Parametric Study on Mutual Coupling Reduction for MIMO Future 5G Antennas

H. Yon, N. H. Abd Rahman, M.A Aris, M. H. Jamaluddin, H. Jumaat

Abstract— **This paper presents the development of a compact Multiple Input Multiple Output (MIMO) antenna using new structure integrated with C shaped parasitic element for mutual coupling reduction and antenna isolation improvement. The antenna has been designed to resonate at 16GHz for future 5G mobile band. The separation of the antennas has been set from $0.5\lambda_0$ to $0.26\lambda_0$ to investigate the mutual coupling between dual antenna elements. The novel C shaped parasitic element has been located around the main radiating patch with 1mm in width to reduce the mutual coupling between the dual element antennas. Meanwhile, the separation distance of $0.32\lambda_0$ between the antennas has been chosen for the final antenna design due to its good performance. By using the novel C shaped parasitic element, the antenna isolation have reduced from -11.77dB for without parasitic condition to -23.92dB when parasitic element was included. The result shows 25.79% isolation improvement has been achieved for antenna with C shaped parasitic element. Furthermore, by introducing the parasitic element, the bandwidth have been improved 32.71% from the design without parasitic element. The antenna was simulated and optimized at 16 GHz using Computer Simulation Technology (CST) with permittivity, $\varepsilon_r = 2.2$ and thickness, $h = 1.57$mm on Rogers RT-Duroid 5885 substrate. The antennas are matched at their corresponding frequency of operations. The simulation results have shown that the antenna works well.**

Index Terms— **MIMO, Parasitic element, CST, Rogers.**

I. INTRODUCTION

WIRELESS systems for the future 5G cellular system are increasingly proposing the utizalition of the high frequency band spectrum due to growing need for support huge number of user and applications. The current and incoming 5G network requires communication systems that can handle larger data rates with high speed and consistent quality of transmission. With these requirements, advanced wireless communication Multiple Input Multiple Output (MIMO) technology plays a key role to meet the requirements of high quality and high data rate communication systems. In 1990, MIMO technology was proposed as a solution to overcome data rate limit by single input single output (SISO)[1].

In order to develope MIMO antenna system, it is requires multiple antenna elements at the transmitter and the receiver to achieve a linear increase in the data rate with an increase the number of antennas. However, it is a big challenge to keep multiple number of antennas within a small and compact space due to the mutual coupling developed between the antenna elements[2]. This mutual coupling arises due to the interaction of radiations from closely spaced antennas and also due to the surface currents flowing on the ground plane[3]. This will make field correlation and mutual coupling increase and thus will degrade the diversity performance of the MIMO antenna system[4].

The most recent research on MIMO antenna design is mainly focusing on mitigating the effects of mutual coupling and investigating various efficient techniques to reduce it. Evaluating and monitoring the antenna surface current was one of the key factors in determining the amount of mutual coupling between the antennas. Some of the MIMO antenna designers have introduced parasitic element[5], defected ground structure (DGS)[6], metamaterial[7], slot[8], neutralization line[9], stacked configuration[10], orthogonal polarization[11], metallic wall[12], decoupling structure[13], and hybrid structure[14] to reduce the mutual coupling in MIMO antenna design.

The easiest way to reduce mutual coupling and improve isolation between antennas is by adjusting the antenna distance to be more than λ/2 as mentioned in[15]. Although this method gives good isolation between multiple antennas, this configuration needs to extend distance between antenna and so that there is an increase the antenna size. Meanwhile in [16] the researcher have design DGS to reduce mutual coupling. However, designing the DGS will shifted the resonant frequency, due to higher coupling by the DGS structure. Meanwhile, in [17] good isolation between multiple antenna has been achieve using parasitic element.

In this preliminary research works, the mutual coupling is reduced by introducing a novel C shaped parasitic element around the radiating patch structure. The performance of the antenna has been investigated between without and with parasitic element to observe the effects of parasitic structure to the antenna isolation performance. The isolation has been improved 25.79% between with and without parasitic element, respectively.

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II. DESIGN OF DUAL ELEMENT MIMO ANTENNA

The design of the proposed antennas are shown in Figure 1 and Figure 2, respectively. The radiating element of the antenna structure is located at the top layer while the full ground plane is at the bottom layer. Comparison is made between two antenna structures; a circular patch and a circular patch with C shaped parasitic element. The MIMO antenna has a size of 15mm x 30mm for both designs with and without parasitic element. Table 1 shows the parameters of the final optimized antenna structure. The purpose in designing the C shaped parasitic element on the antenna design is to improve antenna's mutual coupling for future 5G technology[18]. The antenna has been designed and optimized at 16GHz based on the future 5G mobile band as mentioned in[19]and has been simulated on RT Duroid 5880 substrate with permittivity of 2.2, loss tangent of 0.002 and thickness (h) of 1.57mm.

