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# Compact Orthogonal Wideband Printed MIMO Antenna for WiFi/WLAN/LTE Applications

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***Abstract*— This study presents a wideband multiple-input-multiple-output (MIMO) antenna for Wifi/WLAN/LTE applications. The antenna consists of two triangular patches as the radiating elements placed orthogonally to each other. Two T-slots and a rectangular slot were etched on the ground plane to improve return loss and isolation. The total dimension of the proposed antenna is 30 x 30 mm$^2$. The antenna yields impedance bandwidth of 101.7% between 2.28 GHz up to 7 GHz with a reflection coefficient of < -10 dB, and mutual coupling of < -14 dB. The results including S-Parameters, MIMO characteristics with analysis of envelope correlation coefficient (ECC), total active reflection coefficient (TARC), capacity loss, channel capacity, VSWR, antenna gain and radiation patterns are evaluated. These characteristics indicate that the proposed antenna is suitable for MIMO wireless applications.***

***Keywords*—Bluetooth, ECC, LTE, MIMO antenna, Wideband, Wi-Fi, WLAN.**

## I. INTRODUCTION

Recent years, wireless communication technologies such as world local area network (WLAN), worldwide interoperability microwave access (WiMAX), Wireless Fidelity (Wi-Fi) and Bluetooth urged higher data rate and large bandwidth, come with a compact size of an antenna. Multiple input multiple output (MIMO) technology have gain much interest among researchers recently. MIMO technology used multiple antennas at both receiving end of the system. Higher data rate and realibity can be achieved in rich scattering environment[1-3]. However, designing MIMO antenna in a finite space with wideband capability is a challenging task. Due to the finite space between antenna elements, focus is given in the design to reduce mutual coupling between elements. Lower mutual coupling ~~can~~ results in higher antenna efficiencies and lower correlation coefficient [4].

In recent years, several methods in enhancing the isolation of the MIMO antenna have been reported [5-14]. Techniques such as neutralization line [5, 6], stub [7-10], the position of the antenna elements [11], the EBG structure [12], slots on the ground plane [13] and using separated semicircular monopoles [14] have been utilized. By reviewing existing methods in [5-14], it is noticed that low mutual coupling with dual band performances can be achieved, but large in size.

This paper therefore aims to improve the performance of the antenna especially in term of the impedance bandwidth while reducing the overall size. We propose a compact wideband MIMO covering Wi-Fi 2.4-2.485 GHz, WLAN 2.4/5.2/5.8 GHz, LTE2300 2.3-2.4 GHz and LTE 2600 2.5-2.69 GHz. The total dimensions of the proposed antenna is 30 x 30 mm$^2$ which s relatively smaller that in [7] with an isolation less than -14 dB over wideband frequency range of 2.28 GHz to 7 GHz. Details of the proposed MIMO antenna design are reported and discussed.

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## II. ANTENNA DESIGN CONCEPT

The configurations of the proposed antenna is illustrated in Figure 1. The antenna deployed on FR-4 substrate with relative permittivity of 4.4 and a thickness of 1.6 mm with a total dimension of 30 x 30 mm$^2$. The antenna element consists of two triangular patches fed by a 50 ohm microstrip line placed orthogonally to each other. Two L-shaped stubs are attached to each patches to enhance the impedance bandwidth. T-slots and rectangular slot are etched on the ground plane in order to improve the impedance bandwidth and mutual coupling. The geometry configuration of the optimal dimensions are listed in Table 1.

