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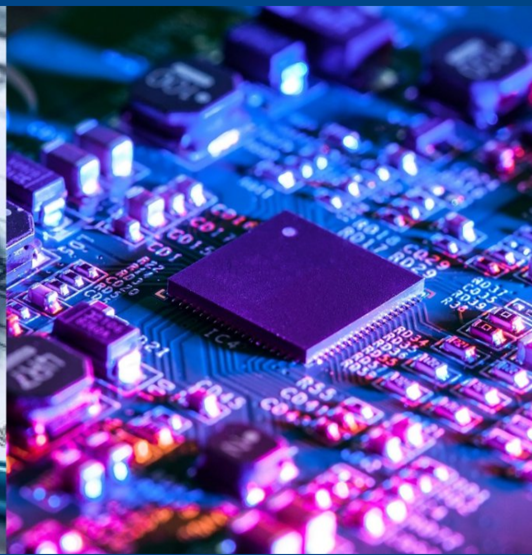

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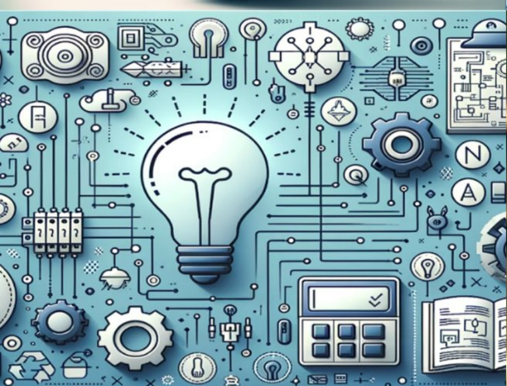

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Volume 9, Issue 4, April 2026

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Design of A Multi-Band MIMO Antenna for Wireless Applications

N. Mounika Deepthi[1] , M. Sravya[2], J. Naga Lakshmi[3], M. Shashi Kumar[4]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[1]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[2]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[3]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[4]

ABSTRACT: In this paper, a compact multi-band MIMO antenna for wireless applications is proposed. Designed in a planar microstrip configuration, the antenna is built on an FR-4 silicon base plate with a dumbbell-shaped radiating patch and defected ground structure (DGS) for improved function. The design can work at 2.342, 4.556 and 5.942 with a good impedance matching system. A low degree of mutual coupling is observed, showing that antenna elements are well isolated. An antenna with stable radiation patterns and gains up to 3.02 dBi is obtained. In addition, favourable MIMO operation is accomplished with less than 0.01 of ECC and around 10 dB of DG. The results confirm the capability of the proposed antenna for multi-band wireless communication systems.

KEYWORDS: Rectangular patch, Dumbbell shape structure, mutual coupling, asymmetrical T-shaped, monopole radiators, sub-6 GHz, Wi-Fi 6E.

I. INTRODUCTION

Wireless telecommunications are an essential part of our lives today, used in mobile phones, Wi-Fi networks and satellite communications. Wireless connections become more popular and require to connect mobile devices of various standards, evolving in the direction of a larger multipurpose. Hence, there is a need for a miniaturized and more reliable integrated wireless system. This project is mainly concerned with the design and development of a Multi-Band MIMO Antenna for Wireless Applications. The high-data rate targeting enabled for modern communication systems increases coverage and enhances spectrum efficiency while reducing signal dependency. Such systems often demand compact, efficient antennas capable of operating across several frequency bands simultaneously. The multichannel approach, known as Multiple-Input Multiple-Output (MIMO), can mitigate the issues of bandwidth limitations, isolation and performance efficiency. A specific issue related to MIMO is the mutual coupling between closely separated antenna elements, which compromises the performance of the MIMO antenna in terms of effective use of available spectrum and high- speed data rate. Thus, the design of MIMO antennas with controlled mutual coupling among their current miniaturized elements is key to the progress of MIMO antenna technology in wireless communications.

To this end, a number of MIMO antennas had been presented for wireless applications with the goal of mitigating mutual coupling between tightly packaged antenna radiators [1], [2], [3], [4], and [5]. In [1] Two port MIMO antenna design requirements support for bandwidth is met to allow Sub-6GHz 5G and Wi-Fi 6E band has also been done. The two- port MIMO antenna confirms dual-band functionality with wide 10-dB impedance bandwidths of 7.25% (2.39–2.57 GHz) and 58.12% (3.82–6.95 GHz), maximum gain of the peak gain of 2.65 dBi and efficiency of 70%. The utilization of a dollar-sign-shaped PDSS as a decoupling structure between the closely spaced monopole radiators of the MIMO antenna results in a mutually coupled response that achieves better than −15 dB. The antenna presented in [2] operates in the 5G Sub-6 GHz band and employs a slot in the ground plane for good isolation. However, they achieved an isolation of −10 dB with 6-dB impedance bandwidth using pin diodes (which increase power consumption and complexity) and a 120 × 60 mm2 space. The antenna referenced in [3], which is an inverted-F, uses an inverted T-shaped slot to improve isolation and thus operates between the 3.3-3.65 GHz and 4.8-5.50 GHz bands of frequencies. [4] proposes a dual bands-using swastika slot in the rectangular patch, and a T-shaped strip to enhance isolation. Presently, a shift in the research area is noticed as many researchers tend to lean toward designing DRA because of some benefits like higher bandwidth, lower losses due to no metal, better gain and efficiency.n [5], a ring- shaped DR is

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used in conjunction with defective ground structure to achieve the required dual-band and polarisation diversity, which has been employed to improve isolation between radiators. On the other hand, a DRA is three-dimensional (3D), so it takes up more physical space and, therefore, becomes less suitable for integration into next-generation wireless devices. This work encompasses a compact two-antenna MIMO, placed on an economical FR-4 dielectric lab that occupies a very small footprint of 45 × 30 mm2. The proposed multi-band MIMO antenna works in Wireless communications – Wi-Fi, IoT devices (2-4 GHz), Sub-6 wireless communication, 5G mobile communications (which operates at 4-8GHz). The dumbbell- shaped structure, used in the proposed antenna, increases the isolation of the proposed MIMO antenna. The proposed MIMO antenna design is suitable for integration in next-generation wireless communication systems because of the compact size and low mutual coupling between the antenna radiators.

