band 5G Applications

B. Bharani
*Department of Electronics and Communication Engineering*
*Vignan's Institute of Information Technology, Visakhapatnam, India*
*bavanabharani@gmail.com*

A. Deepthi
*Department of Electronics and Communication Engineering*
*Vignan's Institute of Information Technology,Visakhapatnam, India*
*ankareddydeepthi@gmail.com*

B. Sri Sai Sanjana
*Department of Electronics and Communication Engineering*
*Vignan's Institute of Information Technology,Visakhapatnam, India*
*sanjubehara01@gmail.com*

B. Adarsh Patnaik
*Department of Electronics and Communication Engineering*
*Vignan's Institute of Information Technology,Visakhapatnam, India*
*adarshbaggam@gmail.com*

B. Ganesh
*Department of Electronics and Communication Engineering*
*Vignan's Institute of Information Technology, Visakhapatnam, India*
*ganeshboddapu333@gmail.com*

**ABSTRACT:**

A multiple-input multiple-output (MIMO) antenna system tailored for high-speed wireless communication endeavors, emphasizing robust isolation, is herein introduced. The inception involves the construction of a single-element antenna fabricated on an FR-4 substrate characterized by a height of 1.6 mm, dielectric permittivity of 4.4, and loss tangent of 0.02. The singular antenna structure, with overall dimensions of 07 mmx 14mmx 1.6mm, exhibits resonant behavior across dualbands, specificallyat 3.5GHzand6.3GHz. Subsequently, leveraging the single-element antenna design, a two-element MIMO configuration is formulated. AprototypeunitcellalongwithacoplanarwaveguideMIMOantenna isdeveloped, and the simulated results are duly corroborated with experimental measurements. The proposed MIMO architecturedemonstratescommendableperformancemetrics,featuringameasureddiversitygainexceeding 9.9dBandanenvelopecorrelationcoefficient(ECC)below0.012.Furthermore,comprehensiveevaluations encompassing channel capacity loss (CCL), total active reflection coefficient (TARC), and mean effective gain are conducted, affirming the viability of the MIMO antenna for high-speed wireless applications.

**KEYWORDS:**
Envelope correlation coefficient (ECC), Total active reflection coefficient (TARC), Multiple-input-multiple-output (MIMO), Channel capacity loss (CCL), Diversity Gain (DG), N78 band.

## INTRODUCTION:

Inpursuit ofbroaderimpedancebandwidth,anelectronicbandgap(EBG)architecturewas integratedasan imperfection within the metallic ground plane. By adjusting the dimensions and positioning of the slots, a notably expanded impedance bandwidth was achieved. For upcoming 5G wireless applications, a ground-based antenna featuring a flawed structure with a stub-slot arrangement has been suggested [1].

To ensure robust transmission reliability, an array of antennas is deployed at both the transmitter and receiver, augmenting channel capacity and signal-to-noise ratio (SNR). The development of a Multiple Input Multiple Output (MIMO) antenna system operating within the Ultra-Wideband (UWB) spectrum contributes to mitigating multipath propagation fading challenges and co-channel interference. Coplanar Waveguide antennas offer inherent advantages such as broad bandwidth and reduced losses compared to microstrip line planar antennas [2].

Antennas feature a configuration wherein the signal line and ground plane coexist on the same plane, facilitating seamless integration. Utilizing technologyenhancestheoperationalbandwidthwithinthe3.1–10.6GHzrange[3].Thedesignofantennas for specific frequency bands necessitates meticulous consideration of feed transmission line length and monopole geometry. Optimal sizing of the ground plane is imperative for achieving effective impedancematching[4].AcompactUltra-Wideband(UWB)MultipleInputMultipleOutput(MIMO) antenna featuring a Defected Ground Structure (DGS) for enhanced port isolation is devised. The methodology employed aims to uphold omnidirectional radiation patterns and minimize mutual coupling across the UWB spectrum. To achieve operational bandwidth spanning 3.1 to 10.6 GHz, the antenna incorporates additional slots in the patch, partial ground plane, and transmission line feeding. Next- generation wireless communication systems prioritize high data rates and improved Quality of Service (QoS). UWB technology garners significant attention due to its attributes including ultra-low power consumption, heightened data rates, and cost-effectiveness [5-8]. UWB, a radio technology capable of transmitting and receiving vast amounts of data over an extensive frequency range with minimal power, offers multiple benefits such as rapid data transfer, cost-effectiveness, facile fabrication, immunity to multipath effects, and concurrent ranging and communication capabilities. Leveraging these inherent advantages, UWBemergesasaprominenttechnologyincontemporaryresearch. UWBtechnologyenables rapid data transmission over short distances, facilitating wireless connectivity among portable consumer electronics like printers, digital cameras, and laptops. UWB antennas are typically fabricated using either microstrip lines. Designing UWB antennas presents various challenges, including achieving a broad impedance bandwidth while ensuring efficient radiation characteristics. MIMO antennas have evolved into indispensable components of modern wireless communication networks [10-12].

Advanced MIMO technologies necessitate MIMO antennas with minimal mutual coupling for compact portable devices. However, the integration of multiple antenna elements within the constrained spatial confines of portable devices inevitably leads to pronounced mutual coupling and consequential diversity performance degradation. Numerous methodologies have been devised to mitigate the adverse impact of mutual coupling and optimize inter-element spacing in these antennas.
Multi-input multi-output (MIMO) technology leverages multipleantennas at bothtransmitter andreceiver endstomarkedlyenhancedatatransmissionperformanceandchannelcapacity,withoutincurringadditional energy or bandwidth overhead. Multiple fading phenomena present a significant challenge in wireless communication,whereinsignalswithvaryingamplitudesandphasesundergodestructiveinterferenceatthe receiver, necessitatingsolutionssuchasspatialdiversityandtimediversity. AsophisticatedMultiple-Input Multiple-Output (MIMO) antenna system holds the promise of augmenting overall antenna performance while concurrently addressing issues like minimized mutual coupling and correlation among antenna elements.

This comprehensive literature review delves into the progression and enhancements in MIMO antennas,withaparticularemphasisontheirapplicationinultra-wideband(UWB)scenarios.UWBMIMO antennas embedded within multifunctional portable devices necessitate a heightened level of isolation. However, craftinga compact, highlyisolated UWBMIMO antenna poses formidablechallenges. Various methodologies have been devised to ameliorate isolation among MIMO antenna elements.

