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Minimization of Mutual Coupling Using Neutralization Line Technique for 2.4 GHz Wireless Applications

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ABSTRACT

This paper presented a planar printed multiple-input-multiple-output (MIMO) antenna with a dimension of 100 x 45 mm^2. It composed of two crescent shaped radiators placed symmetrically with respect to the ground plane. Neutralization line applied to suppress mutual coupling. The proposed antenna examined both theoretically and experimentally, which achieves an impedance bandwidth of 18.67% (over 2.04-2.46 GHz) with a reflection coefficient < -10 dB and mutual coupling minimization of < -20 dB. An evaluation of MIMO antennas is presented, with analysis of correlation coefficient, total active reflection coefficient (TARC), capacity loss and channel capacity. These characteristics indicate that the proposed antenna suitable for some wireless applications.

KEYWORDS

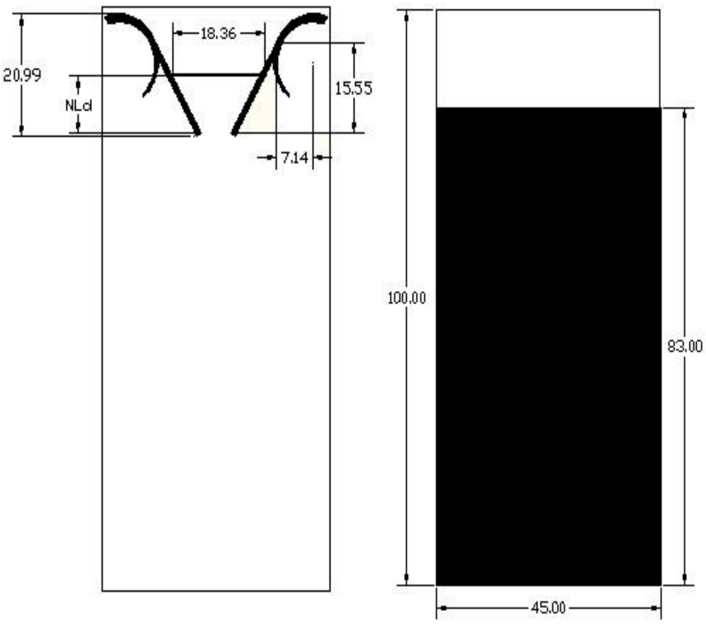
Multiple-Input-Multiple-Output (MIMO), impedance bandwidth, mutual coupling, neutralization line wireless applications.

1 INTRODUCTION

Nowadays and future wireless applications, there is an insatiability demand for having high data rate, high link quality, large bandwidth antenna at both transmitter and receiver. MIMO technologies have gain much attention recently. The potential for MIMO antenna systems to improve reliability and enhance channel capacity in wireless mobile communications has generated great interest[1]. A major consideration in MIMO antenna design is to reduce correlation between the multiple elements, and in particular the mutual-coupling electromagnetic interactions that exist between multiple elements are significant, because at the receiver end this effect could largely determine the performance of the system. Lower mutual coupling can result in higher antenna efficiencies and lower correlation coefficients[2]. Significant research efforts to reduce mutual coupling have been reported in [3-9]. For example, by connecting an additional non radiating folded shorting strip between antenna element and ground plane [3], port to port isolation lower than –28 dB achieved for lower WLAN band. It is also interesting to observed that by applying T-shape slot impedance transformer to both single and dual band PIFA's, the isolation over 20 dB is obtained [4]. In [5], the authors proposed the method to obtained low mutual coupling by cutting two quarter wavelength slots into the ground plane. The use of planar soft surfaces proposed in [6] to reduce mutual coupling. Other methods to reduce mutual coupling and enhanced isolation of the MIMO antenna , such as inserting slits on ground plane [7], I-shaped conductor in modified ground plane [8] and inserting neutralization line between antenna element[9] was also promising methods.

In this paper, two-element crescent shaped MIMO antenna presented for the purpose of wireless applications. The MIMO antenna consists of two crescent shaped radiators placed symmetrically with respect to ground plane with neutralization line (NL) connected in between of the two antennas. The total dimensions of this antenna are 100 x 45 x 1.6 mm^3. Both simulated and measured result of the fabricated prototype details reported and discussed.

