A Compact Low-Profile High Isolation MIMO Antenna For X-Band Applications

Akanksha Singh (akankshasingh5614@gmail.com)
National Institute of Technology Kurukshetra
Arvind Kumar
National Institute of Technology Kurukshetra
Binod Kumar Kanaujia
JNU: Jawaharlal Nehru University

Research Article

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A Compact Low-Profile High Isolation MIMO Antenna for X-band Applications

Akanksha Singh[1], Arvind Kumar[2], Binod Kumar Kanaujia[3],

[1]Electronics and Communication Engineering Department, Amity University, Greater Noida 201308, India

[2]Electronics and Communication Engineering Department, National Institute of Technology, Kurukshetra, Haryana 136119, India

[3]School of Computational and Integrative Sciences, Jawaharlal Nehru University, New Delhi 110067, India

[1]akankshasingh5614@gmail.com, [2]arvind_sharma@ntkkr.ac.in, [3]bkkanaujia@ieee.org,

Abstract: A novel compact low profile MIMO antenna is designed and implemented with high isolation for the X band applications. Proposed MIMO geometry is incorporated with two monopoles which are excited by 50 Ω feed line. To enhance the isolation between inter-elements meander line structures are is identically placed. These meander line structures are reducing the mutual coupling up to 26 dB. In the proposed MIMO antenna two elements cover the entire frequency range between 7.4-11.8 GHz for the X band applications. Meander line structure is working as a decoupling network which improves the isolation considerably. The overall size of the MIMO antenna is $25 \times 30 \times 1$ mm^3, and it offers inter-element isolation of >26 dB, envelope correlation coefficient is less than 0.2, and directivity gain >9.99 over the resonating frequency range. The proposed MIMO antenna model is fabricated, and measurement results are verified with simulated results. The antenna shows the satisfactory gain of around 4.8 dB in entire frequency range. The antenna shows the satisfactory gain of around 4.5 dB in entire frequency range.

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1. Introduction

Multiple-input-multiple-output antennas are made up of numerous resonating elements on both sides of the transmitting networks to bring off high data rate without increasing communication bandwidth or power. Since multiple resonators are integrated into a single wireless system/device, the size of the multi-input-multi-output (MIMO) antenna is an important design factor. The major challenge in the MIMO configuration is to improve isolation between the antenna elements when they are closely placed. In the past, numerous methods have been incorporated to upgrade inter-element isolation, such as slits/slots on the ground plane, defected ground structure (DGS), electromagnetic band-gap (EBG), split ring resonator (SRR), neutralization lines (NL), etc.

In [1], an eight-shaped stub was used to reduce the mutual coupling of the inter-elements, but the size of the antenna was much larger. In [2], mutual coupling has been significantly reduced by decoupling network, but system complexity has increased. In [3], the dual-band MIMO antenna is designed with DGS, in which a high degree of isolation between the antenna components is achieved. In [4], a MIMO antenna antenna for four WLAN applications was introduced, in which the λ / 4 terminal network is used to improve isolation. An inverted F-antenna (PIFA) two-port antenna has been reported in [5], where two feed plates were used to strengthen the isolation. In [6], two dummy elements were used to improve the isolation of the elements, but the process of dummy construction was complicated and the size of the antenna was very large. The structure of the earth plays a very important role in equating impedance and development alone, as discussed in [7].Although the isolation techniques mentioned above are somewhat effective, only a few of them can be used on closely packed antenna systems. Therefore, one of the simplest methods for improving isolation is to introduce slits and slots in the ground plane. In [8], an ultra-wideband (UWB) antenna was developed with a strip on its bottom plane, which offered an additional current path and also improved the impedance matching. In [9], a strip was positioned under the radiating element to provide an additional coupling path to improve isolation. In [10], a MIMO antenna consisted of two X-shaped arms was presented, which functioned as a self-decoupling structure. In [11], the antenna consisted of two uniform radiators, and a ground-coupled loop-shaped decoupling structure was present between them. The decoupling element was used as a series resonator network, and comprised of lumped components. An antenna with two frequency reconfigurable monopole elements placed symmetrically was reported in [12], where pin diodes and DGS were used for inter-element correlation enhancement.