Enhancing MIMO antenna isolation and mitigating mutual coupling can be achieved through orthogonal placement of unit cells in close proximity. Maintaining a λ/16 gap between neighboring MIMO antenna elements serves to isolate them effectively. Electromagnetic interactions between antenna elements contribute to improved mutual coupling in MIMO antennas. Introducing a small strip between antennas proves effective in reducing mutual coupling within the antenna system. Experimental models are constructed for both MIMO systems, with and without a patch element between antennas. Diverse approaches are explored to minimize mutual coupling between unit cells, including Defected Ground Structure, Decoupling Network, Parasitic Elements, Neutralization Lines, and Metamaterials. Enhanced isolation is attained through the implementation of decoupling networks.

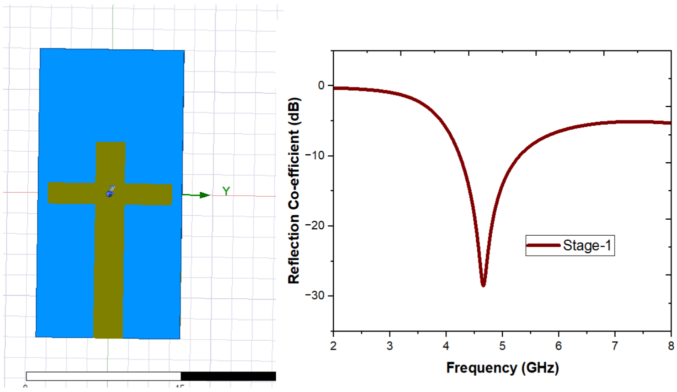
This workintroduces a self-isolatedMIMOantenna withanimpedancebandwidthofGHz. The overall dimension of the proposed MIMO antenna is 51 x 28 x 1.6 mm³. This UWB MIMO antenna is suitableforultra-widebandwirelesscommunicationnetworks.Theproposedantennaisuniquelypositioned because of its symmetric MIMO elements and detached ground plane, overcoming earlier research proposals. The two single-element antennae are positioned in an orthogonal manner and separated by a distance of λ/16. For better isolation between two single-element antennas, a strip is employed. All these designconsiderationsenhancefeaturesincludingself-isolation,smallsize,ultra-widebandcoverage,lower ECC, greater gain and efficiency, and less mutual coupling.

## SINGLEELEMENTANTENNA DESIGN:

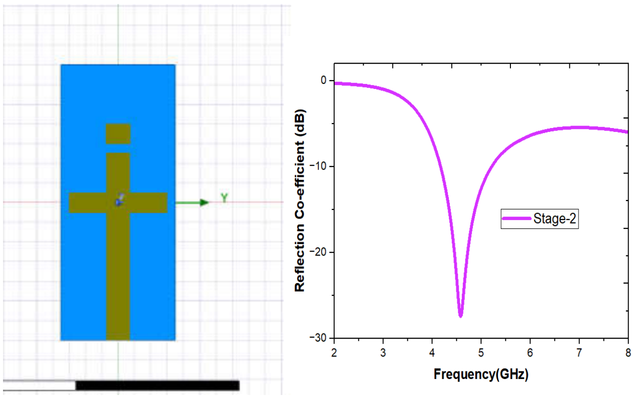
The "Elementary Cell Configuration" refers to thefoundational design layout of theantenna as depicted in Figure 1. This antenna configuration is constructed on a substrate made of FR-4 material, characterizedbyspecificelectricalpropertiesincludingadielectricpermittivityof4.4andalosstangentof 0.02. The substrate itself possesses a height of 1.6 mm. The complete dimensions of the individual unit antenna measure 28mm x 14mm x 1.6mm, indicating its compact form factor suitable for various applications. Notably, this proposed unit cell antenna is designed to operate within the frequency range mandated by the Federal Communications Commission (FCC), spanning from 2 GHz to 10.6 GHz. This frequency range aligns with the requirements of modern wireless communication standards and applications.

The antenna's structure entails the integration of both the patch and the transmissionlines, whichareintricately etched ontothesamesubstrateplane. This co-planar arrangement ensures efficient signalpropagation and minimizes losses. Thesubstrate's properties, namely its dielectric permittivity ($\varepsilon r$ = 4.4) and thickness (h = 1.6 mm), contribute to the antenna's overall performance characteristics. Figures 1(a) and 1(b) provide detailed schematic representations from different perspectives, illustrating the top and bottom views of the proposed antenna design, respectively. These visual depictions aid in comprehending the spatial arrangement and structural components of the antenna configuration.

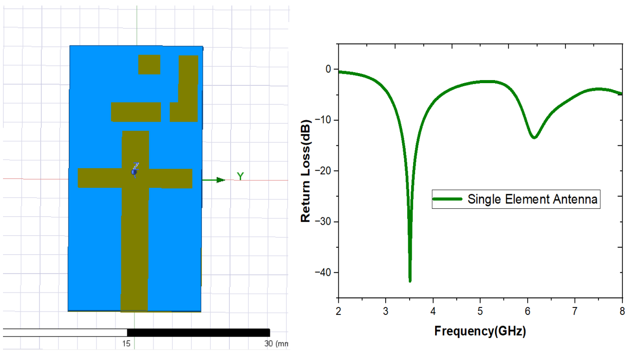
Fig.1Schematicviewof Stages of theSingleantenna.(a)Stage-1,(b)Stage-2, (c) Stage-3




(a)