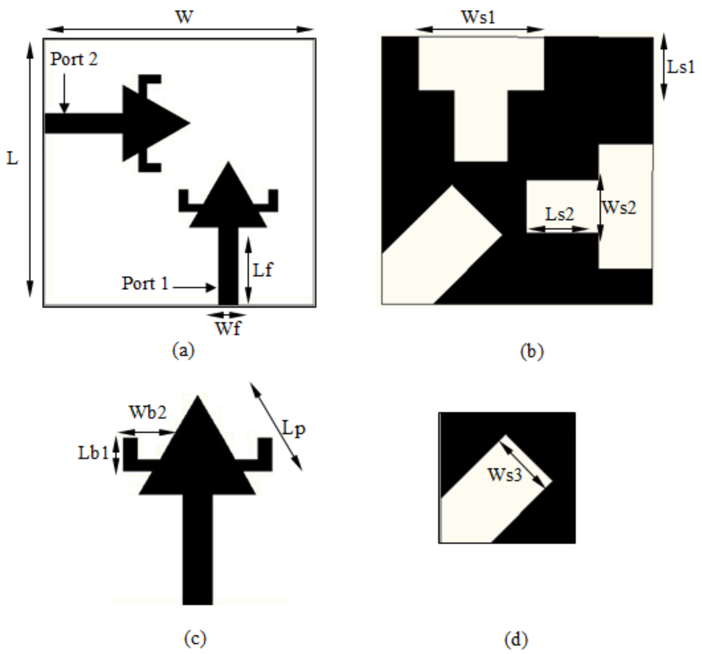



Figure 1: Configuration of the proposed antenna. (a) Front View; (b) Back View; (c) Patch and slot View.

Table 1. Design parameters of the proposed antenna (a) front view, (b) bottom view, (c) triangle patch with L-stubs, and (d) rectangular slot

| Parameters | W | L | Wf | Lf | Ws1 | Ls1 |
|---|---|---|---|---|---|---|
| Unit (mm) | 30 | 30 | 2.2 | 8.75 | 14 | 6 |
| Parameters | Ws2 | Ls2 | Lb1 | Wb2 | Lp | Ws3 |
| Unit (mm) | 8 | 6 | 2.5 | 2.7 | 8 | 4 |

## III. PARAMETRIC STUDY

In order to clarify the effects and obtain the optimized values of the proposed design, the parametric studies of T-slot, L-shaped stub and rectangular slot were carried out.

### A. *Effects of the of T-Slot*

As depicted in Figure 1(b), the T-slot are orthogonally etched on the ground plane. This is to improve the return loss, $S_{11}$ <-10 dB. These T-slots will introduced the resonant frequency of the antenna. As the T-slot etched, the resonance introduced and tend to resonate < -10 dB from 2.345 – 5.205 GHz as shown in Figure 2. With a proper length and position of a T-slot, wideband bandwidth also can be achieved [15, 16]. Figure 2 shows the comparison of the simulated $S_{11}$ and $S_{21}$ with and without T-slot. It is clearly seen that, the resonance frequency tends to resonate < -10 dB after T-slots are etched on the ground plane , nevertheless the mutual coupling becomes higher at the lower frequency band especially at 2.4 GHz.

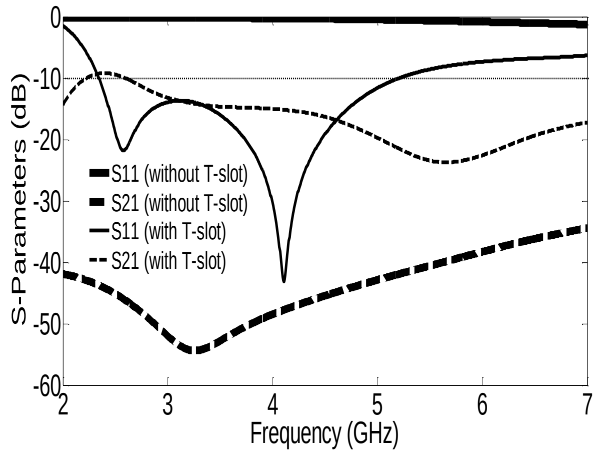



Figure 2. Simulated S-Parameter of the proposed antenna with and without T-slot.

### B. *Effect of the L-shaped Stub*

Two L-shaped stubs are added on each triangular patches as shown in Figure 1(a). As in [16] the existence of the stub could improve the impedance bandwidth of the antenna. Figure 3 shows the comparison with and without L-shaped stub. It can be seen in Figure 3 that the impedance bandwidth have been improved from 2.345–5.2 GHz to 2.38-7 GHz which is approximately 22.9 % improvement and, hence achieve the wideband performance. But, apparently there is still no effects on mutual coupling at the lower frequency band.