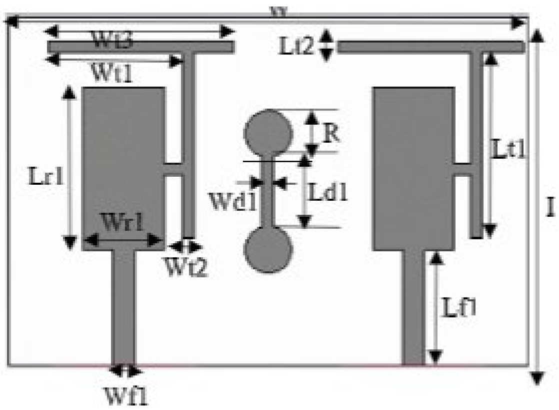
II. LAYOUT AND ANALYSIS OF THE PROPOSED TWO-PORT MIMO ANTENNA

The design and structure of the Multi-Band MIMO Antenna this, primary flat slim with an asymmetrical T-column at its right-hand side. The full periodic MIMO antenna is designed and achieved on a single lossy substrate of FR-4 with dielectric constant 4.4. Both antennas are printed on a thin dielectric substrate in the shape of planar microstrip antenna with inserted defected ground plane (DGP) at the bottom side. The CM antenna in the Microstrip method, contains a straight dumbbell-shaped patch symmetric to the horizontal axis of the patch printer is used. The dumbbell consists of multiple sections, with each section contributing to a specific resonant mode. The dumbbell-shaped geometry is an important component enabling multiband performance alongside compactness and inter-mimo element isolation. The configuration of the ground plane is defected with a rectangle-shaped slot on the bottom side of the substrate for considerable impedance matching, which effectively governs antenna performance.

A. Structure and working mechanism of the ground plane:

As the antenna is designed on FR-4 substrate, so in our proposed design perfect electric conductor (PEC) material is used for modeling of the ground plane, which lies at bottom layer as shown in Figure 1(b) with specifications and dimensions listed in Table 1. Instead of using a normal full ground plane, this design uses a defected ground structure (DGS), in the shape of a rectangular slot, which has significant contribution to improving antenna performance. The ground plane is also partial (not full substrate), modified with the inclusion of a rectangular slot (defect) and centred symmetrically around the antenna elements. This faulty ground plane is then separately engineered to regulate the antenna's electromagnetic response (antenna impedance and mutual coupling reduction).

The structure of the antenna includes dumbbell- shaped radiating patches depicted in Figure 1(a), which contribute to different resonant modes. The image currents corresponding to the patch currents are produced by the ground plane. These three currents combine to produce the radiation of the antenna. There is, therefore, more than one current path through the dumbbell-shaped patch. These defective grounds allow the resonating structure to maintain multiple resonances and effectively radiate high-bandwidth signals. Each circular section of the patch resonates at a unique frequency, and the ground plane sustains these modes. The rectangular opening made in the ground interrupts the unbroken electric current and regulates surface wave spreading. This minimizes undesired coupling between MIMO elements, improving isolation.



1(a)

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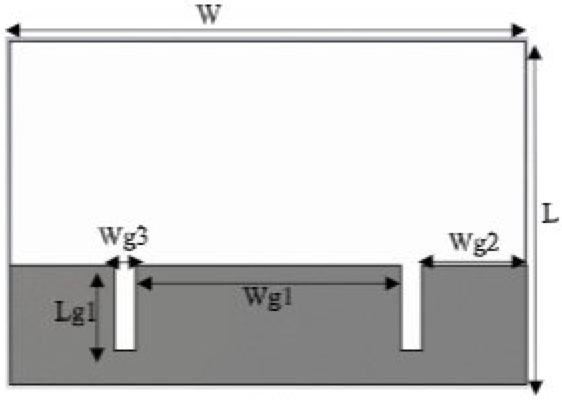

1(b)

Figure 1. (a) Front View of Multi-Band MIMO Antenna. (b) Back View of Multi-Band MIMO Antenna.

The defective ground enhances the wave paths of current, thus resulting in better impedance matching. This leads to the typically low S_{11} values at various resonant frequencies. This implies effective radiation, low power reflection and good multi-band operation. Coupling currents between patch elements propagate along the ground plane at first. The DGS disrupts these currents and weakens the mutual coupling.