The paper presents the design of a planar compact multi-input-multi-output (MIMO) antenna for mutual communication between antenna elements. These are low-profile MIMO antennas suitable for X-band applications. The prepared antenna contains two identical monopole emitters, a modified bottom plane, and, linear meandered-line decoupling geometry to improve insulation. The antenna operates in the frequency range from 7.4 GHz to 11.8 GHz for excellent isolation of the entire band. The MIMO antenna size is 25x30 mm2. Despite being low profile, these antennas have a very high isolation rate of no more than 26 dB For modeling and optimization, it is suggested to use a 3D EM modeling antenna, Ansys HFSS.

2. Antenna Configuration

The initial design started with a simple monopole emitter with a 1 mm high substrate and a partially grounded plane on the other side of the substrate. A rectangular plane, the space is modified to get the operation, X-band. The entire contents of the MIMO antenna are 30 × 25 × 1 mm3, as shown in the photo.1 (ant. 1). At present, our goal is that the MIMO antenna design is using a simple monopole radiator antenna, good characteristics, at the same time, they should correspond to the same band behavior, it turns out that the monopole radiator. We designed a two-element MIMO antenna, with two same monopole radiators in one plane (ant. 2). The two elements are positioned in such a way that without the need to change the size of ground plane with as previous band performance. Two meander design lines inserted between two elements to reduce mutual coupling (ant 3). Here, the lower line structure increases the carrying capacity of the resistance by increasing the surface area of the current path. This is done in three stages, which are used in the development of the proposed ant-1 design, as indicated in the photo.1, ant-2, and finally the proposed design of the ant-3 line, respectively. The subsets of proposed structure (ant 1 and ant 2) are simulated to examine the performance of this subsection, individually. The design of the MIMO antenna module is shown in Fig. 1 (c)). Antenna in FR-4 dielectric materials (ξr = 4.4, δ = 0.02 thickness = 1.6 mm). The monopole radiator is located on the upper side of the dielectric substrate, and partially ground surface (L2 × L3) is located down. Each monopole emitters have a 50 ohm microstrip feed line. The monopole element is selected to improve the performance of a compact size. Two meandered-line structures are placed in between the antenna elements and the isolation is improved appreciably. The ANSYS HFSS® 3-D-EM-a tool is used to simulate a MIMO antenna. The dimensions of the antenna offer are given in the Table 1 below.