2 ANTENNA DESIGN CONCEPTS



(a) Top View (b) Bottom View

Figure 1. Geometry of the proposed antenna (in mm) (a) top view, and (b) Bottom view.

The proposed antenna geometry is illustrated in Figure 1. The antenna system comprises with two crescent shaped radiators that is similar to that in [10] deployed on an economically FR-4 substrate with relative permittivity of 4.4 and a thickness of 1.6 mm operating at 2.4 GHz. The radiators are separated by 0.147λ (18.36 mm) for the minimization of mutual coupling. While, 83 × 45 mm^2 ground plane placed on the other side of the substrate as shown in Figure 1 (b). The overall dimensions of the proposed antenna are 100 × 45 × 1.6 mm^3 which is suitable for wireless application such as a network card or mobile device. In addition, in order to improve the mutual coupling of the proposed antenna, neutralization line with 0.5 mm width inserted between the radiators. Theoretically, neutralization lines transfer some current from the first antenna and delivers to the second antenna to cancel out the existing coupling.

To clarify the effectiveness of the neutralization line (NL) of the proposed antenna, the parametric study of the location of the neutralization line, NL_d was carried out with the width of the NL is kept at 0.5 mm. From Fig. 2, it can be observed that the optimal distance of NLd is at 9.79 mm which gives the lowest mutual coupling at 2.4 GHz.

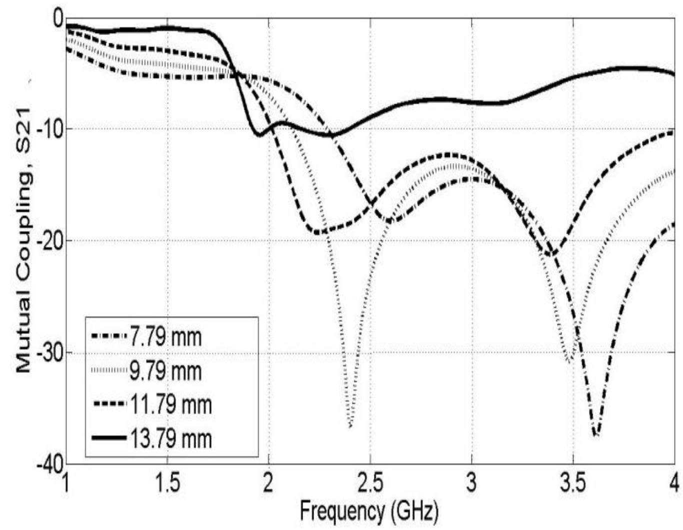


Figure 2. Simulated transmission coefficient, S_{21} of the various distance location of neutralization line.

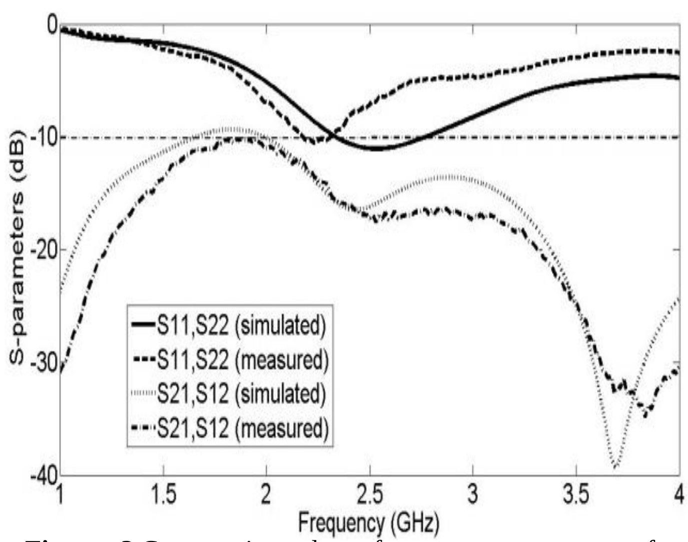


Figure 3. Comparative plot of s-parameters output for simulated and measured results for the proposed antenna without neutralization line.

