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Minimised Four-Port MIMO Antenna for Sub-6 GHz and Satellite Applications

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ABSTRACT

The design and analysis of a four-port Multiple Input Multiple Output (MIMO) configuration antenna have been discussed in this work. Firstly, a single-element antenna has been designed using a monopole feedline, split ring resonators (SRR), and Defective Ground Structures (DGS). The SRRs were designed using rectangular and circular configurations and analysed their characteristics. The DGS is used to enhance the bandwidth of the proposed single-element antenna. Further four port MIMO configurations have been designed using four single-element antennas. To enhance the isolation, antennas are placed orthogonally to each other in MIMO configuration. The coupling between the monopole feedline and SRR plays a vital role in enhancing the impedance matching of the antenna configuration. The proposed MIMO antenna provides improved gain, high isolation, and compactness in size. The diversity performance matrices such as envelope correlation coefficient, diversity gain), Mean effective gain and total active reflection coefficient are <0.01, >9.95 dB, -1.0, and <-10 dB, respectively, which meets the performance criterion of the MIMO antenna. The designed four-port MIMO antennas can be used in sub-6 GHz (3.3 to 3.8 GHz) and fixed satellite television data services (10.7 to 14.5 GHz) applications.

Keywords: Monopole MIMO; SRR; DGS; Mutual coupling; Isolation; Gain

1. INTRODUCTION

Modern antenna technology is based on multiple input multiple output (MIMO) technology, which pioneered wireless communication. MIMO antenna has many elements to radiate or receive signals using three main functions precoding, spatial multiplexing, and diversity code[1-2]. MIMO technology aims to improve the requirements of 5G communication, such as high data rates, low latency, expanding channel capacity, reduced multiple fading, low cost, and compact size[3]. Mutual coupling (MC) is an important design challenge in MIMO structure through achieving a compact size with many antenna elements placed on the substrate, so mutual coupling to be controlled on the space length of the two elements[4].

In the last few years, different methods have been presented to explain the problem of high Mutual coupling in MIMO antennas[5-6]. Some of the design techniques to get low mutual coupling between antennae like Split Ring Resonator (SRR), Defective Ground Structure (DGS), decoupling elements, Parasitic elements, neutralisation line and slots, line resonator, isolation technique, electromagnetic band gap (EBG), metamaterial and metasurface[7]. To look at the wideband (2 GHz-6 GHz) for different wireless applications, to try many designs of MIMO antenna having wide band coverage and UWB coverage on the basics of low mutual coupling[8-9], enhanced isolation with gain and good diversity performances in compact devices[10-12].

To look closely at elements of small-scale MIMO configurations for 5G applications[13]. The study of the role of SRR and metamaterial-inspired antenna with four elements has been discussed[14-15]. The MIMO configuration uses a loaded CPW fed and IDC[16-18]. MIMO antenna with SRR for 5G application is proposed. Wideband monopole MIMO antenna[19] and inverted-shaped monopole MIMO antennae[20-22] with SRR provides good isolation and enhanced gain for different MIMO applications like WLAN/Wi-Fi (2.4 GHz-2.48 GHz), Bluetooth (2.4 GHz-2.48 GHz), WiMAX (2.3 GHz-2.7GHz), ISM (2.4 GHz-2.48 GHz), LTE (2.3 GHz-2.7 GHz), 5G application (3.3 GHz -3.6 GHz)[23-24]. SRR helps to reduce the coupling effect, the size of the antenna, and the noise of the interference problem. It also increases resonance range due to negative permittivity and permeability. The resonant property of a ring allows it to select a filter out of a certain wavelength. There are many challenges for the wide band like maintaining low correlation, compact size, planar structure, good isolation, and high gain. Similarly, this work proposes designing and analysing a compact size four port monopole microstrip MIMO antenna with different SRR, partially grounded ring, and DGS, which offers good isolation between the elements with high gain. The orthogonal arrangement of elements ensures a low correlation value. The performance metrics of monopole MIMO computed from radiation patterns and scattering parameters are satisfied.

