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Reduction of Mutual Coupling in UWB/MIMO Antenna Using Stub Loading Technique

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***Abstract* – The research presents mutual coupling reduction between UWB-MIMO antenna elements using stub loading technique. The proposed 2 × 2 UWB antenna geometry consists of two circular-shaped monopole radiators with a partial ground for perfect impedance matching. Stubs of 20 mm × 0.2 mm are inserted between the two antenna elements in the ground plane to improve the isolation. The decoupling stub leads to a mutual coupling reduction of less than 20 dB. The farfield measurement at a selected frequency of 10 GHz confirms an omnidirectional radiation pattern. Different MIMO antenna metric such as channel capacity loss (CCL), mean effective gain (MEG), total active reflection coefficient (TARC), envelope correlation coefficient (ECC), and surface current are presented. Details of the design considerations and the simulation and measurement results are presented and discussed. The proposed MIMO antenna array can be well suited for UWB applications.**

***Keywords* – Diversity antenna; Error correlation coefficient; MIMO antenna; Mutual coupling; Slotted stub; UWB antenna.**

I. Introduction

Deployment of multiple antennas at both links gives the capability to exploit other advantages than MIMO/diversity gains. MIMO techniques can be characterised when numerous antennas are used at transmiting and receiving end [1], [2]. The main idea of using the MIMO system is that sampled signals in the spatial terrain at both terminals are integrated to elevate the data rate and enhance the communication quality. Electromagnetic interaction among the MIMO radiating element is one of the MIMO system challenges [3]. When several radiating features are situated close to each other, the fields generated by one antenna change the current distribution on the other antenna; therefore, each MIMO element impedance matching and radiation pattern are assigned based on the presence of other features [4]. This mutual coupling between the antenna elements subverts the performance of the MIMO system. All the radiating features have to be in a single aperture, making it a single multiport antenna design problem.

MIMO systems helps us combat multipath fading, providing improved signal-to-noise-ratio (SNR), thus achieving better system capacity.

II. Related Work

Some researchers use a multiport decoupling or matching network to reduce the mutual coupling effect between the antennas. The authors in [6]–[8] utilised a defective ground structure. Study [9] used parasitic elements while the author in [10], [11] employed a neutralization line method to cancel the effect. Metamaterial structure in the form of an electromagnetic bandgap (EBG) is presented in [12], [13]. A rectangular loop resonator was employed in [14] to abate the mutual coupling. The author in [15] proposed the UWB-MIMO sense in which some diodes had been used for that purpose. The pin diodes are turned off with a reversed biased of 0 V for two varactor diodes. A band-notched UWB antenna with band rejection ability is presented in [16]. A letter is presented in [17] whereby the author embedded different slots and slits on the radiating element to achieve UWB frequency.

III. Design Evolution

The geometry and fabricated models of the proposed MIMO/UWB antenna are presented in Fig. 1. The MIMO antenna consists of two printed circular patches on top of the plane and a partial ground plane. Four slots were employed in both the upper and bottom layers to achieve perfect matching. Two perturbed stubs were utilised in the middle of the ground plane, which served as a decoupling structure for mutual coupling reduction. The total design space was 30 mm × 60 mm, with a separation distance of 18 mm between the two elements. The optimized dimension of the MIMO antenna is presented in Table I.

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TABLE I
MIMO ANTENNA PARAMETERS

Parameter	Size, mm	Parameter	Size, mm
D	18	***L_s***	20
G_w	3	***R_p***	9.35
L	30	***R_s***	2.6
L_f	11.05	***W***	60
L_g	10	***W_f***	2.5

IV. PARAMETRIC ANALYSIS OF THE DESIGN

The parametric examination is displayed utilising different R_s values: the radius of the slots from Fig. 1 to have an optimum amount that can give us a better exhibition of the antenna as far as the reflection coefficient, radiation attributes, and data transfer capacity. Fig. 2 shows S_{11} for the slots with various radiuses, as can be seen from the plot. When the value of R_s is 2.6 mm, the resulting S_{11} is perfect at that value. Therefore, we used 2.6 mm as the radius of the slots for both the two reception apparatus. Even though the remaining plots are also within the range of −10 dB and can also have a good result. Still, with 2.6 mm as the value of the radius, the performance has improved. That is why the value is taken as the final value for the proposed reception apparatus design and analysis. It shows that the slot controls the input impedance matching of the MIMO antenna. Finally, low polarization diversity is also considered for having low mutual coupling.