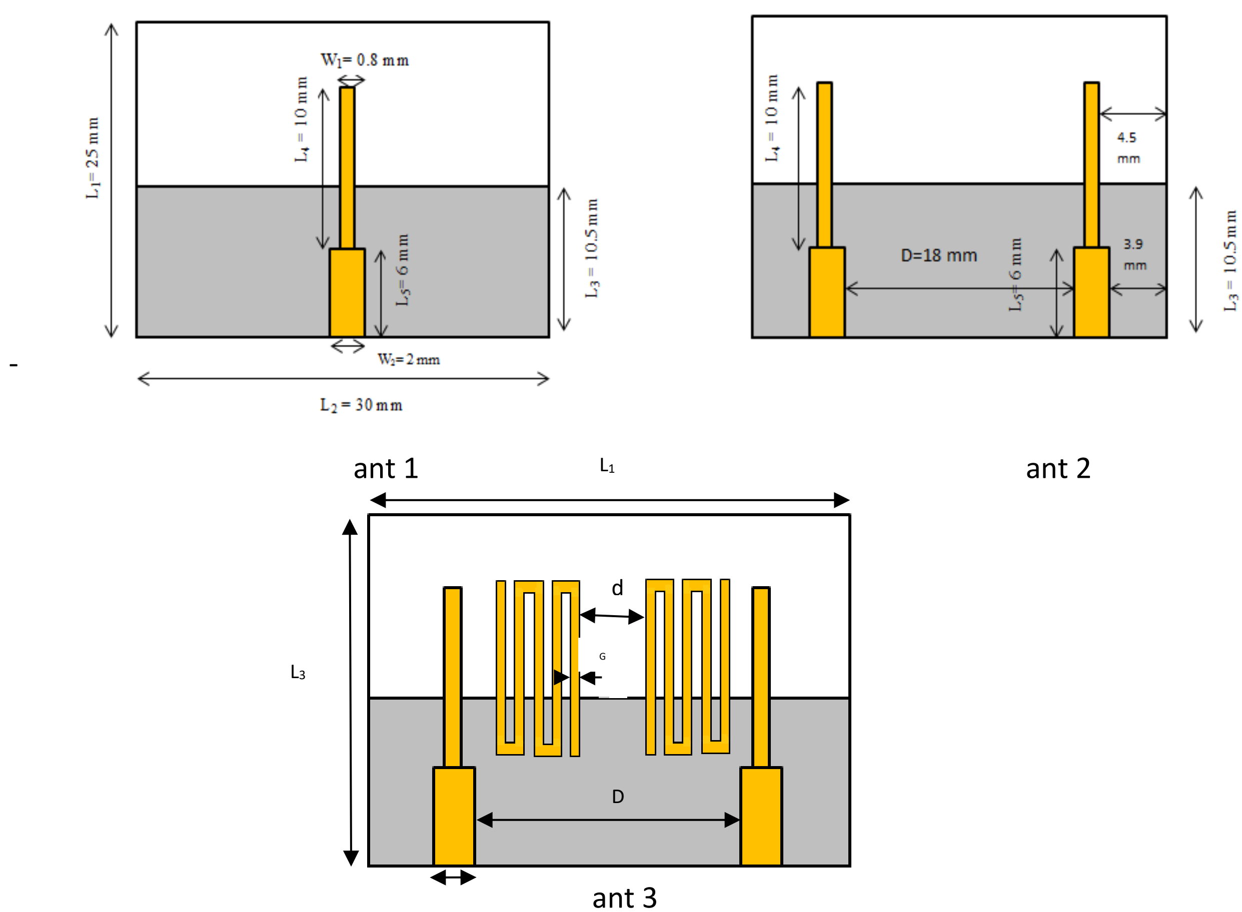


Figure 1. Evolution steps of Suggested MIMO antenna.

Table 1. Design parameters of the proposed MIMO antenna.

Parameter	Unit (mm)	Parameter	Unit (mm)
L_1	25	W_3	4.5
L_2	30	d	6
L_3	10.5	D	18
L_4	10	K	12
L_5	6	G	0.5
W_1	0.8	J	1

The ground plane geometry is optimized to attain the desired band performance. Figure 2 shows the reflection coefficients and S_{11} and S_{21} of all iterations. The isolation of Ant. 2 is 8 dB, which is extremely low and inadequate for MIMO antennas. In Ant. 3, two rectangular-shaped meander lines are placed in the middle of antenna elements for better inter-element isolation. The meander lines offer a stop band property and minimize the mutual coupling between the resonating radiators. The distance between the meander lines is optimized to decrease mutual coupling and improve impedance matching. It is observed from Figure 2 that isolation significantly increases with a little change in impedance bandwidth.

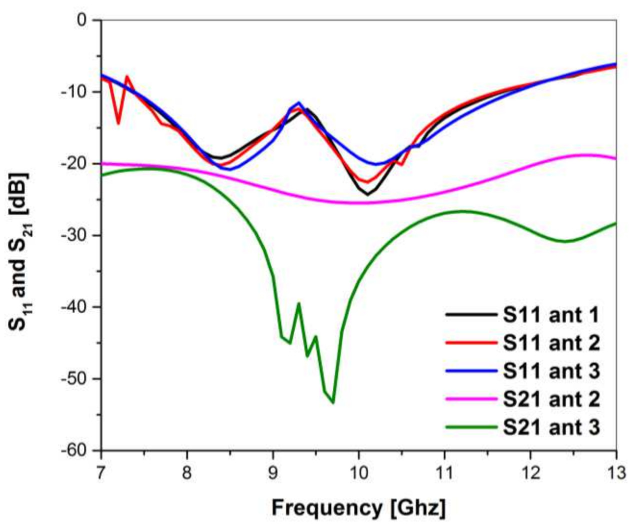
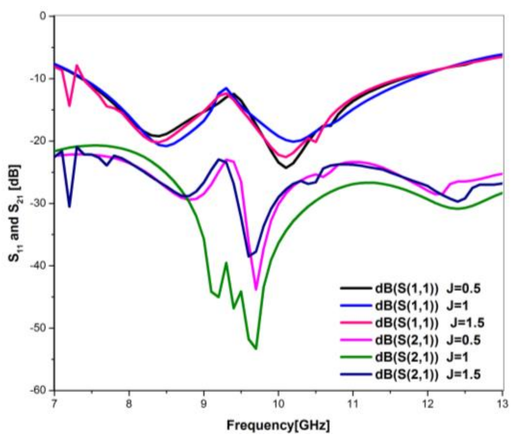