2. MONOPOLE ANTENNA DESIGN

The three-monopole single-element antenna has been designed using different types of SRR and altering their

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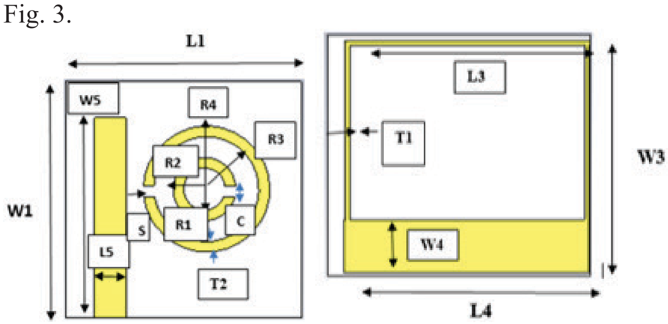
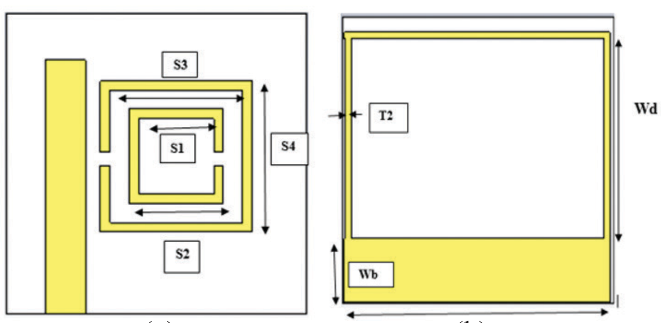
defected ground structures (DGS) using 3D simulation software CST Microwave Studio. These antennas are named design-1, design-2, and design-3 respectively. Figure 1 depicts the structural layout of design-1, which consists monopole feedline, circular SRR at the top of the substrate, and in the ground, having a rectangular ring with some rectangular patches. The dimensions of the structures of single-element designs are 22.5×22.5×1.6 mm^3. The circular SRR of design-1 is replaced with a rectangular SRR, named design-2, illustrated in Fig. 2. The single monopole microstrip element named design-3 with circular SRR and modified DGS is shown in Fig. 3.



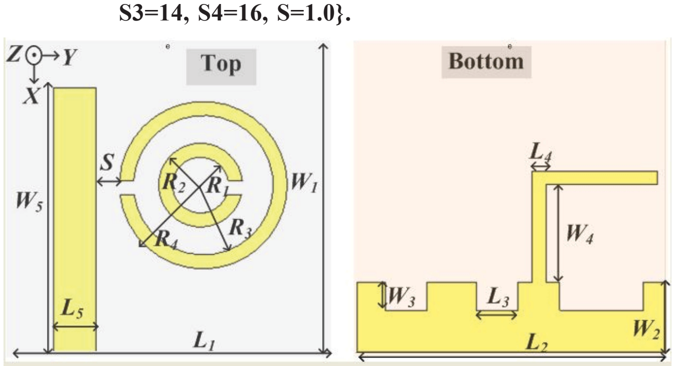
(a) (b)

Figure 1. Structural layout of monopole antenna: design-1; (a) view of front; and (b) backside view. All dimensions in mm {L1=W1=22.0, L5=3.0, W5=19.0, L4=24.0, W4=5.0, L3=20.0, W3=21.0, T1=0.4, R1=2.0, R2=3.0, R3=5.0, R4=6.0, T2=1.0, C=1.0, S=1.5}.



(a) (b)

Figure 2. Structural layout of monopole antenna: design-2 (a) view of front; and (b) backside view. All dimensions in mm {: La=22, Wb=5, Wad=16, T2=0.5, S1=8, S2=10, S3=14, S4=16, S=1.0}.