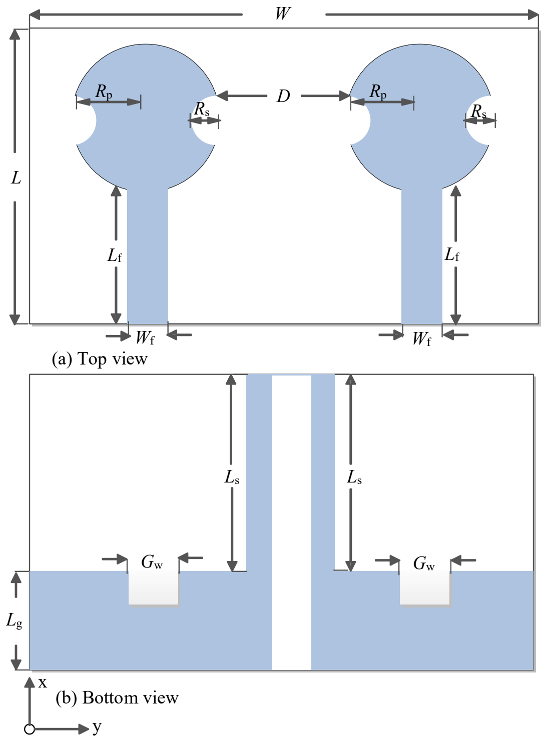


Fig. 1. System model: (a) top view, (b) bottom view.

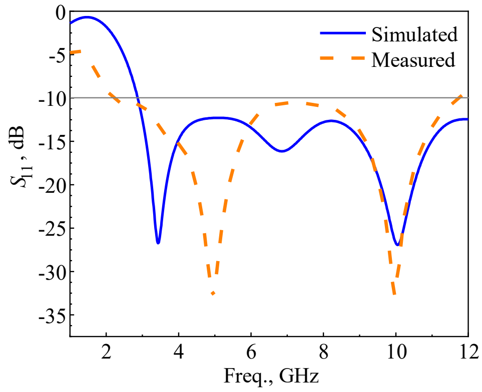


Fig. 2. S_{11} plot for various radiuses R_s in mm.

V. MEASUREMENT SETUP AND RESULTS

The proposed MIMO antenna with a decoupling structure was fabricated and measured using a vector network analyzer (N5244A). Two perturbed stubs are used as a decoupling structure between the antenna for proper isolation between them. The measured and simulated S_{11} is shown in Fig. 3, while Fig. 4 is the measured and simulated S_{21} of the MIMO antenna. The isolation between the two antennas was below −20 dB. The stubs bring about the high isolation between the MIMO components. Figure 5 shows the measured and simulated voltage standing wave ratio (*VSWR*). The S_{21} with and without stubs is depicted in Fig. 6. The current distribution at 4.5 GHz and 5.8 GHz when port one is excited is shown in Fig. 7. The antenna gain is an essential parameter for describing the degree of enlargement and concentration of input power. It is used to measure the antenna ability to send and receive signals in a specific direction. The measured and simulated MIMO antenna peak gain is shown in Fig. 8. The antenna directivity was measured using an anechoic chamber; the measurement setup can be seen in Fig. 9, the *xz*-plane and *yz*-plane radiation characteristics for 10.6 GHz are shown in Fig. 10. The measured values are in agreement with the simulated values. The little shift is due to fabrication errors or connection issues.

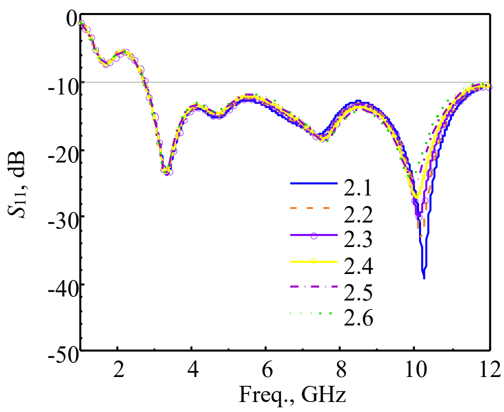


Fig. 3. Measured and simulated S_{11}.

