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Parasitic isolation structure for mutual coupling reduction in a multiple input multiple output antenna

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ABSTRACT

This paper reports a design of 2×1 multiple input multiple output (MIMO) structure of antenna with 23×45 mm^2 dimension. Each element in the MIMO antenna is a quarter wave transformer fed microstrip patch antenna. To lessen the effect of coupling, a rectangular parasitic decoupler is positioned between the two elements. Results report that antenna resonates at 6 GHz, coupling is reduced by 14 dB using parasitic decoupler S12 and S21 obtained with parasitic decoupler are same which -33.06 dB. The diversity gain (DG) is 9.99 dB, which is nearly close to 10 dB, and the envelope correlation coefficient (ECC) is less than 0.00034. These values reflect the good diversity performance. Measured findings match those from the simulation. As we confront the delicate environment, the proposed antenna is suited for number of wireless applications, including 802.11, 802.16 standards of IEEE.

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1. INTRODUCTION

The core of a reliable communications system and the secret to any commercially successful network are speed and efficiency in today's fast-paced environment. Multiple input multiple output (MIMO) technology for communication is a development in wireless communication that has increased scalability and enabled the provision of lower latency services to a higher number of customers. This is a method of antenna diversity that makes use of numerous antennas to boost the strength and signal radio frequency link trustworthiness. At the sending side information is split into different streams which are then gets combined by same MIMO arrangement at the receiving point. MIMO is frequently the best option for communication, especially in urban settings where it can be challenging to establish a clean line of sight and where other RF systems may cause interference.

For a wide range of networks and available channel states, numerous different MIMO strategies have been devised. Spatial diversity, spatial multiplexing and beam forming are three fundamental methods in MIMO communication. In order to get the greatest throughput and scalability, these strategies are frequently combined. Since there are multiple antenna elements, coupling effect among them needs to be reduced to achieve good performance. Due to less space available for the antenna design it is difficult to put antenna elements with high isolation. So, isolation is considered as one of the important design consideration.

Many techniques for increasing isolation have been featured in the literature. Some of the techniques are presented here. A parasitic element (PE) is included. The idea reported here is to make available a path to negate the original surface current [1]. According to Deng *et al.* [2], a small size dual resonance MIMO arrangement which incorporates slot of T structure and meandering structure for improving isolation is reported. According to Alsultan and Yetkin [3], PE based on metamaterial is designed as matrix structure of c-type to decrease the coupling impact. A miniaturized double resonance MIMO layout with deformed ground and micro strip structure is included to lower the coupling influence and orthogonal polarization is created to decrease the coupling impact [4]. The pair of comb shaped slots is incorporated to achieve notch band characteristics [5]. Meta inspired decoupling network is incorporated [6]. Defected ground structure is reported as coupling reduction technique [7]. Using a T-type stub on the ground side, current distribution is shifted there by isolation is raised [8]. To evaluate the effectiveness of the MIMO setup, deformed ground and coplanar strips in asymmetrical pattern are utilized. With these designs coupling influence reduction is accomplished [9]. Surface current is interrupted by meandering resonators, which restrict the current to the monopole antenna [10]. To bring the diversity in the pattern, perturbation to the ground is done so that coupling reduction is achieved in the MIMO [11]. A strip which is attached to the ground traps the current which is going towards the other antenna element than excited. High isolation between antenna ports is obtained as a result [12].