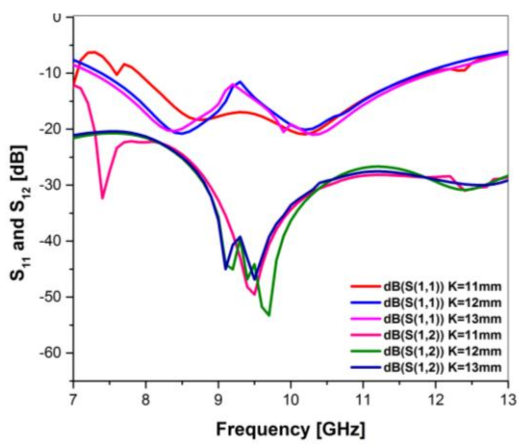
Figure 2. Simulated S_{11} and S_{21} of the antenna design steps.

2.1. Parametric Study

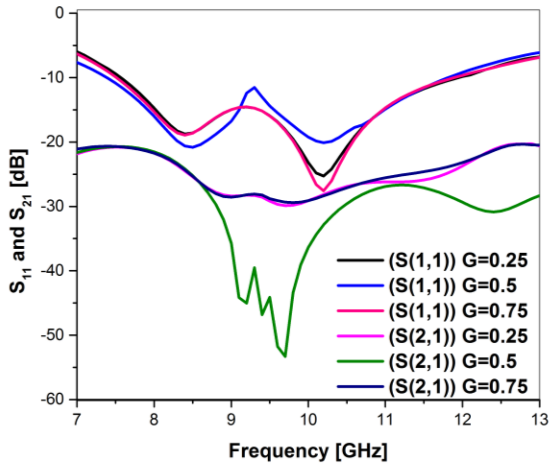
These are parameters of the meander line structure and its effect on the MIMO antenna properties. A parametric study shows that parameters (J, K) and (G) show a significant effect on isolation, as shown in Figure 3(a), (b) and (c). Another parameter changes, the other remains unchanged. 3 (a) increases when the isolation parameter J between antenna elements decreases. Variable time, length, and K of the spiral part, there is a slight decrease in inter-element isolation, as shown in Fig. 3 (a) (b). As can be seen from Fig. 3 (c), the isolation between antenna elements is significantly reduced due to an increase in parameter G.



(a)



(b)

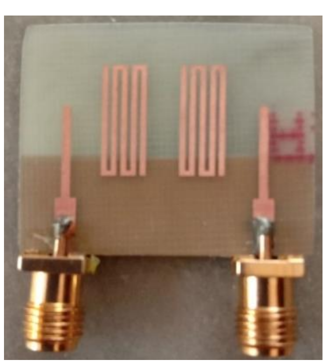
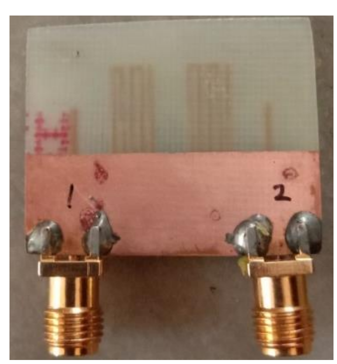


(c)

Figure 3. Parametric study of the proposed MIMO antenna: (a) alteration of *J*, (b) alteration of *K*, (c) alteration of *G*.

3. Results and Discussion

Multi-input multi-input antenna (MIMO) was designed and quantified to confirm the proposed designs. Top and bottom view of the prepared antenna prototype is shown in Fig. 4(a) and (b). To measure the reflection coefficients of the MIMO antenna, use the Agilent N5230A vector network analyzer. Based on the sample and sizes S11 and S21, compare the Figure.5. Apparently, there is a good agreement on the sample and dimensions of the S-parameters. Introduced MIMO antenna, meander line structures, greatly improves various insulation elements. Application before the meander line, the isolation structure between the antenna elements, was not 8 dB, which increased by more than 26 db and after the meander line was passed, the structure between the two radiating monopoles.

(a) (b)

Figure 4. Fabricated prototype of the MIMO antenna: (a) top view, (b) bottom view.