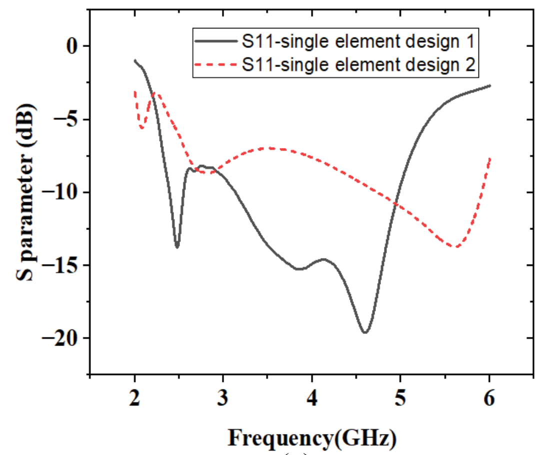


(a) (b)

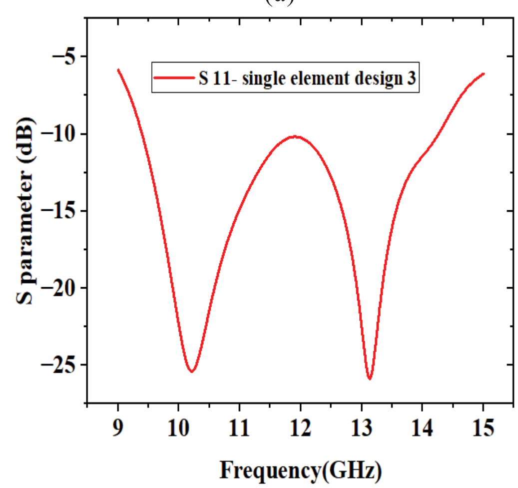
Figure 3. Structural layout of monopole antenna: design-3 (a) view of front; and (b) backside view. All dimensions in mm {L1=W1=22.5, L5=3.0, W5=19.0, R1=2.0, R2=3.0, R3=5.0, R4=6.0, T2=1.0, C=1.0, S=1.5, L4=24.0, W4=5.0, L3=20.0, W3=21.0, T1=0.4, L2=22, W2=5, L3=W4=1.0, L4=W3=8.0, L5=6.0, L6=3.0, W5=W6=2.0}.

2.1 Analysis of Monopole Antenna

All the antenna design structures have been designed on an FR4 substrate having a dielectric constant of 4.4 and a thickness of 1.6mm. The input reflection coefficients (S11) of design-1 and design-2 are illustrated in Fig. 4(a), and design-3 is illustrated in Fig. 4(b). Scattering parameters depict the relationships among the ports in an electrical system. It has an impedance bandwidth between 3.2 GHz and 4.9 GHz (design-1 and design-2) and 9.5 GHz to 14.2 GHz (design-3). Design-3 provides a dual-band response that may work as wide while controlling the spacing between the feedline and SRR.



(a)



(b)

Figure 4. Input reflection coefficient of monopole antenna. (a) S-parameter of design-1 and design-2; and (b) S-parameter of design-3.

The effect of coupling between the monopole feedline and SRR for all three designs is depicted in Fig. 5(a), 5(b), and 5(c), respectively. The resonance frequency and the impedance bandwidth mainly depend on the coupling between the monopole feedline radiator and SRRs. While increasing the space between the feedline and SRR, the coupling capacitance decreases, and due to this, the resonating frequency shifts to a lower value. SRR is used to reduce the size and noise of the interference problem and get better resonance due to the negative permittivity and permeability of the EM field. The resonance property of a split ring allows it to improve the selective filter out of certain wavelengths. Different shapes