B. Structure and working mechanism of the patch in antenna design:

As illustrated in Figure 1(a), the antenna employs a printed microstrip line feed on the same substrate as the patch, and Table 1 tabulates its size. It aims for a nominal characteristic impedance of 50 Ω for appropriate matching with the input port. The RF power is directly fed into the radiating patch through a feed line. It generates some excitement in the surface currents on the patch, which kick-starts radiation. The patch is a rectangular or almost rectangular segment linked to the dumbbell shape above the substrate. Serves as a leading path for high-frequency charge between areas of the patch while extending the effective electrical length of an antenna. It is also useful for tuning resonant frequencies. The second element of the patch design is an asymmetrical T-shaped strip connected to all rectangular portions. It induces extra votes by being at a different physical path distance, and reroutes the current distribution to provide a dampening between MIMO elements with isolation amplification. It is recommended to use a T-shape with asymmetry for various current flows, reducing identical directional currents and limiting electromagnetic interaction between the parts. This leads to a low reflection coefficient (S_{11}) and optimal energy transfer in the proposed antenna design. The rectangular section allows for more resonant modes and better impedance matching in antenna design. It also adds to Multi-band behaviour and improved bandwidth performance. Asymmetric T-shape structure disturbs coupling paths and operates with its ground plane defect. This reduces mutual coupling and provides better isolation in MIMO.

The antenna is a dumbbell-shaped radiating patch that is printed on the upper face of an FR-4 substrate. It is made up of two discs separated by a slender bar. Each dumbbell's circular section corresponds to a different resonant mode, and the connecting strip allows current flows between them and acts as an extended electrical path. Surface currents form on the patch when input current is applied and excited through the feed line. The existing condenses (around) round portions and genuflects through the thin smear of topography connecting them. This forms several current paths, which results in multiple resonant frequencies. Patch currents have a return path through the ground plane. On the ground plane, for each patch there is an image current. This interaction creates fringing electric fields between patch edges and ground, and these fringing fields are responsible for the radiation being done in the operation. The dumbbell's circular components are used for different resonance modes when operated. This connecting strip provides control over how tightly the two portions of the dumbbell are coupled. This combination results in an extended current path thus enabling multi- band operation and small size.

Antenna performance is directly affected by the interaction of the patch with the ground plane. Reflection Coefficient (S_{11}) contains several notches. This means no or little reflection and broad-band operation. MIMO Mutual Coupling (S_{12} / S_{21}) amongst patch elements share electromagnetic fields. Ground plane carries coupling currents. DGS is providing isolation among angle elements as coupling paths are getting disturbances.

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Symbol	Value (in mm)	Symbol	Value (in mm)	Symbol	Value (in mm)
L	30	Wt1	12	Lt1	16
W	45	Wt2	1	Lt2	1
R	2	Wt3	16	Lg1	7.5
Ld1	8	Wg1	23.2	Lr1	14
Wd1	1	Wg2	9	Lf1	10
Wr1	7	Wg3	1.8	Wf1	1.8

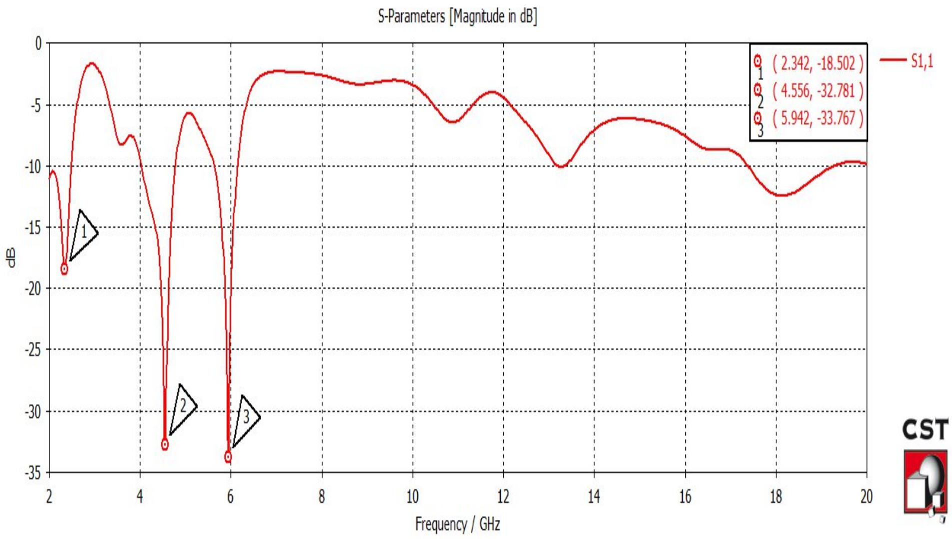
Table 1. Dimensions of proposed two-port Multiband MIMO antenna.

III. RESULTS AND DISCUSSION OF THE PROPOSED TWO-PORT MIMO ANTENNA

A detailed analysis of the performance of the proposed multi-band MIMO antenna is presented in terms of S-parameters, VSWR, gain, radiation patterns, ECC and DG. This indicates the successful operation through propose design over multi-band and with significant contribution towards isolation and radiation properties.

A. SIMULATED AND MEASURED S- PARAMETERS OF THE TWO-PORT MIMO ANTENNA:

Both the simulated and measured S_{11} and S_{12} impedance bandwidth characteristics of the proposed two-port MIMO antenna are shown, since the S_{11} and mutual coupling S_{12} are analogous to S_{22} and S_{21}. Impedance-matching characteristic of the antenna (reflection coefficient S_{11}). The design shows the multiple resonances at 2.342 GHz, 4.556 GHz and 5.942 GHz as shown in Figure 2(a) and 2(b). S_{11} parameters are well below the −10 dB, which provides information about good impedance matching and effective radiation at the required frequency bands. The measured S_{12} values can be considered adequate isolation, particularly at high frequencies.