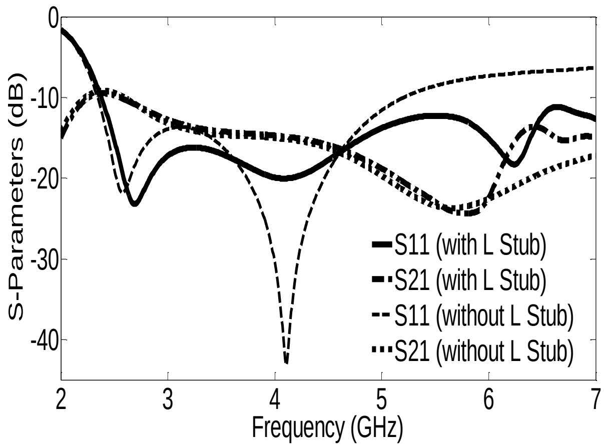



Figure 3. Simulated S-Parameters of the proposed antenna with and without L-shaped stub.

### C. *Effect of Rectangular Slot*

As depicted in Figure 1 (d), the rectangular slot was introduced on the bottom left on the ground plane in order to improve the isolation at the lower band. Figure 4 comparess the simulated S-Parameters with and without rectangular slot. As can be seen, with rectangular slot, the mutual coupling significantly reduced to less than -14 dB ($S_{21}$ < -14 dB) at 2.4 GHz, and at the same time the impedance bandwidth enhanced from 2.38 – up to 7 GHz to 2.28 – up to 7 GHz.

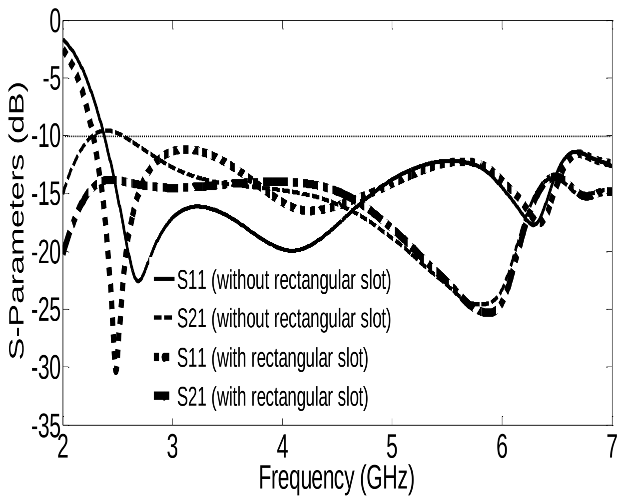
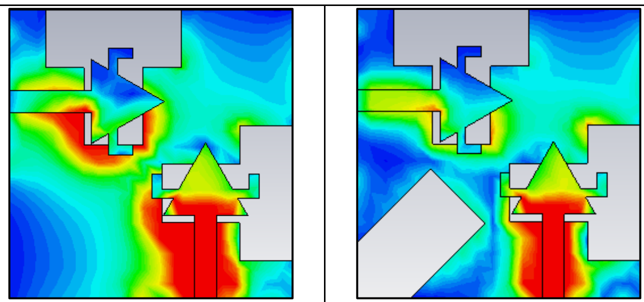



Figure 4. Simulated S-Parameters of the proposed antenna design with and without rectangular slots.

In order to comprehend the effect of rectangular slot on the ground plane, Figure 5 compares the surface current distribution with and without the slot at 2.4 GHz. In this case, port 1 is excited while port 2 is terminated with 50 ohm load. It shows significant reduction in term of surface current density at port 2 due to port 1 with the slot on ground plane. Based on simulation, mutual coupling has improved from -9 dB to -14 dB.



(a) (b)

Figure 5. Surface current distribution at 2.4 GHz. (a) without rectangular slot; (b) with rectangular slot (port 1 excited while port 2 terminated).

## IV. RESULT AND DISCUSSION

To corroborate the simulated results, the prototype of the proposed antenna was fabricated and measured (Figure 6). The measured and simulated S-parameters are illustrated in Figure 7. The measured S-parameters, are in good agreement with the simulated results. Some descripancies can be

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attributed to the reflections from SMA connector and the equipment tolerances. The bandwidth covers operating frequencies of 2.4 GHz to 7 GHz with return loss , $S_{11}$ ≮ of less than -10 dB and mutual coupling lower than -14 dB throughout the band. This bandwidth covers several applications including Bluetooth (2.4 GHz), Wi-Fi (2.4-2.485 GHz), WLAN (2.4/5.2/5.8 GHz) , WiMAX (2.5/3.5/5.5 GHz), LTE2300 2.3-2.4 GHz and LTE 2600 2.5-2.69 GHz .