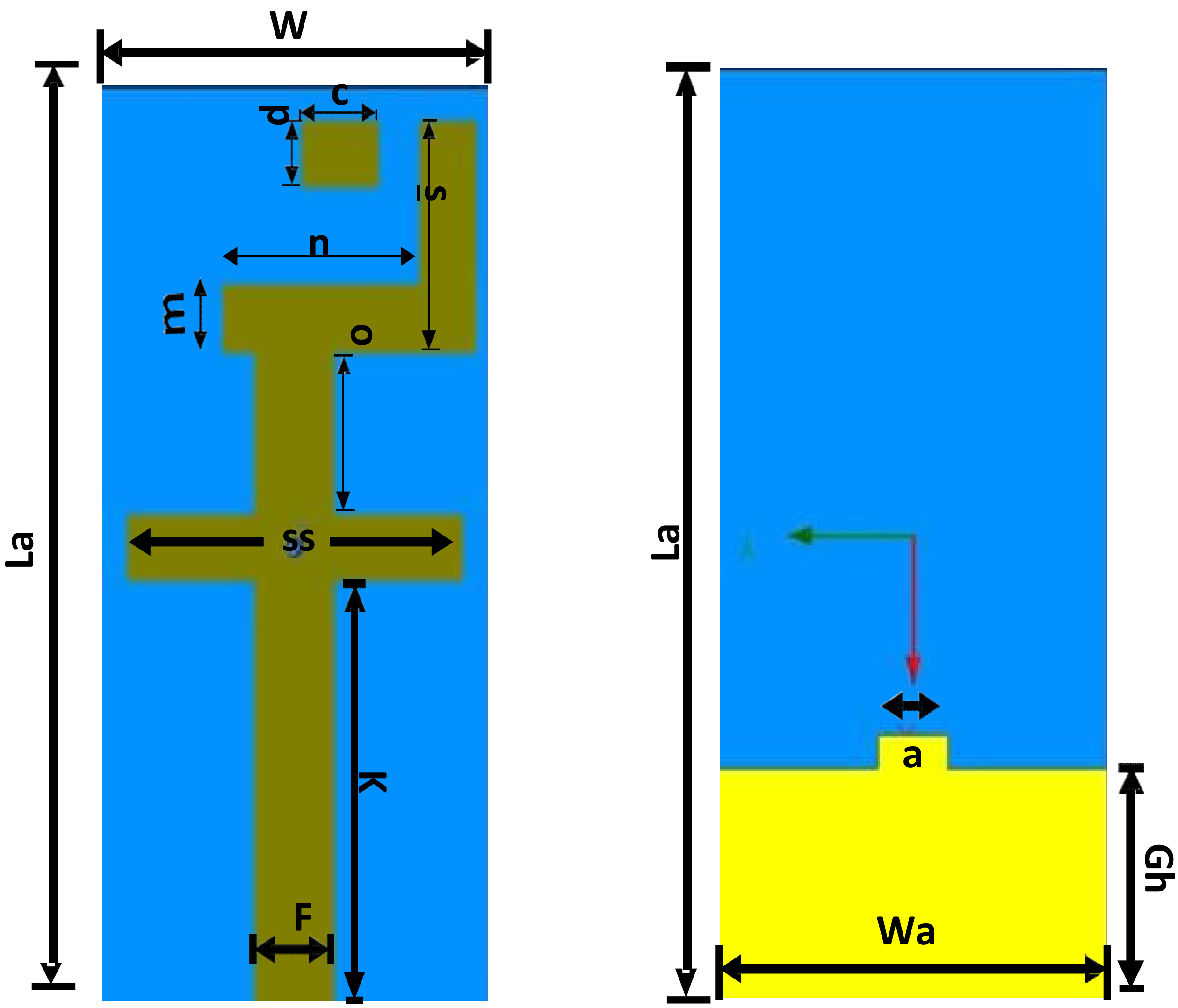



(b)




(c)

Fig.1Schematicviewoftheproposedantenna.(a)Top-view.(b)Back-view

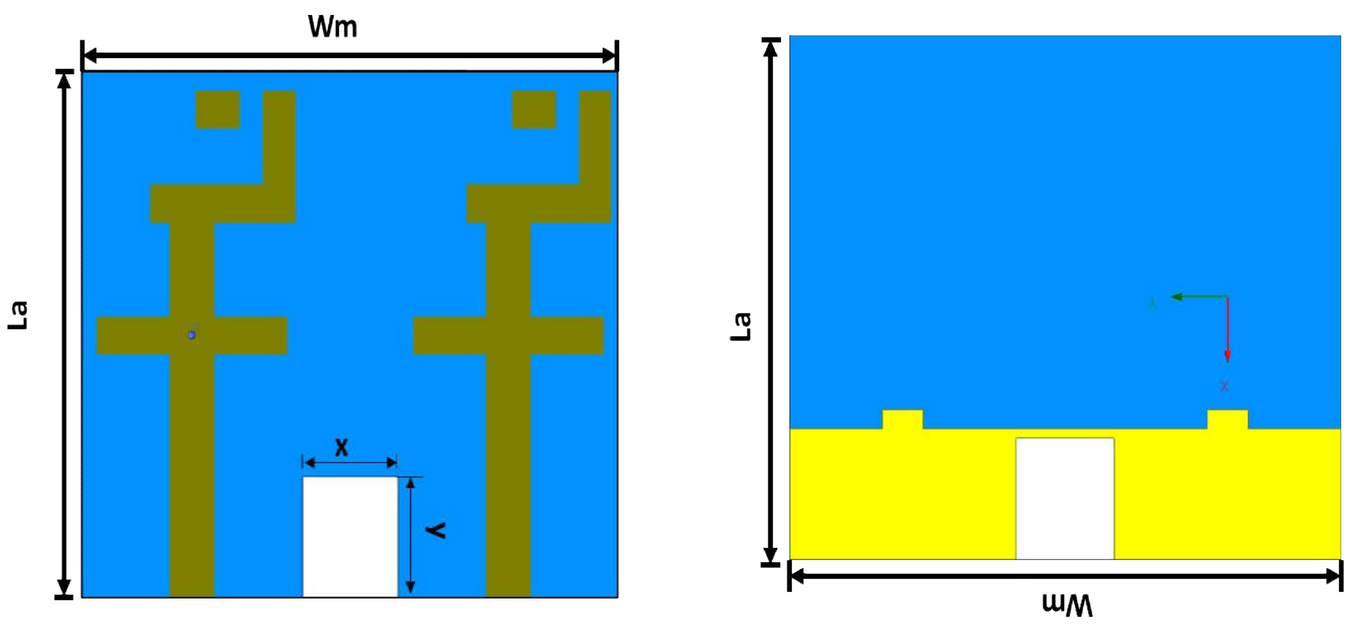



(a) (b)

Table1.DesignparametersoftheAntenna.

