Design of PIFA MIMO Antenna with Parasitic Effect for Future 5G Wireless Applications

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Abstract—**In recent technologies, MIMO systems become one of the promising technology used in wireless applications. Therefore, the demand for integration of using multiple antennas in user applications has enhanced. When involving MIMO system, the mutual coupling among the antennas must be low as possible in order for the antenna to give optimum performance. This paper presents two design configurations of compact two-element PIFA MIMO working at 15 GHz for future 5G wireless applications. The operating frequency met the requirement to work in future 5G environment. Both are designed with the total size of $20mm \times 26mm \times 1mm$. In this paper, a study on technique adding parasitic element to the PIFA MIMO was investigated. The technique proposed is to improve gain as well as improve isolation due to mutual coupling between the antennas. The simulated and measured results show the satisfactory performance of PIFA MIMO antenna, with gain from 6 dB to 8 dB and mutual coupling reduced to around -27 dB at the resonant frequency.**

Index Terms-- **Planar inverted F-antenna PIFA, multiple-input multiple-output MIMO, fifth generation 5G, isolation, gain, wireless.**

I. INTRODUCTION

Multiple-input multiple-output (MIMO) played an important role in wireless communication applications system. This is because, toward future wireless communication technology, the needs of the system of capable accommodating the higher data transmission and more powerful channel capacity link than the current conventional systems are required [1]. MIMO is one of the effective method and potential candidate to fulfil the specifications. Despite that, when handling MIMO in the antenna system, the difficulties appear in term of placing more than one antenna in a single ground plane [2]. The first obstacle appears will be mutual coupling among the antenna. When high mutual coupling arises between the antennas, the efficiency will be decreased, therefore the antenna cannot give full throughput toward the application system. In order to reduce the problem of mutual coupling among the antenna, in the MIMO concept, the specific distance and position of the antenna played a big role. Nowadays, many researchers had found out that by re-position of the antenna is one of the effective methods to reduce mutual coupling [3]. The present study shows that MIMO as well presents diversity techniques to reduce mutual coupling between the antennas and improve the isolation to provide optimum system performance. In this paper, both of the antenna design elements are placed in spatial diversity pattern [4] with reflecting each other on a single ground plane with air as a substrate. Furthermore, today the use of the wireless communication system has rapidly increased and become one of the important segments in the communication industry. The conventional 4G network, cannot support and provide higher user experienced and peak data rate up to 10 to 20 times higher than what is currently available [5].Therefore, the conversion from the current 4G network to the 5G is most highly anticipated in the communication industry today from around the world and to be implemented within the next few years which is 2020 [6][7]. The main aim for implement 5G network is to make improvement in communication to become ubiquitous connectivity, zero latency, and working at high-speed (Gigabyte per sec) connection [8]. This includes operating frequency opening up to 11 GHz based on an announcement by Federal Communication Committee (FCC) in July 2016 in order to ensure the 5G frequency would be facilitated in millimetre wave (mmWave) frequency which is considered very high frequency (VHF) [9].

Based on the recent research study done, a lot of techniques have been studied to mitigate the problem effect by mutual coupling within the PIFA elements in MIMO applications. The various technique such as in [10] the author proposed a four-element MIMO antenna using hybrid diversity method. In configuration 1 the antenna placed in symmetrical and in configuration 2 the antenna placed in orthogonal. The total volume is 100mm x 60mm x 0.8mm. The antenna cover operating low frequency applications such as GPS, WiMAX,