3 SIMULATED AND MEASURED PERFORMANCE

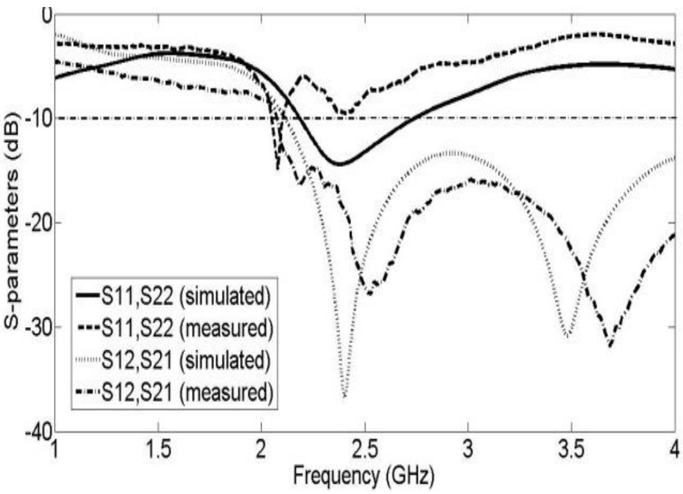
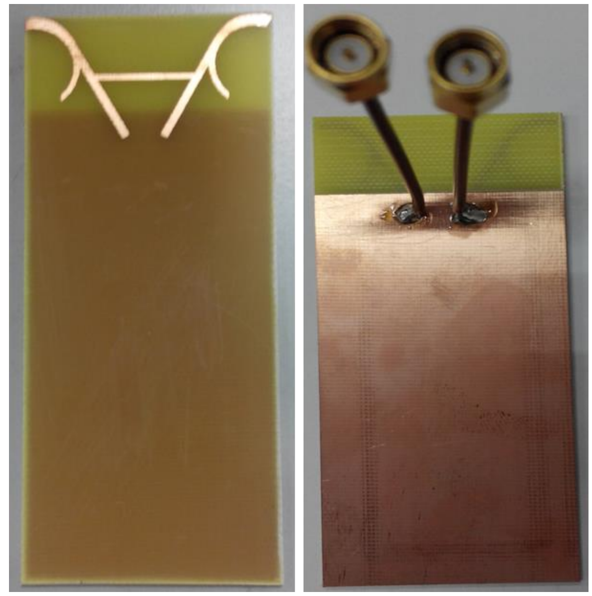


Figure 4. Comparative plot of s-parameters output for simulated and measured results for the proposed antenna with neutralization line.

Figure 3 and Figure 4 show the simulated and measured s-parameters output for the proposed antenna with and without neutralization line, respectively. As can been observed, the measured return loss, $|S_{11}|$ and mutual coupling, $|S_{21}|$ for both figures (Figure 3 and Figure 4) are reasonably good agreement with the simulated results. The resonance frequency is slightly shifted between the simulated and measured results and this is probably due to the discrepancy of SMA connector and fabrication tolerance. It is apparently seen that by implementing the neutralization lines, the mutual coupling, |S21| of the proposed antenna can be improved from -14 dB without neutralization lines to below -21 dB with neutralization line at 2.4GHz.

To validate the simulated results, the physical prototypes of the proposed antenna with and without neutralization line were fabricated and tested, the top and back view of the proposed antenna as shown in Figure 5. The S-parameters of the antenna were measured by Vector Network Analyser 8722ET (VNA). The measured return loss $|S_{11}|$ and mutual coupling $|S_{21}|$ are plotted in Figure 6. As can be seen, when the neutralization line was inserted, the mutual coupling has been reduced around 7.14 dB (from -14.63 dB to -21.77 dB) with an impedance bandwidth of 18.67% (over 2.04-2.46 GHz). The bandwidth achieved fully covered the wireless application such as network card at 2.4 GHz.



(a) (b)

Figure 5. Practical prototype of the proposed antenna (a) top view (b) back view.

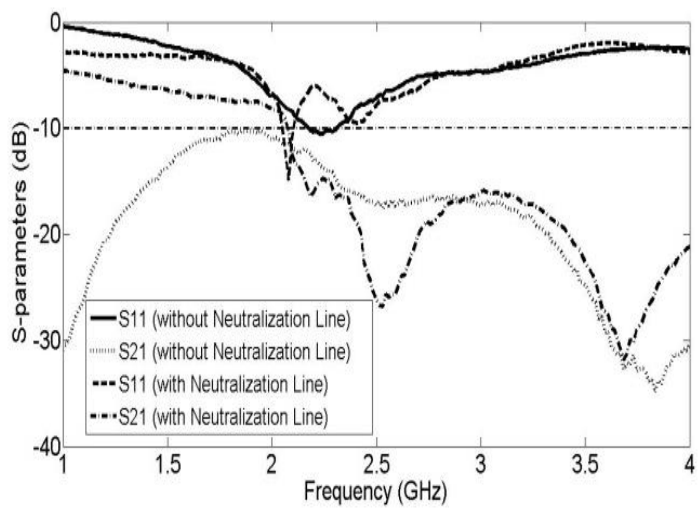


Figure 6. Measured S-parameters of the proposed antenna with and without the neutralization line.