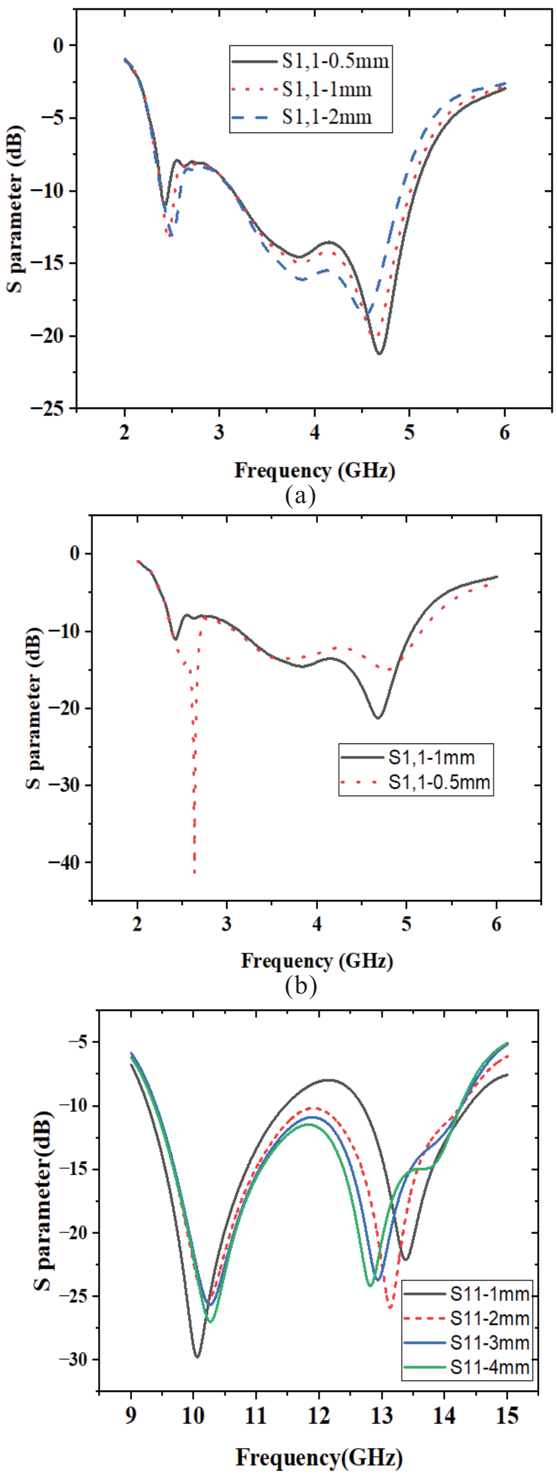


Figure 5. S-parameter performance by varying the feedline and SRR 'S' coupling. (a) Varying the value of 'S' in design-1; (b) Varying the value of 'S' in design-2; and (c) Varying the value of 'S' in design-3.

of SRR are used to reduce mutual coupling with enhanced gain. The ground ring is a reflector to decrease the occupying coupling currents, so increasing isolation in its resonant band extends. The ground ring has a high current density and becomes part of the improved impedance and enhanced bandwidth area. SRR must remain in close range to the monopole radiator and electromagnetically coupled to a monopole antenna. DGS acts as a reflector to disturb the flow of surface current distribution on the ground plane with increased isolation and shift to impedance bandwidth range within its resonant band expands. DGS has a high current density integrated into the radiator to improve impedance matching and bandwidth. Any Parametric change in the Monopole, SRR, ground ring and DGS as to changes happen in impedance matching and wideband resonance behaviour. While increasing the space between the feed line and SRR, the coupling capacitance decreases due to this resonating frequency shifting a lower value.