| OptimizedParameter | Value(mm) |
|---|---|
| La | 28 |
| Wa | 14 |
| c | 2.75 |
| d | 2 |
| n | 5.2 |
| s | 7 |
| o | 4 |
| ss | 12 |
| f | 2.8 |
| K | 13 |
| Aw | 2.5 |
| Al | 1 |
| Gh | 7 |
| m | 2 |
| x | 6 |
| y | 6.5 |
| Wm | 34 |

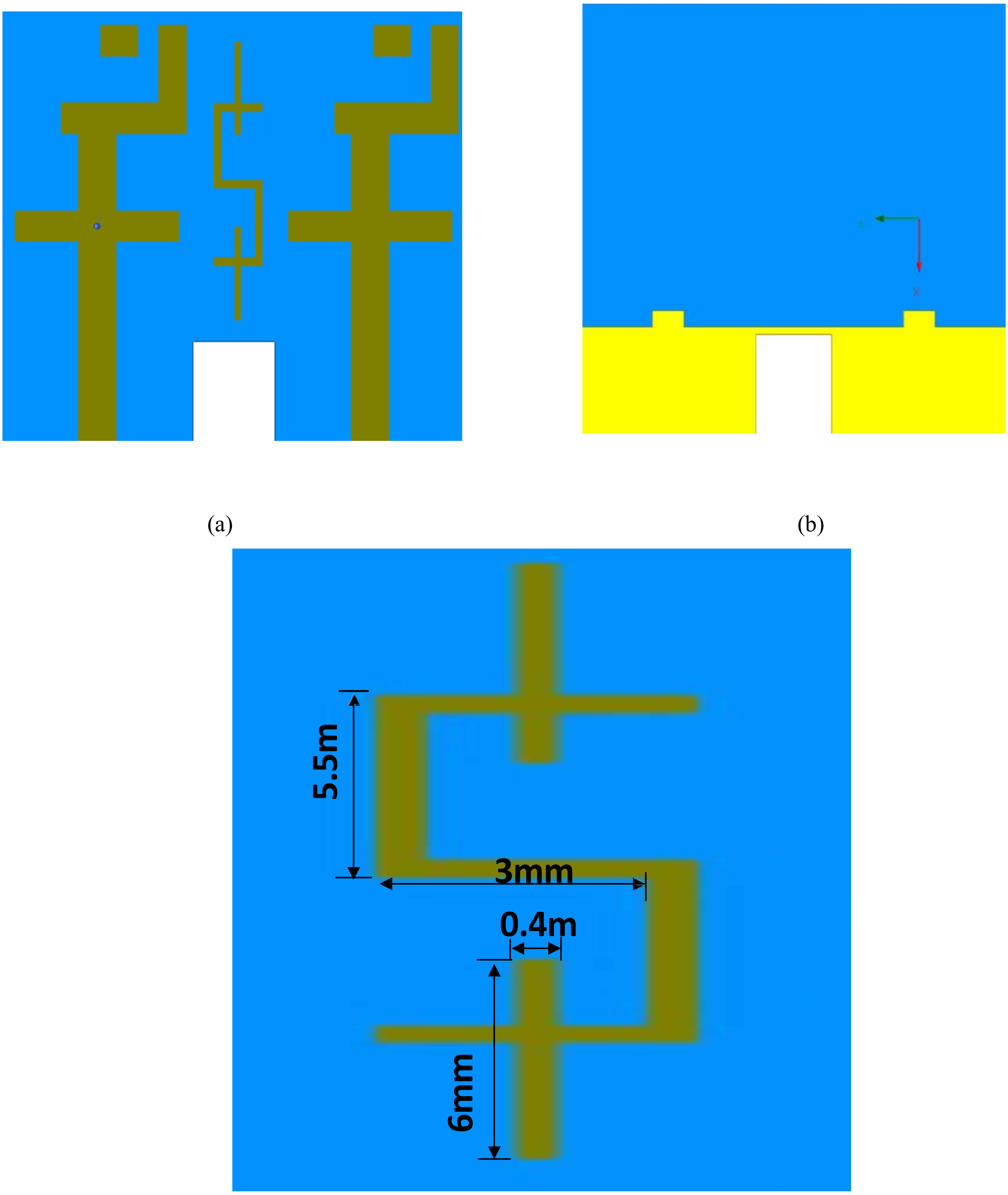
**PROPOSEDMIMOANTENNAWITHOUTPDSS:**




(a) (b)

**Figure2:Schematicview ofMIMOAntennawithoutPDSS(a).TopView(b)BackView**

**PROPOSEDMIMOANTENNAWITHPDSS:**




(a) (b)

**(c)**

**Figure3:Schematicview ofMIMOAntennawithPDSS(a). TopView(b)BackViewand(c)PDSS**

**Table2:ComparisontableoftheproposedantennawithasingleelementandWithoutPDSS.**

| ANTENNA STAGES | Operation Bandwidth (GHz) | $S_{11}$( dB) | Peak Gain(dB) | $S_{21}$( dB) |
|---|---|---|---|---|
| SingleElement | 3.27-3.77& 5.49-6.32 | -39.09& -13.73 | 3.396 | ---- |
| WithoutPDSS | 3.22-3.72& 5.69–6.42 | -30.5& -14.261 | 3.364 | -25.789 |
| WithPDSS | 3.34–3.823& 5.921– 6.426 | -50.262& -33.2265 | 3.486 | -26.362 |

Theproposedantennaoperateswithintwo frequencybandsspanningfrom3.2GHzto3.8GHzand from 5.8 GHz to 6.4 GHz, demonstrating a gain surpassing 2 dB. It consists of two single-element antennas positioned orthogonally, with a separation distance of λ/16, corresponding to 6 mm. This intentional configuration enhances the mutualcoupling of theMIMO antenna system, a pivotalaspect for optimizing its performance. To further alleviate mutual coupling effects and enhance overall antenna performance, a connection is established between the ground planes of the single-element antennas using a strip with a width of 2.8 mm. This strip effectivelybridges the groundplanes, facilitating enhanced couplingbetween theantennas. Additionally, adecouplingnetworkisintegratedintotheantenna designtorefineitsgainand mitigate reflection coefficients (S11, S21). This network plays a crucial role in optimizing the antenna's impedance matching and ensuring efficient power transfer between theantenna and thetransmission line. By minimizing reflections and improving impedance matching, the decoupling network contributes to maximizing the antenna's radiated power and overall efficiency. In summary, through the strategic arrangement of the single-element antennas, combined with the utilization of a connecting strip and a decoupling network. it was stated that the proposed antenna design achieves superior performance characteristics, encompassing enhanced mutual coupling, improved gain, and reduced reflection coefficients across the desired frequency range.