2(a)

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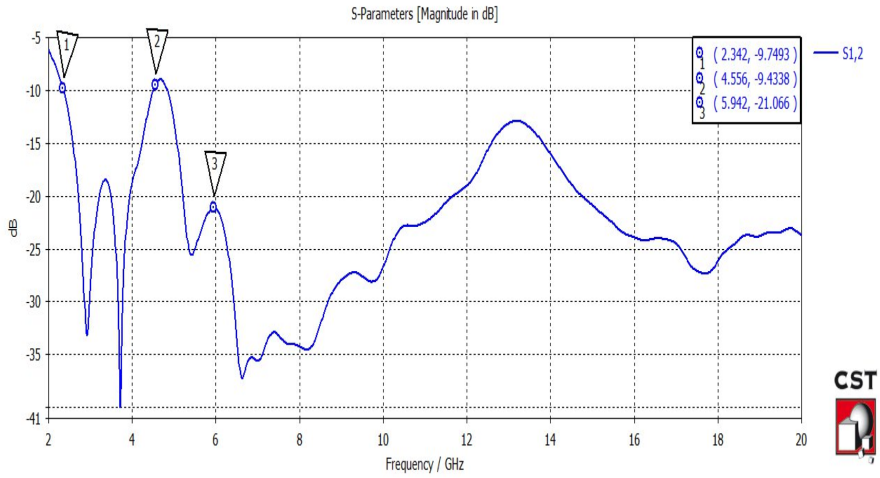
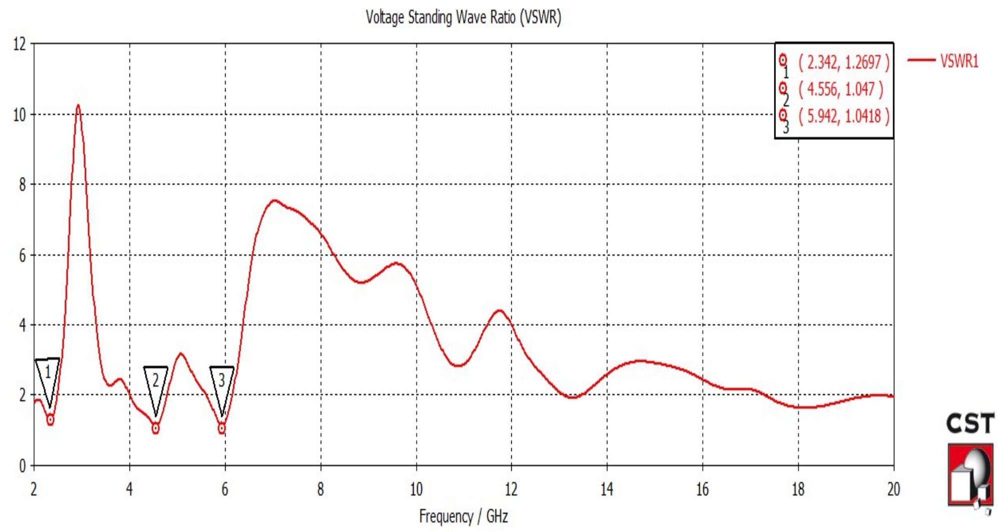


2(b)

Figure 2. (a) S-Parameters(S_{11}). (b) S-Parameters(S_{12}).

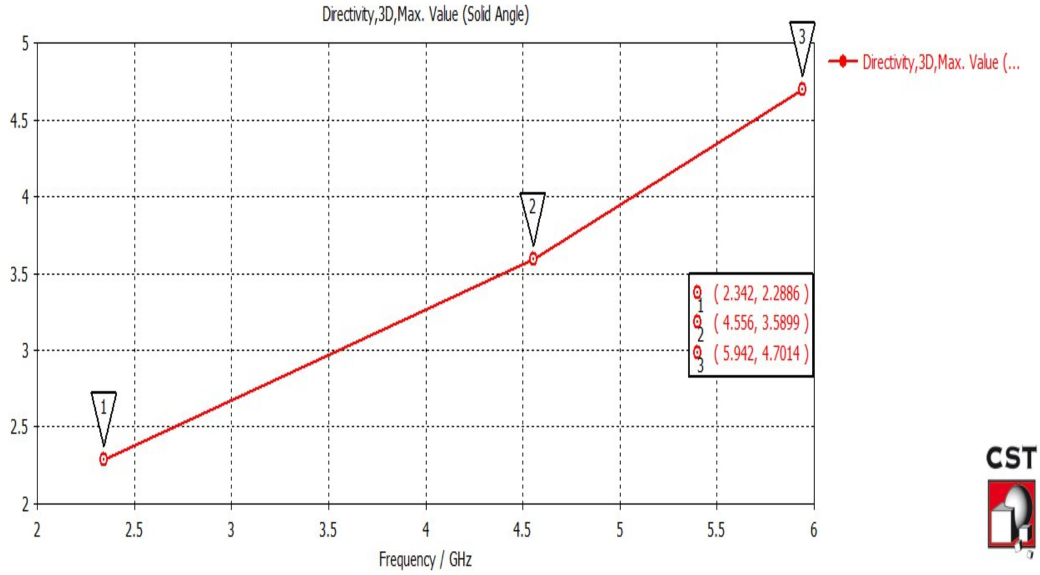
B. SIMULATED AND MEASURED VSWR ANALYSIS:

As illustrated in the below figure, the Voltage Standing Wave Ratio (VSWR) values at the operating frequencies are near unity. Values which suggest great impedance matching in order to achieve little reflection and maximum (almost) power transferred from feed line to antenna.

