A Design of MIMO Prototype in C-Band Frequency for Future Wireless Communications

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Abstract

The main challenges of MIMO design for future wireless communication is the size reduction which leads to more mutual coupling. In this paper, a proposal has presented of MIMO with four antenna elements prototype each one having a dual polarized patch rectangular microstrips. To mitigate the impact of mutual coupling, a twin of annular parasitic of a rectangular shaped and opened rib has been placed in front of each microstrip and over a circular ring slot in the ground. The advantage of such ground slot is to obtain a regular radiation pattern distributed around device body. The four elements with eight ports have integrated on 67×139 mm^2 PCB with FR-4 dielectric layer. The single antenna has simulated by using CST.STUDIO 2019 resulting an operated frequency of 6.23 GHz with a band of 850 MHz (5.81-6.66) GHz at -10 dB. The fabrication MIMO system prototype has tested to show its measurement results which are match the simulated results. All results of the MIMO prototype have operated at C-band frequency which is very important for future wireless applications.

1. Introduction

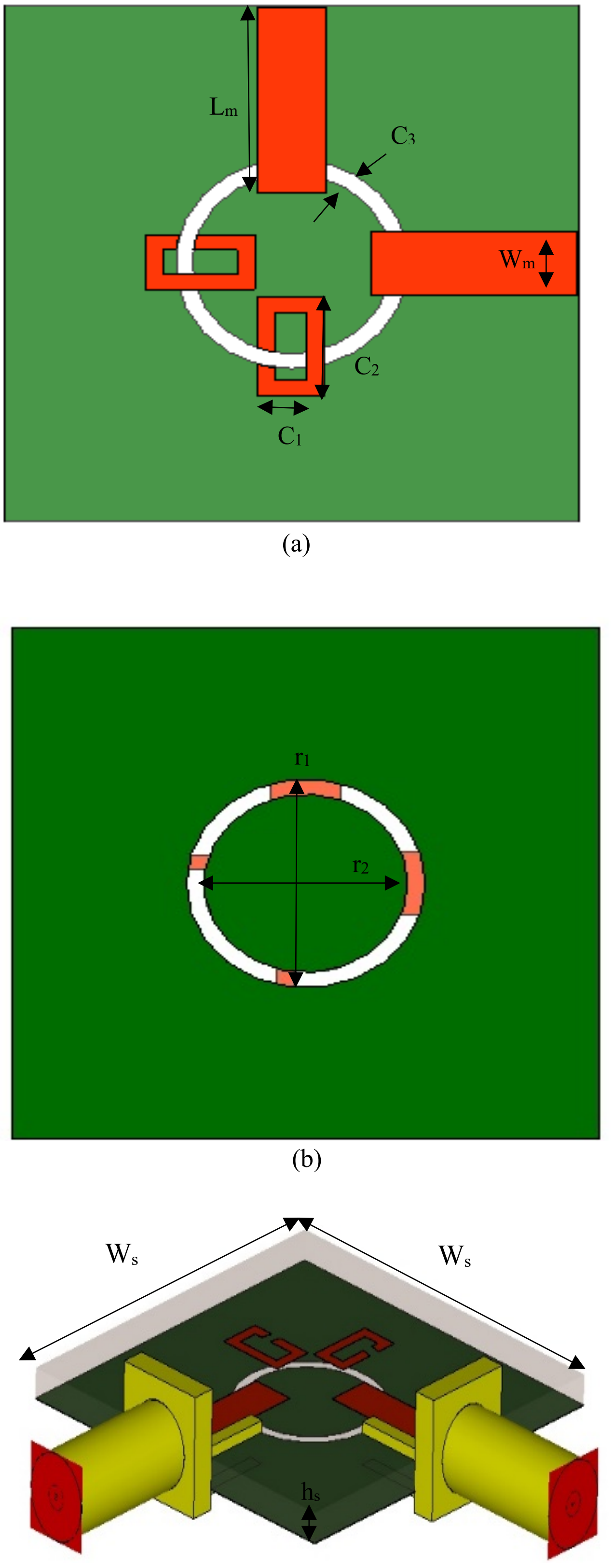
As it is known, the multiple-input- multiple-output (MIMO) antenna technology characterized with mitigation the multi-path interference and capacity enhancement [1]. In the future pivotal wireless technology, the massive MIMO antenna (MA-MIMO) has realized fifth generation (5G) which usually ranged with minimum number started with 6 up to 100 elements or more in a single device [2]. In order to integrate a smartphone with desired quality of MIMO system, many challenges are existed [3]. Because of integrated multi elements in one space leads to more than one challenges like small size, mutual coupling and easy fabrication. To address such requirements, microstrip antenna design technique is specified with ease of fabrication, light weight and low profile [4]. Also, with exploiting the advantage of dual polarization ports of increasing the frequency spectrum can eliminate the huge size of single ports of MIMO antenna system [5]. On the other hand, the isolation can be achieved with adding a parasitic structure or modifying in the ground structure [6]. Furthermore, many researches proposed an antenna mobile operated with 5G applications in order to improve wave propagation [7-11]. However, some of researches deal without dual polarization which result in a huge size while others obtained narrow bandwidth, meanwhile, most of them not obtained a desired mutual coupling. In [12] propose a 5G smartphone applications with multi-ports but concerned with mutual coupling not qualified. In addition, [13] proposed MIMO antenna system with dual polarized ports which obtained a mutual coupling about -20dB and a band width of 600 MHz at -10dB and operated in sub-6 band which qualified for 5G smartphone applications. In this research, as a reflected to [13] antenna structure to improve the bandwidth and mutual coupling with lesser size less size as well as it operated in C-band frequency which is a promising band for 5G applications. Also, to ensure the reliability of the proposed model, a fabrication part will be provided and a comparison between results of simulation and measurement will be applied.