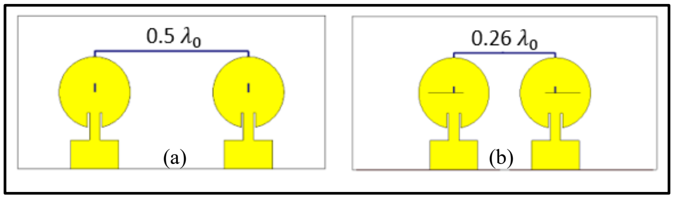

Fig. 1. MIMO antenna without C shaped parasitic element (a) $0.5\lambda_0$ (b) $0.26\lambda_0$

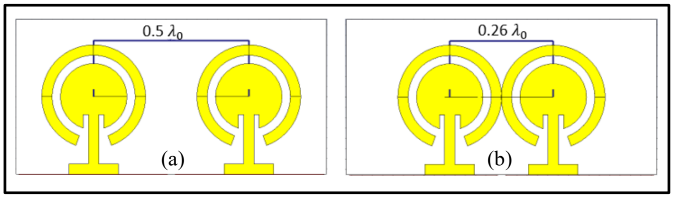

Fig. 2. MIMO antenna with parasitic element (a) $0.5\lambda_0$ (b) $0.26\lambda_0$

TABLE 1.
ANTENNA PARAMETERS.

Parameters	Value [mm]
Diameter of patch	3.22
Length of feed	2
Length of substrate	30
Material thickness	1.57
Width of parasitic element	1
Width of feed	4.77
Width of substrate	15

The simulated reflection coefficients, S_{11} are shown in Figure 3 and the antenna isolations are shown in Figure 4 for both designs. The antenna has shown good response within the selected frequency range. The simulated impedance bandwidth shows good coverage around the resonant frequency of 16GHz. However, significant shift in S_{11} is shown at a distance of 0.26λ due to high coupling between dual element. The same scenario is observed for antenna isolation,where at 0.26λ, the isolation is becoming worse. In this preliminary works, the main focus is to reduce mutual coupling between dual element MIMO at the desired frequency. With these findings, the optimum antenna in this research works has been chosen at 0.32λ distance between dual element due to its overall performance for future mobile MIMO application.

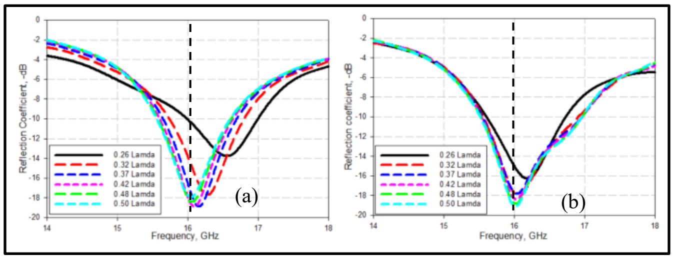

Fig. 3. Reflection coefficient (a)without (b) with parasitic element

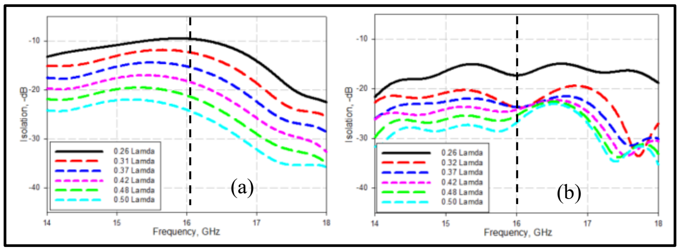

Fig. 4. Isolation (a) without and (b) with parasitic element

III. ANALYSIS OF ANTENNA CURRENT DISTRIBUTION, ECC, DIVERSITY GAIN AND RADIATION PATTERN

Dual MIMO antenna with acceptable isolation value[20] has been achieved through the selected element gap of 0.32λ as shown in Figure 5(b). In this section, the implementation of a novel C shaped parasitic element for isolation improvement has been analyzed and studied through comparison with the original structure (without parasitic element) as shows in Figure 5(a). The purpose of adding the extra element around the main radiating patch is to create an indirect coupling path that opposes the signal going directly from one element to other element. If the two signal strengths are comparable, the two signals add up destructively resulting in the reduction of mutual coupling[21].

Meanwhile Figure 6 shows antenna performance in term of isolation for antennas design without and with parasitic element, respectively.