The polarisation diversity is confirmed by the orthogonal alignment of two ports, which also lowers the mutual coupling value between the ports lesser [13]. The 4 elements double resonance MIMO antenna's inter-element isolation and impedance matching performance are both enhanced by the higher order mode suppression approach [14]. To provide isolation among the antenna elements, ground slots and a circular ring loaded with line stubs were proposed [15]. In order to increase the isolation, reversed L-type stub is introduced into the ground [16]. The strips provide the dummy and reactive loading impact to create a powerful decoupling mechanism [17]. To lessen the coupling impact, a defective ground structure and a decoupling element are used [18]. It was reported that a complementary modified Minkowski fractal (CMMF) was used to improve isolation. The CMMF is built using an iterated function system (IFS) method. It is observed that sufficient current is linked in the vicinity of the CMMF [19]. To lessen the coupling impact, a number of dumb bell-shaped parasitic components are added in between the MIMO radiating elements [20]. For coupling reduction in a closely-coupled wideband MIMO antenna, a new simple wideband decoupling circuit (DCkt) based on a second order filter designed with the aid of admittance parameter and six hexagonal split-ring resonators is employed [21]. Improved isolation is achieved because the antenna elements were positioned orthogonally to one another [22], [23]. The metamaterial unit cell array's effective enhancement in isolation level in the sub 6 GHz band is confirmed by the surface current suppression [24]. The two L-shaped microstrip feeding lines that feed each pair of antennas provide polarisation and radiation pattern diversity function because the feed line is positioned orthogonally on the radiator, which is made up of two concentric annular slots. A rectangular hole is added under each microstrip feedline to decrease the mutual coupling characteristic [25].

In this paper a two element MIMO antenna with high isolation and not very complex decoupling structure has been designed and developed for number of wireless applications including 802.11, 802.16 standards of IEEE. We found many complex decoupling structures such as neutralization lines, EBG structures, meta material based structures, complex stub structures, defected ground structure and complex PEs between the antenna elements. In the proposed work complexity in parasitic structure design is eliminated and made very simple rectangular parasitric element which resulted in tremendous enhancement in isolation as compared to complex designs found in the literature and good diversity performance is achieved. The remainder of the paper is organized as follows: the section design aspects of MIMO antenna describe analytical design approach with relevant design equations. The section results and discussion present simulation and fabricated readings and significance of decoupling structure. The proposed work is compared to relevant works available in the literature in the section under "comparison with other work," using performance-evaluating measures. In the section conclusion, a few final comments are expressed.

2. DESIGN ASPECTS OF MIMO ANTENNA

In this section a detail antenna design and its schematic has been illustrated. Further figures of fabricated prototype of MIMO antenna without parasitic decoupler and with parasitic decoupler are also presented. Each rectangular microstrip patch antenna element dimension of 11.33×15.22 mm^2 is developed in order to get 6 GHz resonance. Following design equations are considered. Patch width estimation is done as (1):

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

The tuning frequency, the dielectric constant, and the speed of light are symbolised by fr, ε_r, and c. The estimation of extension length Δl is done as (2):

$$\Delta l = 0.412h\left(\frac{(\varepsilon_e+0.3)\left(\frac{W}{h}0.264\right)}{(\varepsilon_e+0.3)\left(\frac{W}{h}+0.8\right)}\right) \tag{2}$$

h and ε_e are symbolising the substrate height and effective dielectric constant. The parameter ε_e is figured out by using (3):

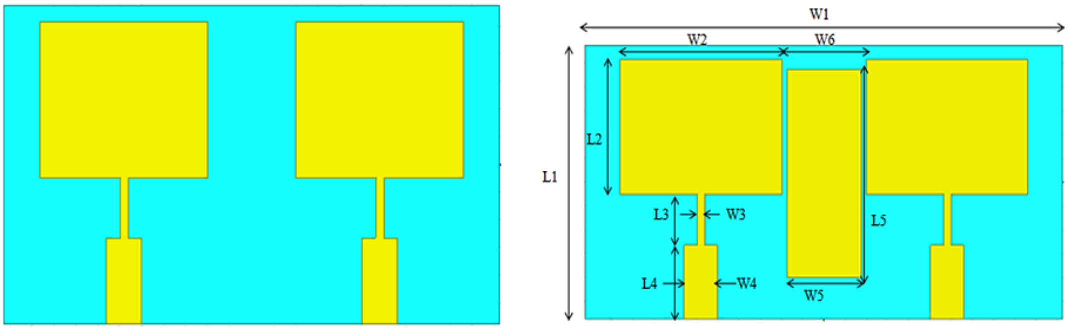
$$\varepsilon_e = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\left(1+12\frac{h}{w}\right)^{-\frac{1}{2}} \tag{3}$$