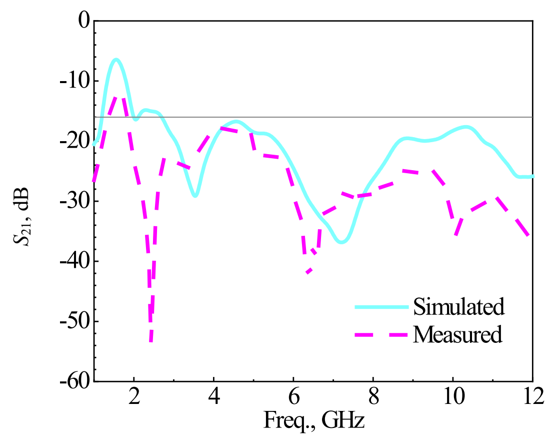


Fig. 4. Measured and simulated S_{21}.

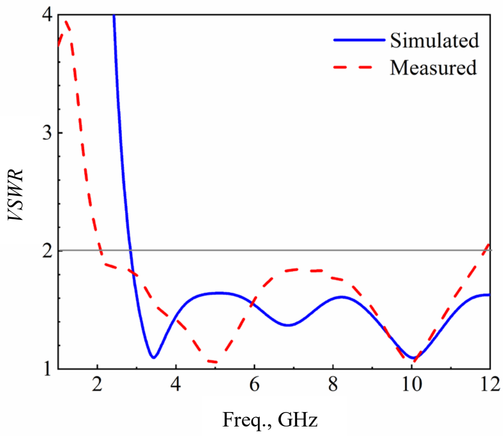


Fig. 5. Measured and simulated *VSWR*.

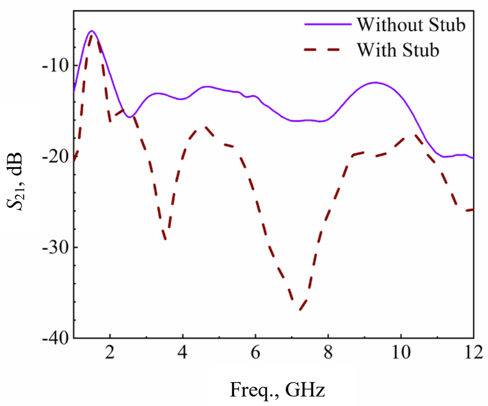
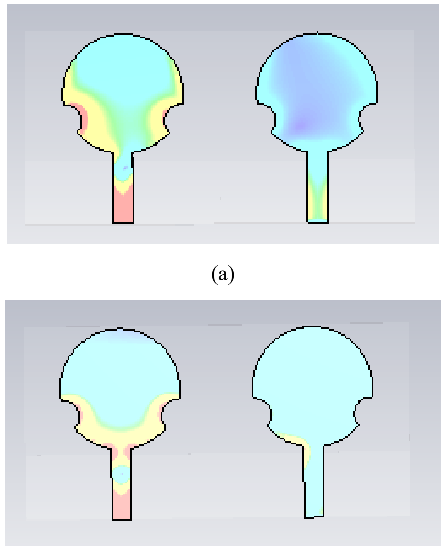


Fig. 6. S_{21} without and with a stub.



(a)

(b)

Fig. 7. Surface current at (a) 4.5 GHz, (b) 5.8 GHz.

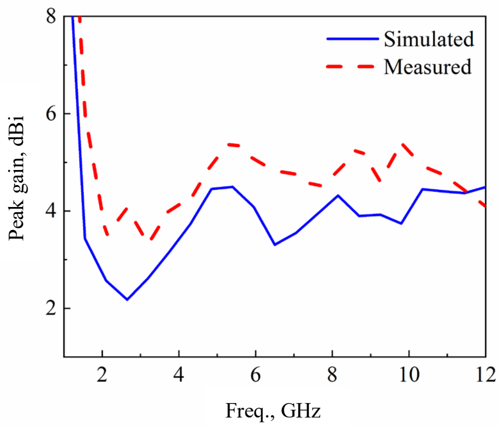


Fig. 8. Measured and simulated peak gain.