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Bluetooth, Wi-Fi and HIPERLAN. This method help to mitigate the multipath propagation effect. In [11] the author used method of inserting capacitive load and capacitive feed as modification to the original design in PIFA array for MIMO applications. The overall size of the modified PIFA is 25mm x 10mm x 6mm. The proposed antenna cover Wi-Fi applications range 2.32 GHz to 2.41 GHz. The method helps to prevent current from the top radiating patch PIFA directly surpass through the ground plane via shorting wall and feed point and goes to the next port. Next, in [12] the authors proposed a study of MIMO four elements PIFA array operate at 5G frequency which is 28 GHz with various arrangement in a single ground plane. This method is to minimize the mutual coupling among the antenna array elements. In this paper, Planar Inverted F-Antenna (PIFA) is used. This is because PIFA characteristics are low profile, simple design, lightweight, conformable nature and produce a dependable performance. Besides, PIFA also trusted to be one of the most use candidate antennae for internal small devices in wireless application [13]. Next in general, for an antenna that shares a common ground plane, the isolation can be as low as -10 dB or less [14]. Thus, to enhance the isolation between the antennas, it needs to increase the physical separation between the antennas. But once we increase the distance separation between the antennas, the size of the antenna will be increase. Therefore, in this paper, the authors try to maintain a small and compact size antenna by adding a parasitic element near to the top radiating patch without affecting the size of the antenna ground plane.

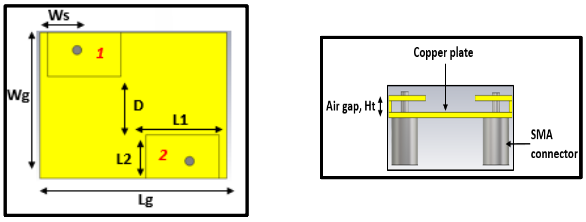
In this paper, we propose a small and compact size of two-element PIFA MIMO with two designs that lead to the improvement in gain with an exceptional good isolation value between the antennas. The operating frequency used is 15GHz which is considered super high frequency in 5G network frequency [15]. This paper is organized into four sections. Section I is for introduction part. Section II described the (Design I) normal two elements PIFA MIMO and in section III, we demonstrate the (Design II) additional of parasitic element to both of the PIFA elements. Both of section II and III are discussed on the simulated and measured result in term of the reflection coefficient, isolation, current distribution, radiation pattern and gain. In section IV, some concluding remarks are provided.

II. Design of Normal Two-Element PIFA MIMO (Design I)

The geometry of the proposed two-element PIFA MIMO antenna is shown in Fig.1. The proposed antenna consists of two PIFA antenna placed with spatial diversity pattern on a single ground plane. The area for each of the top radiating patch of the PIFA is $10 \times 5\ mm^2$ and the total area of the proposed two-element PIFA MIMO is $20mm \times 26mm \times 1mm^2$. The distance separate between the two element PIFA is $D = 10mm$. The resonant frequency of the PIFA is calculated by using the following empirical formula as in "(1)" below.

$$fc = \frac{c}{4}\,(L + W) \tag{1}$$

Where fc is the resonant or operating frequency, c is the speed of light in the free space, W is the width and L is the length of the top radiation patch of PIFA [16]. The proposed two-element PIFA MIMO antenna is designed by using the CST Microwave Studio software [17]. The specifications of the proposed two-element PIFA MIMO are listed in Table 1 and the final optimized parameters are shown in Table 2.



(a) Top view (b) Side view

Fig. 1. The proposed two-element PIFA MIMO (Design I)

TABLE I
DESIGN SPECIFICATIONS OF PROPOSED PIFA MIMO ANTENNA

Features	Specifications
Shape	Rectangular
Frequency operation	15 GHz
Substrate	Air
Ground plane	Full copper plate
The height of the top radiating plate from the ground plane, *Ht*	1mm
Feeding method	Coaxial probe (SMA 50 Ω connector)

TABLE II
DIMENSIONS PARAMETER OF PROPOSED PIFA MIMO ANTENNA

Parameter	***L1 (length of the top patch)***	***L2 (width of the top patch)***	***Lg (length of the groundplane)***	***Wg (width of the groundplane)***
Dimension (mm)	10	6	26	20
Parameter	***Ws (width of the shorting plate)***	***Ht (height from the groundplane to the top patch)***	***Tc (thickness of copper)***	
Dimension (mm)	5	1	0.45	

The reason the author used air as a substrate is one of the ways to tackle the problem of loss due to higher operating frequency used. This is because air has low relative permittivity [18][19][20]. Next, a copper plate with a thickness of *Tc* is used for shorting plate, top radiating patch and ground plane for the proposed antenna. Based on a research study was done, copper is one thing that makes an outstanding choice for antenna due to high conductivity value which is "100" and produces an efficient conductor of electrical energy [21].