The proposed MIMO antenna is constructed on an FR4 substrate renowned for its cost-effectiveness, boasting a dielectric constant (εr) of 4.4. With a substrate thickness of 1.6mm and a loss tangent of 0.02, this antenna provides a harmonious blend of performance and cost efficiency. Measuring 51 x 28 x 1.6 $mm^3$, its compact yet efficacious design is meticulously engineered utilizing HFSS software, ensuring meticulous simulation and optimization for optimal functionality. The proposed MIMO antenna is engineered to deliver cost-effective performance and is fabricated employing an FR4 substrate characterizedbyadielectricconstant(εr)of4.4.Featuringasubstratethicknessof1.6mmandalosstangent of 0.02, it strikes a favorable equilibrium between performance and cost efficiency. The antenna boasts compact dimensions measuring 28 x 34 x 1.6 $mm^3$. It has been meticulously designed utilizing HFSS software, guaranteeing precise simulation and optimization for optimal operational performance. The MIMO antenna design under consideration has undergone physical fabrication and rigorous testing to validate the accuracy of the simulated results

**RESULTS:**

In this section, it was discussed how the simulated outcomes were compared with the empirical data obtainedfromtheMIMOantenna under examination.Duetoitsinherentsymmetry, theanalysisprimarily focused on two key parameters: the reflection coefficient, denoted as |S11|, and the isolation coefficient, represented by |S21|. The physical manifestation of the MIMO antenna, fabricated with dimensions fine-tunedfor optimizedperformance, wasillustratedinFig.2.Throughmeticulousmeasurementandanalysis, theSparametersoftheproposeddesignwereassessed,providinginsightsintoitsoperationalcharacteristics and effectiveness. It was noted that the proposed antenna resonated within dual bands of 3.1 to 3.8 GHz and 6.1 to 6.8 GHz. Furthermore, the measured mutual coupling result of the fabricated MIMO antenna indicated values less than -20 dB within the operating frequency band, demonstrating good impedance matching.

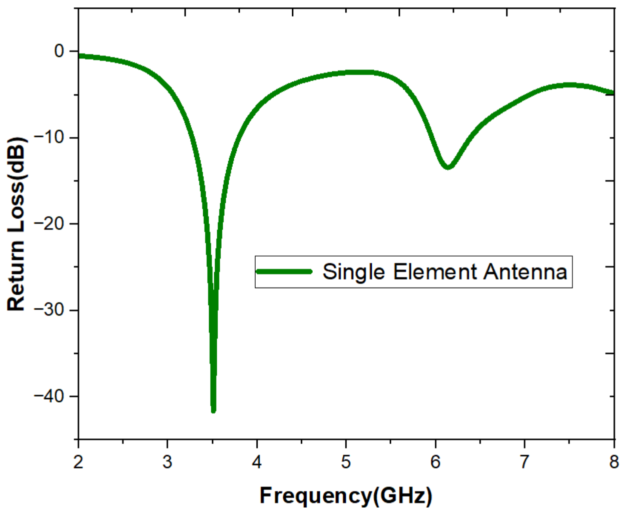



**Fig.4ReflectioncoefficientofSingleElementAntenna**

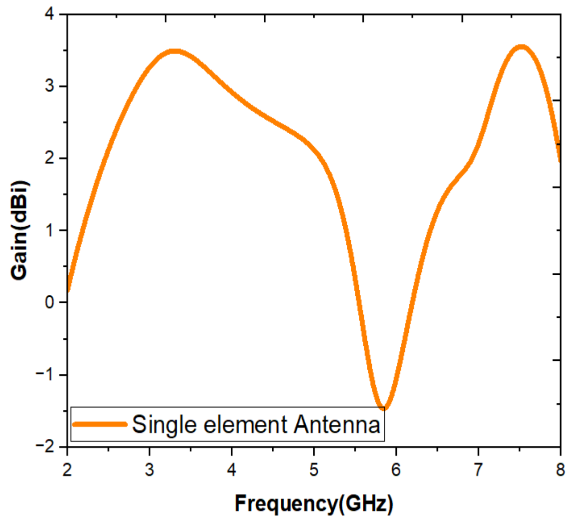
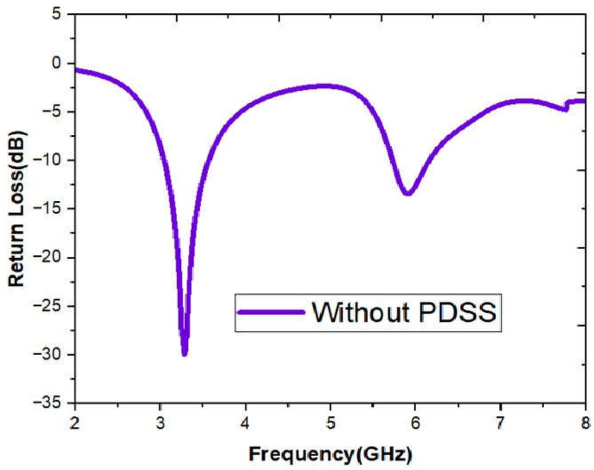
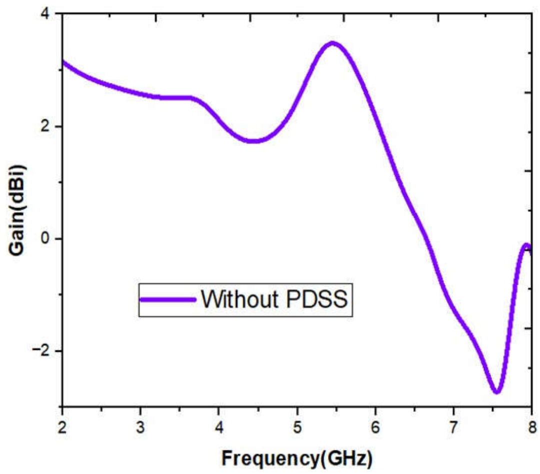