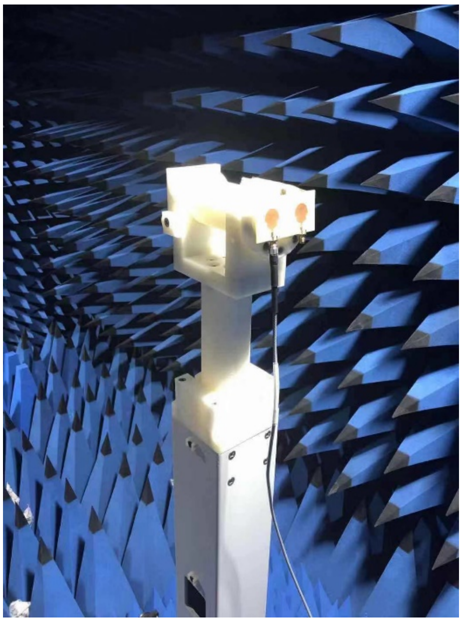
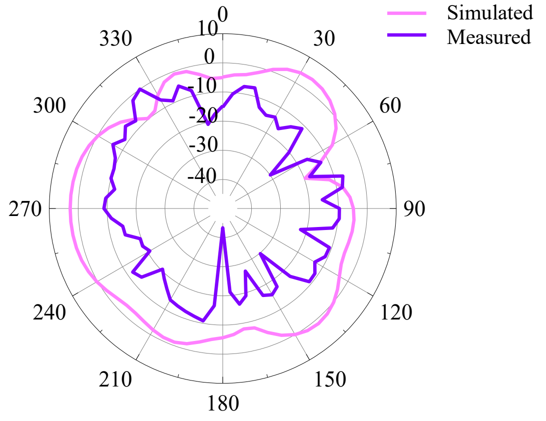
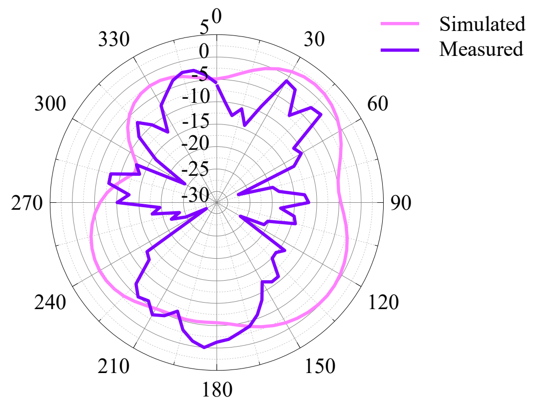


Fig. 9. Far-field measurement setup.



(a)



(b)

Fig. 10. Measured and simulated directivity for (a) E-Plane, (b) H-Plane at 10.6 GHz.

VI. MIMO System Metrics

To verify the MIMO antenna capability, some merits are used to evaluate the envelope correlation coefficient, total active reflection coefficient, channel capacity loss, and diversity gain. They are estimated using the *S*-parameters that has been extracted from the electromagnetic solver. *ECC* and *TARC* are essential parameters to quantify signal interference between MIMO channels [18] to secure the MIMO antenna capability. *TARC* can be computed for a 2 × 2 MIMO antenna using Eqs. (1) and (2).

$$\Gamma_a^t = \sqrt{\frac{\sum_{i=1}^{N} |b_i|^2}{\sum_{i=1}^{N} |a_i|^2}} \tag{1}$$

$$TARC = \sqrt{\frac{\left|S_{11} + S_{12}e^{j\theta}\right|^2 + \left|S_{22} + S_{21}e^{j\theta}\right|^2}{2}} \tag{2}$$

The phase difference between the excitation difference of our MIMO antenna and the *TARC* plot of the MIMO antenna is given in Fig. 11, with a difference of Θ from 0° to 180° with an interval of 30°. The plot reveals that $0 \le \Gamma_a^t \le 1$. The ECC is computed from the *S*-parameter as calculated in Eq. (3).