The simulated S-parameter results in term of reflection coefficient, S_{11} and S_{22} and isolation, S_{21} of the proposed (Design I) are shown in Fig.2. The performance from the simulation software gives the similar results for reflection coefficient S_{11} and S_{22} at -11.072 dB and good isolation value between the two-element antennas with 25.187 dB at resonant frequency 15 GHz. The similar results produced from the reflection coefficient for both of the PIFA, S_{11} and S_{22} is because of the shape and position of the PIFA is the same.

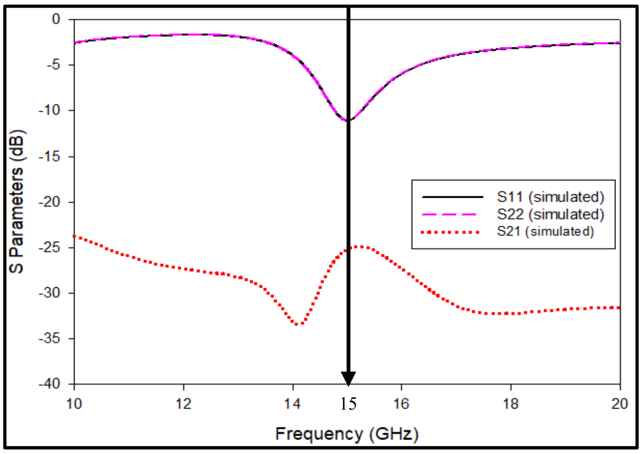


Fig. 2. Simulated result of S-parameters of the proposed two-element PIFA MIMO antenna for (Design I).

The proposed PIFA MIMO antenna fabricated and measured using Keysight Vector Network Analyzer and OTA 500 Aten Lab chamber room. The fabricated prototype is shown in Fig.3.

(a) Top view (b) Side view

Fig. 3. Photographs of the fabricated two-element PIFA MIMO for Design I.

The comparison between the simulated and measured results of the reflection coefficient of both PIFA are shown in Fig. 4. As in theoretical, the minimum value for reflection coefficient is -10 dB. Fig. 4 shows we managed to get -11.072 dB for both of the PIFA elements in the simulated results which is greater than the minimum value. While, for the measured results S_{11}, PIFA 1 is -24.51 dB and S_{22}, PIFA 2 is -34.13 dB. As we can see, the measured result for reflection coefficient is better and deeper compare to the simulated results, even though the measured results is better, but still the efficiency of the simulated is better than the measured results. The efficiency of the simulated and measured results are shown in Table III.

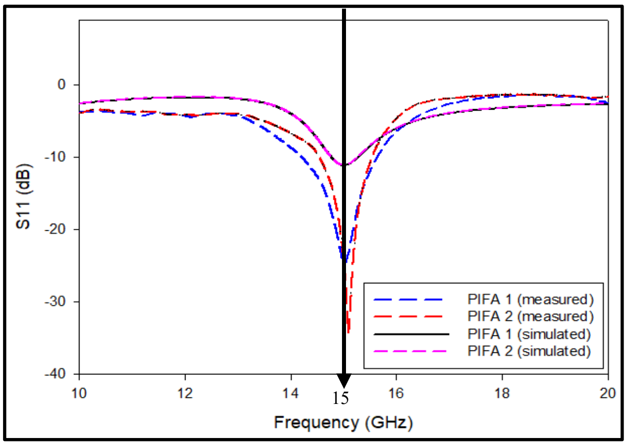


Fig. 4. Comparison of reflection coefficient result for both simulated and measured of PIFA 1 and PIFA 2 for (Design I).