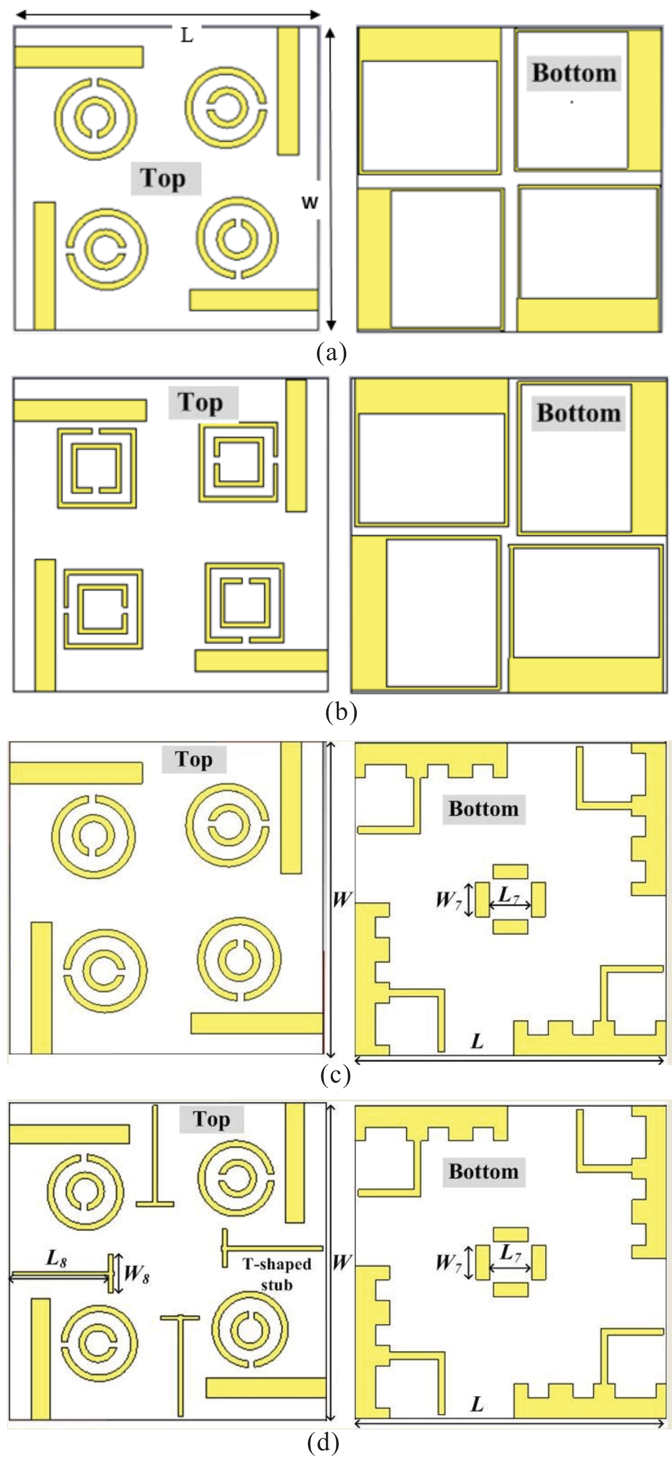


Figure 6. Four-port MIMO antenna configurations: (a) Design-1, (b) Design-2, (c) Design-3, (d) Design-4.

3. FOUR PORT MIMO ANTENNA

The four-port MIMO antenna has been designed by placing four monopole antenna elements orthogonal to each other. All single-element antennas are placed orthogonally to improve the isolation of MIMO configuration. There are three different four-port MIMO configurations are presented in this manuscript using design-1, design-2, and design-3. The structural design configurations of all three MIMO configurations are depicted in Fig 6. The single antenna elements with SRR and DGS are arranged in rotational and symmetrical structures with 90° intervals of each.

When the distance between the elements increases, the notch fades, and the resonance range shifts to a lower frequency.

Monopole MIMO designs to make better impedance matching of wide band frequency (2.2 GHz and 4.6 GHz) and dual-band frequency between 9.4GHz and 14.2 GHz with a notch. Further, by inserting a T-shaped strip in design-3 of Monopole MIMO, the impedance bandwidth has increased. The proposed MIMO design covers WLAN/Wi-Fi (2.4 GHz-2.48 GHz), Bluetooth (2.4 GHz-2.48 GHz), WiMAX (2.3 GHz- 2.7 GHz), ISM(2.4 GHz-2.48 GHz), LTE (2.3 GHz-2.7 GHz), 5G application (3.3 GHz-3.6 GHz), Radar and satellite communications.

4. RESULTS AND DISCUSSION

The scattering parameters of the presented four-port MIMO configuration are shown in Fig. 7.

Scattering parameters depict the relationships among the ports in an electrical system. The reflection coefficient and isolation of design-1 and design-2 four-port MIMO antenna are illustrated in Fig. 7(a). The impedance bandwidth of four-port MIMO antenna designs is from 2.2 GHz to 4.5 GHz. The scattering parameters of design-3 and design-4 are depicted in Fig. 7(b), having a working band from 9.4 GHz to 14.2 GHz. The isolation among antenna elements is more than 15dB throughout the wide working band. The mutual coupling between two elements depends upon the gap between the feedline and SRR. The gap distance increases between the elements, so the isolation improves between them and increases impedance bandwidth. A mutual coupling greater than 10 dB is enough for wideband applications. As to changes of parametric (position, shape, dimension, space) in Monopole and SRR, changes happen in impedance matching and wideband resonance behaviour.