After calculating ε_e, Δl is found and using Δl actual length L is calculated. The actual length L is figured out by (4):

$$L = \frac{c}{2fr\sqrt{\varepsilon_e}} - 2\Delta l \tag{4}$$

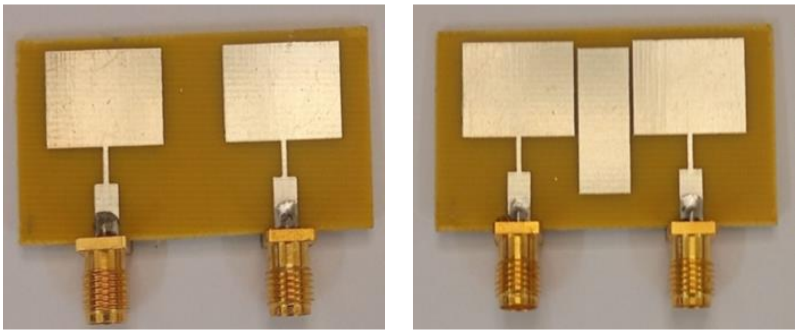
2.1. Schematic layout and fabricated prototype of MIMO structure

In this section figures of schematic layout and fabricated prototype have been given. Figures 1(a) and (b) show the schematic layout of MIMO structure without parasitic decoupler and with parasitic decoupler. Figures 2(a) and (b) show the fabricated prototype of MIMO structure without parasitic decoupler and with parasitic decoupler. Table 1 gives the detail dimension of MIMO configuration considered in this study.



(a) (b)

Figure 1. Layout of MIMO structure; (a) without parasitic decoupler and (b) with parasitic decoupler



(a) (b)

Figure 2. Fabricated prototype of MIMO structure; (a) without parasitic decoupler and (b) with parasitic decoupler

Table 1. MIMO configuration dimension

Parameters	W1	W2	W3	W4	W5	W6	L1	L2	L3	L4	L5
Dimensions in mm	45	15.22	0.7	3.16	7	8	23	11.33	4.3	6.2	17.5

3. RESULTS AND DISCUSSION

The proposed antenna has been simulated using commercially available ANSYS high frequency structure simulator (HFSS) and various parameters such as resonant frequency, s-parameters related to isolation, envelope correlation coefficient (ECC), diversity gain (DG) are investigated for MIMO antenna without and with parasitic decoupler.

3.1. Investigation of s-parameters

The s-parameters represent the antenna resonating behavior and isolation between the antenna elements. Figures 3 and 4 depict the s-parameters without parasitic decoupler from the simulation where it is observed that antenna resonates at 6 GHz with a return loss S11, S22 of -24.57 dB. Isolation parameter S12, S21 is -18.6 dB. Despite the fact that the two antenna parts are closer together than λ/2 sufficient isolation below -15 dB is obtained.