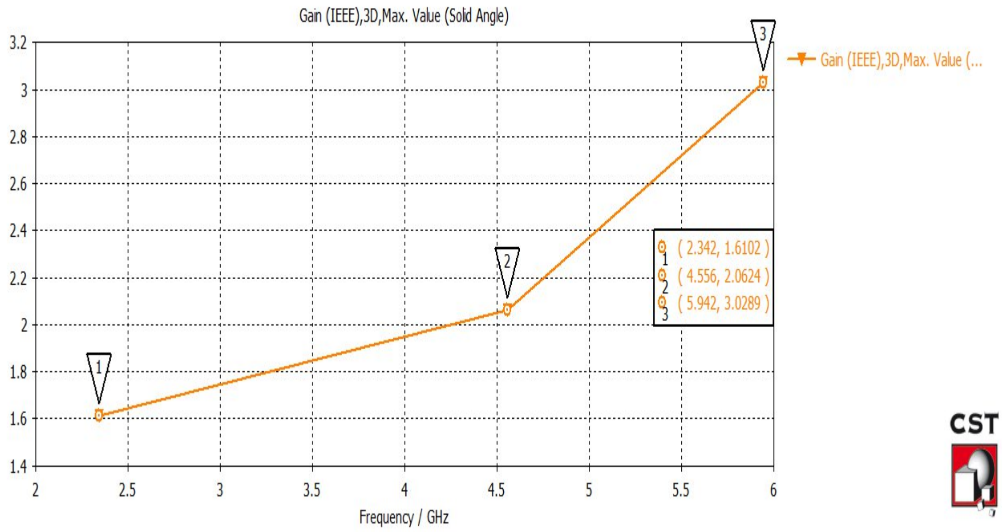


C. SIMULATED AND MEASURED GAIN AND DIRECTIVITY:

Directivity of the designed antenna also measured at multiple resonant frequencies, which is indication for direct either to reduce signal strength and minimizing interference in communication systems. The gain of the antenna was observed at some number of resonant frequencies, which indicates that antenna radiated power towards the required direction. The directivity and gain graphs are shown in Figure 3(a), 3(b).



3(a)



3(b)

Figure 3. (a) Directivity. (b)Gain.

D. SIMULATED AND MEASURED FAR- FIELD RADIATION PATTERNS OF A TWO-PORT MIMO ANTENNA:

Figure 4 visualises the radiation patterns of two-port MIMO antenna in E-plane and H-plane. The radiation properties of the proposed multi-band MIMO antenna are analyzed at resonant frequencies of 2.342 GHz, 4.556 GHz and 5.942 GHz. At 2.342 GHz. The formulated data in the E-plane depicts a bidirectional pattern of radiators, where radiation is established symmetrically opposite to each channel as shown by figure 4. It radiates with an omnidirectional pattern in H- plane. Likewise, at different frequencies, the radiation patterns in Figure 4, are in agreement with the proposed antenna provide stable and efficient radiation over the wide band of frequencies.

At 2.342 GHz :

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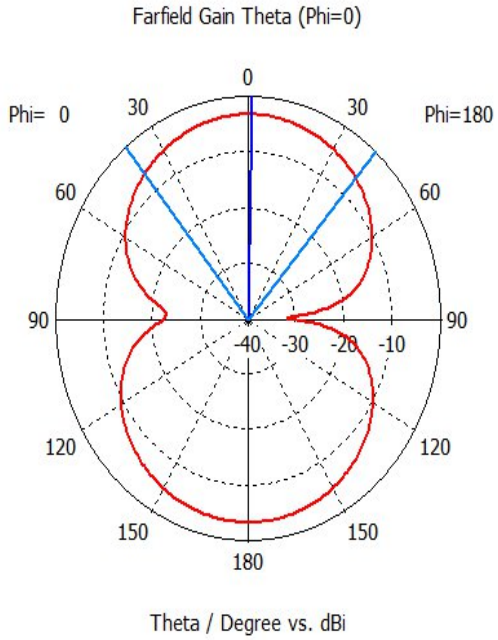
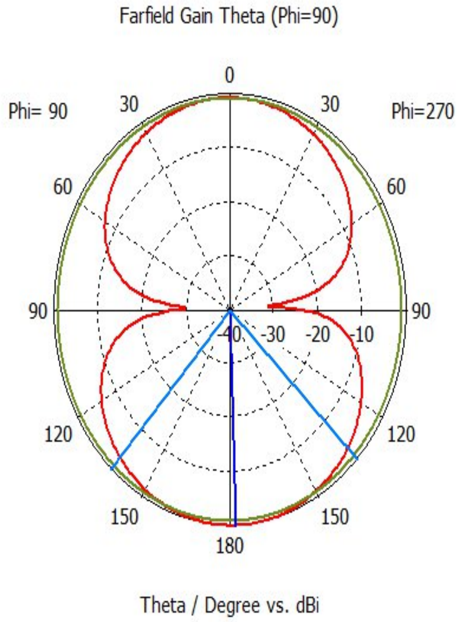
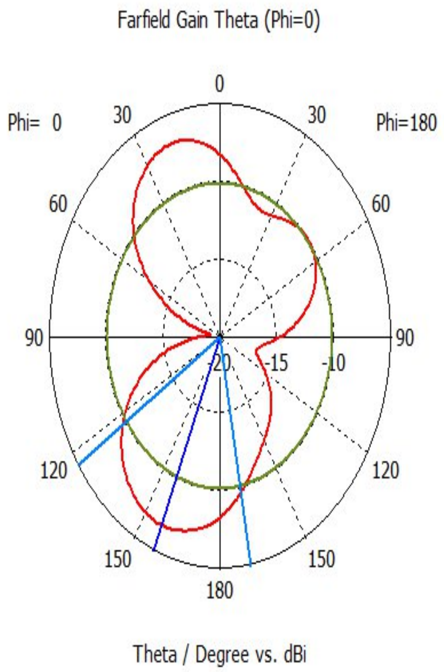
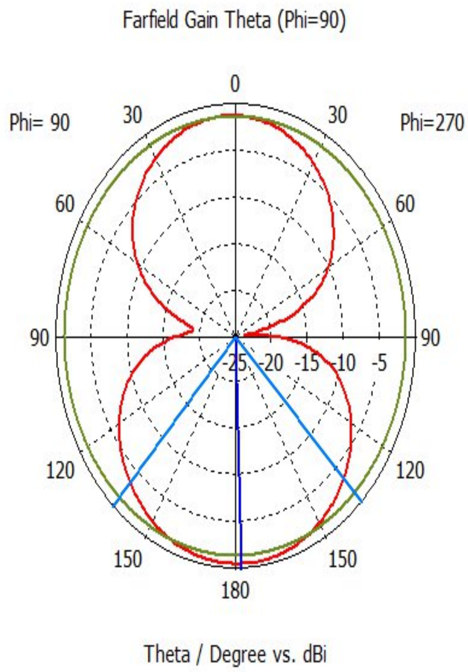