The far-field radiation Patterns of MIMO designs at two different frequencies, 2.4 GHz and 10.4 GHz, are illustrated in Fig 8. At 2.4 GHz, the main lobe has an amplitude of 3.5 dBi and the side lobe -3 dBi. Similarly, at 10.4 GHz, the main lobe is 3.12 dBi, and the side lobe level is -4.1 dBi. The antenna's radiation pattern provides omnidirectional radiation, which is most stable in that frequency band. The position of the antenna decides to receive signals from all directions within the operational bands. The simulation results are to get by exciting port-1 and close the other ports with 50 Ω matched loads. The concentration of an antenna radiation pattern in a specific direction is measured by directivity, while the concentration of input power in a certain direction is represented by gain. Figure 9 illustrates the gain of the presented four-port MIMO

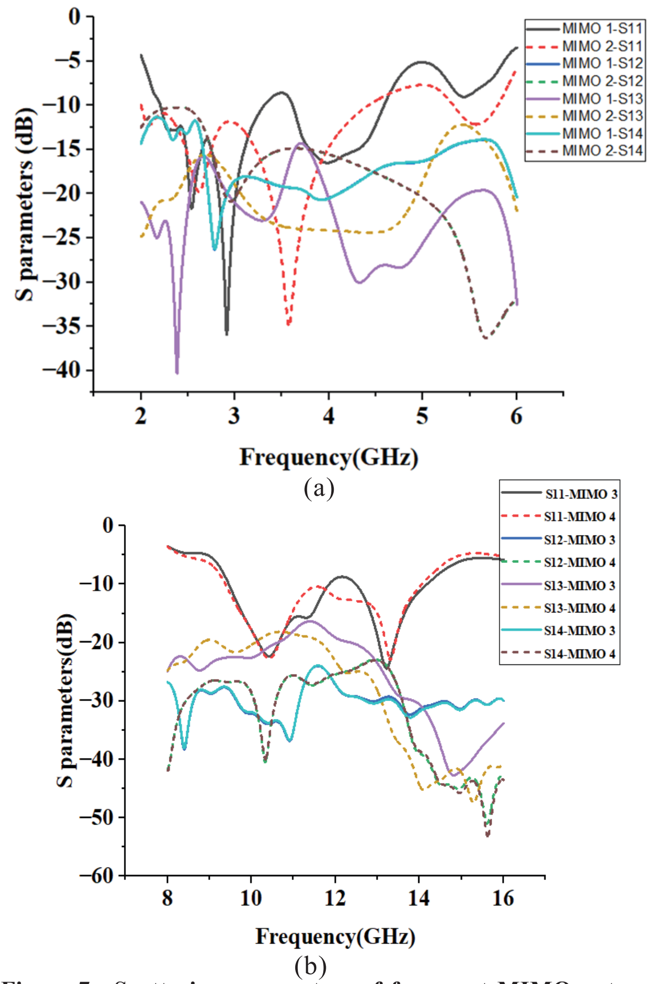


Figure 7. Scattering parameters of four-port MIMO antenna configurations: (a) Design-1 and Design-2; and (b) Design-3 and Design-4.

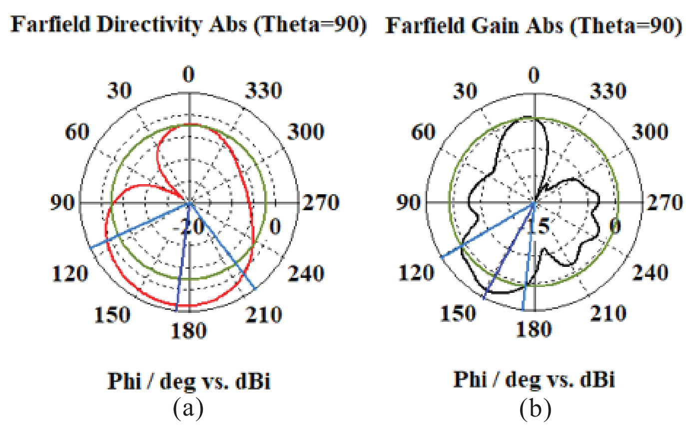


Figure 8. Radiation pattern at (a) 2.4 GHz; and (b) 10.4 GHz.

configurations. As per the results presented, the whole operational frequency of different monopole MIMO design configurations gain value >2 dB (design 1,2) and >4 dB (design 3,4).