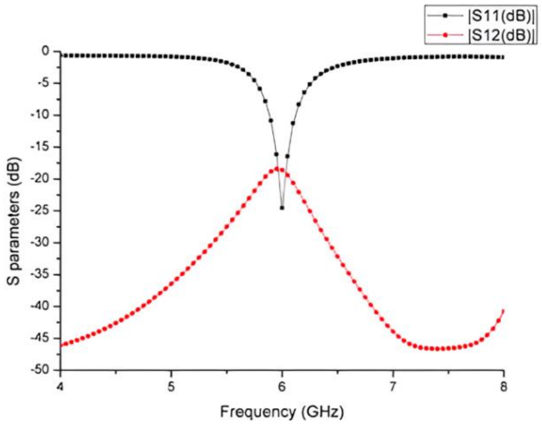


Figure 3. S11, S12 parameters without decoupler

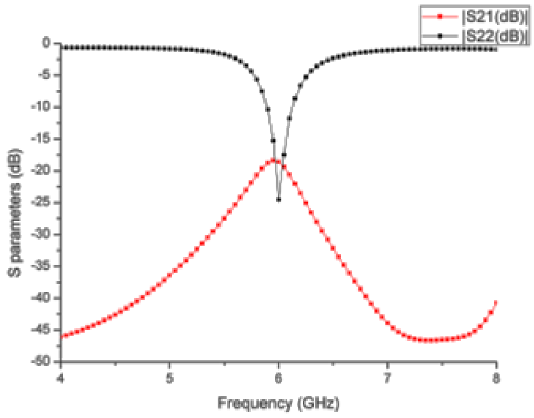


Figure 4. S21, S22 parameters without decoupler

Figures 5 and 6 report the s-parameters with parasitic decoupler. In this result analysis it is seen that 6 GHz resonance with a return loss S11, S22 of -19.53 dB is obtained. Isolation S12, S21 of -33.06 dB is achieved which indicates that parasitic decoupler incorporation between the antenna elements has tremendously enhanced the isolation there by reduced the mutual coupling among them around 14 dB improvement is achieved in the isolation parameter. The reason behind this improvement is that when rectangular parasitic decoupler is introduced then the radiation coupling to the other antenna is blocked by this element where more coupling is seen around itself. When less coupling is there to the antenna elements then it leads to the best diversity performance of the antenna in multipath scenario. This is one of the key aspects of 5G wireless communication as we know multiple antenna elements employment is found in such infrastructures to achieve high speed data communication as well as error free communication. This performance reveals the excellent diversity performance of the proposed antenna.

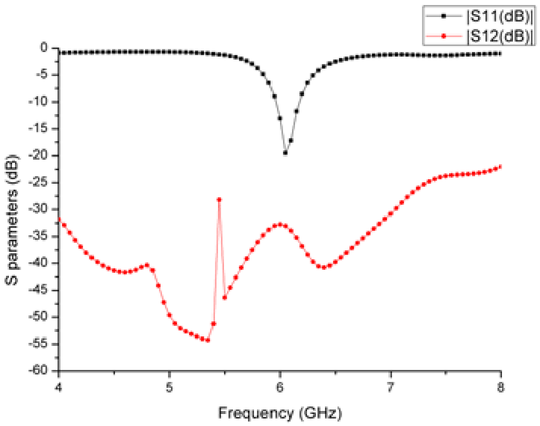


Figure 5. S11, S12 parameters with decoupler

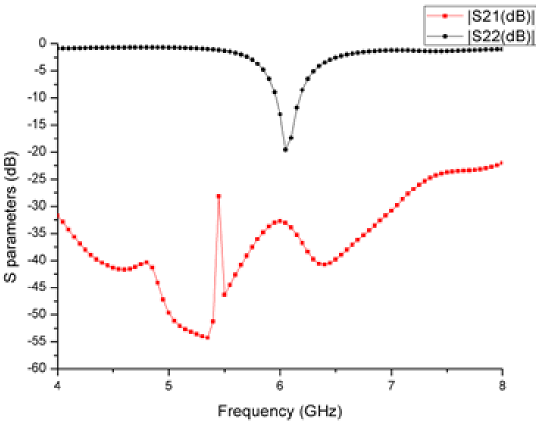


Figure 6. S21, S22 parameters with decoupler

Figures 7 and 8 show the measured s-parameters for the MIMO antenna without parasitic decoupler. output depict that structure resonates at 5.79 GHz, return loss S11 is -23.2 dB and isolation parameter S12 is -19.2 dB. Since two antenna elements are identical S11 and S12 are same as S22 and S21 respectively. Figures 9 and 10 show the measured s-parameters for the MIMO antenna with parasitic decoupler. output depict that structure resonates at 5.83 GHz, return loss S11 is -24.1 dB and isolation parameter S12 is -31 dB. Since two antenna elements are identical S11 and S12 are same as S22 and S21 respectively.