At 4.556 GHz :





At 5.942 GHz :

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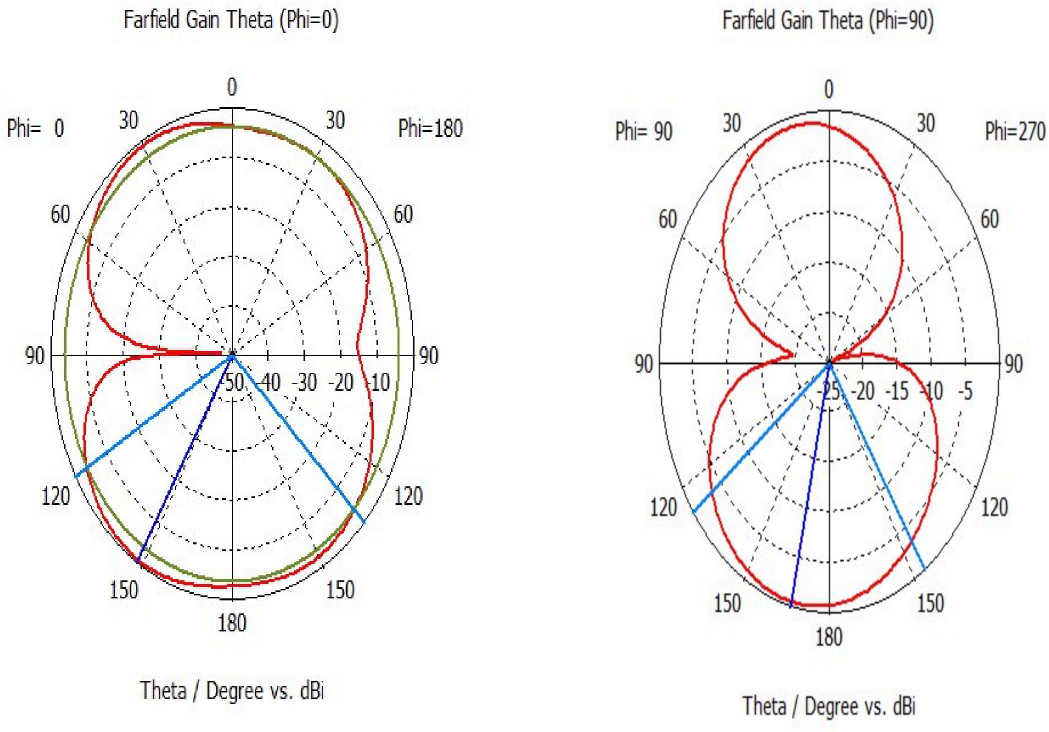

Figure 4. Radiation Patterns

E. DIVERSITY PERFORMANCE ANALYSIS:

To confirm the efficacy of the proposed two- port MIMO antenna, the diversity assessment (ECC and DG, for example) are essential.

ENVELOPE CORRELATION COEFFICIENT (ECC):

To analyzed the antenna across its operation band under how free it radiates across the operating environment, the ECC was investigated. ECC values of two-port MIMO antenna estimated through far field patterns using Equation (1). The ECC of the two-port MIMO antenna is depicted in Figure 5(a).

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

The ECC of the two-port MIMO antenna calculated from equation (1) are well below 0.02 in the full band of operation, thus this MIMO antenna exhibits performance very close to the ideal behaviour of MIMO diversity criteria.

DIVERSITY GAIN (DG) dB:

The advantage in SNR is presented from the spatial diversity technique as it can be calculated by using DG parameter for every symbol path. The DG in the ideal case is 10 dB. Its value is obtained by using equation (2).

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

The DG of the two-port MIMO antenna is shown in Figure 5(b). The far-field radiation patterns yielded simulated DG results that closely approach the ideal 10dB. This allows for greater reliability of the signal and immunity to multipath fading.