2. MIMO Antenna Design

The design is started with a proposed of a single antenna element having a size of 30×30 mm^2 as shown in Fig. 1. It comprises of three layers; the first one is the patch layer which contained a dual polarized feeding line of 50 Ω microstrip connected to power source through SMA connector. Such layer contains a twin of annular parasitic with a rectangular shape opened one of its ribs placed in front each microstrip. Placing such parasitic in this manner in order to improve the isolation between the neighboring ports. The second layer is representing the separation between patch and ground layers having a height of 1.6 mm and made of FR-4 with permittivity 4.4 and thermal conductivity of 0.025. The third layer acts as a ground layer included a circular ring in a bottom of the parasitic mentioned in the patch layer. Furthermore, all dimensions detailed in Table 1 which are marked in Fig.1.

Table 1: Parameter values of the antenna design.

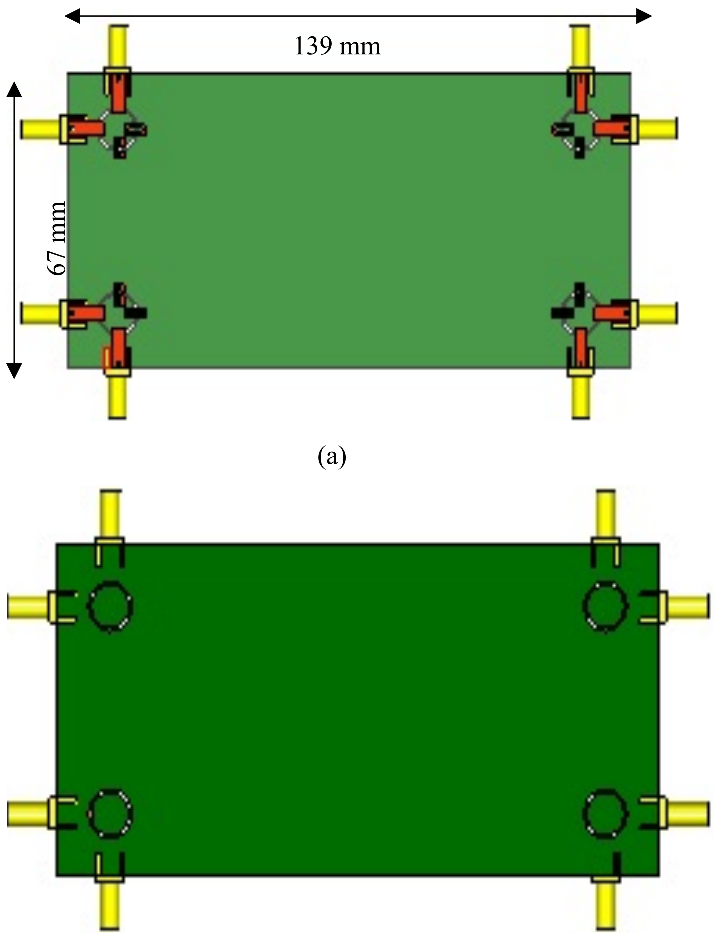
parameter	value [mm]	parameter	value [mm]
W_s	25	C_2	5
h_s	1.6	C_3	0.7
L_m	9	r_1	8.7
W_m	3	r_2	10.2
C_1	2.5		