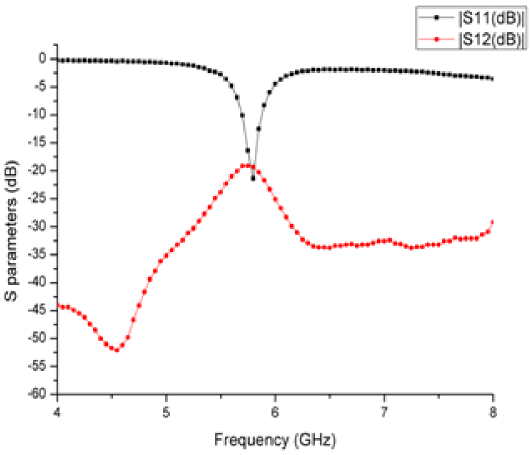


Figure 7. Measured S11, S12 parameter without decoupler

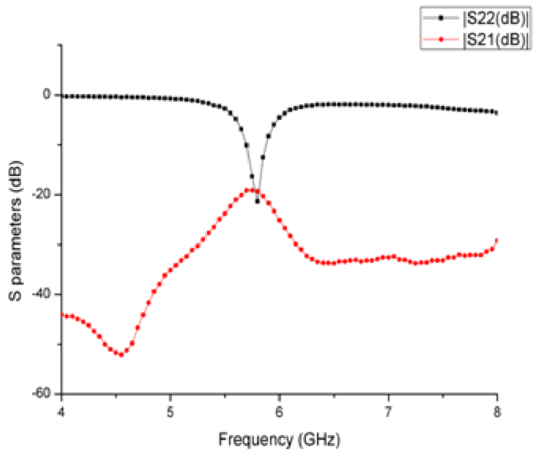


Figure 8. Measured S22, S21 parameter without decoupler

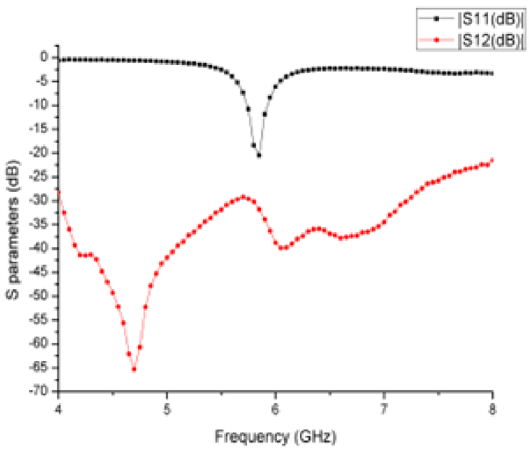


Figure 9. Measured S11, S12 parameter with decoupler

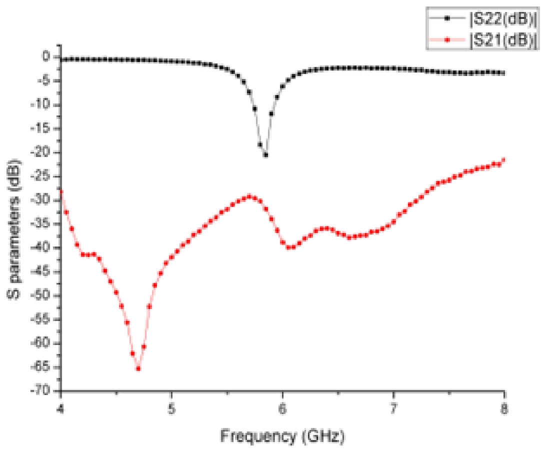


Figure 10. Measured S22, S21 parameter with decoupler

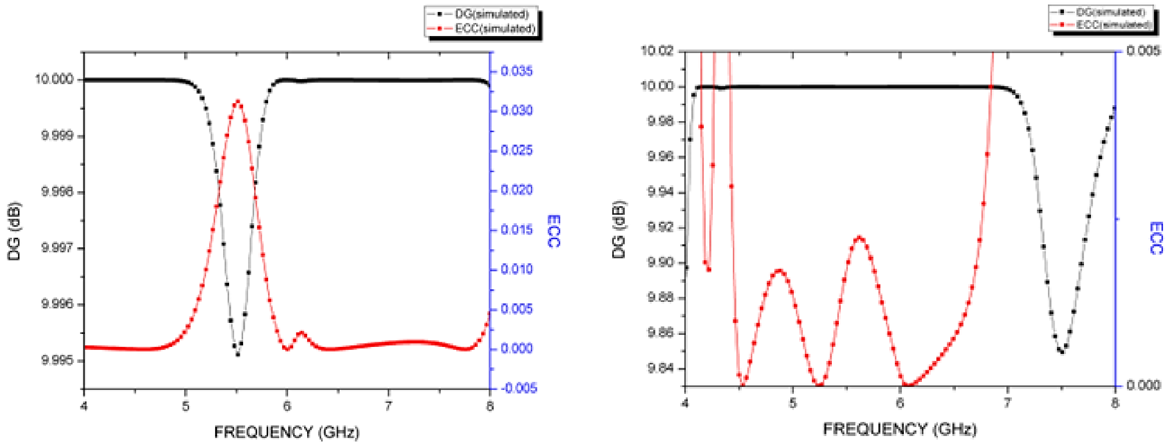
Diversity performance in applications involving diversity and MIMO, the correlation between signals received by the corresponding antennas at the side of a wireless link is a critical determinant of system success. The ECC is typically used to assess a multi-antenna system's capacity for diversity. ECC ρ_e can be estimated using an approach [26], [27] based on radiation pattern and also using the method [28] based on s parameters. According to Boris *et al*. [28], (5) may be used to estimate ρ_e of a two antenna system.