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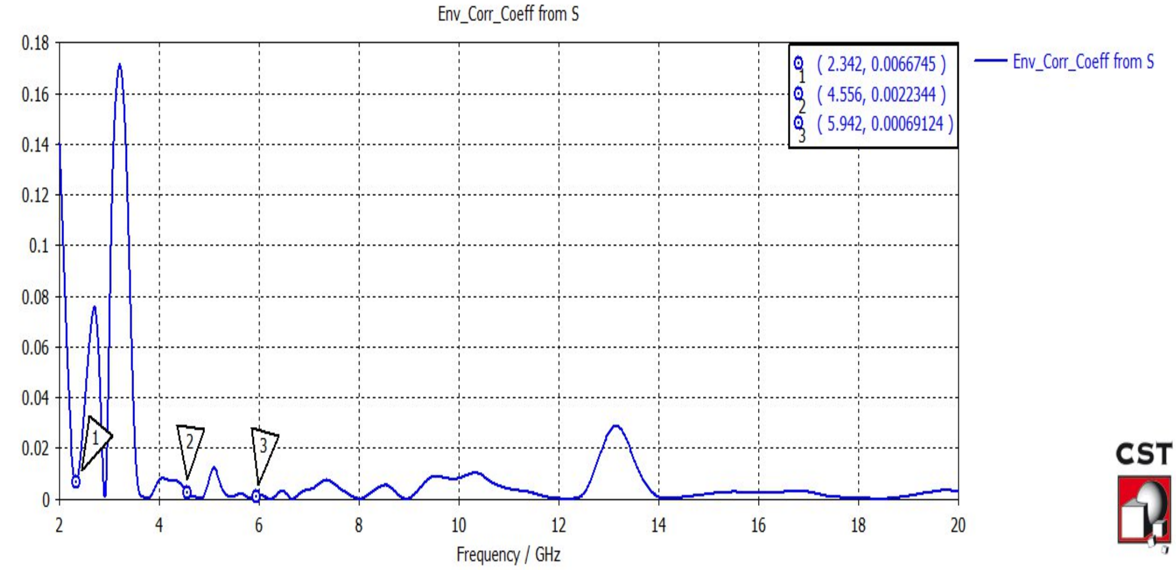
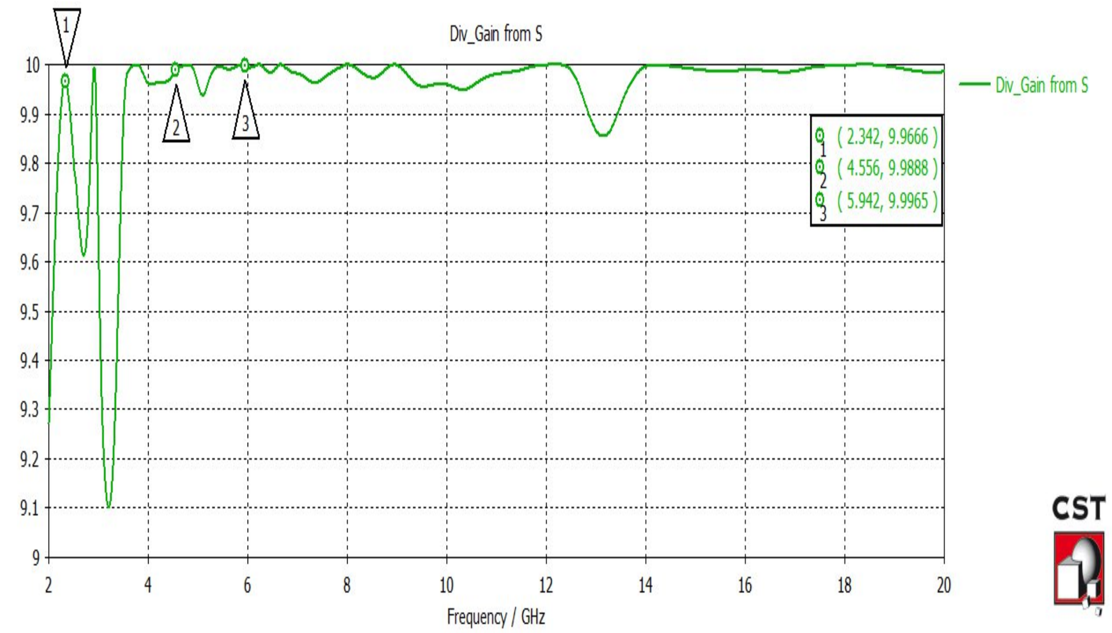


5(a)



5(b)

Figure 5. (a) ENVELOPE CORRELATION COEFFICIENT (ECC). (b) DIVERSITY GAIN (DG).

F. Surface Current Distribution:

The analysis of the surface current distribution demonstrates that the suggested antenna functions via multi-current paths at various resonant frequencies. Indeed, as seen from lower frequencies, current is localised to certain patch regions, but at higher frequency it diffuses through the entire structure suggesting higher order modes. The defected ground structure is very effective in suppressing unwanted surface currents which therefore mitigates the mutual coupling and leads to enhanced isolation. This results in improved radiation properties and antenna performance due to controlled current distribution. Figure 6 below presents the surface currents at various frequencies.