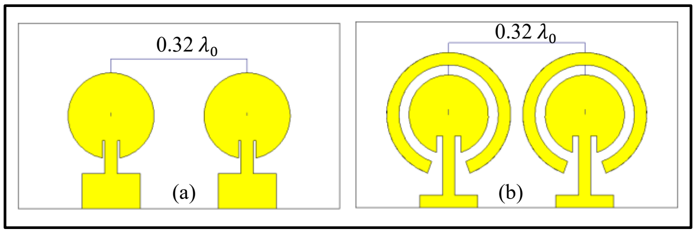

Fig. 5. Proposed antenna (a) without and (b) with C shaped parasitic element

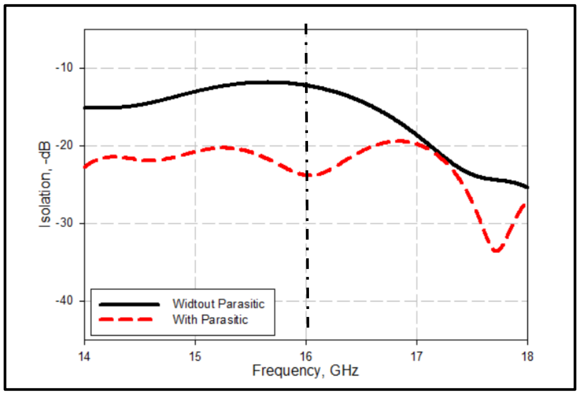

Fig. 6. Comparison of isolation –value for without and with C shaped parasitic element

From the isolation result, it can be concluded that by implementing the C shaped parasitic element, the isolation between MIMO elements can be improved. The dimension of the novel parasitic structure is taken as W=1mm. Based on the simulation result from Figure 6, it can be observed that the isolation between dual element antenna has been improved from -11.77dB without parasitic element and -23.92dB on antenna with C shaped parasitic element structure. It shows an improvement of 25.79% for antenna with C shaped parasitic element as compared to antenna without parasitic element.

Meanwhile, Figure 7 and Figure 8 show the current distribution for both cases. As mentioned in[21], the reason for the reduction of mutual coupling between the antennas and the basic concept in justifying the final shape of the proposed antenna can be understood by analyzing the surface current distribution. The amount of mutual coupling between the two antennas in a MIMO system depends on the directions of the current flowing on the surface of the antennas. If the current flows in same direction on the adjacent sides of both the antennas, the mutual coupling is increased. However, if the currents are in opposite direction, the induced mutual coupling is reduced[22]. As observed from Figure 8, the current propagation on the right arm of the first antenna and parasitic structure placed around the antenna are flowing in the difference directions, thus minimizing the mutual coupling and improve the antenna isolation value.

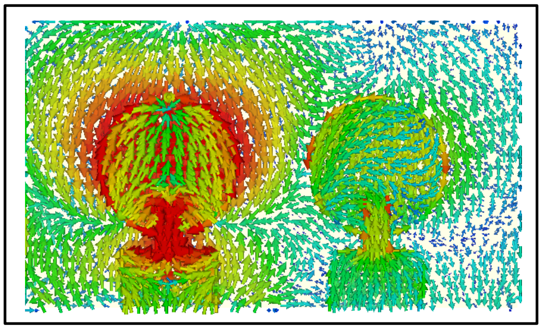

Fig. 7 Current distribution antenna without parasitic element

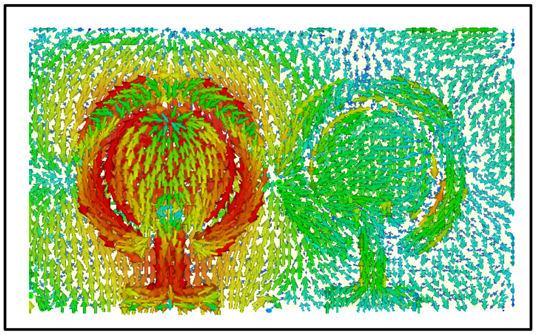

Fig. 8 Current distribution antenna with parasitic element

Further investigation on MIMO parameter has been conducted for both antenna structures. As mentioned in[23], other important parameter to evaluate MIMO performance is Enveloped Correlation Coefficient (ECC). This parameter is useful in estimating the diversity performance of a MIMO system. As mentioned in[24], the correlation coefficient value of 0.3 has been set as an acceptable value for MIMO technology. The ECC is calculated for both the MIMO systems, without and with parasitic element in between the antennas and is plotted in Figure 9. From the plot, it can be observed that the envelope correlation coefficient is very low at the selected resonant frequency, which indicates good isolation between the two antennas in the MIMO system. Meanwhile, Figure 10 shows the antenna diversity gain for both cases. Diversity is usually achieved when the transmitter receives multiple version of the transmitted stream through different channel path[25]. If the signals are uncorrelated, the combination signal at the receiver will provide higher SNR level and thus better signal reception[26] It shows that, both antennas agreed with maximum value of 10dB[27] diversity gain. The simulation values are 9.99022dB, and 9.99916dB at without and with parasitic element, respectively.