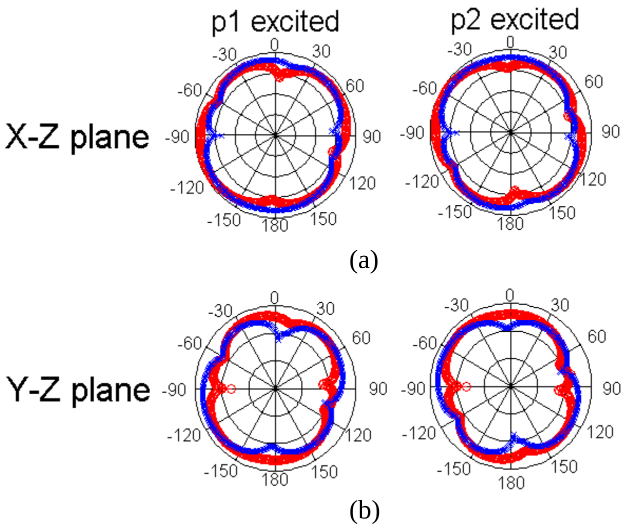


Figure 7. Simulated radiation patterns for the proposed antenna for two planes at 2.4 GHz; (a) X-Z plane. “xxxx” (blue) simulated cross-polarization, “oooo” (red) simulated co -polarization. (b) Y-Z plane. “xxxx” (blue) simulated co-polarization, “oooo” (red) simulated cross-polarization Port 1(left) excited and port 2(right) terminated in 50Ω.

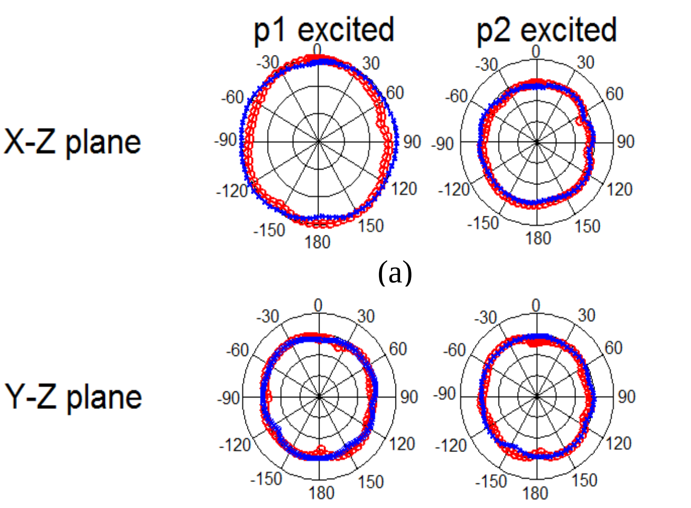


Figure 8. Measured radiatio (b) ıs for the proposed antenna for two planes at 2.4 GHz; (a) X-Z plane. “xxxx” (blue) simulated co-polarization, “oooo” (red) simulated cross- polarization. (b) Y-Z plane. “xxxx” (blue) simulated cross-polarization, “oooo” (red) simulated co-polarization Port 1(left) excited and port 2(right) terminated in 50Ω.

The simulated and measured radiation patterns of the proposed antenna in the x-z plane (E-plane) and y-z plane (H-plane) with port 1 excited while port 2 terminated with 50Ω load plotted in Figure 7 and Figure 8, respectively. The antenna shows a stable omnidirectional pattern in the E-plane and H-plane over the operating frequency of 2.4 GHz.