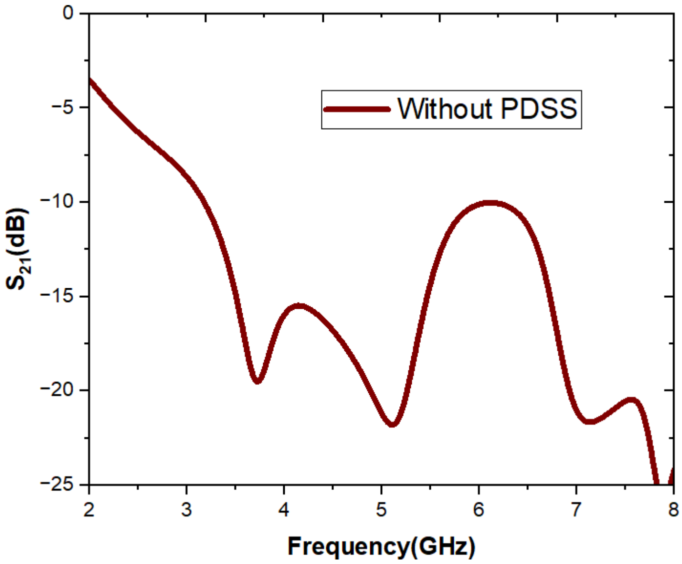

**Fig.5PeakrealizedgainSingleElement Antenna**




**6.(a)**




**6.(b)**



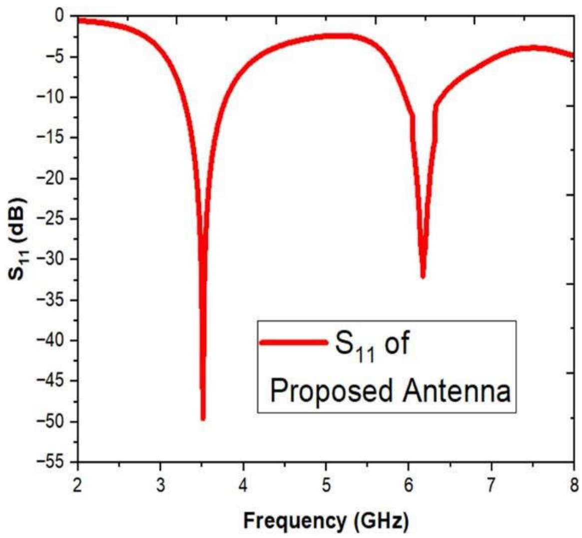

(c)

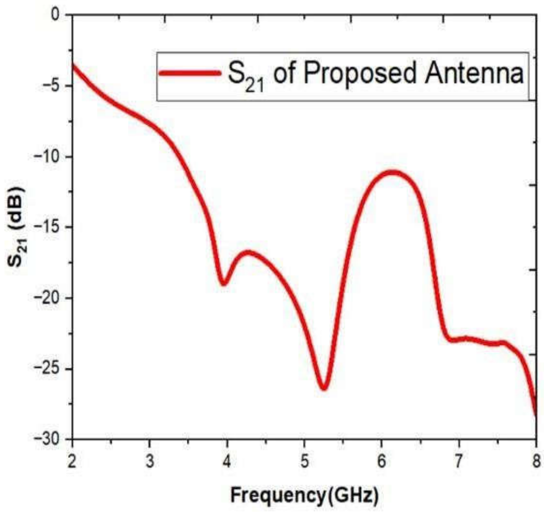
**Fig.6ReflectioncoefficientofMIMOAntennaWithoutPDSS(a).$S_{11}$,(b).Gainand(c)$S_{21}$.**

## MIMOANTENNAEVALUATIONPARAMETERSWITH PDSS:

In this section, theMIMO antenna parameters, such as the$S_{11}$ ,$S_{21}$, Gain, MEG envelopecorrelation coefficient,diversitygain,andtotalactivereflectioncoefficient(TARC),arediscussedinmoredetail.

**ReturnLossandTransmissionco-efficientoftheProposedAntenna:**



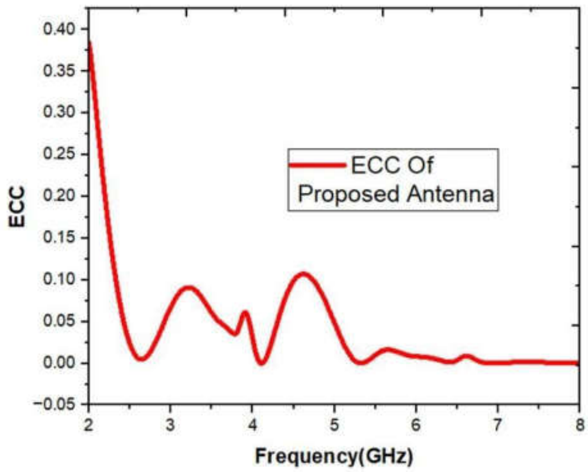




The Proposed Antenna exhibits resonance at two distinct resonant frequencies, namely 3.6 GHz and 6.2 GHz, with corresponding return loss values of -50.262and -33.226, respectively. Additionally, the obtained S21 parameter for the proposed antenna is -26.362dB.

**EnvelopeCorrelation Coefficient(ECC):**

TheconceptoftheEnvelopeCorrelationCoefficient(ECC)servesasametricforassessingtheinterrelation between adjacent elements of MIMO antennas. This metric can be deduced from either the radiation patterns or theS-parameters of theantennas. Thefar-field radiation pattern is favored for ECC evaluation inMIMOsetupsduetoitsabilitytoshowcasetheautonomyofindividualradiatingcomponents.Giventhat many planar antennas incur losses, it is advisable to refrain from relying solely on S-parameters for ECC determination.Theequationpresentedfurnishesamathematicalframeworkfor calculatingECCusingdata derived from the radiation patterns of MIMO antennas.

$$\text{ECC}(1,2) = \frac{(\text{mag}(\text{conjg}(S(1,1))*S(1,2)+\text{conjg}(S(2,1))*S(2,2)))}{((1-\text{mag}(S(1,1))\wedge 2-\text{mag}(S(2,1))\wedge 2)*(1-\text{mag}(S(2,2))\wedge 2-\text{mag}(S(1,2))\wedge 2))}$$




Where:

$S_{11}$isthereflectioncoefficientofMIMOAntenna.