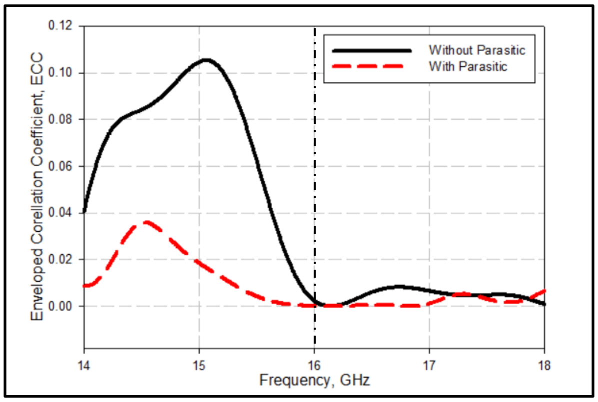

Fig. 9. Enveloped correlation coefficient

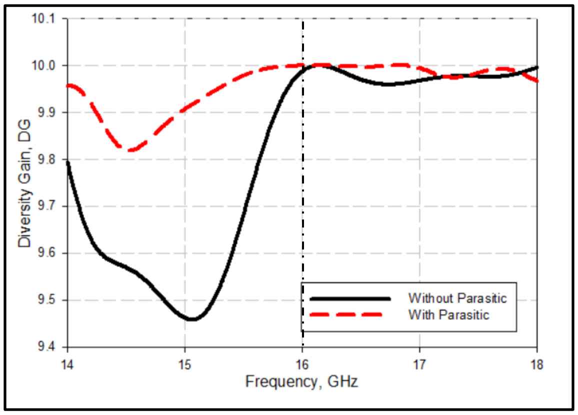

Fig. 10. Diversity gain

Good agreement in radiation pattern has been achieved for both configurations as shown in Figure 11 and 12. The figure shows the antenna normalized radiation patterns in E-plane and H-plane. Meanwhile, Figure 13 shows both cases of the antenna gain in 2D view. Then, Figure 14 and Figure 15 show the antenna radiation patterns in 3D views for all cases. The gain has been decreased as compared with the design without parasitic element. The result shows that the antenna gain for antenna without parasitic structure is 8.95dBi, and for the antenna with parasitic structure, the gain has slightly reduced to 7.28 dBi. From the 3D view, it shows that the efficiency of antenna design with parasitic structure has been increased slightly from 65.8% to 80.4% compared with the antenna without parasitic structure. The bandwidth also has been increased from 1070MHz to 1420 MHz when parasitic element is added.

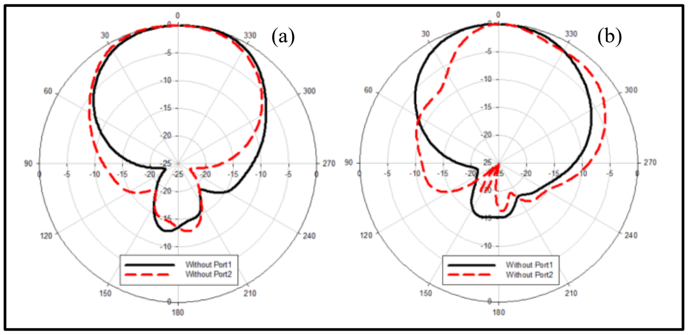

Fig. 11. Radiation Pattern without parasitic on port 1 and 2 for (a) Phi 0 (b) Phi 90

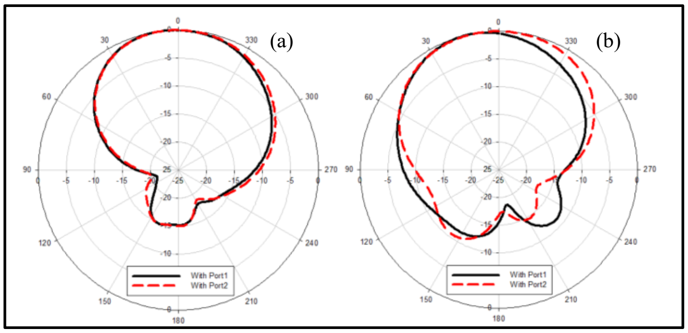

Fig. 12. . Radiation Pattern with parasitic on port 1 and 2 for (a) Phi 0 (b) Phi 90