4 DIVERSITY PERFORMANCES

To evaluate the capabilities of MIMO/diversity antenna, the envelope correlation coefficient (ECC) is an important criterion to be presented. Basically, envelope correlation can be computed by using S-parameters or radiation pattern of the antenna. The envelope correlation of the MIMO antenna system can be expressed by using the following expression[11]:

$$\rho_e = \frac{\left|S^*_{11}S_{12}+S^*_{21}S_{22}\right|^2}{\left(1-|S_{11}|^2-|S_{21}|^2\right)\left(1-|S_{22}|^2-|S_{12}|^2\right)} \qquad (1)$$

The simulated envelope correlation coefficient of the proposed antenna with and without neutralization showed in Figure 9. An improvement of the ECC can be seen after the neutralization line was inserted and it fulfils the characteristic of diversity $p_e < 0.5$ [7]. Therefore, the proposed antenna is suitable candidate for MIMO application.

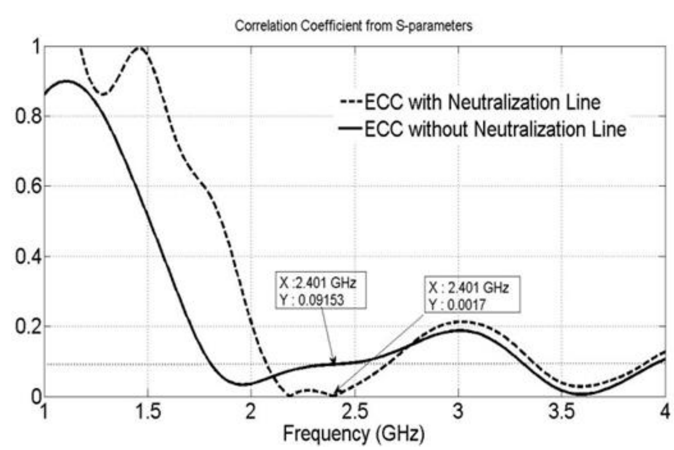
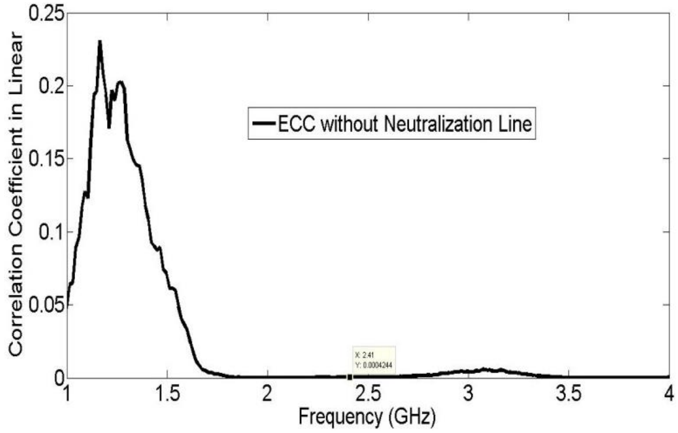
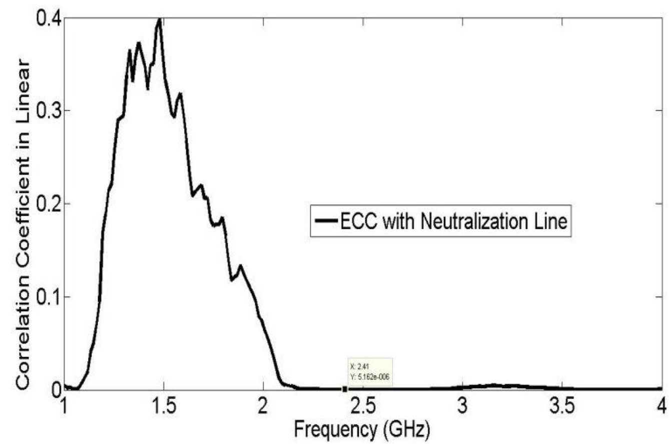


Figure 9. Simulated envelope correlation coefficient for the proposed antenna with and without neutralization line.



(a)



(b)

Figure 10 Measured correlation coefficient of the proposed antenna. (a)without Neutralization line,(b) with neutralization line.

The measured correlation coefficients of the proposed antenna with and without neutralization line are plotted in Figure 10. As can be seen, the correlation coefficient improved from 0.00042 to 5.162×10^{6} after inserting neutralization lines.