(c)

FIGURE 1: Single antenna, (a) top view, (b) bottom view, and (c) side view.

Four replicas of such proposed single antenna design have arranged on a corner of 67×139 mm^2 of PCB which consists of two layers of substrate and ground with same materials used in the four single antenna elements as shown in Fig.2.

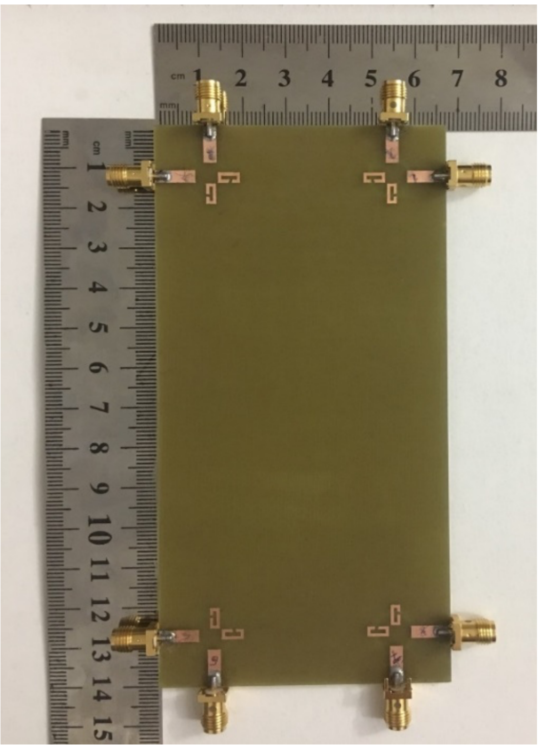


(b)

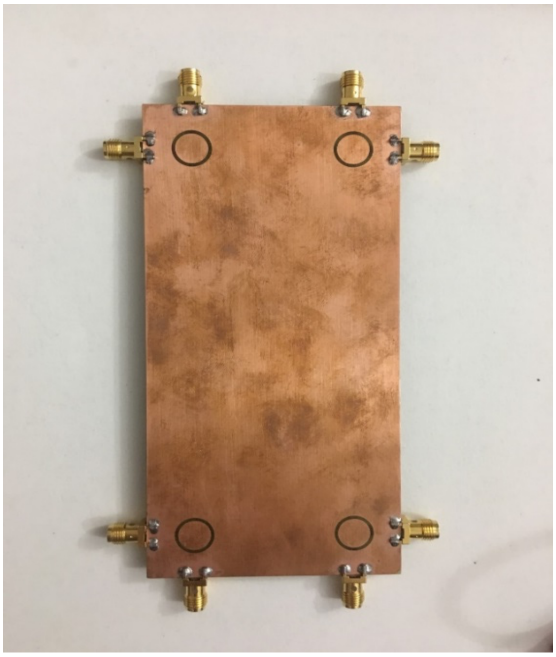
FIGURE 2: MIMIO antenna system (a) top view and (b) bottom view.