$S_{12}$and$S_{21}$arethemutualcouplingoftheMIMOAntenna. $S_{22}$is

the reflection coefficient of Antenna 2.

**Fig7:EnvelopeCorrelationCo-efficient**

**ChannelCapacityLoss(CCL):**

The CCL refers to the greatest amount of information that can be transmitted with little loss across a communication medium. AMIMO system has a predeterminedCCL valueof less than0.4 bits/s/Hz. The equation provides an expression for CCL utilizing S-parameters.

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

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

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

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

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

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

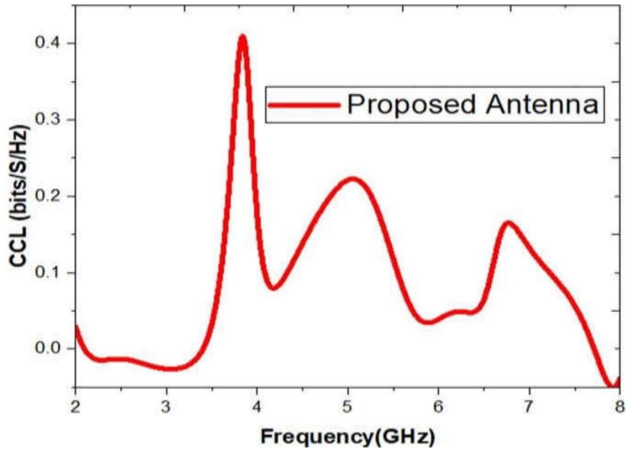



**Fig8:ChannelCapacityLoss**

**Total Active Reflection Co-efficient(TARC):**

It was mentioned that the Total Active Reflection Coefficient (TARC) of a MIMO system represents the proportionofreflectedpower fromtheradiatingelements totheincident power onthepatch.Theequation was discussed to compute the generalized TARC for an N-port MIMO antenna. It was noted that TARC signifiestheratiobetweenreflectedandincidentpower,withtheexpectationthattheantennashouldabsorb allofthepower. Ideally, theTARCvaluefor MIMOantennasisdesiredtobezero. Itwasemphasizedthat during the design phase of the MIMO antenna, optimization of antenna diversity parameters should be carried out within the specified constraints.

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

$$TARC = \frac{P_{\text{reflected}}}{P_{\text{incident}}}$$

Where:

- $P_{\text{reflected}}$ represents the power reflected from the radiating elements.
- $P_{\text{incident}}$ represents the incident power on the antenna patch.

.

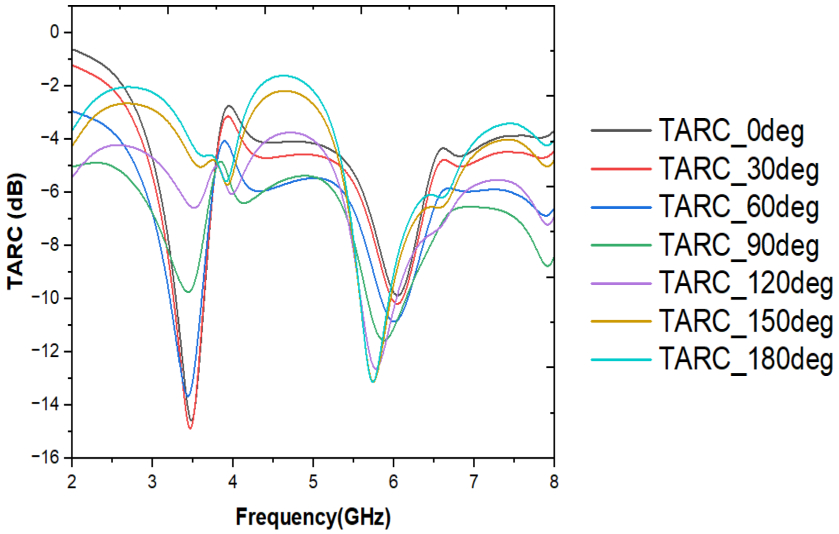



**Fig9:TotalActiveReflectionCo-efficient**

**MeanEffectiveGain:**

ItwasdiscussedthattheMeanEffectiveGain(MEG)inMultiple-InputMultiple-Output(MIMO) antenna systems elucidates the comprehensive performance of the system by computing the average gain across all feasible transmit and receive antenna combinations. This metric encompasses the spatial characteristics of the channel, incorporating factors such as spatial correlations among antennas and the influence of antenna positioning within the environment. MEG plays a pivotal role in assessing signal reception, mitigating interference, and overall link quality within wireless communication systems. Additionally, it contributes significantly to the design and refinement of MIMO antenna configurations, aiming for enhanced data rates, reliability, and spectrum utilization efficiency.

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

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

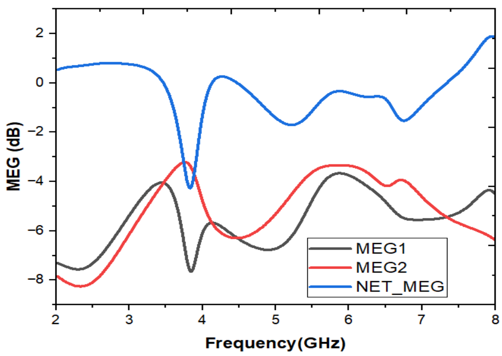



**Fig10:MeanEffectiveGain**

**DiversityGain(DG):**

Theterm"DiversityGain"pertainstotheaugmenteddependabilityofwirelesscommunication systems resulting from the utilization of multiple antennas. It represents an enhancement in signal fidelity brought about by the collective reception of diverse signal instances that have been variably impacted by fading. Diversity gain mitigates the impact of fading, thereby enhancing the resilience, coverage, and capacity of signals in challenging environments. The proposition posits that the diversity antennas exhibit no correlation and yield autonomous fading channels.

$$DG=10\,\square\,\log_{10}(N)$$

Where:

DG isthediversitygainindecibels(dB)

Nisthenumberofindependentdiversitybranchesorantennas.