The coefficient of envelope correlation (ECC) represents the correlation between elements in MIMO designs, and it is one of the parameters for diversity performance. Using Eqn. (1), the ECC value of the MIMO design could be evaluated (where i^{th} & j^{th} is the port of the elements and S_{ij} is the scattering

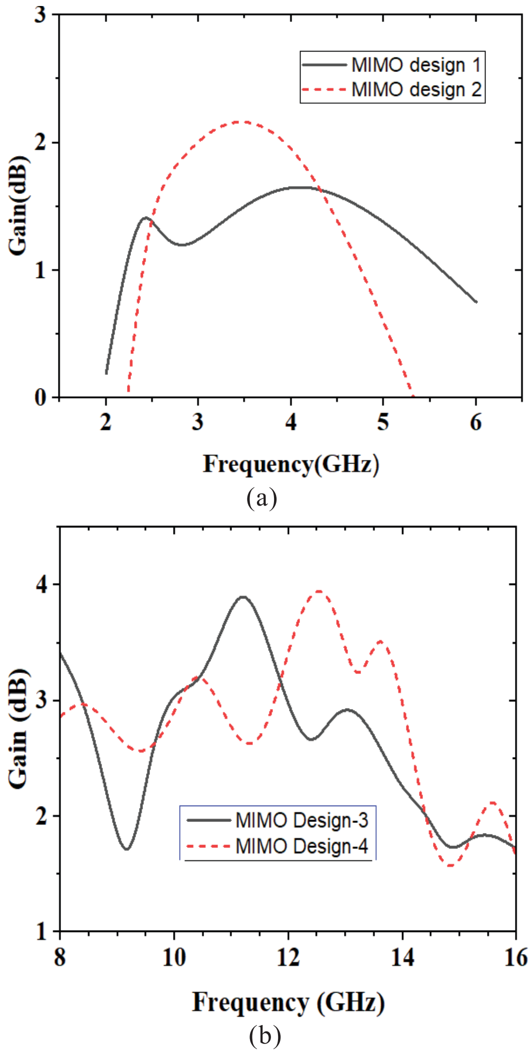


Figure 9. Gain of proposed four-port MIMO antenna; (a) MIMO antenna gain of design-1 and 2; and (b) MIMO antenna gain of designs, and 4.

matrix of the element) by using the S-parameter method[11-12]. The value of ECC is high; the channel diversity performance is weak. So, to accept low ECC value for the best diversity performance in MIMO. In this MIMO design, the value of ECC is <0.01. The correlation coefficients are good, less than 0.01, to ensure better performance metrics of MIMO.

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

Diversity gain (DG) to show the quality and good performance of a MIMO antenna. It is calculated by using Eqn. (2) and substituting the value of ECC as less than 0.01 [3]. The low correlation between the antenna elements leads to obtaining the value of diversity gain in this MIMO antenna design > 9.95 dB, shown in Fig. 10, within the acceptable frequency band, which indicates good diversity performances.

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

Mean Effective Gain (MEG) is defined as the ratio of the power received by the MIMO antenna to the power received by an isotropic antenna. The MEG can be calculated in terms

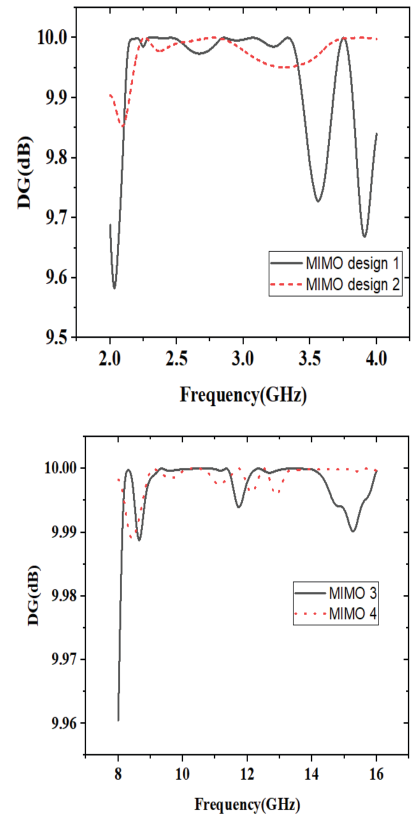


Figure 10. Diversity gain of four-port MIMO antenna.