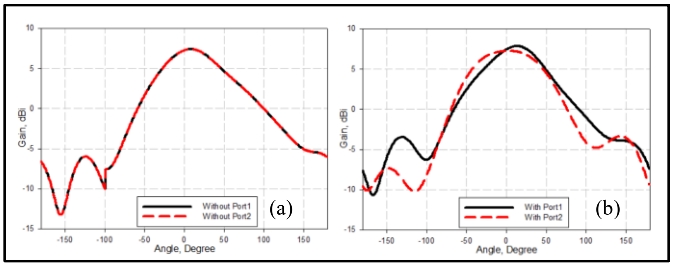

Fig. 13. Antenna gain port 1 and port 2 (a) Without (b) With parasitic element

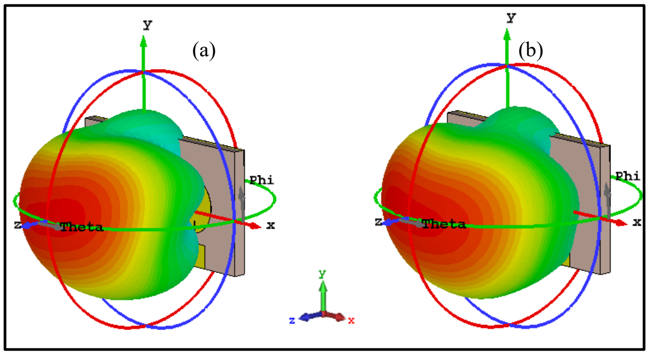

Fig. 14. Radiation Pattern 3D without parasitic (a) Port1 (b) Port2

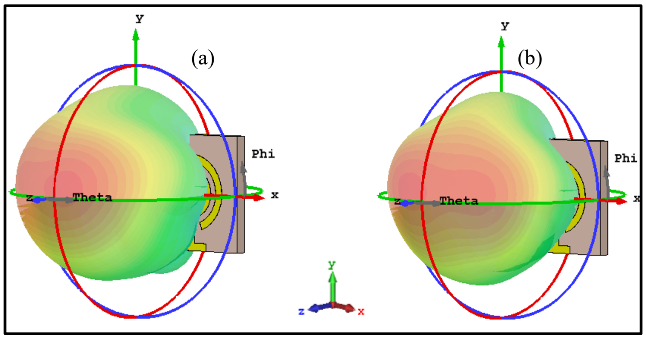

Fig. 15. Radiation Pattern 3D with parasitic (a) Port1 (b) Port2

Table 2 and table 3 show the comparison of the simulation results for antenna design without and with parasitic element. The improvement in MIMO has been analyzed and studied well. With this novel C shaped parasitic element, a new technique in reducing mutual coupling between multiple antennas has been validated to be able to improve antenna isolation and bandwidth. From the simulation result, it also shows that by locating parasitic element, the shifting in resonant frequency has been minimized. As a comparison to previous works, the effect of parasitic elements has been investigated in [28] and the concept of locating parasitic element above radiating patch has been introduced in [29], respectively.

TABLE 2
ANTENNA WITHOUT PARASITIC ELEMENT

Result	Port1	Port2
Frequency (GHz)	16.23	16.25
Gain (dBi)	8.95	8.95
Reflection, Coefficient	-18.60	-17.32
Efficiency (%)	65.8	66.7
Isolation, (-dB)	-11.79	-11.77
ECC	0.0008	0.0008
Bandwidth	1070	1070

TABLE 3
ANTENNA WITH PARASITIC ELEMENT

Result	Port1	Port2
Frequency (GHz)	16.05	16.05
Gain (dBi)	7.28	7.04
Reflection, Coefficient	-18.11	-18.76
Efficiency (%)	80.4	82.3
Isolation, (-dB)	-23.92	-24.06
ECC	0.00016	0.00016
Bandwidth	1420	1420

IV. CONCLUSION

The method and location of the parasitic structure to improve antenna isolation have been investigated and studied well in this research work. The ability of the proposed MIMO antenna that consists of two elements with parasitic structure has been validated toreduce mutual coupling between multiple antennas. This work has been verified by using electromagnetic simulator to determine the effectiveness of both structure. The parasitic element around on the top antenna structure has improved the antenna isolation with an improvement of 25.79% as compared to antenna without any parasitic element. Furthermore, by introducing the parasitic element the bandwidth have been improved by 32.71% when parasitic element is added

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