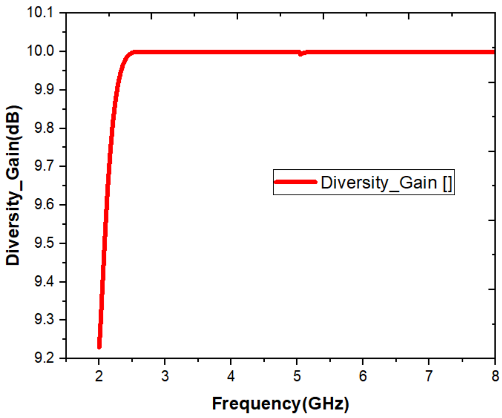



**Fig11:DiversityGain**

**CONCLUSION:**

In the paper, the design of a compact MIMO antenna for high-speed wireless applications was delineated. The proposed MIMO antenna exhibited an impedance bandwidth spanning from 3.34 GHz to 3.823 GHz and 5.921 GHz to 6.426 GHz, coupled with low mutual coupling across the frequency spectrum. Moreover, the proposed MIMO antenna design demonstrated exceptional diversity performance, characterized by an Envelope Correlation Coefficient(ECC)oflessthan0.1,DiversityGain(DG)exceeding9.9,andmutualcouplingbelow-15 dB. The compact size and superior performance of MIMO antennas render them highly suitable for 5G wireless communication applications involving MIMO technology.

**REFERENCES:**


[1] F. Urimubenshi, D.B.O.Konditi,J. D.D.Iyakaremye, P.M.Mpele, andA. Munyaneza, ‘‘A novel approach for low mutual coupling and ultra compact two port MIMO antenna development for UWB wireless application,’’ Heliyon, vol. 8, no. 3, Mar. 2022, Art. no. e09057.

[2] Ranjan, M. Patil, S. Chand, A. Ranjan, S. Singh, and A. Sharma, ‘‘Investigationondual-port printed MIMO antenna with reduced RCS forC-bandradarapplication,’’ Int. J. RF Microw. Comput.-Aided Eng., vol. 30, no. 3, Mar. 2020.

[3] Singh, S. J., Kumar, R., & Dixit, M. M. (2022). Printed monopole antenna design with CPW fed for ultrawideband application. JournalofPhysics. Conference Series, 2236(1), 012010. https://doi.org/10.1088/1742-6596/2236/1/012010

[4] R. G. Mishra, R. Mishra, P. Kuchhal, and N. P. Kumari, “Design and analysis of CPW-Fed microstrip patch antennas for wideband applications,” in *2017 International Conference on Inventive Computing and Informatics (ICICI)*, IEEE, 2017. doi: 10.1109/ICICI.2017.8365216

[5] NagaJyothi, Aggala. "DesignandImplementationofQuadriphaseSequenceswithGood Merit Factor Values." Indian Journal of Science and Technology 9 (2016): S1.

[6] W. A. E. Ali and A. A. Ibrahim, “A compact double-sided MIMO antenna with an improved isolation for UWB applications,” *Int. J.Electron. Commun.*, vol. 82, pp. 7–13, 2017, doi: 10.1016/j.aeue.2017.07.031.

[7] A. Dkiouak, A. Zakriti, M. E. Ouahabi, H. Elftouh, and A. Mchbal, “DesignofCPW-fed MIMO antenna for ultra-wideband communications,” *Procedia Manuf.*,vol. 46, pp.782–787, 2020, doi: 10.1016/j.promfg.2020.04.005.

[8] NagaJyothi,A.,andK.RajaRajeswari."Cross-correlationofBarkercodeandLongbinary signals." InternationalJournalofEngineering Science and Technology(IJEST) 3(2011).

[8] L. Liu, S. W. Cheung, and T.I.Yuk,“Compact MIMO Antenna for Portable Devices in UWBApplications,”IEEETrans.AntennasPropag.,vol.61,no.8,pp.4257–4264,2013, doi: 10.1109/tap.2013.2263277.

[9] K.P.Ray,“Designaspectsofprintedmonopoleantennasforultra-widebandapplications,” *Int.J.AntennasPropag.*, vol.2008,pp.1–8,2008,doi: 10.1155/2008/713858.

[10] M.M.Rahman,M.S.Islam,H.Y.Wong,T.Alam,andM.T.Islam,“Performance analysis of a defected ground-structured antenna loaded with stub-slot for 5G communication,”*Sensors(Basel)*,vol.19,no.11,p.2634,2019,doi:10.3390/s19112634.

[11] J.Li,J.Guo,H.Shi,B.He,andA.Zhang,“Cpw-fedstub-loadedslotdipoleantennadesign for dual-bandoperation,”Prog.Electromagnetics.Res.Lett.,vol.60,pp.67–72,2016,doi: 10.2528/pierl16041408.

[12] K. J. Babu, R.W. Aldhaheri, M. YounusTalha, andI.S.Alruhaili, “Designofacompact two-element Mimo antenna system with improved isolation,” Prog. Electromagn. Res. Lett., vol. 48, pp. 27–32, 2014, doi: 10.2528/pierl14070307.

[13] J.Jervase-YakandA.H.Al-Shamsi,“MIMOAntennaforUWBCommunications,” *Int.J.Commun. Netw. Syst. Sci.*, vol. 09, no. 05, pp. 177–183, 2016, doi: 10.4236/ijcns.2016.95017v.

[14] S. Ahmad *et al.*, “Acompact CPW-fed ultra-wideband multi-input-multi-output (MIMO) antennaforwirelesscommunicationnetworks,”*IEEEAccess*,vol.10,pp.25278–25289,2022,doi:10.1109/access.2022.3155762.

[15] P.Sharma, R. N.Tiwari, P. Singh, P.Kumar, and B. K. Kanaujia, “MIMO antennas: Designapproaches,techniques,andapplications,”*Sensors(Basel)*,vol.22,no.20,p. 7813, 2022, doi: 10.3390/s22207813.

[16] A.ChristinaJosephineMalathiandD.Thiripurasundari,“Reviewonisolationtechniquesin MIMO antenna systems,” *Indian J. Sci. Technol.*, vol. 9, no. 35, 2016, doi: 10.17485/ijst/2016/v9i35/96704.

[17] S.Ahmadetal.,“AcompactCPW-fedultra-widebandmulti-input-multi-output(MIMO) antennaforwirelesscommunicationnetworks,”IEEE Access,vol. 10, pp.25278–25289, 2022,doi:10.1109/access.2022.3155762.