of S parameters by using Eqn. (3) where i and j are the port of the element) [3]. MIMO antenna ports have equal power levels to get the best diversity performance, the value of MEGi values between -3 dB to -12 dB throughout the whole frequency range. The power relation between any two ports should not be greater than 3-dB[12]. The results confirm that the designed MIMO antenna has good diversity performance.

$$MEG_i = 0.5[1 - |S_{ii}|^2 - |S_{ji}|^2] = 0.5[1 - |S_{ij}|^2 - |S_{jj}|^2] \tag{3}$$

$$TARC = \frac{\sqrt{\left(|Sii + Sij\ e^{j\theta}|^2\right) + \left(|Sji + Sjj\ e^{j\theta}|^2\right)}}{\sqrt{N}} \tag{4}$$

Total Active Reflection Coefficient (TARC) is the ratio of the total reflected power from the radiating elements to the total incident power on the patch. TARC value for the MIMO antenna should be below -10 dB to show the best performance of the MIMO antenna throughout the whole operating frequency band.

The relation between TARC and the S-parameter is described in Eqn. (4)[20]. The value of TARC is low (< zero) to show good performance of the MIMO system and better data quality with higher transfer rates. Where i and j are the port numbers, theta value denotes the phase angle between two ports, and N is the number of radiating elements[3]. The proposed four-port MIMO antenna performance has been compared with earlier published similar types of work and depicted in Table 1.

5. CONCLUSIONS

Compact single-port and four-port monopole microstrip

Table1. Performance comparison of proposed work

Ref.	Antenna type	Size (mm²)	No. of ports	Isolation (dB)	Gain (dB)	ECC	DG (dB)	MEG (dB)	TARC (dB)
16	Pair of microstrip line structures+ CSRR+ Square ring slot in the ground	75×150×1.6	8	-	-	<0.01	>9.9	1	-10
19	Monopole+ SRR+ ground ring	90×90×1.6	4	>14	4	<0.25	>9.9	1	-10
20	L-shaped monopoles +CSRR+ square patch+ stubs+ Partial ground Interconnected	80×80×1.6	4	>15	>3	<0.5	>9.9	1	-10
21	ILA (inverted monopole antenna) +interconnected partial ground	40×40×1.6	4	>11	4	<0.05	>9.9	1	-10
22	ILA+SRR+ interconnected partial ground	40×40×1.6	4	>14	4	<0.1	>9.9	1	-10
23	Microstrip line structures+SRR+ Square ring slot in the ground	60×60×1.6	4	>15	3	<0.1	>9.9	1	-10
**	Proposed design-1&2	45×45×1.6	4	>15	2	<0.01	>9.95	1	<-10
	Proposed design-3&4	45×45×1.6	4	>15	4	<0.001	>9.95	1	<-10

MIMO antennas with SRR and DGS have been presented. The size of the proposed monopole microstrip MIMO is 45×45×1.6 mm3, which is designed over a low-price FR-4 substrate. The results of the antenna such as gain (>4 dB) with good isolation(>15 dB). SRR structure acts as a filter used to achieve resonance at frequency range, and the ground ring is a reflector to decrease the occupying coupling currents, so increasing isolation in its resonant band extends. The next important one is DGS to disturb the flow of surface current distribution on the ground plane with increased isolation and shift to impedance bandwidth range within its resonant band expands. DGS has a high current density that is integrated into the radiator to improve impedance matching and bandwidth area. The simulated MIMO performance matrices like ECC are <0.01, DG(>9.95 dB), MEG (1), TARC (<-10 dB), and characteristic results as S-parameters, the radiation pattern is contented. The proposed antenna applications are WLAN, WiMAX, Wi-Fi, ISM band, Bluetooth, LTE-A, 5G communication, Radar, and Satellite communications.

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In the current study: He designed antenna and analysed the results of the paper.

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