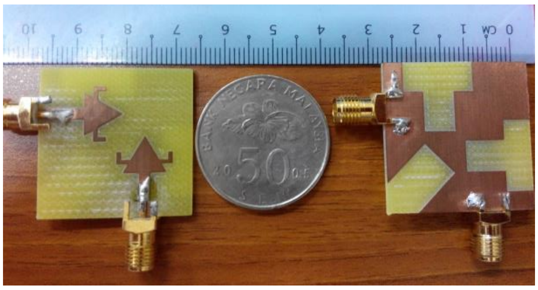
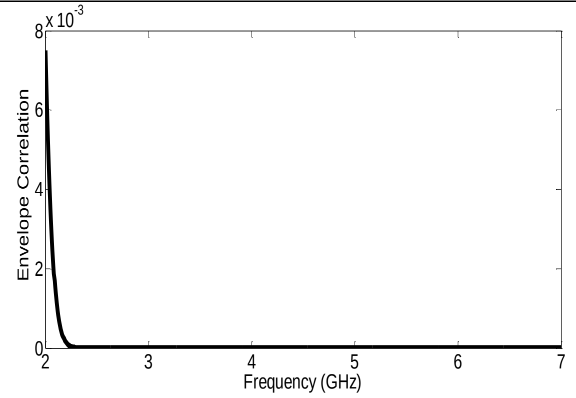
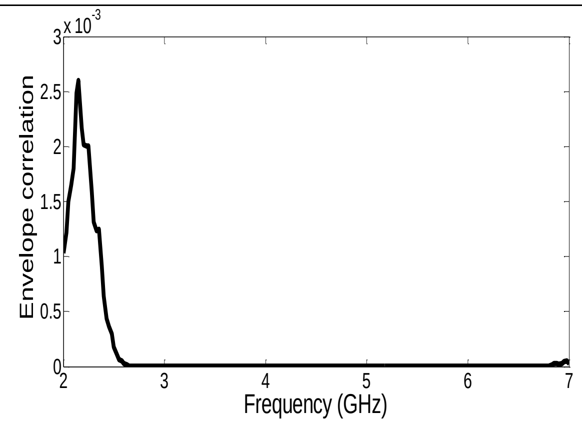


Figure 6. Practical prototype of the proposed antenna




(a)

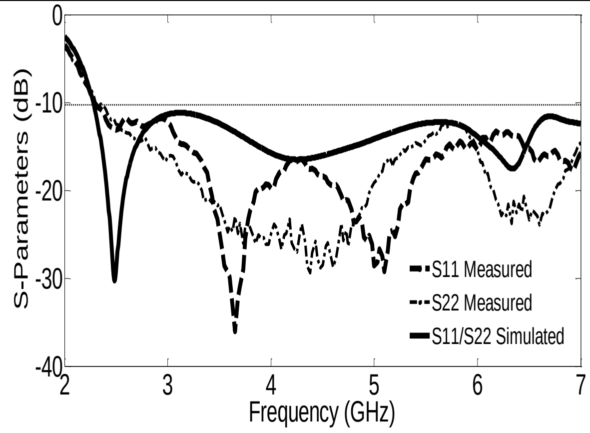



(b)

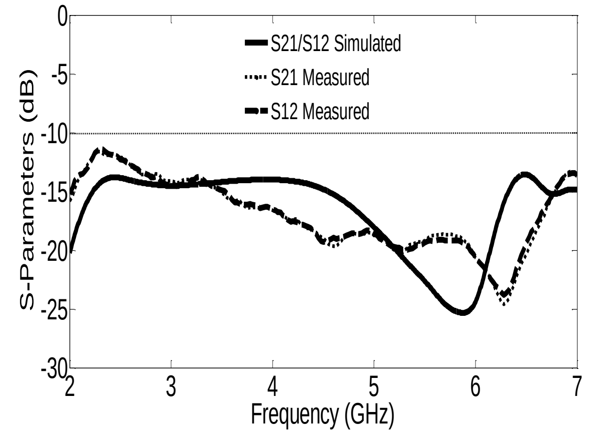
Figure 7: Simulated and measured S-parameters. (a) $S_{11}$, $S_{22}$; (b) $S_{12}$, $S_{21}$.