Fig. 5 shows the comparison of simulated and measured results for isolation in Design I. As it can be seen, at 15GHz the simulated result achieved an acceptable isolation with lower than -20 dB which is -25.05 dB, and measured at -28.63 dB between the PIFA 1 and PIFA 2. There are 3 dB improvement in isolation from simulation to measurement result. The difference between the measured and simulated results arises because of imperfections in fabrication and material parameters.

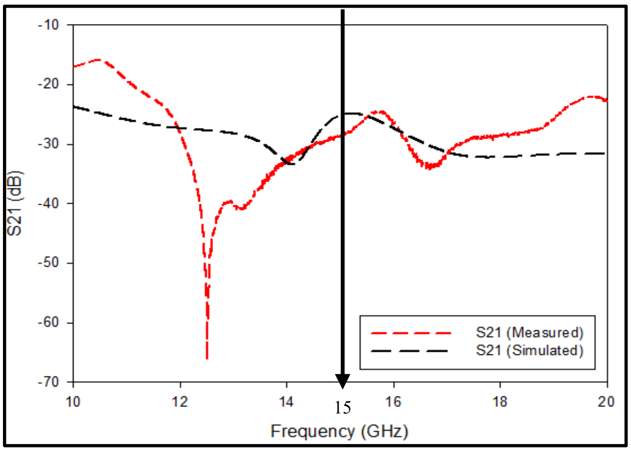
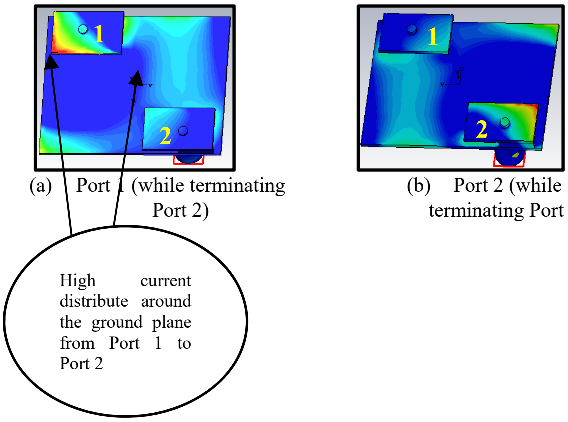


Fig. 5. Comparison of isolation result for both simulated and measured of PIFA 1 and PIFA 2 for (Design I).

The simulated surface current distribution of the proposed PIFA MIMO antenna Design I are shown in Fig. 6. In Fig. 6 (a) when Port 1 is activated and port 2 is terminated the surface current distribute higher around the top radiating patch of port 1. As we can see the current distribution surpass towards the ground plane of port 2 with current flow through the feed point and the shorting wall. The same things happen when activated the port 2 and terminated the port 1 in Fig. 6 (b).

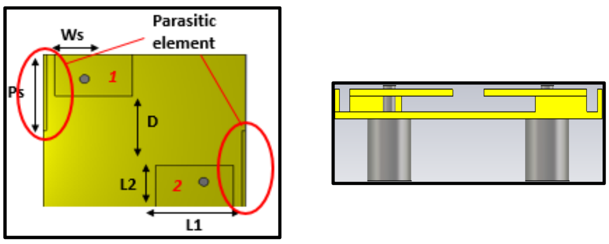


(a) Port 1 (while terminating Port 2) (b) Port 2 (while terminating Port 1)

Fig. 6. Surface current distribution of both PIFA for (Design I)