3. Results and Discussions

The simulation part is applied using CST.STUDIO 2019 to obtain its performance in term of return losses S_{nm}, mutual coupling S_{jk}, radiation pattern, mean effective gain (MEG), channel capacity loss (CCL), envelop correlation coefficient (ECC) and diversity gain (DG). Also, the fabrication part of MIMO antenna system has been integrated using Proto Mat S100 Laser and Electronics machine which is belong to Iraqi Ministry of Science and Technology / Electronic Manufacturing Department. In order to test the prototype of proposed MIMO antenna, has done in the laboratory of the same office mentioned above by using an Agilent N5247A vector network. The fabrication MIMO model is shown in Fig.3. The prototype of single antenna is simulated at beginning before integrated it with other antenna, the results are exhibit in Fig.4 which shows the operating bandwidth is 850MHz (5.81-6.66) GHz at -10 dB with resonance frequency of 6.23 GHz. Such simulation shows that the return losses which represented as $S_{1,1}$ and $S_{2,2}$ has obtained of -20 dB at such operating frequency. On the other hand, the isolation between the adjacent ports which marked as $S_{1,2}$ and $S_{2.1}$ has approached -45 dB.



(a)



(b)

FIGURE 3: The fabrication of MIMO antenna system (a) top view and (b) bottom view

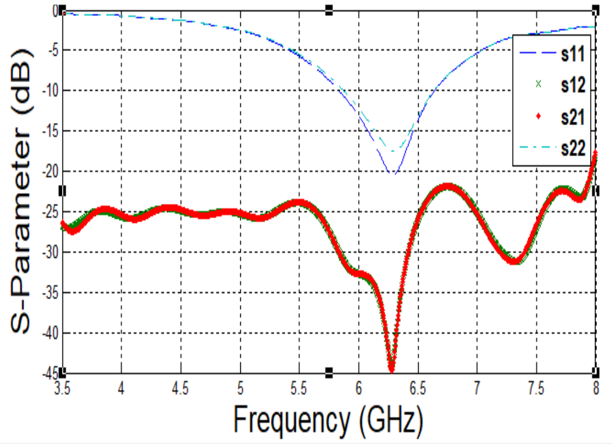
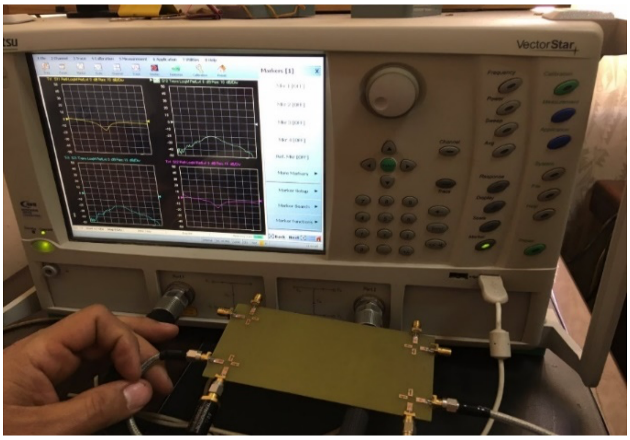


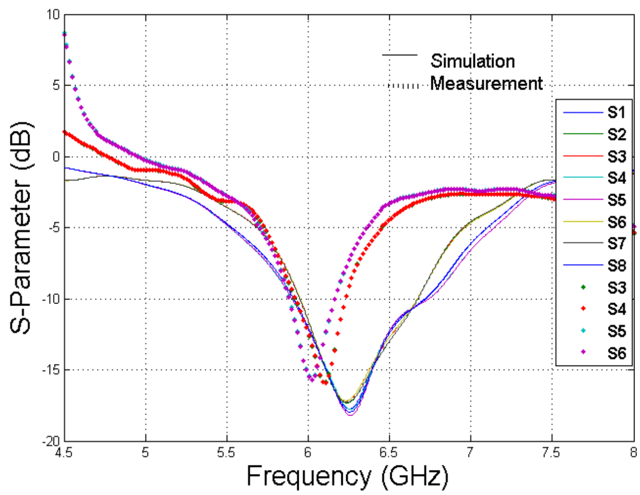
FIGURE 4: S-Parameter for single element