The simplified channel capacity loss of a 2 x 2 MIMO system can be evaluated by using the following equation, given in [9, 12]:

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

Where φ^R is the receiving antenna correlation matrix:

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

with $P_{ii} = \left(1 - \left(|S_{ii}|^2 + |S_{ij}|^2\right)\right)$ and $P_{ij} = -(S_{ii}S_{ij} + S_{ji}S_{jj})$ for i , j = 1 or 2.

The simulated capacity losses of the proposed antenna with and without neutralization line show in Figure 11. It can be seen that the capacity loss after inserting neutralization line neither exceeds 0.6 bps / Hz at 2.4 GHz. The comparison between simulated and measured capacity loss shows in Figure 12.

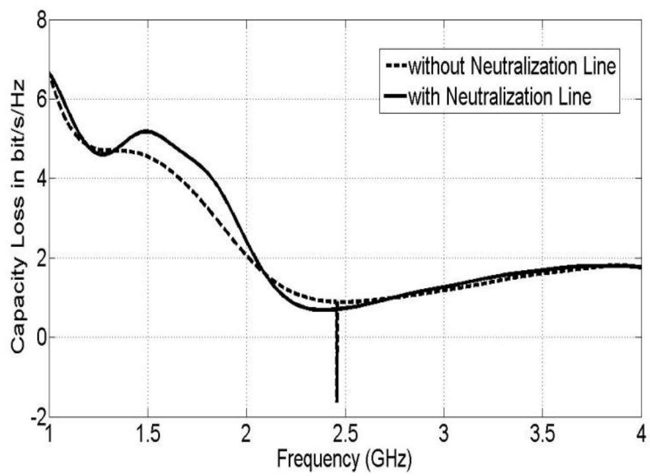


Figure 11. Simulated capacity loss of the proposed antenna with and without neutralization line.

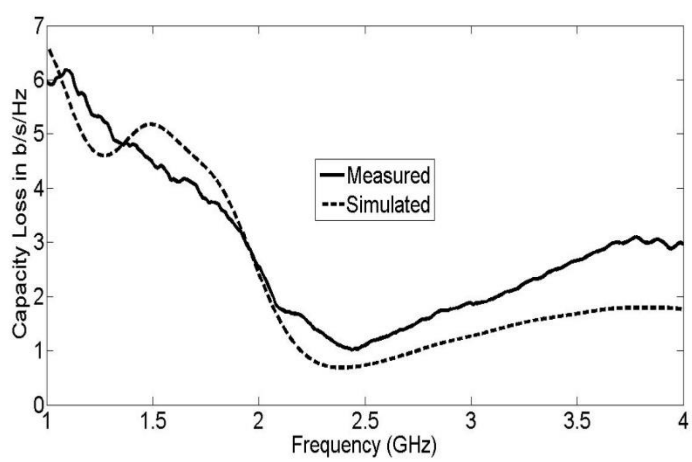


Figure 12. Comparison Between simulated and measured capacity loss of the proposed antenna.

Total active reflection coefficient or known as TARC can be defined as the return loss of the whole MIMO proposed antenna. Figure 13 showed the simulated total active reflection coefficient of the proposed antenna with and without neutralization line. The better performance of TARC obtained with neutralization line inserted.

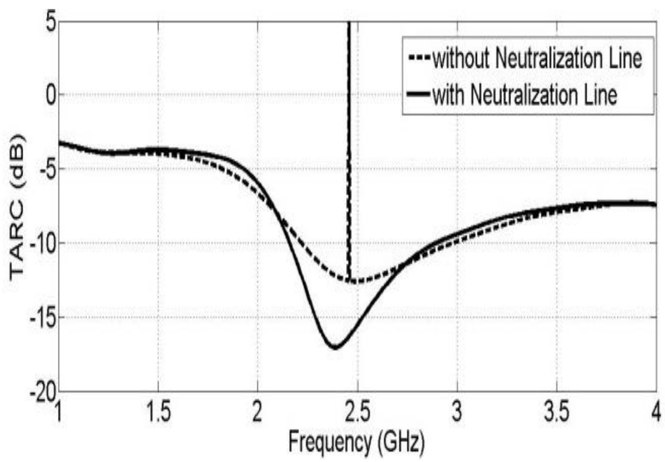


Figure 13. Simulated total active reflection coefficient of the proposed antenna with and without neutralization line.