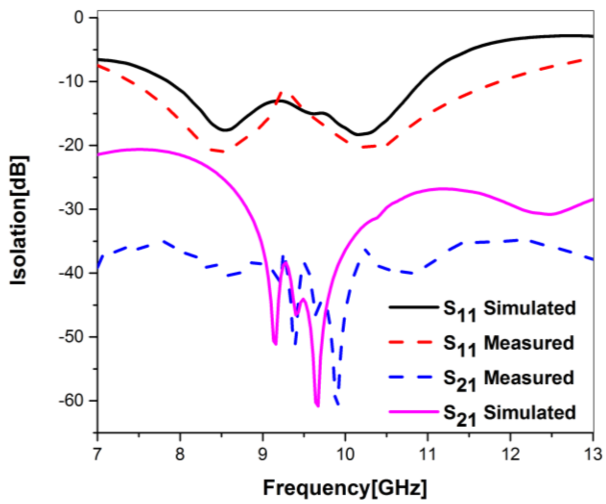


Figure 5. S-parameters of the proposed MIMO antenna.

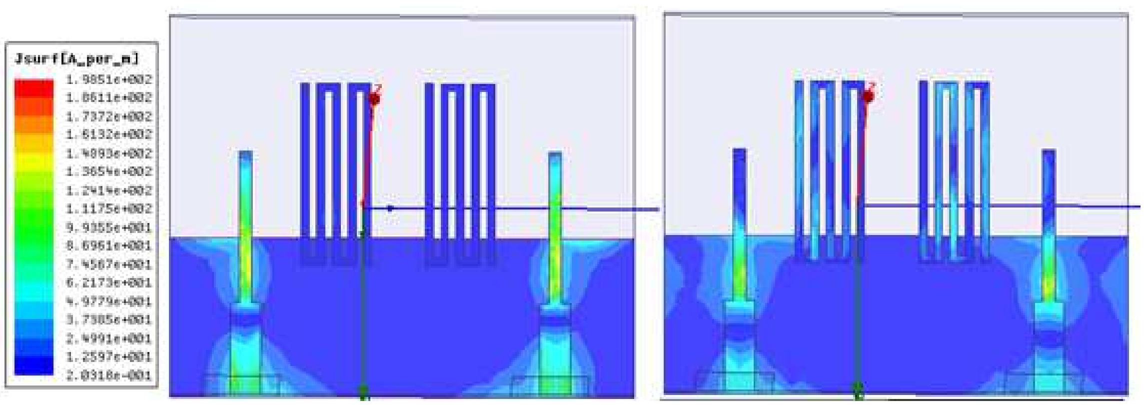


Figure 6. Surface current distribution of the proposed MIMO antenna: (a) 8.5 GHz, (b) 9.9 GHz.

Figure. 6 shows the distribution of the surface current frequency from 8.5 and 9.9 Ghz. It can be seen that the current minimum number of meander lines shows what isolation between the two monopole emitters is needed.

The gain and efficiency of radiation are shown in Figure. 7. The maximum gain of the recording antenna is about 4.5 dB, and the average efficiency is 95%.

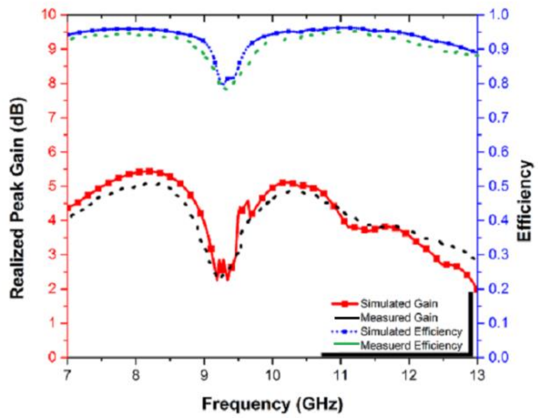
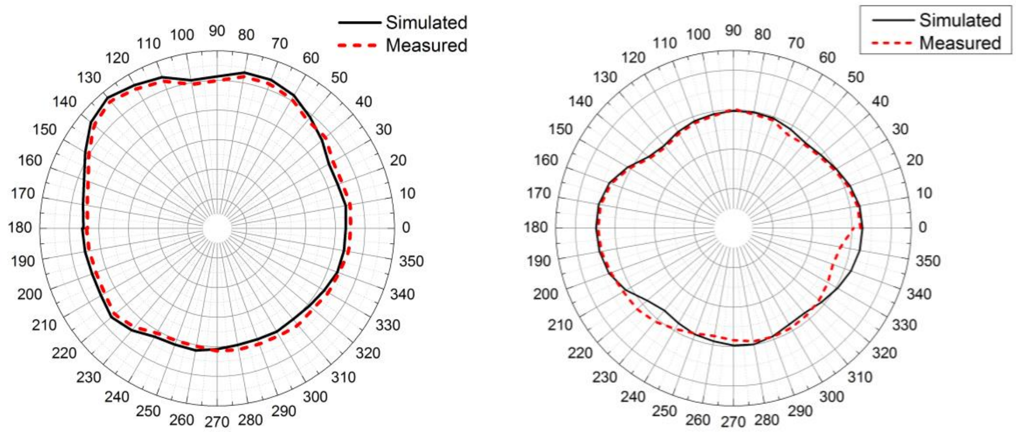