$$\rho_e = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1-|S_{11}|^2-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)} \quad (5)$$

ECC ρ_e<0.5 is the acceptable limit for the good diversity performance. Another diversity parameter is DG. It establishes the degree to which a signal is transmitted with the least amount of loss possible. It can be given by (6) [28]:

$$DG = 10\sqrt{1-|\rho_e|^2} \quad (6)$$

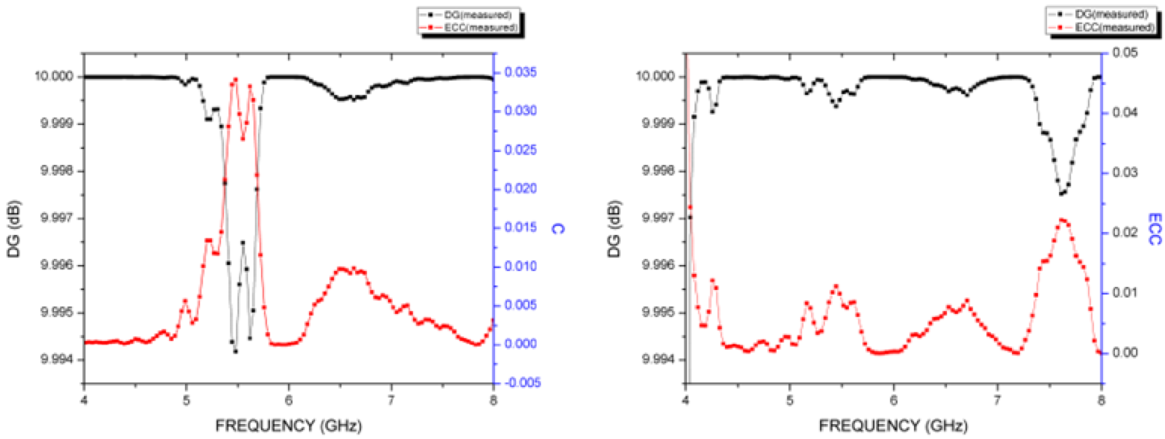
Figure 11(a) shows the simulated DG and ECC for the case of MIMO antenna without parasitic decoupler. In this case ECC obtained is below 0.0023 and DG is 9.999973. Figure 11(b) shows the simulated DG and ECC for the case of MIMO antenna with parasitic decoupler. In this case ECC obtained is below 0.00034 and DG is 9.999999.



(a) (b)

Figure 11. Simulated DG and ECC; (a) without parasitic decoupler and (b) with parasitic decoupler

Figure 12(a) shows the measured DG and ECC for the case of MIMO antenna without parasitic decoupler. In this case ECC obtained is below 0.0048 and DG is 9.999885. Figure 12(b) shows the measured DG and ECC for the case of MIMO antenna with parasitic decoupler. In this case ECC obtained is below 0.00062 and DG is 9.999998.