Fig. 5 (a) shows the results of the integrated MIMO antenna measurement which is clear in Agilent N5247A vector network analyzer screen. It is confirming the operating frequency but slightly differ by 0.23 MHz with same band width, while the return losses less by 1 dB as shown in Fig. 5 (b). It is worth to mention, the capability of testing device is only test two ports and the others are locked by 50 Ω FR load to avoid the mutual coupling effects. So that, all results have included only 3and 4, 5 and 6 ports. Fig.5 (c) shows the mutual coupling of testing results with compared to the simulated results. The results confirm a good matching between simulation and measurement results which indicate that the proposal can be used with currently productions.

In term of radiation pattern, Fig.6 (a) explicit how the radiation has covered all the device body in 3D view with H-max of -22.3 dB and a gain of -5.51 dBi. While Fig.6 (b) determine the radiation in 2D polar which obliviously seen the side lobe of -1.1dB with main lobe angle of 14.2 degree.



(a)



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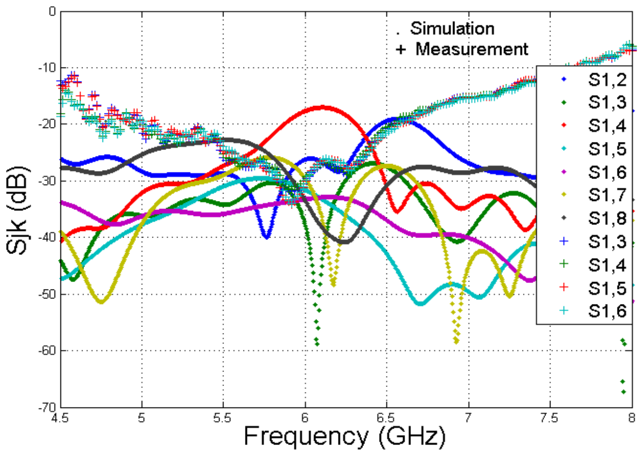
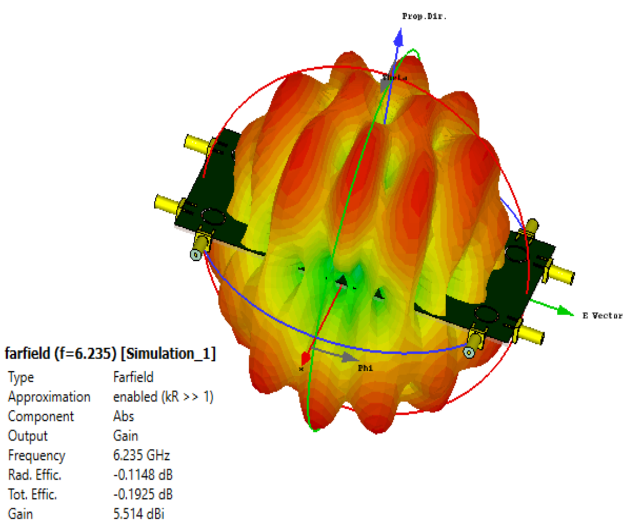
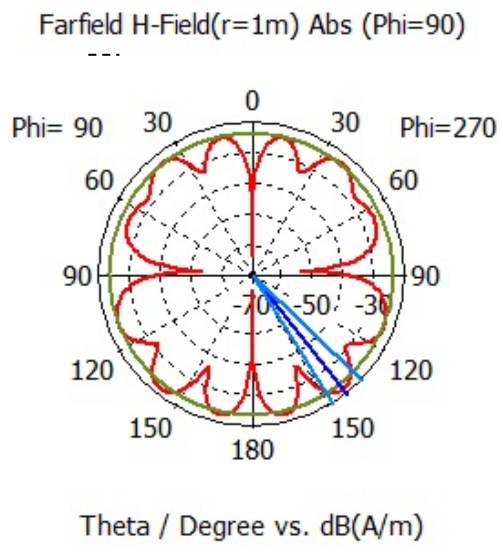


(c)

FIGURE 5: MIMO antenna system results (a) measurement screen, (b) S_{nm} and (b) S_{jk}



(a)



(b)

FIGURE 6: MIMO system radiation pattern (a)3D view and (b) 2D view.