$$ECC = \frac{\left|S_{11}^{*}S_{12} + S_{21}^{*} + S_{21}^{*}S_{22}\right|^2}{\left[1-\left(\left|S_{11}\right|^2 + \left|S_{21}\right|^2\right)\right]\left[1-\left(\left|S_{22}\right|^2 + \left|S_{12}\right|^2\right)\right]}, \tag{3}$$

where S_{11}, S_{12}, S_{21}, and S_{22} are the parameters of the MIMO array. The proposed MIMO antenna *ECC* was calculated from 1 GHz to 12 GHz, as shown in Fig. 12. It can be observed that ECC value is less than 0.002 through the UWB bandwidth, which fulfills a good diversity standard for a MIMO system. Channel capacity can be defined as a data rate supported in a particular channel, and that channel is a fading environment [19]. Considering a high *SNR* value, *CCL* has been evaluated from simulated *S*-parameters using Eq. (4) below [20].

$$CCL = -\log_2 \det\left(\psi^R\right), \tag{4}$$

where ψ^R is the 2×2 correlation matrix in terms of *S*-parameters presented in Eqs. (5)–(9):

$$\psi^R = \begin{bmatrix} \psi_{11} & \psi_{12} \\ \psi_{21} & \psi_{22} \end{bmatrix}, \tag{5}$$

$$\psi_{11} = 1-\left(\left|S_{11}\right|^2 + \left|S_{12}\right|^2\right), \tag{6}$$

$$\psi_{22} = 1-\left(\left|S_{11}\right|^2 + \left|S_{21}\right|^2\right), \tag{7}$$

$$\psi_{12} = S_{11}^{*}S_{12} + S_{21}^{*}S_{12}, \tag{8}$$

$$\psi_{21} = S_{22}^{*}S_{21} + S_{12}^{*}S_{21}. \tag{9}$$

The equations are based on the simulated and measured *S*-parameter, which is plotted in Fig. 13. The plot uncovers that the channel capacity loss is less than 0.35 over the whole UWB span because in practice *CCL* < 0.4 bps/Hz. The diversity gain of MIMO antennas can be computed from ECC using Eq. (10) [20].

$$DG = 10\sqrt{1 - ECC^2} \tag{10}$$

In Fig. 14, the diversity gain of nearly 10 dB is depicted; this signifies that the antenna has low polarization diversity that can give low mutual coupling.

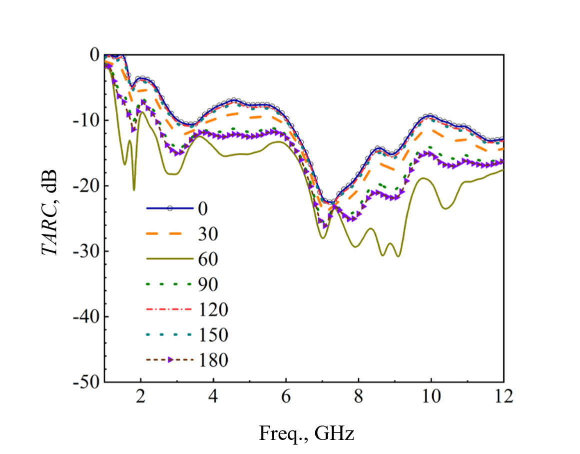


Fig. 11. *TARC* of the MIMO antenna system when Θ changed from 0° to 180°.

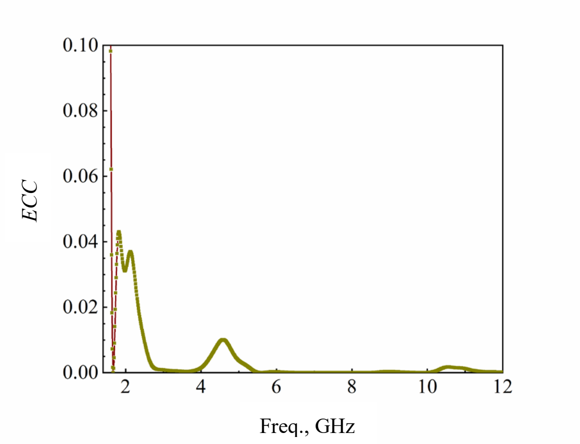


Fig. 12. *ECC* of UWB/MIMO antenna system.