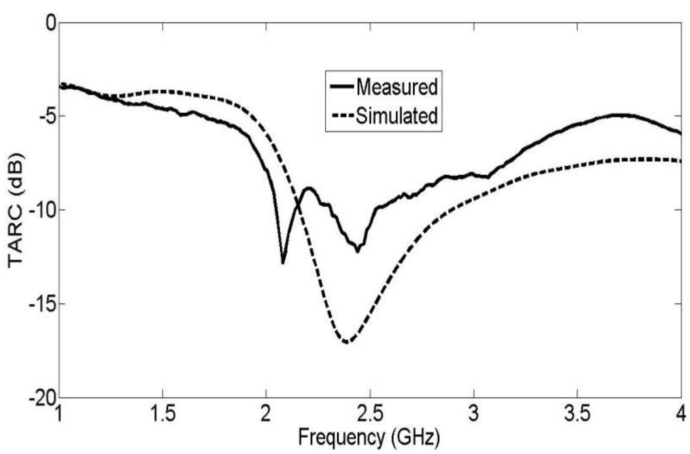


Figure 14. Comparison between simulated and measured TARC of the proposed antenna.

The simulated and measured TARC of the proposed antenna are shown in Figure 14. Small discrepancies between the simulation and measurement results can be attributed to fabrication tolerance and feed cable effects.

The correlation coefficient, TARC and capacity loss are summarized in Table 1. This shows that the proposed antenna with neutralization line have lower loss of capacity and better performance for TARC and envelope correlation coefficient compared to the proposed antenna without neutralization line.

Table 1. Simulated results for correlation coefficient, TARC and capacity loss at 2.4 GHz

Parameter	Proposed Antenna without Neutralization Line	Proposed Antenna with Neutralization Line
Correlation Coefficient (dB)	0.091	0.0017
Capacity Loss (bits/s/Hz)	0.9089	0.6854
TARC (dB)	-12.29	-17.02

In communication system, channel capacity bounded by the Shannon's theoretical capacity. Channel capacity determined as the maximum amount of information that can be transferred and received through the channel. Shannon capacity of the MIMO system can be computed using [13]

$$C(\varepsilon) = log_2 \det\ [I_n + \frac{\varepsilon}{n}.HH^T] bits/s/Hz \quad (4)$$

Where ;

ε = Signal to Noise ratio (SNR)
I_n = Identity matrix of order n
H^T = Hermitian transpose of the H matrix
n = no. of antennas

The channel capacity of the proposed antenna with and without neutralization line is 5.605 bits/s/Hz and 5.657 bits/s/Hz at 2.4 GHz, respectively as shown in Figure 15.

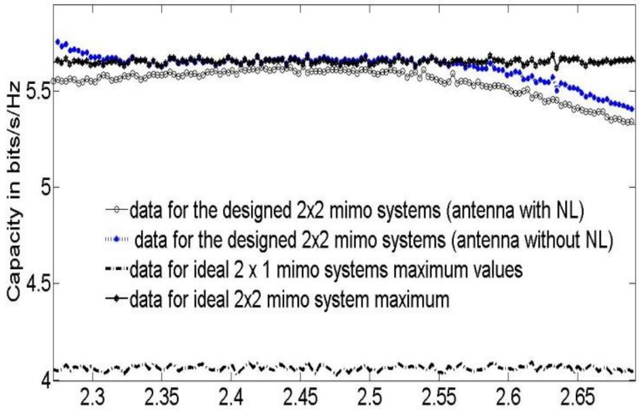


Figure 15. Simulated capacity of the proposed antenna with and without neutralization line.

5 CONCLUSION

A two-element crescent shaped printed MIMO antenna for covering 2.4 GHz wireless applications presented. Neutralization line applied to meet the requirement of MIMO in term of low mutual coupling parameter. Simulated and measured results show that the antenna achieves an impedance bandwidth of 18.67% (over 2.04 - 2.46 GHz) with a reflection coefficient < -10 dB and mutual coupling minimization of < -20 dB. Further, the correlation coefficient, TARC, capacity and capacity loss have been analyzed for antenna with and without neutralization line. It has been shown that the proposed antenna has met the requirements of MIMO practical antenna.

6 ACKNOWLEDGEMENT

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