4. The performance of MIMO antenna

In order to confirm the capability of the MIMO antenna proposal diversity, the following parameters have been calculated and analyzed:

4.1. Envelop correlation coefficient and diversity gain

The aim of calculating the ECC is to measure the correlation between antenna elements. In order to achieve high diversity between MIMO elements, ECC (ρe) value must be < 0.5 which can be calculated using the radiation pattern of the far field as follow [14].

$$\rho e = \frac{\left|\int \int_{4\pi}[\vec{F}_1(\theta,\emptyset) * \vec{F}_2(\theta,\emptyset) d\Omega]\right|^2}{\left|\int \int_{4\pi}[\vec{F}_1(\theta,\emptyset)]\right|^2 d\Omega \left|\int \int_{4\pi}[\vec{F}_2(\theta,\emptyset)]\right|^2 d\Omega}, \quad (1)$$

where $\vec{F}_i(\theta,\emptyset)$ is the MIMO antenna's far field property after exciting all ports. Also, Fig. 7 shows the ECC analysis over frequency which appears less than 0.001.

On the other hand, the DG is another important parameter which must be > 9 dB and can be calculated related to ECC as [14].

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

Also. Fig.8 displays the analysis of DG which approach 10 dB for all ports.

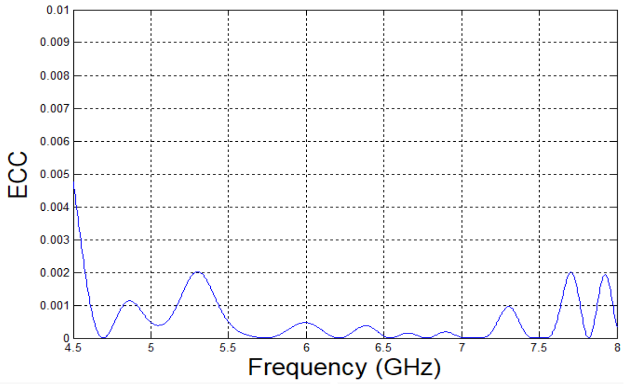


FIGURE 7: ECC of MIMO antenna elements

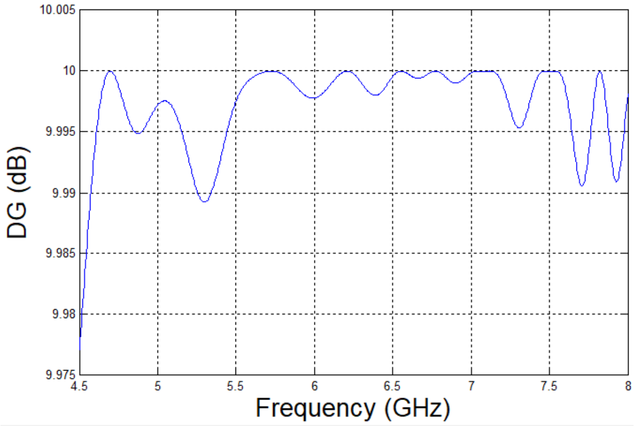


FIGURE 8: DG of MIMO antenna elements

4.2. Channel capacity loss

In order to evaluate the performance of MIMO antenna system, CCL must be taken in account. It is worth to mention, CCL neither increased by incrementing the bandwidth nor the transmitted power in the conventional system [15]. It just depends on the number of antenna elements with a specific assumption [15]. Also, CCL value must be < 0.4 bits/s/Hz and can be calculated as [16].

$$CCL = -\log_2 \det(\Psi^r) \;, \qquad (3)$$

$$\Psi^r = \begin{bmatrix} p11 & p12 \\ p21 & p22 \end{bmatrix}, \qquad (4)$$

where

$$p_{ij} = -(Sii^{*}Sij + Sji^{*}Sij) \text{ for i,j} = 1 \text{ or } 2$$

$$p_{ii} = 1 - (|Sii|^2 + |Sij|^2)$$

Fig.8 depicts the CCL analysis which observed that it achieves the conditional bound over operating frequency.