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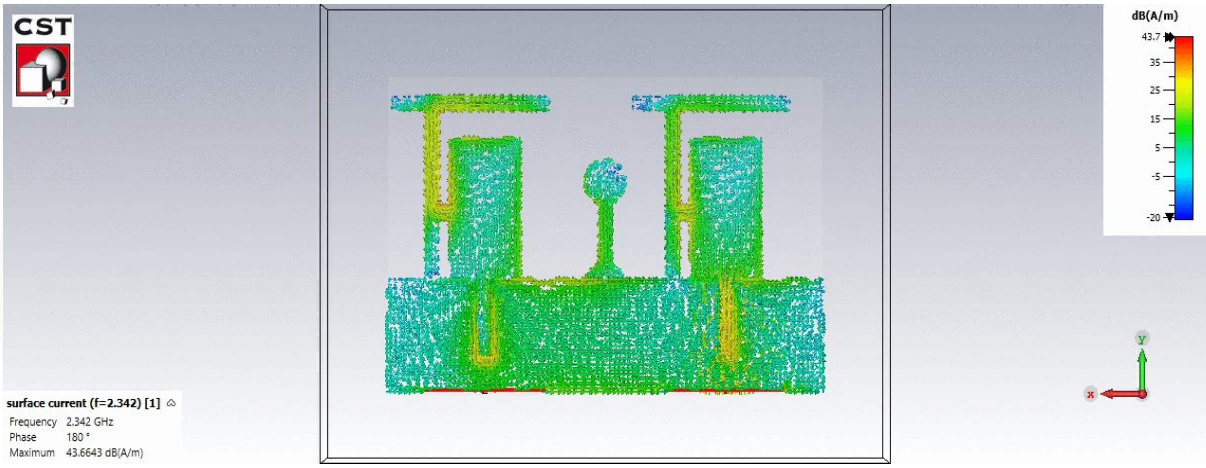
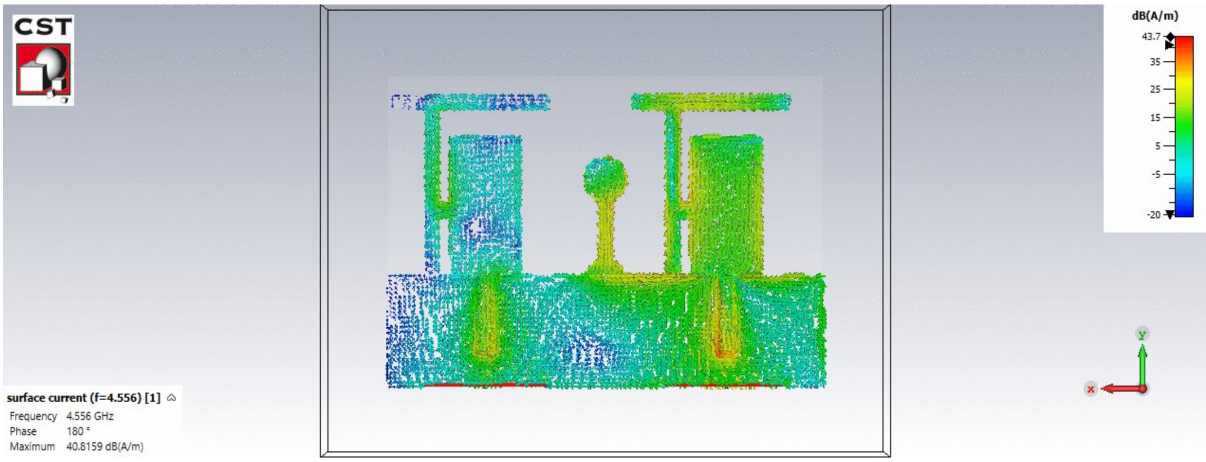
At 2.342 GHz:



At 4.556 GHz :



At 5.942 GHz:

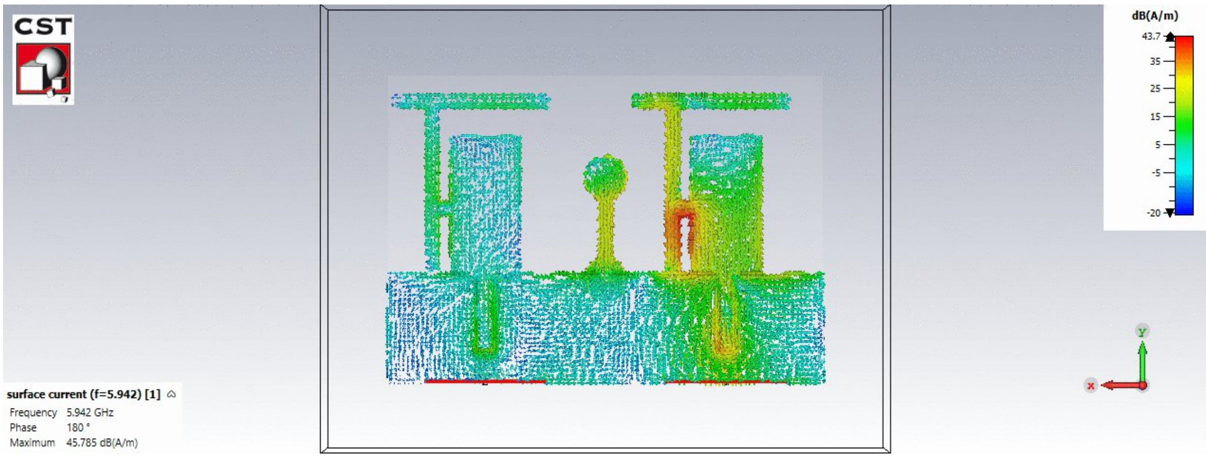


Figure 6. Surface Currents.

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IV. CONCLUSION

This paper presents the design and analysis of a compact multi-band MIMO-based antenna for wireless communication applications. The antenna adopts both dumbbell-shaped radiating patch and defected ground structure (DGS) to optimize impedance matching and mitigate mutual coupling. Good S_{11} values below −10 dB are achieved at 2.342 GHz, 4.556 GHz, and 5.942 GHz when the antenna is in operation; Thus efficient performance is obtained. This design tends to have stable radiation patterns and moderate gain over all working bands. The antenna also achieves very good MIMO performance with ECC < 0.05, and high DG values, which confirms the efficient communication. The proposed antenna is a candidate for the new wireless systems (Wi-Fi, IoT, sub-6 GHz) as its small size and multi-band properties provide enhanced performance.

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| Mobile No: +91-6381907438 | Whatsapp: +91-6381907438 | ijmrset@gmail.com |

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