The envelope correlation coefficient (ECC) to evaluate the capabilities of a MIMO antenna can be calculated based on [16]:

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




(a)




(b)

Figure 8. Envelope Correlation Coefficient computed using measured scattering parameters (a)simulated, (b) measured

Figure 8 shows the measured envelope correlation computed using scattering parameters. Correlation coefficient less than 0.0006 were achieved across entire band and meet up the requirement of diversity performances $p_e < 0.5$[17]. The simplified channel capacity loss of a 2x2 MIMO system can be calculated based on [3, 18];

$$C_{loss} = -log_2 \det\ (\varphi^R) \quad (2)$$

where $\varphi^R$ is the receiving antenna correlation matrix

$$\varphi^R = \begin{pmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{pmatrix} \quad (3)$$

The simulated and measured capacity losses of the proposed MIMO antenna design depicted in Figure 9. It can be observed that the capacity loss is always lower than 0.5 bps/Hz along the bands, and in good agreement with the simulation. This indicates low capacity loss over entire bands.

The total active reflection coeffiecient (TARC) is defined as the ratio of the square root of total reflected power divided by the square root of total incident power[19]. The simulated and measured TARC is compared in Figure 10. There is slight frequency shift between simulated and measured results. This is due to the cable loss and reflection from SMA connector in measurement which is not taken into consideration in simulation process.