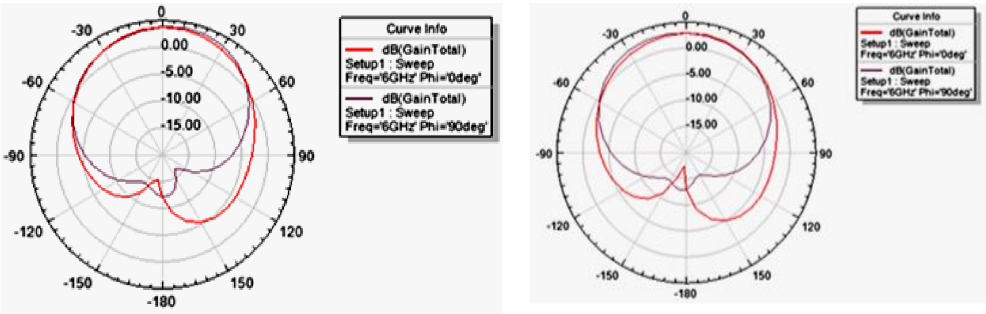


(a) (b)

Figure 12. Measured DG and ECC; (a) without parasitic decoupler and (b) with parasitic decoupler

Radiation pattern at ϕ=0 degree and ϕ=90 degree for the two element MIMO antenna without parasitic decoupler is as shown in Figure 13(a) and with parasitic decoupler is as shown in Figure 13(b). It is observed from the Figures 13(a) and (b) that stable and broadside radiation patterns are obtained.

According to the inference from Table 2, mutual coupling with parasitic decoupler is reduced by about 14 dB when compared to mutual coupling without parasitic decoupler. The measured and simulated readings correlate well with one another. The parasitic structure positioned between the antenna elements is the cause of this reduction since it absorbs the radiation that reaches the other element.



(a) (b)

Figure 13. Radiation pattern at 6 GHz; (a) without parasitic decoupler and (b) with parasitic decoupler

Table 2. Performance evaluation of two element MIMO antenna

Antenna configuration		Resonant frequency (GHz)	S11 (dB)	S12 (dB)	S22 (dB)	S21 (dB)	ECC	DG (dB)
Without decoupling structure	Simulated	6	-24.57	-18.6	-24.57	-18.6	<0.0023	9.999973
	Measured	5.79	-23.2	-19.2	-23.2	-19.2	<0.0048	9.999885
With decoupling structure	Simulated	6	-19.53	-33.06	-19.53	-33.06	<0.00034	9.999999
	Measured	5.83	-24.1	-31	-24.1	-31	<0.00062	9.999998

3.2. Comparison with other work

A summary of our suggested MIMO antenna's performance in relation to other previously published works is shown in Table 3. The works are tabulated in terms of various criteria such as dimensions of the antenna, frequency band, isolation, ECC and DG. It is being observed in the comparison process that the proposed MIMO antenna has some outstanding characteristics high in terms of isolation, reduced ECC and increased DG indicating the good diversity performance.

Table 3. Comparison with previous work

Ref. number	Dimensions(mm×mm)	Resonant frequency	Isolation	ECC	DG
[5]	20×34	2.11-4.19 GHz, 4.98-6.81 GHz	<-21 dB	<0.004	>9.97
[6]	100×60	2.4 GHz, 5.2 GHz, 5.8 GHz	<-18 dB, <-38 dB, <-34 dB	<0.04	-
[17]	18.5×56	2.5 GHz, 3.7 GHz, 4.3 GHz, 5.5 GHz	<-20 dB	<0.05	>9.98
[21]	45×40	5.08-6.30 GHz	<-25 dB	<0.1	-
Proposed	23×45	5.97-6.145 GHz	<-33.06 dB	<0.00034	>9.99

4. CONCLUSION

A two element MIMO antenna with high isolation using parasitic decoupling structure has been designed and developed. The complexity in parasitic structure design is eliminated and very high isolation <-33.06 dB is obtained in the 6 GHz resonance band. The two-element MIMO antenna in the suggested design exhibits a good coupling reduction of about 14 dB due to the inclusion of a rectangular structure between the components that aids in blocking radiation from reaching the other element. It has been demonstrated that the suggested decoupling structure works well in attaining outstanding isolation of less than -30 dB and a lower level of design complexity. Due to the antenna's resonance at the 6 GHz frequency, it is suitable for many wireless communication applications, such as WLAN and WIMAX. The recommended MIMO antenna works well in terms of diversity since the antenna elements have excellent isolation.

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