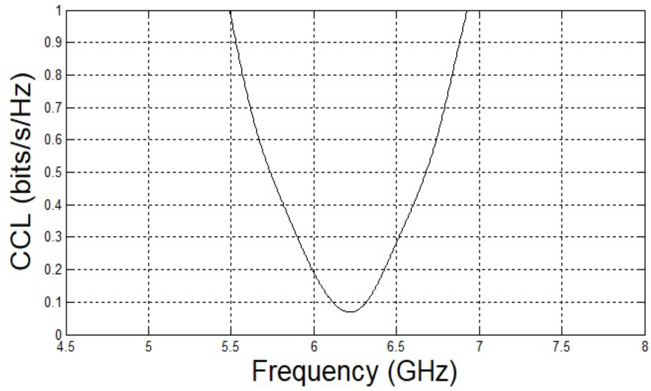


FIGURE 9: CCL of the MIMO antenna system

4.3. Mean effective gain

The antenna gain is measured statistically in the mobile environment by the MEG. It is defined as '*the ratio of the average power received at the antenna to the sum of the average power of the vertically and horizontally polarized waves receives by isotropic antenna* "[17]. Fig. 10 shows the MEG which is less than -3 dB. Also, it can be calculated as [17].

$$MEG = 0.5\left[1 - \textstyle\sum_{j=1}^{N} |Sij|^2\right], \qquad (5)$$

where N is the number of antenna element.

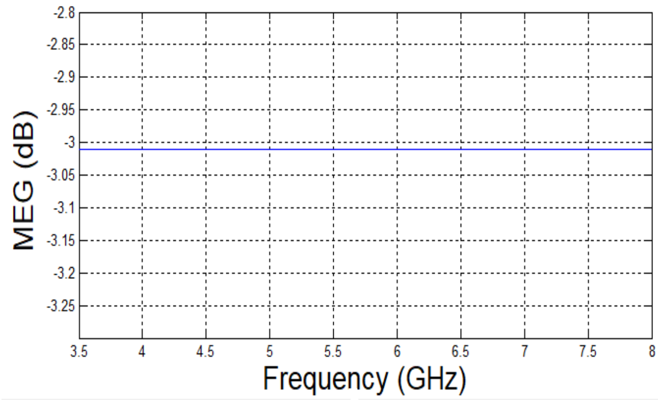


FIGURE 10: MEG of MIMO system

In order to show the proposed MIMO system performance, Table 3 shows abbreviate compression in term of bandwidth (BW), ECC, S_{nm} S_{jk} between the currently proposal and other previous references. However, the proposed MIMO system operates in C-band which is the bandwidth of future communication applications.

Table 3: Performance comparison of the MIMO

ref.	N	port no.	BW (MHz) at -10 dB	ECC	S_{nm}	S_{jk}
proposed	4	8	850	< 0.001	-18	< -15
[7]	8	8	400 and 200	0.01	-16 and -20	-15
[8]	2	2	660	0.1343	-16	< -15
[9]	8	8	200	-	-18	-10
[10]	1	16	200	≅ 0.2	-16	-15
[11]	4	8	200	< 0.001	≅-15	< -15
[13]	4	8	800	< 0.01	-18	< -15

5. Conclusion

In this research, a proposed MIMO prototype with four elements that each has a dual polarized port. A method of applying the parasitic rectangular is to investigate low mutual coupling. Also, a slot of circular ring has etched in the ground in reverse of the gabs made in such parasitic in order to achieve uniformly radiation pattern distribution. The proposed model has fabricated and tested to evaluate its performance. The results show that such design has operated at C-band frequency (5.81-6.66) GHz at -10 dB. It is worth to mention that we achieve a matching result in both simulation and measurements for in the visual and integrated of operating frequency.

Acknowledgements

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