III. DESIGN OF PARASITIC TWO-ELEMENT PIFA MIMO (DESIGN II)

It can be observed that in Section II, Design I antenna gives an isolation result for simulation with -25.05 dB and measurement at -28.63 dB and gain of both PIFA as shown in Table 3. In this section, the proposed technique for Design II gives a better improvement of gain for both PIFA with 8.308 dB for PIFA 1 and 8.305 dB for PIFA 2. This showed that based on simulation result Design II improving the gain from 7 dB up to 8.3 dB. In case of Design II, based on simulation the author try to investigate the effect of parasitic element towards the proposed antenna. The technique is by design and placing the parasitic element at the major surface current distribution of the proposed antenna. In the present work, the technique to improve gain and achieved stable isolation by adding two rectangular parasitic wall at the edge of each of the top radiating plate antenna as shown in Fig. 7. The overall dimension for the Design II is the same with the Design I. The value addition of the rectangular parasitic element with length and height taken as Ls = 11mm and Hs = 1 mm. Due to the material used is same copper plate as for the ground plane, top radiating patch and the shorting wall, therefore the width is the same as the thickness of the copper plate. The photograph of the fabricated two-element PIFA MIMO with parasitic element is shown in Fig. 8.



(a) Top view (b) Side view

Fig. 7. The proposed two-element PIFA MIMO with the parasitic element (Design II)

(a) Top view (b) Side view

Fig. 8. Photographs of the fabricated two-element PIFA MIMO with parasitic element (Design II)

"Fig. 9" illustrates the simulated results of S-parameters consists of reflection coefficient and isolation of the Design II. The simulation shows a good results with reflection coefficient greater than the minimum value -10dB and isolation greater than -15 dB.

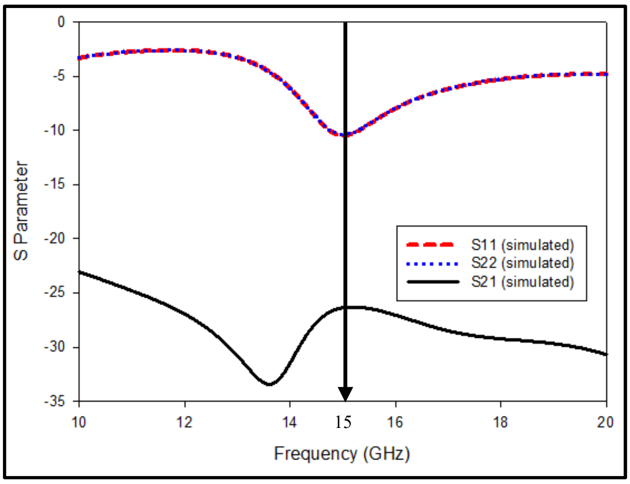


Fig. 9. Simulated result of S-parameters of the proposed with parasitic element (Design II)

The comparison between the simulated and measured results of the reflection coefficient of both PIFA are shown in Fig. 10 and the isolation are shown in Fig 11. As we can see in Fig.10 the measured result shows a deeper S_{11} and S_{22} for both PIFA 1 and PIFA 2 compare to simulated results. But for the measured results PIFA 1 shows a frequency slightly shifted to the 15.1GHz. Overall results for simulated and measured achieved the desired requirement value which is greater than the minimum value -10 dB for reflection coefficient. Simulated results for S_{11} and S_{22} for PIFA 1 and PIFA 2 are -11 dB (same due to the symmetric size and position) and measured results S_{11} and S_{22} for PIFA 1 and PIFA 2 at -19.69 dB and -25.86 dB. In Fig. 11, we can see that the simulated result resonant at 15GHz with S_{21} at -25 dB and measured S_{21} at -24 dB. The shifted frequency and the arises value between the simulated and measured results can be taken due to the fabrication tolerances such as soldering effect of SMA connector, irregular soldering whose (perturbative disturb effect) sensitive towards high frequency antenna measurement and the improper handling during isolation measurement connection in VNA happen during the fabrication process.