Figure 7. Gain and efficiency of the proposed MIMO antenna.

Figure 8 shows the radiation patterns of the MIMO antenna at 8.5 GHz and 9.9 GHz. Figure 8 shows the radiation patterns of the MIMO antenna at 8.5 GHz / Airplane, 8.5 GHz / H plane, 9.9 GHz / E plane and 9.9 GHz / H-plane. The results produced and measured show a reasonable agreement between them. Minor deviations are due to structural and measurement errors.



(a) E Plane at 8.5 GHz

(b) H Plain at 8.5 GHz

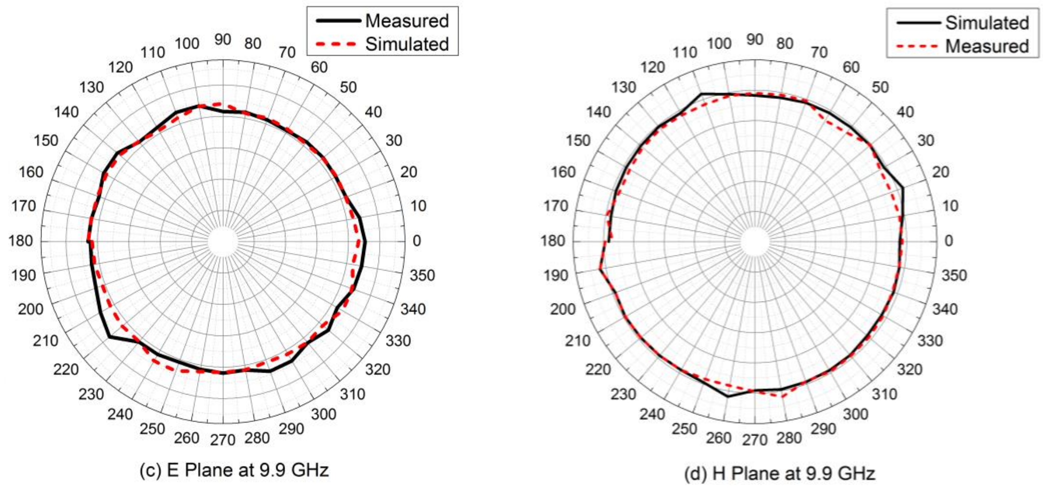


Figure 8. Radiation patterns of the MIMO antenna: (a) 8.5 GHz/E-plane, (b) 8.5 GHz/H-plane, (c) 9.9 GHz/E-plane, (d) 9.9 GHz/H-plane.

4. MIMO Performance

In MIMO, diversity and multiplexing parameters, such as the coefficient of envelope integration ECC, DG, TARC, CCL and mean effective gain (MEG)), it is important to ensure the functionality of the proposed structure. The ECC shows the interaction between the two antenna components and can be given as [21]

$$\rho = \frac{\left|Sii^{*}Sij + Sji^{*}Sjj\right|^{2}}{((1-\left|Sii\right|^{2}+\left|Sji\right|^{2})+(1-\left|Sjj\right|^{2}+\left|Sij\right|^{2}))} \tag{1}$$

The ECC for the proposed antenna design is given in Figure.9. It is noted that the ECC is less than 0.2 in the operating frequency band, which satisfies an acceptable limit of <0.5. From the result, it can be concluded that the proposed design provides good performance for diversity.