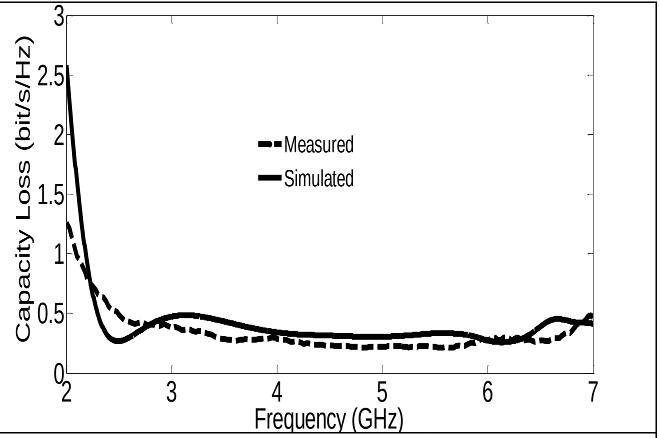


Figure 9. Simulated and measured capacity loss of the proposed antenna

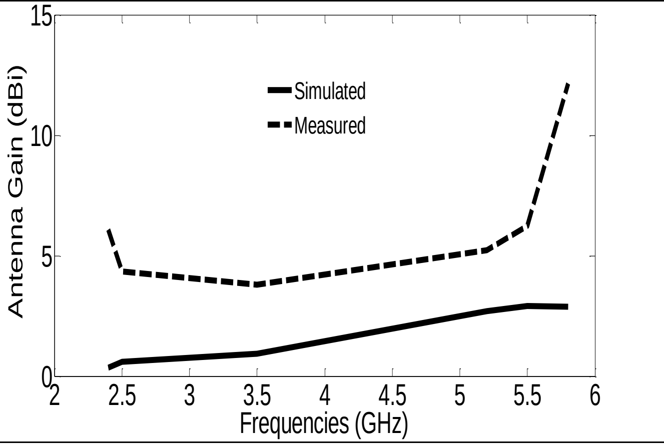


Figure 12. Simulated and measured antenna gain of the proposed antenna

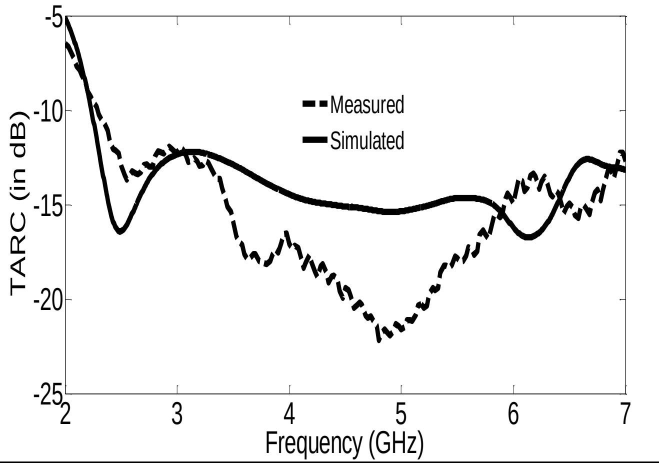
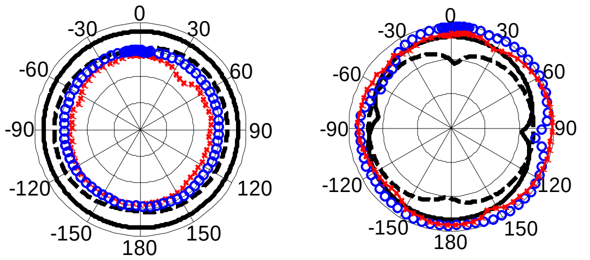
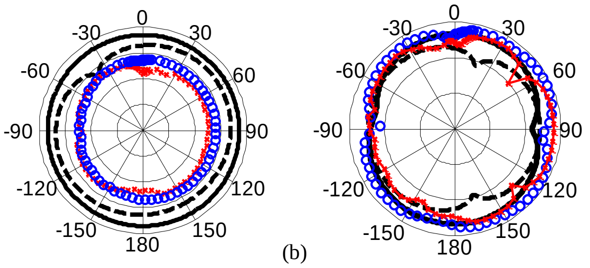
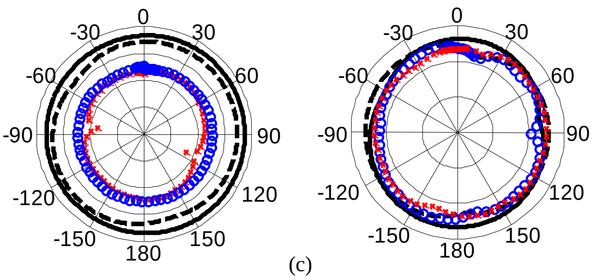


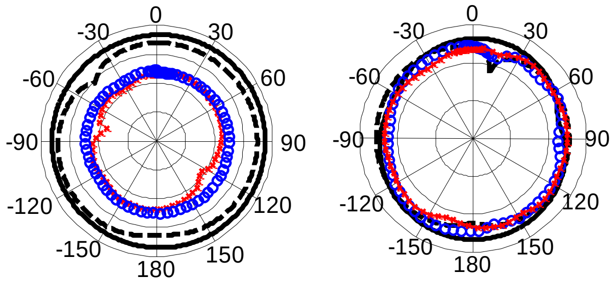
Figure 10. Simulated and measured TARC of the proposed antenna

The simulated and measured antenna gain of the proposed MIMO antenna is as depicted in Figure 12. Measurement show higher gain is achieved compared to simulation.


(a)


(b)


(c)


(d)

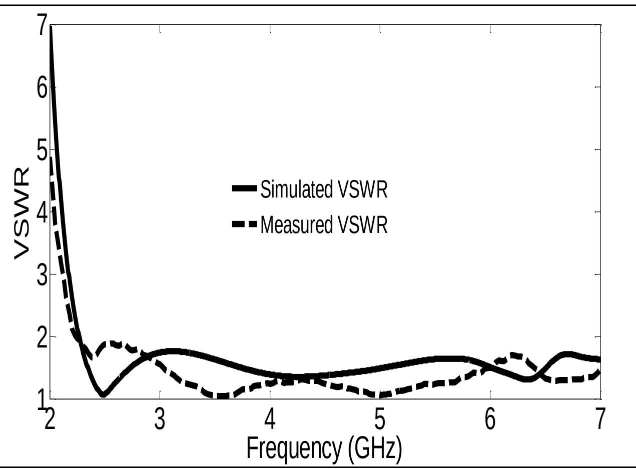


Figure 11. Simulated and measured VSWR of the proposed antenna

The simulated and measured voltage standing wave ratio (VSWR) of the proposed MIMO antenna design shows in Figure 11. Good agreement between simulated and measured results were observed. It clearly shows lower VSWR (< 2) from 2.3 to 5.8 GHz is achieved.