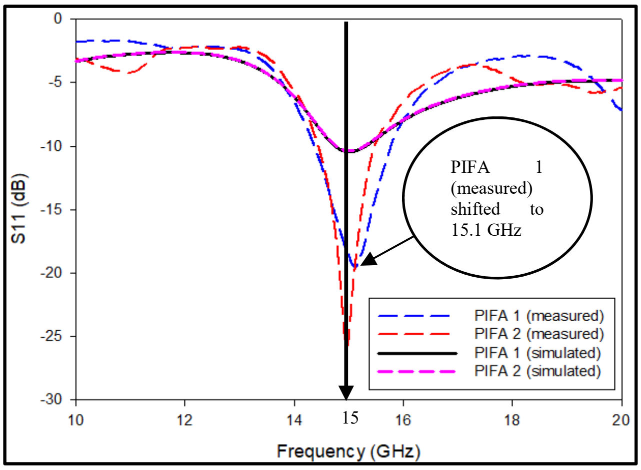


Fig. 10. Comparison of reflection coefficient result for both simulated and measured of PIFA 1 and PIFA 2 for (Design II)

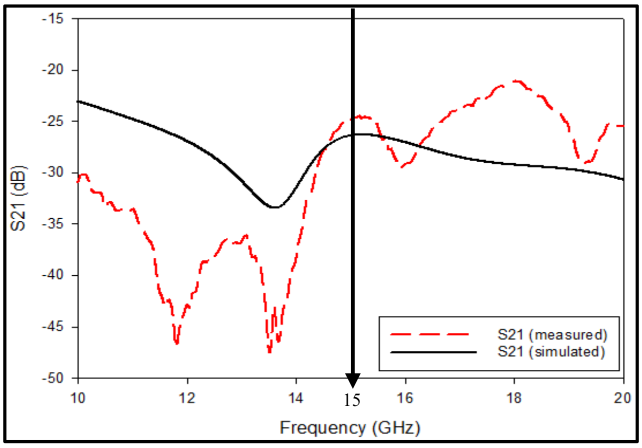
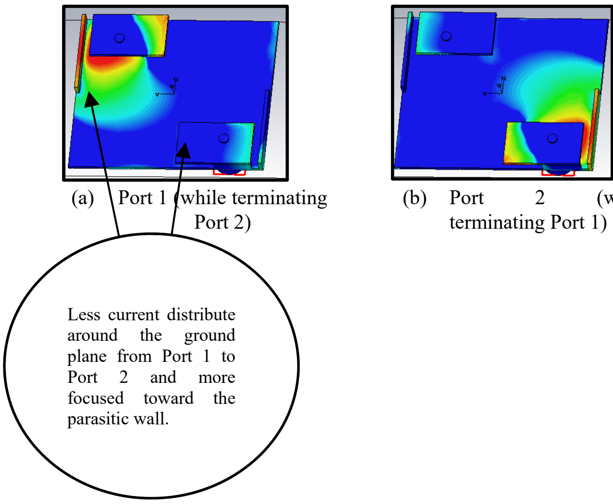


Fig. 11. Comparison of isolation result for both simulated and measured of PIFA 1 and PIFA 2 for (Design II)



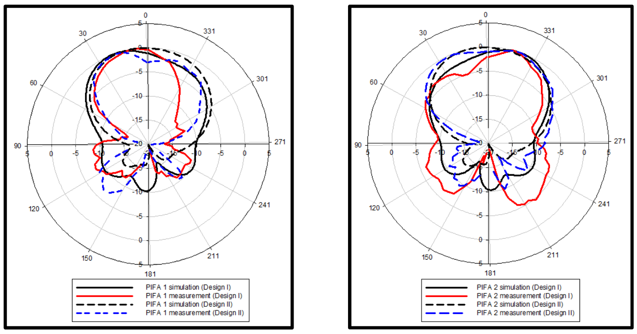
(a) Port 1 (while terminating Port 2)

(b) Port 2 (while terminating Port 1)

Fig. 12. Surface current distribution of both PIFA for (Design II)