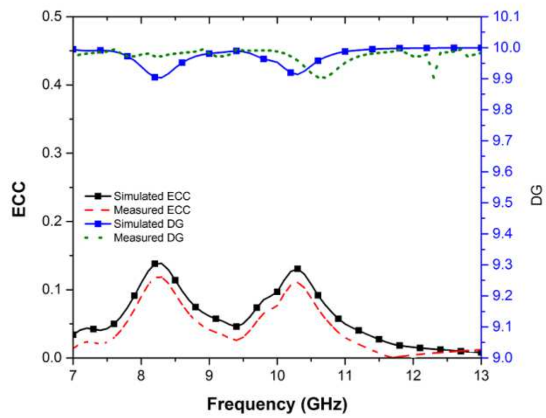


Figure 9. ECC and DG of the presented MIMO antenna.

DG is another leading parameter of the MIMO antenna. It is used to determine the diversity effectiveness and is calculated as

$$DG = 10\sqrt{1 - ECC^2} \tag{2}$$

A high DG (>9.9) is noticed in the operating frequency band of the MIMO antenna.

In the MIMO system, the neighboring antenna elements influence each other's performance. As a result, the overall operating frequency range and efficiency of the multiport antenna are affected when the antenna elements work together. TARC is taken into account to calculate this effect and is described as the ratio of the square root of total reflected power to the total incident power [21].

$$TARC = \sqrt{\frac{(\mathrm{Sii} + \mathrm{Sij})^2 + (\mathrm{Sji} + \mathrm{Sjj})^2}{2}} \tag{3}$$

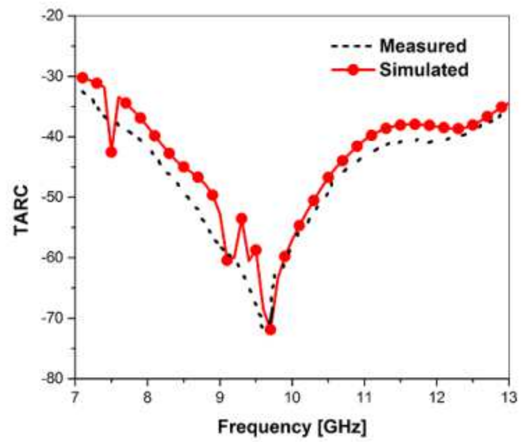


Figure 10. TARC of the proposed MIMO antenna.

The measured and simulated TARC of the proposed MIMO antenna are presented in Figure 10.

CCL is another significant variable to evaluate the diversity performance of the MIMO antenna system. The maximum limit of transmission and reception is characterized by CCL, and it can be evaluated as [21]

$$CCL = -\log_2(\psi^R) \tag{4}$$

where

$$\psi^R = \begin{bmatrix} \psi_{ii} & \psi_{ij} \\ \psi_{ji} & \psi_{jj} \end{bmatrix}$$

$$\psi_{ii} = 1 - (|S_{ii}|^2 + |S_{ij}|^2)$$
$$\psi_{jj} = 1 - (|S_{ji}|^2 + |S_{jj}|^2)$$
$$\psi_{ji} = -(S_{ii}^* S_{ji} + S_{ji}^* S_{jj})$$
$$\psi_{ij} = -(S_{jj}^* S_{ji} + S_{ii}^* S_{ij})$$

The CCL is conveyed in Figure 11(a), and it is noticed that the channel capacity loss (CCL) is less than -0.2 dB.

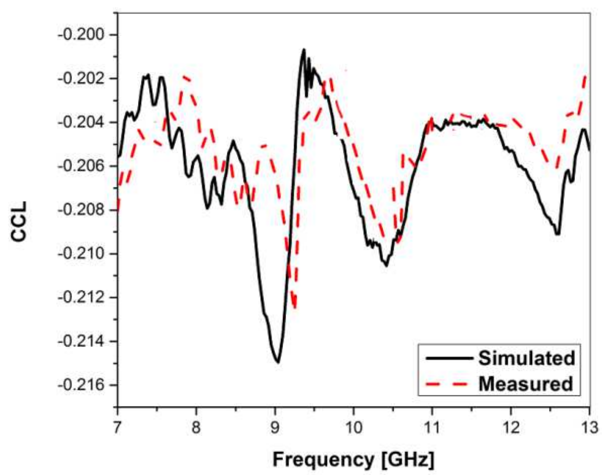
MEG is another important parameter to evaluate the diversity performance of the MIMO systems. It is a measure of the median power obtained from the event power used and can be determined as [21]