Figure 13. Simulated and measured normalized radiation patterns of the proposed antenna for two planes [(left) x-z plane, (right) y-z plane] at (a) 2.4 GHz, (b) 3.5 GHz, (c) 5.2 GHz,and (d) 5.5 GHz). Port 1 is excited and port 2 is terminated in 50Ω"oooo" measured co-polar, "xxxx" measured cross-polar, "----" simulated co-polar, "- - - -" simulated cross-polar.

Figure 13 and Figure 14, respectively compares radiation patterns for several frequencies across the band. Good agreement between simulation and measurement results.

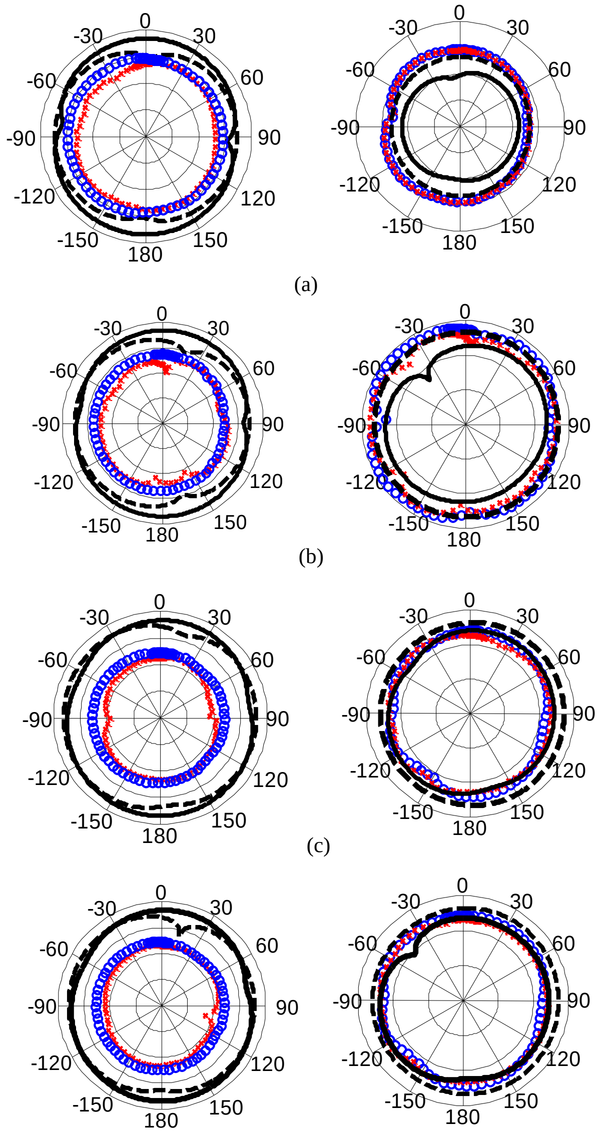



Figure 14. Simulated and measured normalized radiation patterns of the proposed antenna for two planes [(left) x-z plane, (right) y-z plane] at (a) 2.4 GHz, (b) 3.5 GHz, (c) 5.2 GHz,and (d) 5.5 GHz). Port 2 is excited and port 1 is terminated in 50Ω"oooo" measured co-polar, "xxxx" measured cross-polar, "----" simulated co-polar, "- - - -" simulated cross-polar.

## V. CONCLUSION

A compact MIMO antenna with total dimensions of 30 x 30 mm$^2$ is proposed. The antenna operates across frequency band of 2.3 to 7 GHz with mutual coupling of less than ≤ -14 dB. The overall results indicate that the proposed antenna has met the requirement of practical MIMO antenna and suitable candidate for wireless applications especially in WiFi/WiMAX/WLAN and LTE applications.

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