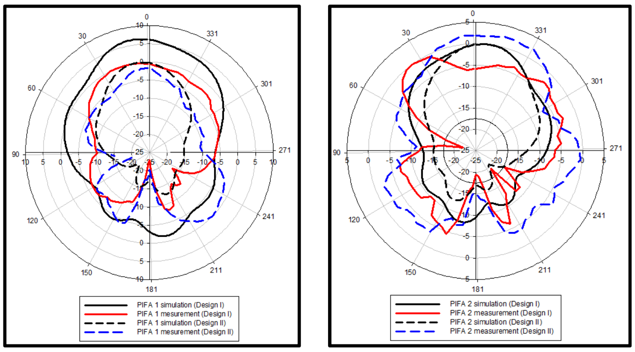
The simulated and measured 2D radiation patterns H-plane ($\varphi = 0$) and E-plane ($\varphi = 90$) of the both proposed two-element PIFA MIMO for Design I and Design II are shown in Fig. 13 and Fig. 14. As we can see, from the Fig. 13 and Fig. 14 the radiation pattern of the H-plane and E-plane for both simulated and measured are not the same. In Fig. 13 (a) the simulated and measured 2D radiation pattern PIFA 1 at H-plane the directivity front lobe are covered and focused more towards the left direction while in Fig. 13 (b) PIFA 2 the directivity covered and focused more towards the right direction. Same concept goes to the Fig. 14 (a) and Fig. 14 (b) in the E-plane. These because both of the PIFAs were in spatial diversity pattern and it exploited at a certain point to obtain diversity gain.

The parasitic elements were design with distance 1 mm away from the top radiating patch and at the edge of the ground plane in between the shorting wall and the feed point. The main aim is to avoid the flow of current from one port to another. First of all, before integrated the parasitic elements, the author's try to identify where is the higher current distribution at the PIFA element. It was found out that from the simulation of electric field plane in CST Microwave, the current distribution is higher around the edge of the ground plane and the shorting wall of the top radiating patch. Based on simulation result, due to the existence of the parasitic element, we can see in Fig. 12 (a) when Port 1 is excited and Port 2 is terminated the current distribution is more focused on the parasitic wall that was designed. Compared to Fig.6 (a) and Fig. 6 (b) the spread of ground current from Port 1 to Port 2 is also less.



(a) PIFA 1 (b) PIFA 2

Fig. 13. Comparison for simulated and measured results of the 2D radiation pattern of the developed two-element PIFA MIMO (Design I and Design II) at H-plane ($\varphi = 0$)



(a) PIFA 1 (b) PIFA 2

Fig. 14. Comparison for simulated and measured results of the 2D radiation pattern of the developed two-element PIFA MIMO (Design I and Design II) at E-plane ($\varphi = 90$)

TABLE III
COMPARISON SIMULATED AND MEASURED ISOLATION, GAIN AND EFFICIENCY OF PROPOSED TWO-ELEMENT PIFA MIMO ANTENNA BETWEEN DESIGN I AND DESIGN II

	Design I			
	Simulated		***Measured***	
The range of frequency (GHz)	15	15	15	15
Isolation (dB)	-25.05		-28.63	
	PIFA1	PIFA2	PIFA1	PIFA2
Gain (dB)	7.665	7.649	6.64	5.20
Efficiency (%)	96.26	94.98	65.52	60.81
	Design II			
	Simulated		***Measured***	
The range of frequency (GHz)	15	15	15	15
Isolation (dB)	-25.00		-24.00	
	PIFA1	PIFA2	PIFA1	PIFA2
Gain (dB)	8.26	8.23	6.10	4.45
Efficiency (%)	99.63	99.47	78.34	57.54

IV. CONCLUSION

The gain and isolation of the two-element PIFA MIMO design for future 5G wireless application was evaluated in this paper. Overall results of the proposed antenna for simulation and measurement shows that the concept meets the requirement and produce reliable results. The two-element PIFA MIMO achieved low mutual coupling and increase in gain. There are some only slightly degrade in measured results due to the fabrication process. The addition of the parasitic element at the edge of each of the top radiating patch PIFA helps to improve the efficiency of the antenna with improve in reflection coefficient and lead to improve 1dB in gain and achieve an acceptable range of isolation between the two antennas.

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