$$MEG1 = 0.5(1 - \left|S_{ii}\right|^2 + \left|S_{ij}\right|^2) \tag{5(a)}$$

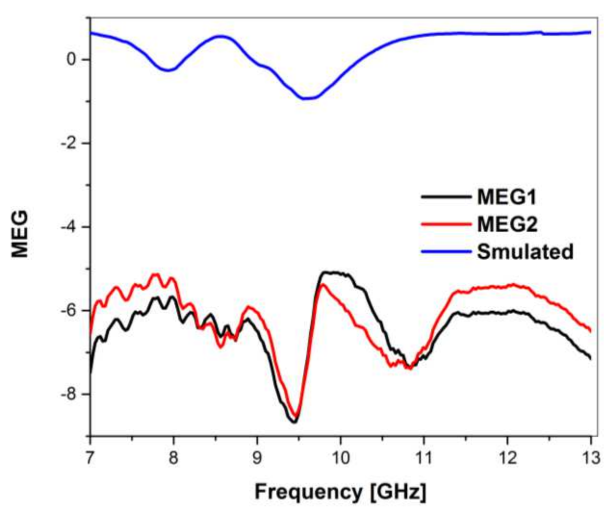
$$MEG2 = 0.5(1 - \left|S_{ij}\right|^2 + \left|S_{jj}\right|^2) \tag{5(b)}$$

$$MEG = MEG1 - MEG2 \tag{5(c)}$$

Measurements and simulations show that the proposed MIMO antenna is indicated in Figure 11 (b). This MIMO antenna show the MEG is less than 3 dB, which is below the acceptable limit.



(a)



(b)

Figure 11. Proposed MIMO antenna: (a) CCL, (b) MEG.

Furthermore, the proposed MIMO antenna is compared with the previously presented MIMO antennas shown in the Table2. The structure, small size and low mutual coupling are proposed and in accordance with it for use in the X-band.

Table 2. Comparison with the previously reported MIMO antennas.

Ref.	Size (mm × mm)	Gain (dB)	Efficiency (%)	Resonating Bandwidth (GHz)	Isolation (dB)	ECC
[1]	55 × 35	6.9	---	2.74–12.33	>26	<0.026
[2]	40 × 80	5	59	2.4–2.5, 5.1–5.8	>20	<0.2
[3]	50 × 100	2.4	---	0.803–0.823	>17	<0.21
[7]	38.5 × 38.5	4.5	75	3.5, 5.2, 5.8	>15	<0.02
[9]	60 × 48	4.6	80	3.4–3.7, 5.15–5.35	>17.2	<0.002
[12]	40 × 40	5.8	---	1.88–2.64	>41.2	<0.005
[18]	40 × 70	3.2	70	4.82	>23.5	<0.05
[20]	48 × 48	<3	---	2.5–12	>18	---
[21]	40 × 40	5.1–5.8, 7.25–7.75	---	3.4–12	>15	---
Prop.	**25 × 30**	**4.2**	**95**	**7.4–11.8**	**>26**	**<0.2**

5. Conclusion

In this work, a low-profile compact size MIMO antenna is proposed for X-band (7.4 GHz -11.8 GHz) applications. Each antenna element consists of microstrip fed monopole radiator and a common ground plane. Two meandered-line elements are introduced between the radiating elements to enhance isolation. The antenna configuration is fabricated and measured result the agreement between the measured and simulated result. The proposed MIMO antenna offers inter-element isolation greater than 26 dB and a gain of ~4 dBi in the resonating frequency band. Various MIMO performance parameters, such as ECC, DG, TARC, CCL, and MEG, are examined and found within acceptable limits. The MIMO antenna configuration present in this work can be used for the X band applications in the wireless communication systems.

Declarations

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Author information

Affiliations

Akanksha Singh
Electronics and Communication Engineering Department, Amity University, Greater Noida 201308, India
Arvind Kumar
Electronics and Communication Engineering Department, National Institute of Technology, Kurukshetra, Haryana 136119, India
Binod Kumar Kanaujia
School of Computational and Integrative Sciences, Jawaharlal Nehru University, New Delhi 110067, India
Corresponding author
Correspondence to Akanksha Singh

Ethics declarations

Conflict of interest

The author declared that there is no conflict of interest.

Data are available on request due to privacy or other restrictions

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