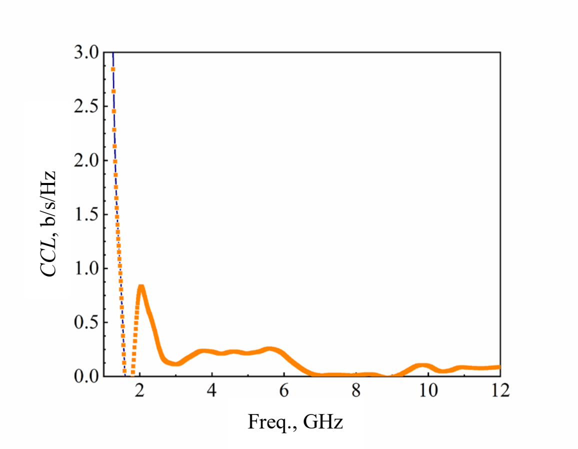


Fig. 13. *CCL* of UWB/MIMO antenna system.

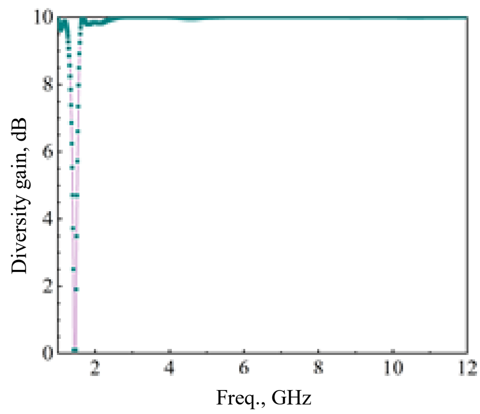


Fig. 14. Diversity gain of UWB/MIMO antenna.

The antenna mean effective gain (*MEG*) is defined as the ratio of the average power received at the microwave circuit (antenna) to the sum of the average power of the vertically and horizontally polarized waves received by an isotropic antenna [21]. Figure 15 shows the *MEG*, which is less than −3 dB. It can be calculated as in Eq. (11):

$$MEG = 0.5\left[1-\sum_{j=1}^{N}\left|S_{ij}\right|^{2}\right], \tag{11}$$

where N is the number of antenna elements. A definite comparison between the proposed and the UWB-MIMO antenna presented in the literature is classified in Table II. It is perceptible that the proposed MIMO antenna is compact with high isolation.

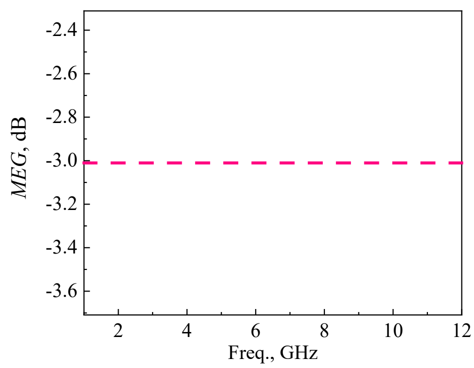


Fig. 15. *MEG* of the MIMO system.

TABLE II

PERFORMANCE COMPARISON WITH OTHER ANTENNAS PRESENTED IN THE LITERATURE

Ref.	Size, mm	Bandwidth, GHz	S_{21}, dB	*DG*
[3]	46 × 27.2	3.6–17.6	18	9.99
[6]	50 × 30	2.5–14.5	20	7.4
[16]	30 × 30	3.08–10.98	20	n.a.
[17]	39 × 39	2.3–13.75	22	n.a.
[19]	24 × 32	3.1–12.5	16	n.a.
This work	30 × 30	2.6–12	20	9.99

n.a. means not available.

VII. CONCLUSION

A compact, printed low-profile UWB MIMO antenna with a low mutual coupling has been proposed in this article. Good isolation has been realised by using a perturbed stub from the ground plane. The MIMO antenna exhibits a bandwidth of 2.6–12 GHz, covering the entire UWB spectrum. The *ECC* value is less than 0.01, *CCL* is less than or equal to 0.35 bps/Hz, *TARC* is less than 0 dB, and *MEG* is less than −3 dB throughout the UWB band, fulfilling a good diversity performance for a wireless system.

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